Global-Change Scenarios
Their Development and Use

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Executive Summary

Introduction to Scenarios

A scenario is a description of potential future conditions, which is developed to inform decision-making under uncertainty. Originally developed for study of military and security problems, scenarios are now widely used for strategic planning, analysis, and assessment by businesses and other organizations. Scenarios are also increasingly used in planning, analysis, and policy debate for environmental issues, including global climate change. Major decisions setting mitigation and adaptation strategies have the conditions – e.g., high stakes and deep or poorly characterized uncertainty – that make scenarios potentially useful. Although such decisions are being made in the near term, making them responsibly requires considering their potential consequences over the longer term, including the substantial associated uncertainties.

Scenarios are distinct from assessments, models, decision analyses, and other decision-support activities. Scenarios provide inputs to these activities when they need descriptions of potential future conditions. Scenarios can also be distinguished less sharply from other types of future statements to inform decisions, called projections, predictions, and forecasts. Compared to these, scenarios tend to be more multivariate, to be produced in groups to explore key uncertainties, and to presume lower predictive confidence, because they pertain to processes for which weaker causal understanding or longer time horizons make uncertainties deeper.

Scenarios vary on many dimensions, of which three are particularly prominent. First, scenario exercises vary in their proximity to specific decisions. Some may directly inform an identified decision, while others support decision-making indirectly, by helping to clarify an issue's importance, frame a decision agenda, shake up habitual thinking, provoke insights, clarify points of agreement and disagreement, identify and engage needed participants, or provide a preliminary structure for analysis of potential future decisions. A related dimension of variation is the degree to which a set of scenarios are intended to be predictive, versus exploratory or heuristic. Scenarios can also differ in how much they explicitly incorporate normative elements, i.e., in the degree to which they include descriptions of future conditions included on the basis of their desirability or undesirability, as opposed to on the basis of their perceived plausibility or likelihood.

Table ES-1 Idealized Sequence of Major Choices in Scenario Development.

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

The main dimensions of choice involved in constructing a scenario exercise are shown in highly simplified form in Table ES-1. Most fundamental is identifying the main focus of the exercise: what issues do the scenarios address, what decisions do they inform, and for whom? Deciding the process of a scenario exercise includes what range of expert knowledge and stakeholder perspectives to include, which can be decisive for the usefulness of the exercise. Deciding what few uncertainties to represent, usually by constructing multiple scenarios that embody alternative realizations of key uncertainties, is a crucial judgment that shapes much of what follows in a scenario exercise. The complexity of scenarios can vary greatly, from merely specifying time-paths of a few quantitative variables, to constructing rich, coherent, multivariate narratives. Complex scenarios may combine qualitative and quantitative elements.

Scenarios in Climate-Change Applications

Scenarios to inform climate change mitigation and adaptation decisions, directly or indirectly, come in five types according to where they fall along a simple linear causal chain representing the climate-change issue, from the socio-economic determinants of greenhouse-gas emissions through the impacts of climate change, as in Figure ES-1. (Note: this figure does not represent the actual causal structure of the climate issue, which has multiple feedbacks. This simple structure only illustrates the ways scenarios have been used to fit within the simplest and most prominent causal pathway of the issue.)

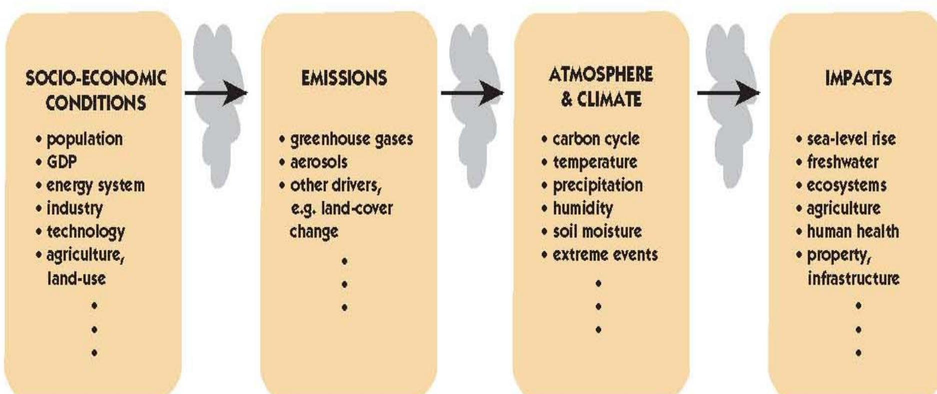

Figure ES-1: Anthropogenic climate change: Simple linear causal chain

The types of scenarios differ in what parts of the issue they specify, and what part of the issue is the focus of the subsequent analysis or use of the scenario.

Emissions Scenarios for Climate Simulations: Emissions scenarios stipulate future paths of greenhouse-gas emissions or other climate perturbations, to provide inputs to climate models. They can include simple arbitrary specifications of future emissions or concentrations (e.g., doubling atmospheric CO_2), or time-paths reflecting specified assumptions for evolution of socio-economic drivers such as population, economic growth, and technological change.

Emissions Scenarios for Exploring Alternative Energy/Technology Futures: Emission scenarios can also be used with the causal logic reversed, stipulating an environmental or emissions target and examining what patterns of socio-economic change, energy resource availability, or technology development are consistent with the target or what interventions might be needed to meet it. The target may be set based on normative criteria, political targets, or arbitrarily. While the most frequent use of this type of scenario has been to examine emissions trajectories that stabilize atmospheric CO_2 concentrations at specified levels, recent projects have instead adopted stabilization of radiative forcing as the target, in order to examine the role of non-CO2 greenhouse gases in stabilization regimes.

Climate-Change Scenarios: Climate scenarios describe potential future climate conditions, to inform assessments of impacts, vulnerabilities, and adaptation options, and inform decision-making related to either adaptation or mitigation. They can be produced by simple arbitrary perturbations to present climate conditions, by using climatic conditions from the past record or from some other location as an analog for potential future climate in a given location, or by climate-model simulations, which require some specified scenario of future emissions.

Scenarios of Direct Biophysical Impacts: Sea Level Rise: Scenarios can be constructed of important dimensions of climate impact that influence many other impacts. The primary example is sea level rise, the major pathway of climate impact in many coastal regions. Scenarios of sea level rise can be constructed by combining climate-change scenarios with information about coastal uplift or subsidence and other specific regional characteristics. In addition to its gradual impacts, sea level rise is subject to large uncertainties associated with potential loss of continental glaciers in Greenland and West Antarctica.

Multivariate Scenarios for Impact Assessment: Many potentially important impacts of climate change cannot be adequately assessed by considering only climate change. For these, scenarios are required that include not just climate and its impacts, but also other characteristics likely to influence impacts. These may include other dimensions of environmental change, and multiple socio-economic characteristics likely to influence specific vulnerabilities and capacity for adaptation. The factors that influence specific dimensions of vulnerability are likely to vary among specific types of impact, locations, and cultures, and many include many demographic, economic, technological, institutional, and cultural characteristics. Consequently, scenarios may have to be generated in an exploratory manner in the context of attempting to assess specific local and regional impacts.

Major Climate-Change Scenario Exercises:

We summarize and seek to draw insights from four major examples of experience generating or using scenarios for climate-change applications, plus eight brief descriptions of smaller-scale experiences that are particularly unusual or illuminating.

The IPCC has conducted three exercises to generate scenarios of 21st-century greenhouse-gas emissions, of which the largest, most ambitious, and most important was the Special Report on Emissions Scenarios (SRES), conducted form 1997 to 1999. Established in response to criticisms that the previous scenario exercise relied excessively on one model, treated important areas such as sulfur emissions and land-use change inadequately, and failed to represent income convergence between industrialized and developing countries, the project initially reviewed the prior scenarios literature and ran an open process by which any researcher was invited to submit scenarios. In addition, they developed a set of new scenarios, beginning with four qualitative storylines that were then quantified by six participating energy-economic modeling teams. The exercise published forty scenarios with supporting documentation, although the most prominent outputs of the exercise were six “marker” scenarios – one model quantification of each of the four initial storylines, plus two technological variants on one storyline that stressed fossil-intensive and low-carbon energy supply technologies respectively.

The marker scenarios have been the most prominent scenarios in subsequent climate modeling, impact assessment, and decision support. They highlighted several insights, including the ability of alternative paths with similar emissions in 2100 to follow widely differing interim pathways and so yield divergent atmospheric concentrations; the ability of alternative technological assumptions alone to generate as wide a range of emissions futures as substantially divergent socio-economic pathways; and the fact that similar emissions paths can come from widely different combinations of underlying socio-economic factors and so pose distinct mitigation problems. The most prominent controversy over these scenarios concerned alternative measures to compare incomes between industrial and developing countries, an issue of minor importance for emissions trajectories or challenges facing future scenarios exercises. Other challenges associated with these scenarios of greater significance for future scenario exercises included how to balance and integrate qualitative and quantitative scenarios; how to deploy and coordinate multiple models to generate the most useful insights; and whether, when, and how it is appropriate to assign explicit probability judgments to alternative scenarios or quantitative variable ranges.

The U.S. National Assessment was a comprehensive assessment of potential impacts of climate change and variability on the United States, conducted between 1997 and 2002 by analytic teams examining major US regions and sectors (agriculture, water, human health, coastal areas and marine resources, and forests) with some central coordination. The Assessment needed scenarios of 21st-century US climate and socio-economic changes. For climate scenarios, it relied principally on runs of the UK Hadley Centre climate model and the Canadian climate model, each driven by a single emissions scenario, with statistical downscaling based on detailed local conditions and present patterns of fine-scale climate variation. Other proposed approaches to constructing climate scenarios, including historical scenarios and inverse methods to probe for key vulnerabilities, were used less. For socio-economic scenarios, a two-level approach was proposed, combining national specification of scenarios for a few key variables such as population and economic growth, and a common process to elaborate and document additional socio-economic assumptions needed for specific regional and sector analyses. The Assessment was criticized for relying on just two climate-model runs and one emissions scenario, although these choices were dictated by time limits and the availability of climate-model runs at the time. Limited use was made of the socio-economic approach, principally due to time limits and communication problems, so the validity of the proposed approach was not effectively tested.

The UK Climate Impacts Program supports research and analysis of impacts for particular regions, sectors, and activities in the UK, by university researchers and stakeholders. The program provides common datasets and tools, as well as ongoing assessment support to stakeholder groups. As part of this support the program has produced three sets of scenarios: climate scenarios in 1998 and 2002 based on the Hadley Centre climate model, and socio-economic scenarios in 2001. The program has followed a substantially different model from the US National Assessment, based on building a sustained assessment capability rather than a single project. In addition, the central program has less authority over the separate assessments, instead acting more as motivator, resource, and gentle coordinator.

The Millennium Ecosystem Assessment (MEA) examined the status, present trends, and longer-term challenges to the world's ecosystems, including climate change and other stresses. One of the assessment's four working groups constructed scenarios of global ecosystems to 2050 and beyond, largely independently of the group examining current status and trends. All components of the assessment used a common large-scale conceptual framework, which distinguished indirect drivers of ecosystem change (e.g., population and economic growth, technological change, policies and lifestyles), direct drivers (e.g., climate change, air pollution, and land-use and land-cover change), ecosystem indicators, ecosystem services, measures of human well-being, and response options. The Scenarios working group applied this framework to long-term ecosystem trends through 2050, with more limited projections to 2100. They constructed four scenarios, based on two dimensions of uncertainty, globalization and the degree of proactive vs. reactive response to ecosystem changes. The qualitative storylines comprising these scenarios were more richly developed than in other climate-change scenario exercises. Key issues and challenges with these scenarios concerned integration and consistency between qualitative and quantitative scenarios, concerns about breadth and potential circularity within scenarios, and unexplained similarity of projected effects between scenarios.

Other experience with climate-change and related scenarios are examined more briefly, highlighting several additional issues and potential insights. Climate-change scenarios can be used to inform concrete decisions related to impacts and adaptation, and there are increasing attempts to do so. Collaboration with users and decision-makers is important to the success of such exercises, and scenarios need to provide information in form and detail that decision-makers can use. Although interest in such uses is increasing, many applications that could clearly benefit from considering climate-change scenarios have not yet done so or are only starting to. Scenarios can contribute to broad perceptions of the character and seriousness of an issue, particularly when presented as part of large-scale, official assessments. They can then influence diverse decisions that respond to such aggregate perceptions of seriousness, including mitigation decisions by diverse actors. Extreme case scenarios can make useful contributions to risk assessment, but are vulnerable to misunderstanding and misinterpretation in policy debates.

Issues, Challenges, and Controversies in Climate-Change Scenarios

Scenarios and Decisions

Scenarios can inform climate-change mitigation and adaptation decisions, but most uses so far have had relatively indirect connections to such decisions. Although there is no single global climate-change decision-maker, scenarios can inform the many decision-makers with diverse responsibilities that will affect and be affected by climate change. To consider potential contributions of scenarios more specifically, real climate-change decision-makers can usefully be considered in three groups: national officials, impacts and adaptation managers, and energy resource and technology managers.

National officials make both adaptation and mitigation decisions. In their impacts and adaptation responsibilities, they need scenarios of potential future climate change under specified assumptions about global emissions trends, and resultant impacts on particular resources and communities within their nation, with particular focus on the areas of greatest vulnerability. In their mitigation responsibilities, they need information about aggregate climate-change impacts, and also projections of future emissions in the absence of additional mitigation efforts, the consequences of alternative policies, and information about the context in which these decisions are made, mainly mitigation strategies adopted and implemented by other major nations.

Impacts and adaptation managers have responsibility for particular assets, resources, or interests that might be sensitive to climate change. To assess the threats and opportunities they face and evaluate responses, they need scenarios of potential future climate change, its impacts in their areas of responsibility, and the factors that influence vulnerabilities. Particular decision-makers' needs will be highly specific in the variables they require, and their time and space scale and resolution.

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, mostly but not entirely in the private sector. The consequences of their decisions will predominantly be influenced by the mitigation policies in effect, nationally and internationally, over the lifetime of the relevant investments. Consequently, these actors will most benefit from scenarios that explore alternative policy regimes and their consequences for the value of energy and technology assets.

For all these decision-makers, a key issue in scenarios is the reflexivity of decisions, i.e., how to represent decisions within scenarios. The appropriate treatment depends on the intended user of the scenario. Decisions by others outside their control should be represented like any uncertainty, based on estimates of their likely outcomes and importance for the user's decisions and concerns. Decisions by the user, however, must be explicitly examined relative to baseline conditions specified in scenarios. This difference is most pronounced for mitigation decisions: scenarios for impacts and adaptation should presume a likely range of mitigation efforts, while scenarios for mitigation decisions should allow explicit examination of the entire range of decisions being considered. Consequently, scenarios for impacts and adaptation will typically include a narrower range of potential emissions futures than scenarios for mitigation.

Scenarios in Assessments and Policy Debates

In large-scale assessments of climate change, scenarios can provide required inputs to other parts of the analysis, and can serve as devices to organize and coordinate multiple components of the assessment, particularly those that are forward-looking. Because of the prominence that scenarios used in assessments can gain, they may be used in planning or decision-support processes outside the original assessment. Scenarios can also contribute to the broad framing of public and policy debate on the issue, in part by serving as aggregate metrics for the issue's degree of seriousness or concern.

In these roles, scenarios become prominent in pluralistic policy debates where many contending views and interests are represented. They consequently become subject to politically motivated attempts to influence their development and content, and political reactions to them once developed, particularly because a scenario may be perceived as implying the desirability or undesirability of particular policy actions. The unavoidable judgments underlying construction of scenarios provide opportunity for partisan distortion and efforts to make scenarios policy-prescriptive, and for claims in policy debates that only certain scenarios are plausible (e.g., high or low-emissions scenarios, depending on the critic's motivation), or that a particular scenario is implausible.

Scenario Development Process: Expert-Stakeholder Interactions

Scenario exercises must decide how and how much scenario users and stakeholders are involved in scenario development. In other areas of scenario use where users are typically clearly identified, relatively small and homogeneous, close, intensive collaboration between scenario developers and users or their representatives is widely advocated. Although similar arguments for intensive user involvement have been widely advanced for climate change scenarios, the decision is more complex since some climate-change scenario exercises serve a large and highly heterogeneous set of potential users and stakeholders, who may not be identified or may have contending material interests in the scenarios' content or use. Under these conditions, the most useful nature and extent of stakeholder participation will vary from case to case. The more clearly identified the potential users and the more consistent their perspectives and needs, the stronger is the case for close collaboration in scenario development, e.g., when users are analysts or modelers producing other components of an assessment. But even in providing climate scenarios to impacts analysts, users' specific needs are likely to have substantial differences in addition to their commonalities. Involving a representative collection of users in scenario production is likely still productive, but potential users' numbers and diverse needs may require including only selected representatives. The larger and more diverse the potential users and stakeholders, the more difficult is the decision who to involve in what capacity in scenario production. With extreme user diversity, scenario exercises may serve only a subset of needs, or be limited to broad, exploratory purposes.

Communication of Scenarios

Climate change scenarios must be communicated to multiple audiences with diverse interests and information needs. In addition to the scenarios' content, sufficient information must be provided about the process and reasoning by which the scenarios were developed, to allow users to scrutinize the underlying data, models, and reasoning, judge their confidence in the scenarios, and have opportunities to critique the scenarios and suggest alternative approaches. Ideally, effective communication can engage a broad user community in updating and improving scenarios. Providing transparency rather than claiming authoritative status for scenarios is likely both to increase users' confidence that the scenarios have reasonably represented current knowledge and key uncertainties, and help them develop alternatives if they are unconvinced.

Consistency and Integration in Scenarios

Scenarios must strive for internal consistency. At one level, this means avoiding clear contradictions given well established knowledge, and not moving inadvertently far outside bounds of historical experience or presently recognized causal processes – although such sharp departures from experience may be useful if they are pursued intentionally to examine low-probability risks or broaden decision-makers' perceptions. Internal consistency can be interpreted as a claim that the multiple factors stipulated in a scenario are more likely than alternative combinations, but this claim usually rests on scenario developers' subjective judgments. Subjective judgments cannot be avoided, but raise well known risks of error and bias. These difficulties can be compounded when a scenario exercise pursues integration in addition to consistency. This can impose on scenarios the burden of describing most or all relevant components of the issue. Consistency problems grow when scenario exercises involve multiple models and attempts are made to harmonize model outputs. Using multiple models in parallel can aid exploration of causal relations and helps to characterize uncertainty, but when models use different variables as exogenous inputs it is particularly difficult to avoid inconsistency in values that are specified for some models and calculated for others. Attempting to avoid such inconsistency can pose even more serious problems, however, by requiring reverse-engineering of internal model relationships to match specified outputs, thereby obscuring interpretation of results and precluding use of model variation to illuminate uncertainty.

Attempts to connect qualitative and quantitative aspects of scenarios have been particularly challenging for pursuit of consistency. Narrative scenarios typically specify deep structural characteristics like social values and the nature of institutions, which are associated with behavioral characteristics represented in model structures, such as the determinants of fertility trends, labor-force participation, savings and investment decisions, and substitutability in the economy. Consequently, different narrative scenarios correspond more closely to different model structures than to variation of parameters, because they reflect different assumptions about how the world works. Better integrating the two approaches will require developing ways to connect narrative scenarios to model structures, rather than merely to target values for a few variables that models are then asked to reproduce.

Treatment of Uncertainty in Scenarios

Representing and communicating uncertainty is perhaps the most fundamental purpose of scenarios. In most scenario exercises, uncertainty is represented by variation between scenarios. The choices to be made in deciding how to represent uncertainty include what characteristics are varied; how much they are varied, how many scenarios are considered, and whether explicit characterizations of probability are assigned.

When scenarios are complex and multivariate and their use is costly – e.g., running a large costly model or spending much time and energy of busy senior people – only a few can be included in any scenario exercise. Consequently only one or two fundamental uncertainties can typically be considered. One must judge what uncertainties to consider, and how many outcomes of each: just high or low values? Are departures in both directions from the middle important enough to consider? For example, one might judge that scenarios of small climate change do not need explicit consideration in an impact assessment, since associated impacts are likely to be small. Extreme outcomes may need to be considered, if the gravity of their consequences or their effect on preferred decisions is extreme enough to offset their low probability. For example, in a coastal assessment the great difference between a half-meter and five-meter sea level rise, together with the known mechanism for such a rise, may suggest including a scenario with loss of one of the major continental ice masses. Because such scenarios carry the risk that their probability will be exaggerated, developers have special responsibilities to communicate clearly the special status of such scenarios.

Complex narrative scenarios pose special problems in representing and communicating uncertainty. In contrast to simple quantitative scenarios, these lie in a higher-dimension space and may lie in no clear ordinal relationship. Even greater selectivity is required to choose a few scenarios, typically by seeking underlying structural uncertainties – e.g., deep societal trends such as globalization or values shifts – that are judged to influence variation in many other factors including outcomes of concern. Although the likelihood of any scenario must decrease as the number of characteristics specified increases, such scenarios may still meet the condition of being likely enough to consider if the chosen structural uncertainties do in fact strongly condition outcomes on many other characteristics, or are regarded as drawn from a set of discrete possibilities.

A major debate in climate-change scenarios, engaged most prominently over the SRES scenarios, has concerned whether or not to explicitly assign probabilities to scenarios or associated ranges of quantitative outcome variables. The debate rests in part on different views of the typical contents of scenarios. At the simplest extreme, scenarios that specify time-paths of just one quantitative variable can readily assign subjective probabilities to the intervals so defined. Such explicit assignment would offer various advantages for assessing alternative decisions, and declining to provide them risks users assigning their own, perhaps less informed, probability judgments – as many subsequent users did with the distribution of emissions from the SRES scenarios. Opponents of explicit probability assignment raise practical objections even in simple cases, but focus primarily on the case of rich multivariate scenarios, often including narrative elements. They argue that probabilities cannot be sensibly estimated for such rich, multidimensional descriptions, that there is no clearly defined interval "between" such scenarios and their boundaries are not clearly defined, and that attempting to assign probabilities consumes scarce time and attention at little value to scenario users.

Conclusions and Recommendations

Use of Scenarios in Climate-Change Decisions

- Scenarios can make valuable contributions to climate-change decision-making, but there is a big gap between the use of scenarios in current practice and their potential contributions.

- Interest in considering and using climate-change scenarios is sharply increasing.
- Scenarios of global emissions and resultant climate change are required by many diverse climate-related decision-makers, but beyond these variables decision-makers' needs from climate-change scenarios are highly diverse.
- Impacts and Adaptation Managers are a major group of scenario users with distinct information needs.
- Meeting information needs for impacts and adaptation may require a cross-scale organizational structure.
- Scenarios for Impact and Adaptation Managers should be based on emissions assumptions that include a likely range of mitigation interventions.
- Mitigation Policy-Makers are also a major group of climate-change scenario users with distinct needs.
- Scenarios for mitigation decisions should include a wide range of baseline emissions assumptions and not pre-judge the likely level of mitigation effort.
- Mitigation Decision-Makers can use target-driven scenarios for backcasting.
- Mitigation decisions require scenario development capacity at the national level.
- Energy Resource and Technology Managers are a third major group of climate-change scenario users with distinct needs.

Use of Scenarios in Climate-Change Assessments

- Large-scale, official assessments are the major use for scenarios at present, and are likely to remain an important use.
- Within assessments, scenarios are principally used to support further analysis, modeling, and assessment.
- Presentation of scenarios in assessments leads to additional unforeseen uses.
- In assessments, scenarios can be an effective issue-framing device.
- Scenarios contain unavoidable elements of judgment in their production and use.

A Sustained Capacity for Scenarios

- CCSP should provide resources to support a new capacity for to produce, analyze, support, and update scenarios of global emissions and resultant climate change.
- Several institutional models would be feasible for this capacity – US-based or international; governmental, non-governmental, or a multi-party network; producing scenarios, convening activities to produce scenarios, or receiving and reviewing scenarios produced by others.
- Several criteria would have to be met, however, for this capacity to be effective:

- Adequate sustained resources.
- Connections with outside expertise, analysis, models.
- Insulation from political control.
- Maximum transparency.
- A mandate to support development of methods and models.
- Authority for effective coordination and quality control.

What should centrally provided emissions and climate scenarios look like?

- Scenarios should be global in scope and century-scale in time horizon.
- Several distinct logical types of emissions scenarios should be developed, e.g., alternative baselines, alternative degrees of explicitly represented mitigation effort, and alternative environmental targets.
- Emissions scenarios should be based on diverse socio-economic futures.
- Scenarios should reflect various explicit degrees of coordination.
- Global socio-economic and emissions scenarios should include and link qualitative and quantitative components.
- Emission scenarios should connect narratives to model structures, not parameters
- Centrally provided scenarios of global emissions and climate change cannot provide all information needed for either mitigation or adaptation decisions at national or smaller scale.

Scenario Process: Developer-User Interactions

- In general, there are benefits in collaboration between scenario developers and users, particularly at the beginning and ending stages of a scenario exercise.
- The value of such interactions, and the ease of achieving them, are likely to be greater when scenario users are few in number, clearly identified, and similar in their interests and perspectives.

Communication of Scenarios

- Effective communication of scenarios is essential, including the means to reach audiences of diverse interests and technical skills.
- Transparency of underlying reasoning and assumptions is crucial.

Consistency and Integration in Scenarios

- Each scenario needs internal consistency.

- In scenario exercises using multiple models to explore potential future conditions, model inputs should be controlled for consistency, rather than model outputs.
- An important exception to the advice not to control for consistency in model outputs is that such control can be valuable in exercises that specify common output targets for policy evaluation.
- Transparency in reporting model differences, assumptions, and reasoning can help to overcome the presence of some inconsistencies in scenario generation.

Treatment of Uncertainty in Scenarios

- More explicit characterization of probability judgments should be included in some future scenario exercises than has been practiced so far.
- Including explicit probability judgments is likely to be more useful when key variables are few, quantitative outcomes are needed, and potential users are numerous and diverse.
- Including explicit probability judgments is likely to be less useful when scenarios specify multiple characteristics, including prominent narrative or qualitative components; when the purpose of a scenario exercise is sensitivity analysis or heuristic exploration; and when potential users are few, similar, and known.
- The centralized capacity we propose should endeavor to provide probability estimates for global emissions and climate-change scenarios.
- Providing explicit probability and likelihood statements allows users to choose whether to use them or not.
- Scenario exercises should give more attention to extreme cases.

Introduction

This report examines the development and use of scenarios in global climate change applications. It considers scenarios of various types – including but not limited to emissions scenarios – and reviews how they have been developed, what uses they have served, what consistent challenges they have faced, what controversies they have raised, and how their development and use might be made more effective. The report is Synthesis & Assessment Product 2.1b of the US Climate Change Science Program. By synthesizing available literature and critically reviewing past experience, the report seeks to assist those who may be conducting, using, or commissioning scenarios related to global climate change.

Scenarios are used to support planning and decision-making when issues have deep or poorly characterized uncertainty and high stakes, often accompanied by long time horizons. These conditions apply to the major decisions of how to respond to global climate change. As scientific research advances our knowledge of the climate's present state and trends, its patterns of variability, and its responses to external forcings, we are gaining an increasingly clear view of risks that may be realized late this century or beyond. Although this growing knowledge is not fully certain or precise, it shows that these future risks are linked to near-term socio-economic trends and decisions in both public and private sectors. Some near-term decisions – such as investment in long-lived capital equipment in the energy sector, or development of new energy resources and technologies – can exercise long-term influence over trends in the emissions contributing to climate change, and how readily these trends can be deflected in the future. Other near-term decisions – such as investment in long-lived capital equipment in water resources, infrastructure, or coastal development – can exercise long-term influence over how adaptable and how vulnerable future society will be to the impacts of climate change.

Although decisions of all these types are being made in the near term, making them responsibly requires considering their potential consequences over the longer term, including the substantial associated uncertainties. This requires thinking about the future conditions that will shape their consequences, not just next month or next year but 10, 30, 50, or 100 years in the future – longer periods than we are practiced at thinking about systematically, and longer than the horizon of conventional methods of planning or analysis.[2] Attempting to describe potential future conditions over this long time horizon presents a seeming paradox. On the one hand, conditions this far in the future are deeply uncertain, not just in the values of important factors but in the identity of the most important issues and the factors and actors influencing them.[3] On the other hand, we have a great deal of knowledge that is relevant to making informed assumptions about future conditions, even over such long horizons. This includes well established scientific knowledge about physical, chemical, biological processes; more weakly, certain relatively well established mechanisms of causal influence in the domains of economics, sociology, and politics; and more weakly still, certain seemingly robust empirical regularities in patterns of historical change in population, economics, and technology. These all provide some guidance to support judgments about future conditions that are more or less likely, virtually

[2] Morgan et al 1998.
[3] Lempert et al 2006.

certain, or virtually impossible. In some respects we might be highly confident that the future will resemble the present, e.g., in the radiative properties of atmospheric trace gases. In others, we might judge it highly likely that future conditions will lie within some envelope extrapolated from present conditions and recent trends, e.g., in projecting rates of change in fertility, mortality, or labor productivity. In still other areas, such as the development and social consequences of major technological advances, or large-scale political events such as wars, political realignments, or epidemics, there may be more fundamental uncertainties, which might be adequately represented as larger uncertainty bounds on known quantities or might represent discontinuities or other changes that lie outside what we can presently imagine.

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

Early climate-change debates mainly concerned scientific questions such as whether and how the climate is changing, how much change is being caused by human activities, and how sensitive the climate is. Scenarios did not figure prominently in these early debates. As climate science has advanced, however, many former disputes have been clarified or settled and many remaining uncertainties have been better characterized. As this advance of knowledge has increasingly shifted the climate-change debate from confirming and describing the problem toward deciding what to do about it, the need for long-term decision-support tools like scenarios has increased, as has the scrutiny and criticism these have attracted.[4] In a contentious public-policy area like climate change, controversy over scenarios is to be expected: scenarios are a method to structure and communicate the most important uncertainties, and conflicting judgments about uncertainties are a major source of disagreements over what to do. Consequently, we expect the trend of scenarios' increasing prominence and contentiousness to continue – particularly for emissions scenarios, since these are the relevant metric of human environmental burden and the point of most contested proposed intervention.

In this report, we try to cast some light on current and coming debates over climate-change scenarios. These debates are presently quite confused, to the level of basic confusion about what "scenario" means, what purposes scenarios are used for, and what benefits they can provide. We aim to provide clarification and practical advice to two related audiences: those conducting climate-change assessments or analyses that involve developing or using scenarios; and those commissioning, receiving, or using these products. For the first group, we seek to provide an organized summary of relevant experience in past similar efforts, discussion and clarification of key choices and challenges, and – to the extent present knowledge allows – practical guidance regarding pitfalls, challenges, and opportunities in particular approaches. For the second group, we seek to provide guidance on what to ask for, how much and in what way to be involved in its production, how to interpret what you get, and what questions to ask.

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[4] E.g., See, e.g., Lomborg, Michaels, Castles and Henderson, UK House of Lords.

Because the charge of this report is quite unlike those of other Synthesis and Assessment products, the approach we have taken to producing it is necessarily different as well. We were not tasked with a focused question about present knowledge, and there is not a well developed scientific literature on which we can draw for answers. Rather, we were tasked with reviewing, interpreting, and evaluating experience with scenario methods in global climate change applications. To accomplish this, we have engaged in several different types of activity. We have reviewed the existing literature on scenarios, most of it concerned with scenarios in other decision domains than global climate change. We have reviewed several major recent exercises that have used scenarios in global-change applications. In this review, we have drawn on published materials, both publications from the exercises themselves and published commentary and criticism, as well as documentary materials and records, interviews with participants and users, and the experience and judgments of team members.

It is important to note that our review of global-change scenario experience has not been entirely independent, since members of this writing team were involved in two of the scenario exercises we review, the IPCC SRES process and the U.S. National Assessment, as participants, reviewers, and critics. While we have drawn on the experience of these team members, we have attempted to limit the risk of idiosyncratic interpretations and bias by drawing on other sources as well, and by engaging all team members in developing our summary and discussions of these exercises. Moreover, our purpose is not to either attack or defend these past exercises, but to seek to understand the decisions they made, the factors that influenced them, and the constraints under which they operated, in order to assess their experience, identify both successes and pitfalls, and to the extent possible, provide guidance to advance the practice of scenario methods for climate change and other similar environmental issues. Because the experience we review does not provide a sufficiently large, well defined, or random sample to support strong scientific inference, the diagnoses, interpretations, and recommendations we present rely on our collective judgment in view of the information and experience we have reviewed. We have endeavored to follow our own advice to scenario developers, and be as transparent as possible about the foundation and reasoning underlying our conclusions and recommendations.

The report is organized as follows. Drawing on the broader literature on scenarios – most of which concerns domains other than climate change – Section 1 introduces scenarios, sharpens their definition, and outlines a few major dimensions of variation and decisions that must be made in developing a scenario exercise. Section 2 focuses specifically on scenarios for global climate change, and outlines the types of decisions that could use scenarios and the main types of scenarios that have been developed for this issue. Section 3 reviews four major experiences in developing and using global-change scenarios. Section 4 discusses several key issues that have posed particular challenges in climate-change scenarios and that are likely to require particular attention in designing new scenario exercises. In addition to drawing on the material in Section 3, this discussion also takes advantage of briefer discussions of eight other examples of global-change scenario development or use that illustrate particular issues or challenges, which are presented as short boxes spread throughout Section 4. Section 5 provides our conclusions and recommendations for future development and use of global climate-change scenarios.

1. Scenarios, their Characteristics and Uses

1.1 Defining Scenarios

A scenario is a description of potential future conditions, which is developed to inform decision-making under uncertainty. The decisions in question can be by individuals, groups, organizations, or governments, and may pertain to any subject matter. The potential future conditions described in a scenario can also pertain to any subject matter, whatever is judged necessary or useful to probe and inform the decisions at issue. While many writers on scenarios give no explicit definition, others have offered a wide range of definitions, many of them substantially more complex and restrictive than the simple one we offer here. The collection of published definitions gathered in Box 1.1 gives a sense of both the broad commonalities among many analysts' conceptions of scenarios, and the significant differences among them.

> ***Box 1.1. Scenarios: a Sampling of Published Definitions.***
>
> A scenario is a coherent, internally consistent, and plausible description of a possible future state of the world.[5]
>
> A scenario is a story that describes a possible future. It identifies some significant events, the main actor and their motivations, and it conveys how the world functions. Building and using scenarios can help people explore what the future might look like and the likely challenges of living in it.[6]
>
> Scenarios are images of the future, or alternative futures. They are neither predictions nor forecasts. Rather, each scenario is one alternative image of how the future might unfold. A set of scenarios assists in the understanding of possible future developments of complex systems. Some systems, those that are well understood and for which complete information is available, can be modeled with some certainty, as is frequently the case in the physical sciences, and their future states predicted. However, many physical and social systems are poorly understood, and information on the relevant variables is so incomplete that they can be appreciated only through intuition and are best communicated by images and stories. Prediction is not possible in such cases.[7]
>
> A climate scenario is a plausible representation of future climate that has been constructed for explicit use in investigating the potential impacts of anthropogenic climate change. Climate scenarios often make use of climate projections (descriptions of the modeled response of the climate system to scenarios of greenhouse gas and aerosol concentrations), by manipulating model outputs and combining them with observed climate data.[8]

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[5] IPCC TAR WG2, p. 149.
[6] Shell International 2003.
[7] IPCC SRES, pg. 62.
[8] IPCC TAR WG1, p. 741.

> (Scenarios) are created as internally consistent and challenging descriptions of possible futures. They are intended to be representative of the ranges of possible future developments and outcomes in the external world. What happens in them is essentially outside our own control.[9]
>
> Scenarios are coherent, internally consistent and plausible descriptions of possible future states of the world, used to inform future trends, potential decisions, or consequences. They can be considered as a convenient way of visioning a range of possible futures, constructing worlds outside the normal timespans and processes covering the public policy environment.[10]
>
> Scenarios are plausible, challenging, and relevant sets of stories about how the future might unfold. They are generally developed to help decision-makers understand the wide range of potential futures, confront critical uncertainties, and understand how decisions made now may play out in the future. They are intended to widen perspectives and illuminate key issues that might otherwise be missed or dismissed. The goal of developing scenarios is often to support more informed and rational decision-making that takes both the known and the unknown into account.[11]

The historical roots of the use of scenarios for planning and analysis lie in war games, exercises of simulated conflict used for military training, planning, and operational decision-making. Although the first formalized war games were developed for officer training in 19th-century Prussia – and their benefits sometimes credited for the Prussian victory in the Franco-Prussian war of 1870-1871 – the roots of war games and related activities extend to antiquity.[12] In the 1940s and 1950s, exercises resembling war games began to be applied outside the purely military domain, to study potential international crises that included both high-level political decision-making and the potential for military conflict. These exercises were informed by the then-new field of game theory, which promised new formal insights into situations of conflict and strategic decision-making,[13] and motivated by the recognition that the new nuclear age had both raised the stakes of international diplomacy and created profound new uncertainties over how to proceed. In these exercises, principally developed at the Rand Corporation, scenarios provided sketches of challenging but plausible situations to which participants had to respond, allowing exploration of associated threats and opportunities. They adopted the term "scenario" from film and theatre, where it denotes a brief sketch of a story that includes only enough detail to convey broad points of plot and character. As in classic war-games, scenarios in these exercises served to help organizations and their leaders prepare for novel, complex challenges that their normal procedures and planning devices might not anticipate, and which – if they did arise – would likely develop too fast to allow adequate reflection or analysis in real time.[14]

9 van der Heijden 1996, p. 5.
10 Berkhout et al 2001, pg. i.
11 MEA 2006. p. xvii.
12 Brewer and Shubik 1983.
13 Von Neumann and Morgenstern 1942; Nash 1950
14 Brewer and Shubik 1983.

Over the past few decades, the use of scenarios has broadened further still, moving outside the realm of military and diplomatic activity. Practice extended from Rand to other organizations, particularly developed in strategic planning at Royal Dutch/Shell.[15] Scenarios are now widely used for strategic planning, analysis, and assessment by businesses and other organizations. They have also figured increasingly prominently in planning, analysis, and policy debate for long-term environmental issues, in particular global climate change. Because the total body of experience with scenarios provides useful insights into their use in any particular domain, this section elaborates on the meaning, characteristics, and potential uses of scenarios in general. The next section turns to their specific use for global environmental issues.

Distinguishing Scenarios from Assessments, Models, and Analyses

Confusion is widespread in discussions of scenarios, in part because their form and usage is highly diverse and in part because many writers' uses of the term are often imprecise and occasionally contradictory. To clarify and sharpen meaning of "scenario" beyond the simple definition provided above, scenarios must be distinguished, on the one hand, from the various types of assessment, decision support, or analysis that often use scenarios; and, on the other hand, from other types of statements about future conditions, such as predictions, projections, or forecasts.

An assessment is any process that reviews and synthesizes scientific or other expert knowledge to provide information of relevance to policy or decision makers.[16] There are many possible ways of doing assessments. While the most common methods are deliberations of expert panels and formal models, there are also other methods that combine human deliberations with formal analysis or modeling, diverse in their particular forms and names, including simulation games (including war and crisis games), policy exercises, political-military exercises, constructing future histories, backcasting, and others.[17] These methods may use specifications of potential future conditions – i.e., scenarios – as an input to or a component of their work. Scenarios may even be essential for some of these methods. For example, a war or crisis gaming exercise needs a scenario that specifies the nature of the threat or crisis, while a formal model used to represent future development of some issue of concern needs a scenario to specify future values of those inputs not explicitly calculated within the model. But these methods are broader than and distinct from scenarios. For example, models can be used in other modes than representing future developments – e.g., to reconstruct past conditions or study causal processes – in which case they do not need scenario-based inputs. The distinction between assessments and scenarios is perhaps clearest in conventional assessments based on deliberations of expert panels, such as the IPCC, US National Assessment, or Millennium Assessment.[18] Such assessments often construct representations of future development of an issue, usually based on formal models. These representations require scenario-based inputs, and may produce outputs

[15] Relevant history in: Hausrath 1971; Shubik 1975; Greenberger et al 1983; Schoemaker 1995; Schultz and Sullivan 1972; Schwartz 1991; Shell International 2003.

[16] Parson 2003, p. 89; Mitchell et al 2006.

[17] NRC 1996; Hausrath, 1971; Brewer, 1986; Shubik 1975; Svedin and Aniansson, 1987; Schultz and Sullivan, 1972; Jones 1985; Parson 1996, 1997.

[18] IPCC TAR, USNA, MEA.

that are themselves used as scenarios in other activities. But the scenario-related activities are frequently a small part of the overall assessment, which may also examine the state of knowledge in particular scientific areas, the status of and trends in particular environmental conditions, the evidence attributing particular environmental changes to particular human inputs, or particular policy-relevant scientific questions. Assessments may also include explicit evaluations of proposed actions or proposed criteria for conducting such evaluations. For many of these assessment methods, scenarios may provide required inputs but are distinct from the assessment activities themselves.

Distinguishing Scenarios from Projections, Predictions, and Forecasts

Scenarios must also be distinguished from other types of statement about the future, such as predictions, projections, and forecasts. This is a subtler task than distinguishing scenarios from assessments and models, because all of these satisfy the basic definition above: they are descriptions of potential future conditions whose primary purpose in most cases is to support decisions. Examining the ways scenarios are used and discussed by practitioners and researchers suggests four characteristics that distinguish scenarios from these other types of future statement. Although these characteristics are not essential, they are all more likely to be present in scenarios than in other types of future statement, so they sharpen and delimit what is meant by a scenario.

First, scenarios are multi-dimensional: they describe multiple characteristics that collectively make up a coherent representation of future conditions. To achieve this, scenarios assemble and organize available knowledge, information, and assumptions from diverse bodies of research and expert judgment. The elements of a scenario can be of diverse types: quantitative or qualitative, defined precisely or fuzzily, based on well established research or informed speculation. Effective scenarios integrate their diverse elements in a way that is coherent, that communicates a clear theme or organizing principle, and that to the extent present knowledge allows, avoids internal contradiction.

Second, scenarios are schematic: that is, they are multidimensional, but not without limit. Scenarios do not seek to describe potential future conditions with complete precision or detail. Rather, they highlight essential characteristics and processes with enough detail that knowledgeable observers perceive them as realistic and relevant, but not so much detail as to distract from large-scale patterns. Since one benefit scenarios sometimes provide is to stimulate creative thinking and insights, they must leave something to the imagination. How much detail and precision is appropriate in each case is a judgment that depends on the particular application.

Third, scenarios tend to come in groups. To be a useful tool to inform decision-making under uncertainty, scenarios must represent uncertainty. This is usually done by providing multiple scenarios, each presenting an alternative realization of uncertain future conditions.[19] How many scenarios are appropriate depends on the particular application. Scenario exercises usually use between two and seven, depending on the stakes of the issue being examined, the resources invested in the exercise, and the depth of analysis devoted to each scenario. The most

[19] Crisis-response exercises are often an exception, presenting one scenario at a time showing a novel challenge to which participants must respond, and which is implicitly contrasted to the status quo.

frequently proposed number is three or four. Three scenarios permit exploring one dimension of uncertainty, perhaps with a surprising or challenging scenario added as a wild card. Four scenarios permit joint exploration of two outcomes for two top-priority uncertainties.

Finally, scenarios usually claim less confidence than other types of future statements. Although different authors' usage is not consistent, "prediction" and "forecast" usually denote statements for which the highest confidence is claimed. "Projection" denotes a less confident statement, which may have some specified confidence level and may be explicitly contingent on specified assumptions about other future conditions. Calling a future statement a "scenario" usually implies still less confidence and more associated contingencies. Any use of a scenario for serious planning or analysis does, however, presume some minimal, threshold level of likelihood. The situation described, or something like it, must be judged sufficiently likely to merit attention, and to justify expending resources and effort to study its implications and potential responses to it. There may also be a time ordering among these three types of statements – predictions or forecasts tend to describe nearer-term futures and scenarios longer-term futures – but there are exceptions, and the meaning of near-term and long-term depend strongly on the particular context.

1.2. Creating a Scenario Exercise: Key Characteristics and Choices

Beyond these general characteristics, there is great variation in what scenarios are used for, how they are produced, and what they contain. Usage and understanding is so diverse that extensive scholarly effort has been spent providing alternative scenario taxonomies.[20] Scenarios can be distinguished, for example, by whether they present a snapshot of a future state or a dynamic account of changes over time to reach that state; by their degree of complexity; by the relative balance of deliberation and intuition versus formal analysis used in producing them; or by their temporal and spatial scale. Because the set of characteristics on which scenarios could be sorted is long and open-ended, we do not attempt to define an exhaustive list of categories. Instead, we provide a partial summary of the main dimensions of scenario diversity below in a set of potentially open-ended design choices that must be made in developing a scenario exercise.

Variation among Assessments: Three Basic Dimensions

There are, however, three dimensions of scenario variation that are more fundamental and that we discuss separately. These concern the purpose of a scenario exercise, and have far-reaching implications for its design and use. First, the intended use of a scenario exercise can vary from more predictive to more exploratory or heuristic. In the extreme, this distinction can degenerate into a straw man, in that writers on scenarios are far more likely to criticize other uses of scenarios as being inappropriately predictive than to state that they are using them predictively themselves. It is of course a fundamental and potentially dangerous error to take an illustrative description of potential future conditions in a scenario as a confident prediction of what will actually happen – in our terminology above, to take a scenario as a projection or even a

[20] See, e.g., Duncan and Wack 1990; Godet and Roubelat 1996; van Notten et al 2003.

prediction.[21] Still, as we argue above, the decision to invest effort into developing a scenario implies some threshold level of judged likelihood sufficient for it to be worth the attention of busy people. Exploratory uses of scenarios may presume no higher likelihood than this low threshold, yet have great value. For example, scenarios can be used to probe and challenge the mental models, thought habits, and unrecognized presumptions of decision-makers, and to seek insights into potentially unrecognized opportunities, risks, causal linkages, or uncertainties.[22] While we have described the primary purpose of scenarios as supporting decision-making under uncertainty, such insights can arise not just from examination of uncertainties, but also from meticulous critical examination of future factors that are essentially certain, e.g., strongly determined demographic trends such as the aging of industrialized-country populations, or even of present conditions whose significance had not been appreciated.[23] For example, in a cold-war crisis exercise on a Soviet invasion of Iran, one participant realized that the supply of jet fuel locally available to support a rapid US response was ten times larger than had been thought, because kerosene – an acceptable substitute – was used for domestic cooking and heating.[24] Still, the predictive confidence or belief accorded to scenarios is a matter of degree, and when carefully developed scenarios are judged to have captured the most important uncertainties, it may well be appropriate to impute some moderate degree of confidence, particularly to a set of scenarios – the appropriate unit of evaluation – and even in some conditions to a particular scenario. The appropriate degree of confidence will vary, and reasonable distinctions may be drawn between scenarios that represent conventional versus surprising futures, the playing out of present trends versus surprising discontinuities, best and worst cases, etc.

A related dimension of variation among scenario exercises is their proximity to decision-making – i.e., to decisions not just concerned with other scenarios, assessments, analysis, and research.[25] In some uses, scenario exercises may involve actual decision-makers and seek to directly advise a specific, identified, near-term decision, but more frequently their relationship to concrete decisions and decision-makers is indirect. They may be used for risk assessment, contingency planning, identification of potential threats or actions to be considered, or to provide early characterization of a poorly understood issue. In such applications, the exploratory uses of scenarios discussed above tend to dominate. They can help clarify the importance of an issue, frame a decision agenda, shake up conventional thinking, provoke creative insights, clarify points of agreement and disagreement, identify and engage needed participants, or provide a preliminary structure for advance analysis of potential future decisions – i.e., generally promoting learning about a poorly understood issue and the implications of alternative responses to it. Scenario exercises that are closer to, and expected to contribute to, decisions with significant stakes, operate under quite different requirements, which are likely to be driven by specific user needs. Their uses are likely to be more predictive rather than exploratory – constrained, one hopes, by the limits to available knowledge and uncertainties – so they might be expected, for example, to provide more explicit and complete characterization of major

[21] Several such errors are collected and discussed in Bracken 1977 and Brewer 1992.

[22] Brewer 1992.

[23] Shell International 2001, 2003.

[24] Schelling 1964.

[25] This dimension is presented by Van Notten et al 2003 as “exploration” versus “decision support.”

uncertainties. They are also likely to be more integrated with explicit methods to evaluate alternative courses of action and identify preferred ones.

A third basic dimension of variation concerns whether scenarios are defined primarily normatively, on the basis of their perceived desirability or undesirability, or primarily on the basis of their perceived plausibility or likelihood. While all scenarios include both positive and normative elements, it is important to avoid confusing the two and keep as clear as possible which elements are included based on perceived likelihood or plausibility, which elements because of perceived desirability or undesirability.

The most frequent use of explicitly normative scenarios involves constructing some hypothetical future end-state primarily on the basis of its desirability. Such a future end-state might be constructed to embody participants' general intuitions about desirable social trends, or to achieve specific environmental, development, or other goals.[26] The scenario exercise then consists primarily of "backcasting" – attempting to construct paths that connect present conditions to the specified future target conditions, to elaborate conditions jointly sufficient to either attain or miss the target, examine the feasibility of the target, and identify costs and tradeoffs associated with meeting it.[27] Similarly, one can posit an undesirable future state and then reason through conditions associated with avoiding it. This approach is sometimes proposed to reduce the risks of hidden bias in construction of scenarios which, like any form of assessment or policy analysis, can be misused to provide legitimation for a decision already made for other reasons, rather than to inform a decision not yet made. By bundling normative assumptions into the future target state or boundary conditions, it is hoped to reduce their penetration into the subsequent instrumental reasoning about actions and conditions that are more or less likely to reach the specified target state. (Of course, this approach does not eliminate the possibility for such misuse: if a particular goal or action is strongly desired, scenario developers are at risk of biasing the analysis, whether consciously or not, to make the target appear easy to achieve or the action clearly preferable. Japanese war-games prior to the Battle of Midway provide striking examples of scenarios biased to exaggerate the perceived feasibility of a course of action.[28]

Developing Scenarios: Main Dimensions of Choice

Table 1.1 extends the preceding discussion, summarizing the main areas of variation and choice involved in constructing a scenario exercise. This is a highly simplified representation of a complex process. In any particular scenario exercise some of these choices may be made by default, without explicit consideration, perhaps because the preferred choice is immediately obvious in context. Moreover, although we present these choices in simple sequential order for clarity of exposition, this order is not necessary or normative: choices might be made in some other order, or repeatedly and iteratively adjusted. But while the process and sequence of

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[26] See, for example, the simple scenario exercise in NRC 1999 (pp. 161-176) that posited specific targets to reduce world hunger and greenhouse-gas emissions by year 2050.

[27] Robinson 1982a, 1982b.

[28] Bracken 1977.

choices may be idealized, the set of choices is not: creating a scenario requires a choice, explicit or implicit, on each of these design dimensions.

Table 1.1 Idealized Sequence of Major Choices in Scenario Development.

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

The most basic decision in developing scenarios is identifying the main focus of the exercise: what issues are the scenarios intended to address, or what decisions are they intended to inform, for whom? This basic definition of a scenario exercise includes specifying the three characteristics discussed above. The mere fact that a decision has been made to conduct a scenario-based exercise does not necessarily mean that these matters are clearly understood. The closer a scenario exercise is to concrete decisions, the more likely it is that these definitional issues will be understood clearly, in part through discipline on the process imposed by the involvement of decision-makers. But most often, the coupling of scenarios to decisions is relatively weak.[29] In some applications (e.g., corporate strategic planning, responding to a novel military threat) the relevant decision-makers may be clearly identified at the outset, but the issues to be addressed and relevant decisions may not be. In other applications, scenarios may be developed to address some broad issue or concern (e.g., climate change, emerging infectious diseases, or terrorism), but the potential users and decisions to be informed might both be unspecified. Clarifying the overall focus of a scenario exercise may require broad consultations or scoping workshops involving many potentially interested decision-makers, other stakeholders, and analysts and researchers. But whether the relationship of a scenario exercise to decisions is near or far, direct or indirect, clear understanding of its focus and purpose is important, and infrequently achieved: many scenario exercises muddle through with vagueness, confusion, or disagreement regarding the focus, purpose, and intended user of the exercise.

Once the principal focus and purpose of a scenario exercise is well enough established, a second basic set of decisions concerns the process by which the scenarios will be developed. As with deciding the focus of the exercise, decisions about the process of developing scenarios often receive little thought, or are not even explicitly recognized as choices, but they are nevertheless highly consequential. What range of expertise must be included to ensure the scenarios adequately reflect the best available scientific knowledge, data and models? What range of

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[29] E.g., note the predominance of scenarios on the "exploration," rather than the "decision support" side in the survey of Van Notten et al 2003.

decision-makers, stakeholders, or surrogates for these must be involved to keep the scenarios relevant, plausible, and credible? For scenario exercises that must integrate knowledge across diverse domains, choosing individual participants for their knowledge, flexibility, and boldness of imagination can be as important as the disciplines or stakeholder groups they represent. How intensively, for how long, and by what means will these participants interact? Will the scenario development process be open to outside observers or participants? How and when will feedback and criticism on the scenarios be sought, and how will it be used? How and to whom will the scenarios, and information about the process and reasoning underlying them, be communicated? And crucially, how will be process be led, and how will disagreements be resolved? With good process management, resolving differences in a scenario exercise can be more illuminating and less arbitrary than in other collaborative tasks, because when disagreements persist after careful critical examination, these can be treated as important uncertainties to be retained as alternative scenarios, not suppressed by picking a winner, splitting the difference, or retreating to vague language.

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

What uncertainties are to be explored, and how? There may be many dimensions of uncertainty relevant to the issue being examined, but only a few can be examined explicitly in any scenario exercise. The selection and definition of these few is a crucial act of framing and judgment that shapes much of what follows in a scenario exercise. For those uncertainties judged most important, alternative outcomes are usually represented in alternative scenarios. For example, scenarios might represent high-growth and low-growth futures, or alternative forms that a competitive threat might take. Other uncertainties judged to be less crucial are typically represented by a single “best guess” or “reference case.” For the few uncertainties explicitly represented by alternative scenarios, how they are represented – as realized in the number and character of the scenarios based on them – also depends on the intended use. A particular uncertainty might be represented by high and low values of some quantity, or by a middle or reference case supplemented with high and/or low variants. If two or more uncertainties interact with each other, they can be represented by scenarios that combine different outcomes of each: in the simplest form, the interaction of two realizations of two key uncertainties can be represented by four scenarios, presented as a two-by-two matrix.[30] Several alternative scenarios might seek to span the plausible range for some key quantitative variable, or present distinct qualitative outcomes for a single uncertainty, e.g., three different types of competitive threat, or three alternative political futures for a region in turmoil. Alternatively, scenarios can represent plausible extreme or “worst-case” scenarios, to assess the robustness of decisions or strategies. These choices are discussed in Section 4.2.

How rich and complex should each scenario be? Defining scenarios as multivariate but synoptic, as we have done above, still leaves a vast range of levels of complexity to choose from.

[30] Alternative interpretations of this matrix structure are discussed in van’t Klooster and van Asselt 2006.

At one extreme, many scenarios only specify time-paths for a few quantitative variables, or just one. This is by far the most frequently used type of scenario, common in such applications as analyzing a firm's profitability under alternative scenarios for oil prices, or projecting tax revenues under alternative scenarios of productivity growth and inflation, often in a standard "high, middle, low" format. A scenario can accommodate more complexity by projecting additional quantitative variables, but as the number of variables increases, so also does the need for an organizing principle or gestalt to tie them together in a non-arbitrary way.

At the other extreme, the core of a set of scenarios can be a set of rich, coherent narratives. This approach is frequently called the Shell approach, because its methods have been extensively developed since the 1960s in the corporate strategic planning offices of Royal Dutch/Shell, extending earlier work at the Rand Corporation and elsewhere.[31] Each narrative, described principally in text, reflects a distinct conception of how the world might develop with a persuasive underlying causal logic. A narrative scenario can stand alone without any quantitative variables, but may also include specifications of time-paths of important quantitative variables, e.g., of population or economic growth, that are consistent with the broad causal logic underlying the scenario. The narrative provides the context and explanatory logic that tie together the time-paths of quantitative variables and relations among them, although the particular time-paths are regarded as illustrative quantifications of the scenario, not the scenario itself. While particular time-paths need to be specified, somewhat different paths would still be consistent with the scenario. A different scenario would imply substantial differences in trends of, and relationships among, the quantitative variables.

The choice of how rich and complex to make scenarios has far-reaching implications for the process of developing the scenarios, what can be done with them, and the uses they can serve. The two extreme approaches imply large differences in how uncertainty is treated, what aspects of the problem receive attention, and the relationship between scenarios and their users, which we discuss for climate-change scenarios in Section 4. In addition, many practical aspects of running a scenario exercise depend on this choice. For example, richer and more complex scenarios require more time and effort to develop, so fewer can be produced. Complex narrative-based scenarios may require many person-months to develop realistic and persuasive narratives, to test whether relationships among scenario elements are persuasive and consistent with present knowledge, and to repeatedly check for plausibility and relevance to users.[32] In return for the extra effort, this approach allows much more flexibility in the way potential futures are described. Narratives can convey different aspects of a future situation with varying degrees of salience or specificity, and they can compactly convey the tone or character of a future situation by allusion, where a precise specification would appear arbitrary or labored. The narrative approach avoids limiting the defining characteristics of a scenario to any particular set of pre-specified variables, but attempts to be alert to a wide range of potentially important characteristics and mechanisms of causal influence. Proponents of this approach argue that a coherent narrative at the core of a scenario is necessary to avoid arbitrariness in specifying

[31] Van der Heijden 1996; Wack 1985a, 1985b; Schwartz 1991; Shell International 2003.

[32] Note that quantitative scenarios are not necessarily cheaper or easier to develop. The complex models used to develop quantitative scenarios may embody many years of work.

multiple variables, and to make the exercise useful to decision-makers: e.g., "Most scenarios merely quantify alternative outcomes of obvious uncertainties (for example, the price of oil may be $20 or $40 a barrel in 1995). Such scenarios are not helpful to decision makers".[33]

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

The discussion in this section has concerned the uses, types, and characteristics of scenarios broadly, in any application area. The next section narrows the focus to climate change and related areas of global environmental change, summarizing the types of scenarios that have been used and proposed, and that might be required, to explore and inform decision-making in this area.

[33] Wack 1985a, p. 74.

2. Scenarios in Global-Change Analysis and Decision Support

There have been efforts to develop scenarios for global environmental change issues since the 1970s, beginning with the global models of the mid-1970s and the attempts to use scenario-based thinking in early assessments of acid rain and stratospheric ozone in the late 1970s and early 1980s.[34] The motivations for using scenarios in global change are similar to those that apply to other decision domains: high-stakes decisions that must be made under deep uncertainty about the conditions that will determine their consequences, the values at stake, or the relevant set of choices and actors. As in other domains, well designed scenario exercises can provide a structure for assessing alternative choices, and can help focus broader investigation of the nature of the issue, the relevant choices and actors, the values that might be at stake, and the types of research or analysis that might help clarify preferred choices.

Focusing more narrowly on climate change rather than other linked aspects of global environmental change, several scenario exercises have been conducted that are diverse in form, details, and purposes. These have been conducted and sponsored by governments, international organizations, non-governmental organizations, and collaborative activities involving several of these groups. These have tended to focus more on heuristic and exploratory uses than on supporting specific decisions. In part, this focus may reflect the fuzzy boundaries of the climate-change issue. Climate change implicates and connects to multiple existing areas of policy, including energy, agriculture, hazard protection, and the broadest questions of economic development. Moreover, the agenda of relevant decisions is only partly established and clarified: while there are some decisions clearly of primary relevance to climate change, many decisions and policy areas that appear to be connected have not yet incorporated consideration of climate change or even recognized the connection. Indeed, there remains substantial uncertainty about what all the relevant decisions, decision-makers, and potentially affected values are. The vague boundaries of the climate-change issue extend to attempts to use scenarios to inform the issue, in that there has been substantial overlap between scenario exercises developed for climate change and other exercises primarily focused on ecosystems, energy, and broad issues of world development. While the fuzziness of the issue's definition increases the challenge of developing useful scenarios, it also increases the potential value of well crafted and executed scenario exercises, which can help to clarify precisely these obscure issues.

2.1. Climate-Change Decisions and Potential Contributions of Scenarios

Decisions related to climate change are conventionally sorted into two categories, mitigation and adaptation.[35] Mitigation consists of actions that reduce the human perturbations of the climate system, by reducing net anthropogenic greenhouse-gas emissions or other stresses such as land-use change. Adaptation consists of actions to reduce the harm or increase the

[34] See, e.g., Meadows et al 1972, Barney et al 1982; summary of early ozone assessments in Parson 2003. What was the earliest scenario work in global change depends, of course, on how the boundaries of global change are defined. Herman Kahn's "The Year 2000" (1964) might be considered an early example.

[35] While this categorization has frequently been criticized for neglecting actions with overlapping effects and the third category of direct interventions in the climate system (Schelling 1983; Keith 2000; Keith et al 2006; Parson 2006), it remains a useful approximation for most currently proposed responses.

benefit from climate change and its impacts. Despite uncertainty about the precise decision agenda, we can identify in general terms the type of information scenarios might provide that would be useful to each type of decision.

Adaptation-related decisions will typically concern planning, investment, and management decisions for resources, assets, or values that are likely to be affected by climate change, such as coastal zones, water-management systems, forests, or farms. The relevant decision-makers can be either private or public actors – e.g., owners or managers of long-lived assets such as ports or water-management facilities, public health authorities, officials making zoning or coastal development policy, or firms in insurance or financial markets who may bear secondary risks from impacts or seek to develop new instruments to exchange these risks. Many of the decisions will concern highly specific assets or resources that might be at risk – e.g., how high shall we build this oil-drilling platform, or should this town modify its zoning requirements for coastal property – although some decision-makers, principally in the public sector, will have responsibilities related to multiple specific impacts.

The relevant decisions will have many time-scales of effect and response: e.g., some decisions such as what varieties to plant, can be revised frequently (in this case annually) and have consequences extending over a similarly short time horizon. Others may have tails of consequences, and implied commitments ranging from several decades (e.g., what range of flood conditions to consider in designing and building a water-management system), or even centuries (e.g., location decisions for key infrastructure investments such as roads or other transport right-of-way, coastal facilities, and water and sewer systems, which can influence subsequent settlement patterns for far longer than the lifetime of the original investment)

To help inform adaptation decisions, scenarios might help to characterize the nature and severity of relevant potential impacts; identify key vulnerabilities, particularly those that might not otherwise have been recognized; identify research or monitoring priorities that might give advance warning about impacts, particularly acute vulnerabilities; help to expand the perceived set of potential responses;[36] and provide a framework for evaluating alternative adaptation measures: feasibility, effectiveness, cost, tradeoffs with other values. They may also help to clarify the structure of overlapping time-horizons of relevant decisions, helping to identify those near-term decisions that might have important but under-recognized connections to future impacts and vulnerability.

Mitigation-related decisions are also highly diverse in character, and in who makes them for what reasons. They include explicit adoption of policies to influence future emissions, at the national, international, or sometimes sub-national level, but also many investment decisions, private and public, in energy resources and equipment that produces, processes, or uses energy and in research and development of related technologies. As with adaptation decisions, scenarios can help inform these decisions in part by characterizing the potential impacts of climate change and their severity, since these provide motivation for mitigation. But in addition, mitigation decisions can benefit from information about potential emissions trends, which determine the nature of the challenge of limiting emissions; about potential pathways of the

[36] Schelling 1983.

extraction and depletion of current energy resources and development of new ones; and about potential pathways of technological development that will influence energy demand and the availability of energy supplies with various levels of emissions. Mitigation decisions may also benefit from scenarios representing potential policy context in which they are made.

2.2. Scenarios for Climate-Change Modeling, Assessment, and Analysis.

We now shift from how scenarios could in principle inform global-change decisions to how they have principally been developed and used to date. To date, most uses of global-change scenarios have been embedded in larger exercises of assessment, modeling, or analysis that seek to characterize the climate-change issue. These uses have included formal integrated-assessment models,[37] comprehensive assessments conducted by multi-disciplinary expert bodies (e.g., IPCC), and more narrowly focused assessment exercises targeting specific aspects of the climate-change issue. In these uses, scenarios represent components of the climate-change issue that are required inputs to an assessment or model.

The causal logic of the climate-change issue is complex, including multiple two-way causal links and feedbacks between socio-economic, geophysical, and ecological systems. Integrated-assessment models seek to represent many of these linkages and feedbacks explicitly: Figure 2.1 shows a typical example of the "wiring diagrams" used to illustrate these linkages and feedbacks. Such models have increasingly sought to add causal links and feedbacks to represent real dynamics of the climate issue, making their causal logic increasingly dense and complex. But while such diagrams might be taken to indicate that all relationships are represented explicitly within the model – endogenously – this is not the case. All models of the climate-change issue rely on scenarios to specify some future quantities exogenously, and in virtually all cases, scenario-specified inputs are not modified to account for results of the subsequent analysis: i.e., they are truly exogenous, and the causal logic does not close.

When scenarios are used to specify exogenous inputs to a model of some aspect of the climate-change issue, the causal logic of the analysis can be greatly simplified from that shown in Figure 2.1. Instead, the logic of the issue can be represented by a simple linear structure that extends from human activities to emissions to climate change to impacts. This highly simplified causal structure is illustrated in Figure 2.2. This representation is even more suitable for the uses of scenarios in other types of global-change assessments, which have been organized around much simpler causal structures than those that integrated-assessment models seek to represent. Note that we are not claiming this simple logical structure adequately represents the true structure of the climate-change issue: only that it illustrates the ways that scenarios are used to provide exogenous inputs to global-change models and assessments.

[37] Weyant et al 1996; Parson and Fisher-Vanden 1997.

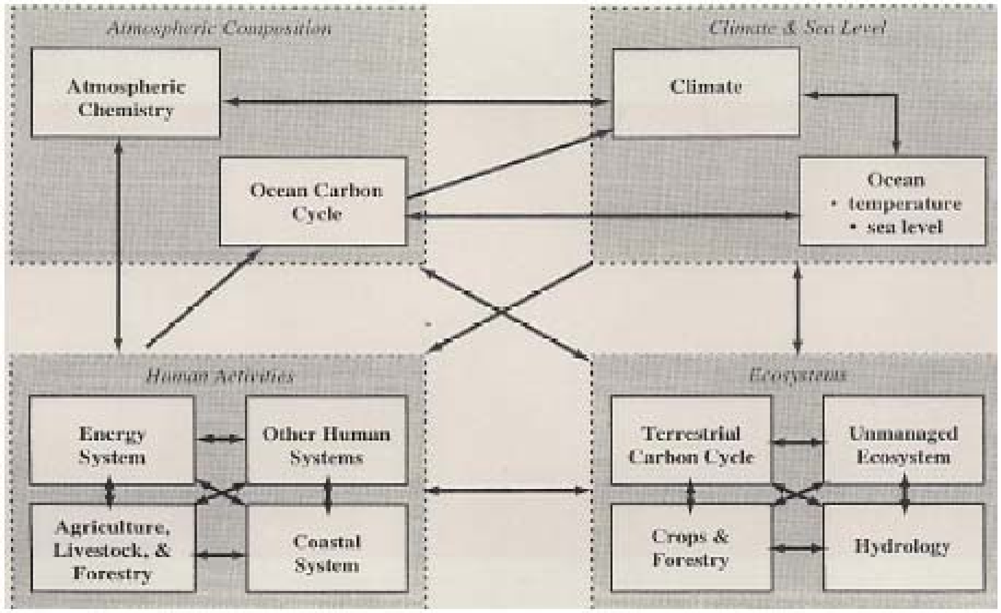

Figure 2.1: Wiring Diagram for Integrated Assessment models of climate change. (Source: Weyant et al, 1996, IPCC 1995 WG3)

This linear logical structure allows a simple, practical categorization of five types of climate-change scenarios, defined by what quantities are specified within the scenario, and what the primary area of analysis is for which the scenario provides input. The five types differ in where they cut the causal chain in Figure 2.2, so that the scenario specifies quantities lying on one side of the cut, and the assessment or other activity using the scenario lies on the other side.

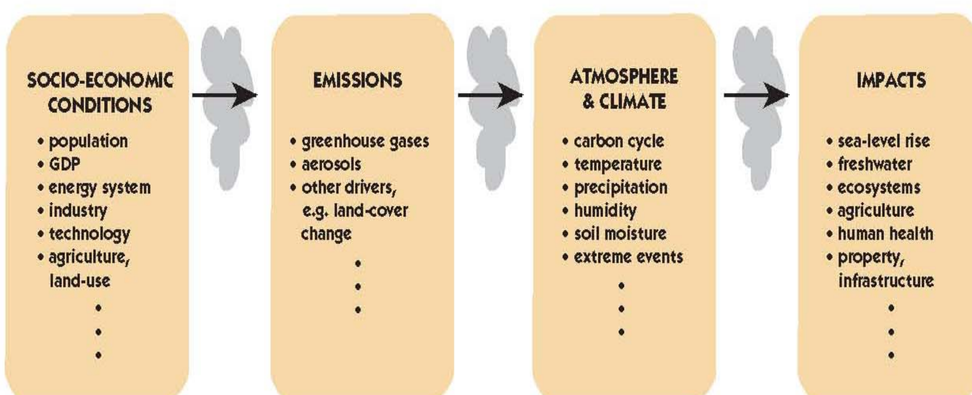

Figure 2.2: Anthropogenic climate change: Simplified linear causal chain

The next five sections briefly introduce these five types of scenarios and discuss how they have been developed and used. The five types are illustrated in a series of figures derived from Figure 2.2 that use highlighting to identify the parts of the causal chain for each type that comprise the main content of the scenario and the use of the scenario. A third, weaker type of highlighting identifies conditions underlying the scenario that might or might not be explicitly stated as part of the scenario development. Scenario exercises differ strongly in the detail and analytic rigor with which they treat these underlying conditions, or whether they even state them explicitly. Some scenarios simply stipulate values for the main content of the scenario with no reference to the underlying conditions that might have influenced those values, while others conduct detailed modeling and analysis of these underlying factors, reasoning back to some prior conditions underlying the scenario development that are themselves specified exogenously.

2.3. Emissions Scenarios for Future Climate Simulations

Scenarios of greenhouse-gas emissions, sometimes supplemented by information about other environmental perturbations such as land-use change, are the best known type of global-change scenario. Emissions scenarios have been used in two ways: to provide inputs to climate models; and to explore alternative socio-economic, energy, and technological futures. The first use, as inputs to climate models is discussed in this section and illustrated in Figure 2.3. The second use is discussed in the next section.

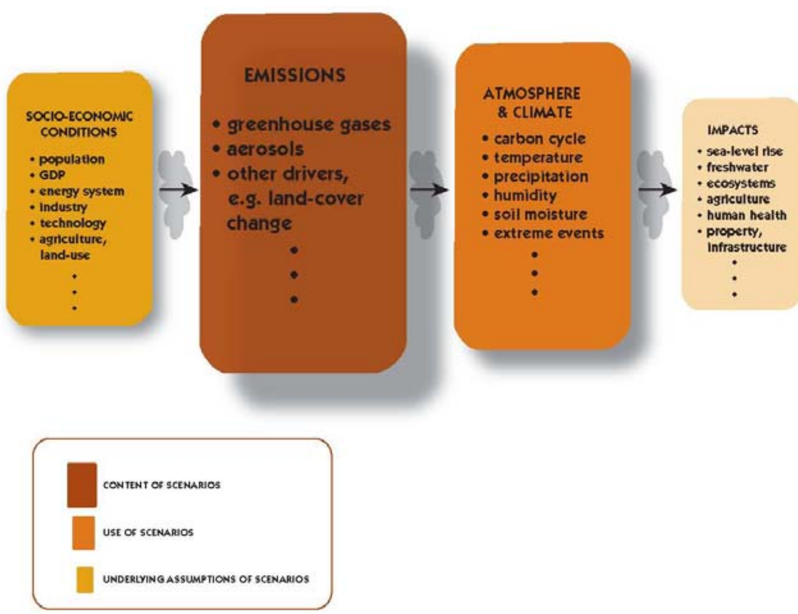

Fig 2.3: Emissions Scenarios for Climate Simulations

In order to produce a model-based projection of future climate change, future emissions must be specified. As the focus and intended use of climate-model studies has shifted over time, however, so has the role of emissions scenarios. Early, research-oriented studies examined the climate system's response to potential (rather than projected) emissions inputs, in individual model studies or standardized model comparisons that sought to identify and explain variation among projections. In such exercises, the purpose of a scenario is to provide a known, consistent perturbation that is big enough to generate an informative model response. These scenarios must be standardized, so differences between model runs can be traced to scientific uncertainties and model differences, but they can be simple and arbitrary, making no claim to being a realistic picture of how emissions will actually change.

The earliest such model studies used a "step-change" increase in atmospheric concentration of CO_2 from its pre-industrial value, to either twice or four times that value.[38] The models' equilibrium responses to doubled CO_2 provided the climate sensitivity, a standard benchmark of model responsiveness, which has remained around the range of 1.5 to 4.5°C for more than twenty years. This range of modeled equilibrium responses to a standardized perturbation says almost nothing about how the climate will actually change under human perturbations, although it has often been mistakenly treated as such. The next generation of climate-model studies, beginning in the early 1990s, specified a time-path of atmospheric concentrations rather than a one-time perturbation. These studies for the first time allowed comparison of models' transient responses, examining not just how much the climate changes, but also how fast it gets there. They still used a simple, highly idealized standard scenario of greenhouse gases, most frequently a 1 percent per year increase in atmospheric concentration of greenhouse gases, expressed as CO_2-equivalent. Only two such transient simulations had been conducted by the first IPCC assessment (1990),[39] but by the time of the second assessment (1996), most modeling groups had produced at least one.

Since the mid-1990s, climate-model projections have increasingly sought to produce realistic pictures of how the climate may actually change, requiring a new approach to emissions scenarios. Rather than arbitrary standardized perturbations, scenarios instead must present well founded judgments, or guesses, of actual future emissions trends and their consequences for atmospheric concentrations. The required emissions scenarios have been constructed either by extrapolating from recent emissions trends, or particularly for energy-related CO_2, representing emissions in terms of underlying driving factors such as population, economic growth, and technological change, and projecting these factors using some combination of modeling and trend projection. Driven by such scenarios, climate models for the first time can claim to be reasonable estimates of how the climate might actually change. In addition, comparisons using multiple models and emissions scenarios have allowed partitioning of uncertainty in future climate change into roughly equal shares attributed to uncertainty in climate science and models, and in emissions trends.[40] These comparisons have also allowed estimation of the climate-change benefits available from specified emissions reductions.

As the focus of climate-model studies shifted from simple standardized scenarios to realistic emissions scenarios, advances in climate models – e.g., improved representations of atmospheric aerosols, tropospheric ozone, and atmosphere-surface interactions – have produced

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

[39] Washington and Meehl 1989, Manabe, Souffer, Spelman, and Bryan 1991.

[40] Cubash et al 2001.

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

Consequently, as the representation of more atmospheric processes in climate models has increased the realism of their projections, it has also reduced the comparability of model results as they are increasingly based on complex, non-standard emissions assumptions and (for species other than the well-mixed greenhouse gases), conversions between emissions, concentrations, and radiative forcings. In addition, as even standard emissions scenarios have changed over time, maintaining comparability with past model runs has also become more challenging. For example, the IS92 scenarios projected that future SO2 emissions would roughly double then stabilize, while the later SRES scenarios projected sharp decreases, giving emissions in 2100 about one quarter the IS92 value. This scenario change caused significant increases in projected warming that were not due to changed scientific understanding of atmospheric response. To help maintain backward comparability, many climate-model groups have continued to run simulations using older standardized scenarios, to provide benchmarks for comparisons both among current models and between current and previous-generation models.

2.4. Emissions Scenarios for Exploring Alternative Energy and Technology Futures

Emission scenarios can also be used to examine the socio-economic implications of alternative emission paths. For example, a scenario specifying a particular trajectory of emissions over time can be used to explore what patterns of demographic and economic change, energy resource availability, and technology development are consistent with that trajectory. Alternatively, scenarios can be used to examine what policies, technological changes, or other changes would be required to shift emissions from some assumed baseline onto a specified lower path, and to estimate the size and distribution of the costs of such a shift. Figure 2.4 illustrates this type of scenarios. As in Figure 2.3 the content of the scenario is emissions, but the scenario is now used to examine the socio-economic conditions that lie upstream in the causal chain. The specific emissions scenarios used for this purpose might be specified arbitrarily, to support general exploration of socio-economic conditions associated with different emissions paths, or might be fixed to achieve some environmental target or goal that is judged desirable. This is the one type of global-change scenario that has been used backcasting mode, working back from future targets that might be set based on normative criteria, as discussed above in Section 1.2. While the most frequent use of this type of scenario has been to examine emissions trajectories that stabilize atmospheric CO_2 concentrations at specified levels, recent projects have instead adopted stabilization of radiative forcing as the target, in order to examine the role of non-CO2 greenhouse gases in stabilization regimes.[41]

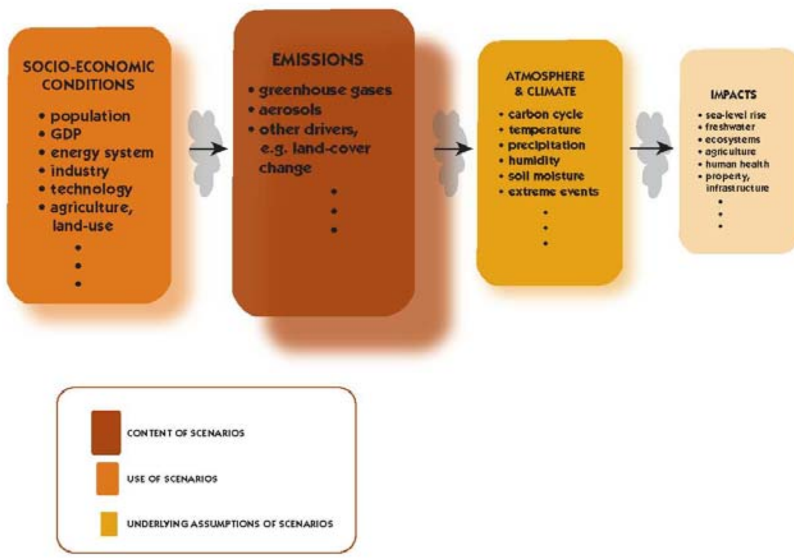

Fig 2.4: Emissions Scenarios for Energy/Technology Futures

An important early example was provided by the WRE scenarios, which presented emissions pathways that stabilized atmospheric CO_2 concentration at five different levels ranging from 450 to 1000 ppm.[42] Working heuristically with a simple model of the global carbon cycle and two energy-economic models, these scenarios illustrated the large cost savings attainable by approaching stable concentrations through emission paths that initially rise and then decline steeply, rather than by beginning a more gradual decline immediately. Although these were not strictly optimal (cost-minimizing) scenarios, they demonstrated that this qualitative shape of emissions trajectory would tend to reduce costs for four reasons. First, it allows more time to develop technological innovations that lower the cost of emissions reductions in the future. Second, it allows lower-emitting equipment to be phased in with normal capital turnover, avoiding premature abandonment of long-lived equipment. Third, it takes advantage of natural carbon-cycle dynamics, which gradually remove CO_2 emissions from the atmosphere and so allow more room for increases in earlier emissions than later emissions while still meeting the

[41] EMF 21 and 23; CCSP SAP 2.1a.

[42] Wigley, Richels, and Edmonds 1997.

concentration target. And finally, by shifting mitigation expenditures further to the future, it reduces their present value through discounting.

Several other sets of stabilization scenarios have been proposed and used for similar explorations. For example, the Energy Modeling Forum (EMF) has convened several multi-model scenario exercises focusing on emissions, emissions constraints, and their socio-economic effects. These have included studies of decision-making under uncertainty, international distribution of costs and benefits, the costs and benefits of the Kyoto Protocol, the implications of potential future energy technologies and technological change for emissions, and the implications of including non-CO_2 gases and carbon sequestration in mitigation targets and policies.[43]

In a current scenario exercise of this type, three modeling teams are each constructing a separate reference-case scenario, then examining the implications of stabilization scenarios for radiative forcing similar to CO_2 concentrations of 450 ppm, 550 ppm, 650 ppm, and 750 ppm. Without suppressing uncertainty by forcing conformity in models' base cases, they are examining the energy system, land-use, and economic implications of moving to stabilization. A major goal is to aid understanding of the role of multiple greenhouse gases, and alternative multi-gas control strategies, in pursuing stabilization. These scenarios may also serve as a point of departure for future analyses by the CCSP, the Climate Change Technology Program (CCTP), or others.[44]

2.5. Climate Change Scenarios

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

[43] Results of EMF 16 are in "The Costs of the Kyoto Protocol: A Multi-Model Evaluation", *The Energy Journal*, 1999. Results of EMF 19 are in "Alternative Technology Strategies for Climate Change Policy", *Energy Economics*, Volume 26, Issue 4, 2004. The results of EMF 21 are forthcoming in a special issue of Energy Economics. EMF 23, stabilization scenarios, is still in progress.

[44] CCSP Synthesis and Assessment Product 2.1a.

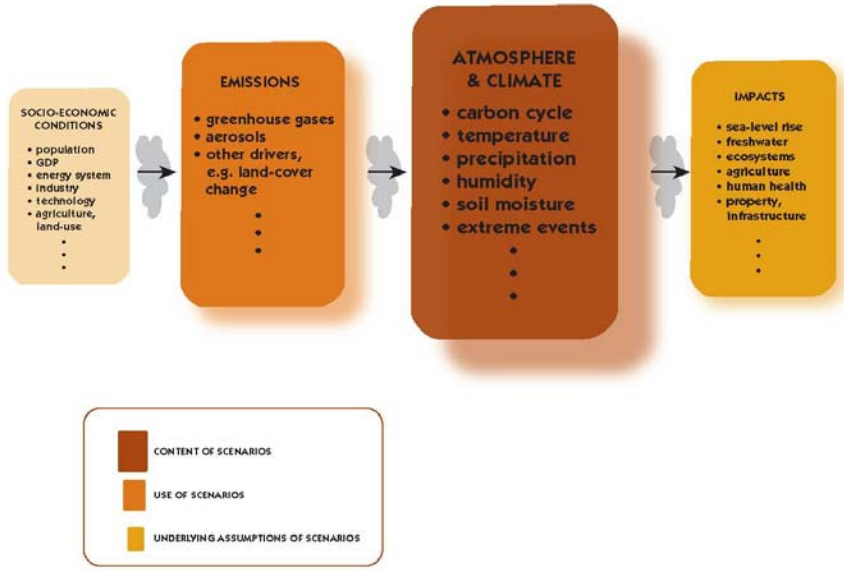

Fig 2.5: Climate-Change Scenarios

Three major types of climate scenarios are distinguished by how they are produced: incremental scenarios, analog scenarios, and climate-model scenarios.[45] Incremental climate scenarios change current conditions by plausible but arbitrary increments. For example, a region's temperature might be warmed by 2, 3, or 4°C from present conditions, or its precipitation increased or decreased by 5, 10, or 20 percent. Such adjustments can be made to annual or seasonal averages, to finer-period measurements of current conditions, or to the variability of temperature or precipitation over days, months, or years.[46] Like the simple emissions scenarios used for climate-model comparisons, incremental climate scenarios are simple to produce but make no claim to represent actual future conditions. They are used for initial exploratory studies of climate impacts and to test the sensitivity of impacts models.

Analog climate scenarios represent potential future climates by the observed climate regime at another place or another time. A spatial analog imposes the climate of one location on another, e.g., representing the potential climate of New York in the 2050s by that of Atlanta today or that of Illinois in the 2050s by that of Kansas today.[47] A temporal analog imposes some climate observed in the past, either in the historical record or in earlier paleoclimatic observations, e.g., using the hot, dry climate of the 1930s to study impacts of potential hot, dry climates in the future.[48] Like incremental scenarios, analog climate scenarios are more useful for exploratory studies of the climate sensitivity of particular resources or ecosystems than for projecting likely impacts. While they represent climate states that are known to be physically possible, since they actually happened or are happening, they are limited as representations of

[45] Mearns et al 2001.

[46] e.g., Mearns et al 1992, 1996; Semenov and Porter 1995.

[47] e.g., Kalkstein (***complete cite)

[48] e.g., Easterling et al., 1995.

potential future states since they take no account of the changes in greenhouse-gas concentrations that are the principal driver of climate change.

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

Unlike incremental and analog scenarios, climate-model scenarios use emissions scenarios as inputs. Model-based scenarios have greater claim than the other types to being realistic descriptions of how the climate might actually change, because they are based on specified assumptions of future emissions trends acting on modeled representations of known physical processes. Even with a given emissions scenario, model-based climate scenarios are uncertain. Since climate models are driven by the radiative effects of atmospheric concentrations of relevant species, some of this uncertainty comes from the carbon-cycle and chemical processes by which specified emission paths determine concentrations. Some of the uncertainty can be seen in the slight differences in projections from different runs of the same climate model, because the models are sensitive to small differences in starting conditions. And some of the uncertainty can be observed in differences between different models' projections, principally caused by differences in the parameterizations they use to represent small-scale processes and the computational methods they use to handle the errors introduced by finite grid-cells.

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

As with all scenarios, the requirements for a useful climate scenario depend on the information needs of the users. The climate-data needs of impact analyses can be highly specific, and sometimes are not readily provided by climate-model outputs. Provision of information from climate-model scenarios must, however, consider both users' needs and modelers' judgment of the validity of the data: it can be misleading to provide impact analysts climate-model data of whose validity the modelers are not confident.

Mismatch between impact analysts' needs and climate-model output is especially common with respect to the spatial scale of data. Impact analyses frequently need data at substantially finer scale than the relative coarse grid of a climate model, which might have only 60 to 100 cells over the continental USA. One advantage of incremental and analog scenarios is that they can typically provide data at substantially finer scale. There are several techniques that seek the benefits of model-based scenarios – physical realism and explicit emissions-scenario drivers – yet provide climate-scenario data at finer scales. These techniques are called downscaling, for which the two major approaches are statistical downscaling and nested regional modeling.[49] Statistical downscaling involves estimating statistical relationships between large-scale variables of observed climate, such as regional-average temperature, and local variables such as site-specific temperature and precipitation.[50] These relationships between smaller and larger-scale climate variables are then assumed to remain unchanged under global climate change. A regional climate model provides an explicit physically modeled representation of climate for a specific region, with boundary and initial conditions provided by a global climate model. Regional climate models include representations of factors that influence local climates such as mountain ranges, complex coastlines, lakes, and complex patters of surface vegetation, and can provide projections at scales as small as 10 to 20 kilometers. Although downscaled results are anchored to local features with well understood climatic effects (e.g., precipitation falls on the windward side of mountains), downscaling also introduces additional uncertainties beyond those already present in global climate-model projections.[51]

2.6. Scenarios of Direct Biophysical Impacts: Sea Level Rise

Although climate-change scenarios can be used to study any form of impact, scenarios can also be constructed of particularly important forms of climate-change impact, such as sea level rise – one of the more costly and certain consequences of climate warming. Sea level rises as the climate warms, because of thermal expansion of seawater and the melting of alpine and continental glaciers, which adds more water to the oceans. Because of the large heat capacity of the ocean, sea level rise will continue for centuries even after stabilization of atmospheric greenhouse gases.[52]

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

Sea level rise will increase circulation and change salinity regimes in estuaries, threaten coastal wetlands, alter shorelines through increased erosion, and increase the intensity of coastal flooding associated with normal tides and storm surge. Scenarios of sea level rise are consequently needed to assess multiple linked impacts on coastal ecosystems and settlements. In specific locations, these impacts will depend on many characteristics of coastal topography, ecosystems, and land use – e.g., coastal elevation and slope, rate of shoreline erosion or

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[49] Giorgi et al 2001.

[50] Wilby and Wigley 1997.

[51] Mearns et al 2001, Giorgi et al., 2001.

[52] IPCCa 2001.

accretion, tide range, wave height, local land use and coastal protection, salinity tolerance of coastal plant communities, etc. – in addition to local sea level rise.[53]

In addition to its gradual impacts, sea level rise is subject to large uncertainties associated with the potential loss of continental ice sheets in Greenland and West Antarctica. The consequences of these events for global sea level rise are well known because they can be calculated quite precisely from the volume of the ice sheets – roughly 7 meters rise from complete loss of the West Antarctic Ice Sheet and 5 meters from Greenland. But the probabilities of these events and their likely speed of occurrence are both highly uncertain. One recent study has suggested a probability of a few per cent that the West Antarctic Ice Sheet will contribute an additional one meter per century beyond that calculated from gradual warming.[54]

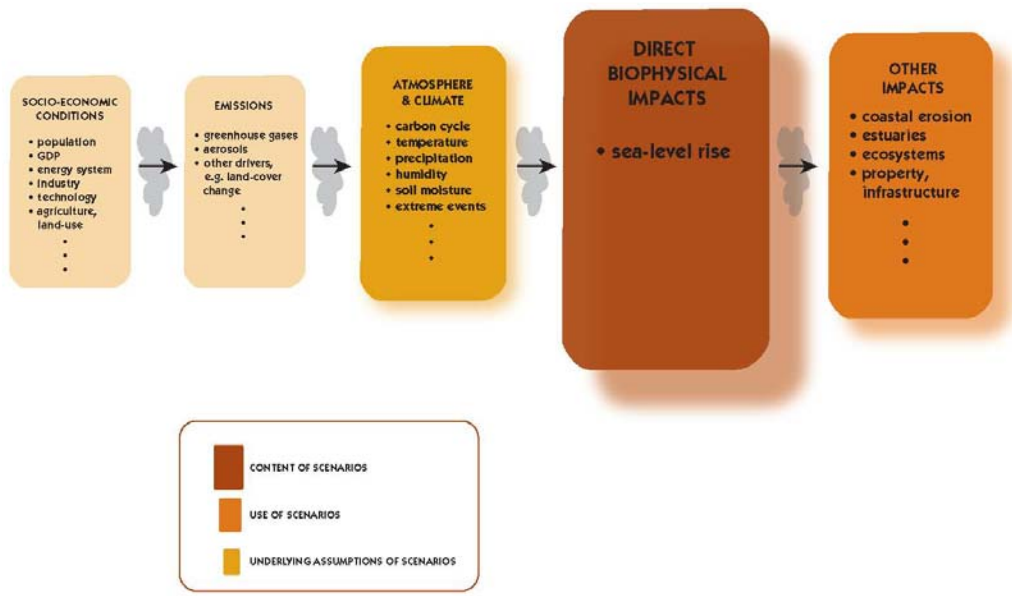

Figure 2.5: Scenarios of Direct Biophysical Impacts: Sea Level Rise

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

[53] Burkett et al. *In Press.*

[54] Vaughan and Spouge 2002.

Finally, because it is subject to large uncertainties with known consequences but unknown probabilities, sea level rise is a useful variable for exploratory analysis of worst-case scenarios in long-range planning. Other forms of climate impact might also merit being called out in separate scenarios. This might be the case for other direct biophysical impacts of climate change such as snowpack in mountain regions, seasonal flow regimes in major river basins or changes in the structure and function of major ecosystem types. Based on present knowledge, however, only sea level rise has shown these characteristics strongly enough to motivate construction of separate scenarios.

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

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

Ecosystems are affected by climate change, but also by many other changes in environmental conditions that are influenced by human activities, such as nitrogen and sulfur deposition, tropospheric ozone and smog, and changes in erosion, runoff, loadings of other pollutants, land-use, land-cover, and coastal-zone characteristics. Consequently, realistic projections of future impacts on ecosystems require specifying the most important forms of human-driven stresses jointly, not just climate.[55]

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

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

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55 Millennium Ecosystem Assessment 2005.

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

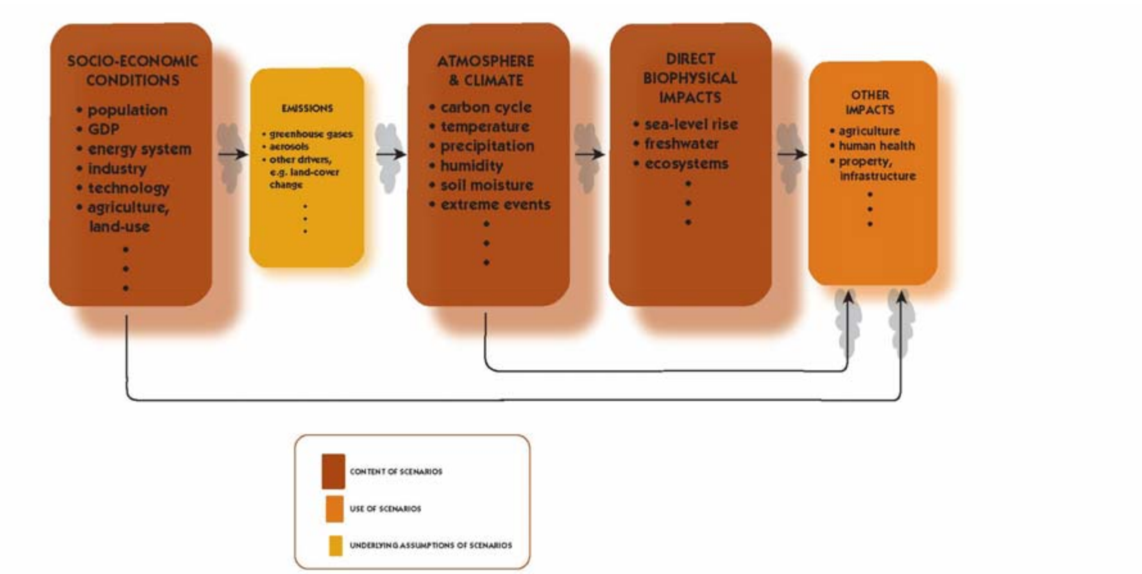

Figure 2.6: Multivariate Scenarios for Impact Assessment

Some socio-economic characteristics that are likely to be relevant for many impact assessments – e.g., the size and perhaps the age structure of population, the size and perhaps the sectoral mix of GDP – are normally generated in the course of producing emissions scenarios. Consequently, when current emissions scenarios exist for the region for which an impact assessment is being conducted, it makes sense to strive for consistency with them.[56] Even for these variables, however, there may be significant problems of incompatible spatial scale. Impact assessments are often conducted at smaller spatial scale than emissions projections, and so may need these socio-economic data at finer scale than is available. Downscaling future socio-economic projections has proven challenging thus far. There is no generally accepted method for doing so, and several research groups are now doing exploratory development of alternative methods.[57]

In contrast to the few clearly identified aggregate characteristics needed to construct emissions scenarios, the socio-economic factors that most strongly shape adaptive capacity and vulnerability for particular impacts may be detailed, subtle, and location specific. The identity of the most important characteristics may not even be clear before doing a comprehensive analysis

[56] Berkhout et al 2001, citing UNEP 1994 guidelines.

[57] Pitcher 2005.

of potential causal pathways shaping impacts. The most important characteristics may interact strongly with each other, or with other economic or social trends defined at national or international scale. And they may not be readily described or analyzed quantitatively. All these factors make the development of socio-economic scenarios for impact assessment a much more difficult endeavor than constructing emissions scenarios.

Because scenarios are schematic, it is not possible to create a set of scenarios that include all factors. Details are typically not included, and when they are, they are intended to be merely illustrative, with minimal confidence placed in their specifics. But in determining vulnerabilities to climate impacts, it may be particular details – which cannot be identified a priori – that are crucial.[58] Impact assessments have made various responses to this challenge. These all involve acknowledging the need for subjective expert judgment, regarding both what factors to include and what variation in them to consider. They also all recognize the unrealism of extrapolating recent trends or assuming current conditions will persist unchanged in the future,[59] and the risk of under-estimating uncertainty and so not projecting future possibilities broadly enough.

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

This section has sketched a typology of global-change scenarios, and identified major types of decision-makers who might use global-change scenario-based information. The next section turns to current experience with global-change scenarios, summarizing the development, contents, and uses of several major exercises. We also provide much shorter and more narrowly focused reviews of additional scenario-related experiences. Informed by these cases, section 4 will summarize and discuss the major challenges for making and using scenarios that are raised by this experience, providing the basis for our conclusions and recommendations which are presented in Section 5.

[58] Berkhout et al 2002.
[59] Berkhout et al 2001; Parson et al 2001.

3. Review of Major Climate-Change Scenario Exercises

In this section, we review experience to date in developing and using scenarios for global climate change applications. Because little or no scholarly literature on these activities yet exists, our selection of case has been inevitably both limited by the time and resources at our disposal, and somewhat reliant on the knowledge and experience of team members. We have selected four exercises for detailed discussion, in an attempt to cover the largest-scale and most important activities. Section 3.1 reviews the IPCC scenarios, with particular detail on the most recent and important exercise, the Special Report on Emissions Scenarios (SRES). Section 3.2 considers the US National Assessment, which both developed and used scenarios of climate and socio-economic conditions. Section 3.3 considers the UK Climate Impacts Program, which has also both developed and used scenarios, following a different approach from the USNA. Section 3.4 reviews the Millennium Ecosystem Assessment, an ambitious scenario-generating exercise in which climate change was one of several dimensions of stress considered on global ecosystems.

For each exercise, we have attempted to limit our attention to the development and use of scenarios, rather than comprehensively examining the assessment processes in which some of the activities were embedded. In each case, we consider how the scenarios were developed, including both methods of reasoning and managerial process; how, and by whom, they were used; and subsequent evaluations when these are available, including the most salient criticisms advanced. General issues and challenges that emerge from these experiences are discussed in Section 4.

In order to provide more illustrative variation in types, methods, and uses of scenarios, we have also provided shorter summaries of eight additional activities, some related to the major four we examine in detail and some not. Presented in text-boxes throughout Section 4, these are intended to provide additional information to highlight particular issues we discuss there. In choosing these additional cases for short treatments, we have particularly sought experiences that illuminate potential relationships between scenarios and decision-making.

We recognize that all these scenario exercises represent early work in an immature field. Our aim is not to criticize particular exercises, but to seek insights from their experience into the general problems of making useful global-change scenarios.

3.1. IPCC Emissions Scenarios

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

The 1990 Scenarios

For its first Report IPCC's Working Group 3 on "Response Strategies" included a sub-group on emissions scenarios. After meeting three times in 1989, this group produced four emissions scenarios in December 1989. Two models were used, principally to provide accounting frameworks by which the assumptions contributing to alternative emission paths could be compared: the Atmospheric Stabilization Framework (ASF), developed at US EPA,[60] and the Integrated Model for Assessment of the Greenhouse Effect (IMAGE 1.0).[61] Four scenarios were produced: a baseline called "high emissions," in which equivalent CO_2 concentration reached 550 ppm by 2030; a "low-emissions" scenario in which 550 ppm was reached in 2060; a "control policies," scenario, in which moderate mitigation policies delayed 550 ppm until 2090; and an "accelerated policies" scenario, in which aggressive mitigation policies stabilized CO_2 below 550 ppm. Each scenario represented emissions of CO_2 plus highly simplified representations of five other gases for five world regions, under high and low-economic growth variants.[62] Although prepared for the assessments of climate change and its impacts conducted in parallel by IPCC Working Groups 1 and 2, the scenarios were little used in this assessment, because of time limits and because with one exception only doubled-CO_2 equilibrium climate-model runs were available at the time.[63]

The 1992 Scenarios

IPCC decided in March 1991 that updated scenarios were needed because of several events and policy changes since 1990 – e.g., the Montreal Protocol's decision to phase out several ozone-depleting chemicals that were also greenhouse gases, new population projections from the UN and World Bank, and political transformations in the Soviet Union and Eastern Europe. In contrast to the 1990 scenarios, the new mandate explicitly excluded scenarios that assumed mitigation policy.[64]

The exercise produced six new scenarios, called IS92a through IS92f. These were the first global emissions scenarios with a full suite of greenhouse gases and at least some explicit calculation underlying each. The middle scenarios, IS92a and IS92b, updated the "high emissions" or "A" scenario from 1990. Assuming a 2100 world population of 11.3 billion and 2.3% average annual world economic growth through 2100, these projected world CO_2 emissions of roughly 20 GtC and 19GtC in 2100.[65] IS92a was the most prominent and widely used of these scenarios. Of the other scenarios, two assumed lower population and economic growth, giving world emissions of 5 - 10 GtC in 2100, while the other two assumed higher growth and projected 27 - 35 GtC of world emissions in 2100.[66] The ASF model was used as an accounting framework to track assumptions and emissions for all six scenarios, which were presented with more detailed reporting of underlying assumptions than the 1990 scenarios.[67]

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

[61] Rotmans 1990

[62] 3% average GDP growth in OECD 5% in rest of world for high, 2% OECD 3% rest of world for low.

[63] The scenarios were mentioned in a 1-page Appendix to the Working Group 1 report, which replaced their descriptive names by letters A through D. The one non-equilibrium run available was a preliminary transient run using 1% annual CO_2 concentration increase. See Mitchell et al 1990 and Bretherton et al 1990., both in Houghton, Jenkins, and Ephraums (1990).

[64] Swart et al, 1991

[65] The small difference reflected different assumptions about compliance with newly enacted CFC phaseouts and recent CO_2 reduction commitments announced by a few OECD nations.

[66] Leggett et al 1992, Table A3.6, pg. 80.

[67] Leggett et al 1992, Swart et al 1991.

In the climate-model comparisons conducted for the next IPCC assessment, published in 1996, the IS92a scenario was used in several model runs along with the simpler transient scenario of 1% annual increase in equivalent-CO_2 concentration and further equilibrium runs.[68] The new transient runs still represented all greenhouse gases as CO_2-equivalent, rather than explicitly representing each gas separately.

The Special Report on Emissions Scenarios (SRES)

The third and most ambitious IPCC scenario exercise was established partly in response to two widely circulated criticisms of the IS92 scenarios. The first of these criticized the 1992 scenarios for inconsistency with other published scenarios of energy and carbon intensity for major world regions; failing to reflect economic declines in Eastern Europe and the former Soviet Union and increasing restrictions on sulfur emissions; relying inappropriately on a single model; and being useful only as inputs to climate models, not for other purposes such as mitigation studies or supporting climate-change negotiations.[69] The second criticized the IS92a scenario for assuming further divergence in per capita emissions between industrialized and developing regions, and argued that this represented a strong bias in favor of already developed regions.[70]

In response to these criticisms, the May 1996 IPCC Plenary session asked Working Group 3 to develop a new set of emissions scenarios. The new scenarios were instructed to improve treatment of sulfur aerosols and emissions from land-use change, and to not rely on a single model or expert team, but instead draw on the existing literature and invite any group with relevant expertise to participate through an “open process.”[71] They were also charged to serve more purposes than just providing inputs to climate models, such as supporting impact analyses, but to assume no new climate-policy interventions. Although not explicitly stated in the terms of reference, it was also clearly understood that the scenarios would address the criticism of the IS92 scenarios by focusing convergent development paths between North and South.

In January 1997 a writing team was established to prepare the report and the new scenarios. The team included members of several energy-economic modeling groups, plus experts in various related issues (e.g., population, technological change, scenario development methods). The process ran under tight time pressure, particularly in view of the charge to provide preliminary scenarios by early 1998 for use in climate-model runs in the IPCC Third Assessment. As in all IPCC activities, direct funding was minimal and largely limited to developing-country participants, and all modeling groups were independently funded and participated on a volunteer basis.

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[68] The 1% scenarios was similar to IS92a, but gave total radiative forcing about 20% greater by 2100. Washington and Meehl 1989, Stouffer et al 1989, Bretherton et al 1990, pg. 180-182.

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

[70] Parikh 1992.

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

As part of the team's review of published scenarios and open process, a web-based database of scenarios was developed by Japan's National Institute for Environmental Studies (NIES).[72] Prior scenarios were compiled here, and any researcher was invited to submit new ones. By mid-1998 the database contained more than 400 scenarios from more than 170 sources. The great majority of these projected only energy-related CO_2 emissions: otherwise, the scenarios were highly diverse in their temporal and regional coverage and resolution, the variables included, and their methodologies. The usefulness of these scenarios in constructing new ones was limited by several weaknesses, however. Many were incomplete, lacked documentation of inputs, or made inconsistent assumptions. Few included sulfur and land-use emissions, which were specifically requested of the new scenarios. Many were unclear on whether they assumed mitigation efforts, while the new scenarios were instructed to exclude them. Consequently, the development of new scenarios had to proceed largely independent of the collection of existing scenarios through the literature review and open process.

Work on new scenarios began in early 1997, aiming to provide preliminary scenarios to climate modelers by early 1998 and final scenarios by late 1998.[73] Early on, it was decided to use narrative scenarios in addition to quantitative models, and include experts in this approach on the writing team. This decision responded to the charge to make the scenarios more integrated and serve more purposes than emissions projections, and recent successes using such scenarios for energy and environmental applications.[74] An April 1997 workshop in Paris began the process of developing the narrative scenarios. Here, participants sought to identify a few key uncertainties and develop coherent narratives around them. They chose two: whether world values would mainly stress economic prosperity or balance economic and ecological concerns (labeled “A” vs. “B” scenarios); and second, whether the organization of economies and institutions would keep shifting toward global integration, or reverse and shift toward regional fragmentation (labeled “1” vs. “2” scenarios).[75]

Combined, these gave four scenarios, which were sketched in preliminary terms at the workshop. In the A1 (economic, global) scenario, economic growth and inter-regional income convergence continue strongly worldwide – all developing countries grow like Japan and Korea from the 1950s to the 1980s – while world population peaks at 9 Billion by 2050. Rapid innovation yields many advanced energy sources, while acid rain and other local and regional environmental problems are aggressively controlled. In contrast, the A2 (economic, regional) scenario has higher population growth, lower economic growth with more continuing regional disparities, slower innovation, and weaker international institutions. B1 (ecological, global) has low population growth, moderate economic growth with strong convergence, and strong reductions in per capita energy use, mostly through higher efficiency, while B2 has intermediate population growth, low economic growth with weaker convergence, and moderate improvements in energy efficiency and development of non-carbon energy sources.[76] The storylines were

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

[73] Minutes, Lead Authors' Meeting, Geneva, February 7-8 1997.

[74] E.g., the IEC and WBCSD scenario exercises.

[75] Minutes, Lead Authors Meeting, Paris, 13-15 April, 1997.

[76] Minutes, Lead Authors Meeting, Paris, 13-15 April, 1997.

elaborated in short text descriptions (one to two pages) with some preliminary numbers attached, between September and November, 1997.[77]

Modeling teams were asked to produce initial quantifications of these scenarios in fall 1997, to match specified 2100 target values within 10%. At this point, the set of modeling groups participating in the exercise was not finalized. Participation posed delicate management issues because while the process had to be open, it was clear from the outset that only a few groups, most of them already included on the writing team, had the capability to produce scenarios meeting the requirements of the mandate. In February 1998, the preliminary quantitative targets were re-confirmed and modelers asked to continue work on quantifications, now including a breakdown of economic output into four world regions.[78] In April, one model's quantification was chosen as a "marker scenario" for each of the four scenarios – a particular scenario that would provide the basis for interim reporting to climate modelers, some of whose results other participating models would be asked to replicate.

Table 3.1.1 Target Values for 2100 in Initial Scenario Quantifications

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

(source: Minutes of Laxenburg meeting, 2-3 July 1998)

These interim marker scenarios were used to provide emissions scenarios to climate models participating in the IPCC third assessment. An IPCC meeting in June 1998 agreed to use SRES scenarios and asked for three cases, central emissions, stabilization, and high emissions.[79] The writing team initially discussed identifying scenarios they had produced, including markers and others, as providing each of these cases,[80] but later decided to provide only the marker scenarios and recommend that climate modelers use all four without identifying any as "central."

These marker scenarios also provided the basis for coordination of subsequent scenario development. Up to this point, there had been substantial discrepancy between different models' quantifications of the same scenario, particularly at regional level. With the adoption of the marker scenarios, other modeling groups were asked to replicate (within 5 – 10%) the marker results on population, GDP, and final energy for the four world regions, both for the 2100

[77] Minutes, informal modelers meeting, Berkeley, Feb 7-8.

[78] Draft minutes, Berkeley meeting, Pg 4.

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

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

endpoint and for several interim years.[81] Achieving the requested replication posed significant challenges for modelers.[82]

With a further year of work, modeling teams produced a total of 40 scenarios that were retained in the report, of which 26 replicated one of the marker scenarios. Although a few of the 14 non-replicates reflected a model's inability to match the results of a marker scenario, most were produced because a modeling team intentionally sought to explore alternative assumptions. For example, the A1 scenario, which originally balanced fossil and non-fossil energy sources, was augmented by variants with different assumptions about fossil resources and non-fossil technology development, giving widely divergent emissions paths stressing coal, gas, and non-fossil energy technology. Modifications of the scenario set continued until late in the process. For example, it was decided at Beijing to drop several B variants with explicit mitigation, including one stabilization scenario.[83] At the final IPCC approval meeting, it was decided at the request of the Saudi delegation to reduce the two fossil-intensive variants of A1 to one, a variant of the gas-intensive scenario which was renamed A1FI (for "fossil-intensive").[84]

Significance and Use

The SRES scenarios have been the most comprehensive, most ambitious, most carefully documented exercise producing emissions scenarios to date. They represented a substantial advance from prior scenarios, and contributed to assessments and subsequent research on climate impacts and responses. The SRES scenarios formed the basis for climate-model comparisons in the IPCC Third Assessment (2001) and current work for the Fourth Assessment. Most subsequent climate-model work has used only a few of the marker scenarios – typically A2 and B2, sometimes with A1B added. SRES scenarios also provided baselines for analysis of mitigation scenarios in the Third assessment.[85]

Several significant insights were illuminated by the SRES scenarios.

- Alternative scenarios with similar emissions in 2100 can follow markedly different paths in the interim, giving wide differences in cumulative emissions and atmospheric concentrations.
- Technology and energy-resource assumptions can strongly vary future emissions, even with constant socio-economic assumptions. For example, the three A1 variants

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

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

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

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

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

show that changing these assumptions alone can generate as wide a range of emissions futures as substantial variation of demographic and economic futures.

- Highly distinct combinations of demographic, socio-economic, and energy-market conditions can produce similar emissions trajectories, suggesting that a particular emissions trajectory can pose very different mitigation problems depending on what combination of driving factors underlies the emissions.

Criticisms and Controversies

The SRES scenarios have been subject to two forceful public criticisms. We discuss these, followed by several other issues that have received less attention but which in our view pose more central and instructive challenges for future scenario exercises.

Assigning Explicit Probabilities

The SRES team decided at the outset of their work to make no probabilistic statements about the scenarios. Their report uses great care in its language to avoid any suggestion that one scenario might be more central or more likely than any other.[86] This decision was consistent both with standard practice in developing narrative scenarios, and with the instruction in their terms of reference not to favor any model.[87]

They were sharply criticized for this decision.[88] Critics argued that there were no technical obstacles to assigning probabilities to emissions ranges bounded by the marker scenarios; that scenario developers must have made probabilistic judgments in generating and evaluating the scenario quantifications and that not making these judgments explicit would withhold relevant information; and that if scenario developers decline to assign probabilities, others who are less informed will do so. Indeed, many probabilistic emissions calculations have been produced since the SRES, using various methods such as assigning uniform or other specified distributions over the emissions of the SRES marker scenarios, counting scenarios in the larger SRES set that lie in specified intervals in the larger SRES set or the literature (a particularly troublesome approach, in view of the tendency to over-sampling and re-publication of well-known prior scenarios), unbundling and recombining the underlying inputs to SRES emissions figures, or sampling over parameter distributions within a single model. In response to these criticisms, SRES authors argued that attempting to assign probabilities to scenarios would require assigning joint distributions to the underlying driving factors, and that this would lead to an explosion of combinatoric possibilities over which any attempt to assign probabilities would be spurious and arbitrary.[89]

The situation of the SRES scenarios is in fact more nuanced than either of these arguments suggests. It may be unhelpful to assign probabilities to rich, multidimensional narrative scenarios, yet useful to assign interval probabilities when scenarios principally

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86 E.g., Minutes of London meeting, March 1999.

87 Washington DC (April 29-30 1998), draft minutes, pg. 6.

88 E.g., exchange of letters between Schneider and Nakicenovic, Science, 2001.

89 Grubler and Nakicenovic, 2001.

represent uncertainty in one or two quantitative variables. And while the SRES scenarios began their lives like the former type of storyline scenario, they finished more like the latter. For many users, the scenarios ***are*** their projections of greenhouse-gas emission trends. When they are viewed in this way, it would appear reasonable for a potential user to ask, how likely are emissions to be higher than this – a distinct and more well-posed question than what is the probability of an A1 world. The uncertainty issue is deep, there is no clear resolution in this case, and it poses hard design problem for scenarios and assessments more broadly. Although SRES is the exercise that has raised this controversy most explicitly to date, the problem is a general one that any scenario exercise must confront. We discuss it further in section 4.6.

Exchange Rates: PPP versus MER

The most prominently publicized criticism of SRES focused on the fact that most participating models scenarios compared GDP across regions at market exchange rates (MER), instead of using the more correct purchasing-power parity (PPP) approach. All but one model used in SRES calculated regional GDP in MER terms. PPP comparisons correct for price differences among countries, providing a more accurate comparison of real incomes. Because lower-income countries have lower price levels, MER-based comparisons overstate the income gap between rich and poor countries.

In a series of letters to the IPCC chairman and several subsequent publications, two critics argued that the use of MER caused SRES scenarios to over-estimate future income growth in developing countries (because they over-estimated the initial income gap), and consequently to over-estimate future emissions growth. Their criticism was widely circulated and repeated by prominent climate-change skeptics.[90]

While the criticism is correct that using MER overstates future income growth, it does not follow that future projections of emissions growth are also over-stated. MER is universally recognized as a flawed measure of income, whose use in global-change scenarios is only justified by better availability of current and historical data, and the fact that international emissions trades in any future mitigation regime will likely be made at market exchange rates. But in switching from MER to PPP, changing the measure of income also changes the relationship between income and such physical quantities as energy and food consumption, which determine emissions. Consequently, while MER overstates future income growth in poor countries, it also overstates future reductions in energy and emissions intensity. These opposing errors are likely to be similar in size, in which case any error in emissions projections from using MER will be small.[91]

A related, more serious concern is that regardless of how exchange rates are converted, all SRES scenarios assumed varying degrees of real income convergence between North and South. In this, they responded to criticisms that the 1992 scenarios were biased to favor the North. But an exercise to construct potential climate-change futures may need to consider less

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

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

optimistic and less desirable futures in which some currently poor regions fail to solve the development problem. Not considering less fortunate futures, including ones that might challenge the adequacy of current responses, institutions, and decision-making capacity, may limit scenarios' usefulness in supporting long-term risk assessment and planning for the societal response to climate change.

Under-Development of Narrative Scenarios

Although the SRES storylines were produced first and were featured prominently in publications, they remained underdeveloped and underused throughout the process. In part due to time pressure, in part due to the predominance of quantitative modelers in the process, little attention was given to further development of the storylines once initial quantifications were established and work on model runs began. Nor was significant effort devoted to integration and cross-checking between storylines and quantitative scenarios, although a major purpose of the narratives was to give coherent structure to quantifications.[92] Concerns raised about the storylines included lacking specification of characteristics other than those needed to generate emissions; imbalance between the storylines, with A1 much more developed than the others and B2, the least developed, likely to be heavily used as the median scenario for emissions; apparent inconsistencies within A2; and lack of clarity regarding the distinctions between A2 and B2 – a serious enough concern that merging them was repeatedly considered until late in the process.[93]

There was even substantial divergence among participants over the meaning of some of the scenarios – indicated by the persistent difficulty they had in agreeing on descriptive names.[94] These were eventually dropped, in the context of a broad retreat from attempting to flesh out the storylines late in the project. By spring 1998, it was agreed that only brief narratives would be posted on the web for use in the open process. By late 1998, it was agreed that storylines should be kept simple, that any evaluative language should be avoided in storylines, and that any conflict between quantifications and storylines should be addressed by revising the storyline to fit the quantification.[95] That so little integration of qualitative and quantitative components was achieved when this project appears to have engaged the task more seriously and persistently than any other climate-change scenario exercise suggests the magnitude of the analytical and methodological challenges involved in realizing the potential benefits of such integration.

Harmonizing Scenarios, Interpreting the Results

The quantitative population, GDP, and final energy targets that were specified in the initial sketching of the four storyline scenarios were intended to provide consistent values for

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[92] Beijing minutes, pg 10.

[93] Bilthoven draft minutes, p. 7-8; Berkeley draft minutes, pg. 6; DC draft minutes.

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

[95] Beijing lead authors' meeting minutes, pg 10.

exogenous inputs, or "driving forces," in subsequent model quantifications of the scenarios. This is one of several potentially useful modes of coordination in scenario exercises using multiple models. Other approaches include choosing one or a few illustrative scenarios as coordinating devices for subsequent analyses, as was done with the SRES marker scenarios; fixing values of a small set of exogenous inputs to multiple models, to characterize resultant uncertainties and examine its origins through focused model intercomparisons; or fixing key outputs as targets, to reason backwards and examine requirements for achieving them (with key exogenous inputs also standardized, to ensure that variation in the manner of target attainment is not due to these).

Choosing a few quantitative variables as the initial link between storylines and models makes these variables serve as a framework to capture the storylines' basic logical structure. Which variables best serve this purpose for a particular storyline or set of storylines is not obvious, and the variables chosen here appear reasonable choices for this purpose. But the causal structure of a model will not generally mirror the presumed causal logic of a narrative, so a model cannot be expected to take specifications of a few variables chosen to frame a storyline's logic, and calculate values for other variables that flesh out the scenario consistently with the presumed logic. Even harder, there is no reason to expect that the few variables that are key to framing a storyline's logic will be exogenous inputs for all models used in the subsequent quantification. Of the three variables specified in this case, only population was exogenous for all participating models. Because GDP and final energy were endogenous for some or all participating models, matching their specified values required manipulating other internal model characteristics. Once one model run was chosen as the marker for each scenario, subsequent attempts by other models to replicate the results posed the same problem more acutely, since more outputs were specified at this point.

The problems associated with attempting to harmonize model outputs are related to the under-development of narrative scenarios and limited integration of qualitative and quantitative components. The initial quantitative targets were specified as part of sketching the narrative scenarios, but there was little subsequent re-examination of either the narratives or the associated numerical targets. Consequently, the storylines were associated with these relatively restrictive targets even though the storylines did not develop the richness or detail needed to cohere as narratives that would carry implications for additional characteristics beyond those explicitly specified. The preliminary targets were only slightly modified throughout the project, despite subsequent discovery of significant problems. For example, the UN 1998 population projections, with substantial reductions in projected fertility, were completed while the scenario development work was underway but not incorporated.[96]

Clarity about Uses, involving Users:

The SRES scenarios were charged to serve other uses beyond driving climate models. But while the guidance documents for the SRES mentioned a few examples of other uses, such as supporting assessments of impacts and evaluating mitigation strategies, they did not provide

[96] Bilthoven minutes, p. 11.

guidance on what specific additional uses or users to serve, or on how the scenarios might best serve them – neither of which is obvious.[97]

Providing emissions inputs for climate models remained the most prominent and most clearly specified use, as well as the single use that had an early deadline. But while climate modelers became by default the primary targeted users – and a substantial downscaling effort was appended to the SRES process to address their needs – they were not involved in the scenario development process and there were some differences of detail over the usability of the scenarios. A September 1997 briefing identified the principal needs of climate modelers as haste and greater emissions detail.[98] They wanted separate emissions trajectories for major greenhouse gases, not just CO_2-equivalent, including regional detail for some emissions such as sulfur – even suggesting that it would be desirable to have sulfur emissions disaggregated by stack height, to distinguish dispersed emissions from large point sources. Although SRES provided gridded sulfur data by post-processing model outputs, in most cases the emissions included and their spatial detail (not to mention stack height) were limited by the structure of participating models, so there was limited ability to respond to these requests.

For other potential uses, the SRES process received less detailed and specific requests and potential users or their representatives were still less involved in the process. Supporting assessment of mitigation strategies was largely deferred to the post-SRES scenarios prepared for the IPCC Third Assessment Report, although ambiguity about the degree of mitigation effort implied by some SRES scenarios complicated that subsequent task. For supporting impact and vulnerability assessment, the basic organization of the activity limited the detail and specificity of information it could provide, since many dimensions of impacts depend on diverse small-scale socio-economic and ecological factors that a global exercise centered on energy-economic models cannot provide.[99] For the population and economic projections that were provided in the course of generating emissions scenarios, the key issue for impacts and adaptation was the degree of spatial detail provided. For consistency among scenarios, and to avoid base-year discrepancies with national and regional datasets, SRES scenario results were reported only for four large world regions. Greater regional detail was available from individual models, but not with consistent regional boundaries. Providing the greater regional detail desired for impact assessments would generate discrepancies between the global-model results represented in scenarios and the more detailed data and projections available at national and regional levels.[100] Developing valid methods to down-scale socio-economic scenario information and integrate it with national and regional datasets remain key challenges for producing useful scenarios for impact assessment, on which further progress is needed.[101]

In sum, the SRES experience raised four issues of greatest significance for subsequent attempts to develop more useful climate-change scenarios: methods for developing and using narrative scenarios and integrating them with quantitative model results; the desirability of and

[97] Alcamo et al, 1995.

[98] Bilthoven draft minutes, p. 5.

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

[100] January 1998, meeting with Richard Moss, WG2 Technical Support Unit, in Berkeley minutes.

[101] Pitcher 2005.

appropriate methods for characterizing probabilities associated with scenarios; alternative modes for coordinating use of multiple models and their implications for the interpretation and use of scenarios; and relationship between scenario exercises and their users, including the need for clarity about specific intended uses, appropriate methods for engaging users in scenario development, and how to improve utility of scenarios when not all potential user groups are specifically identified. We discuss these in Sections 4 and 5.

3.2. The US National Assessment

The U.S. National Assessment (USNA) was the most comprehensive attempt to date to assess climate impacts on the United States over the 21st century and to consider both major sub-national regions and sectors.[102] Organized in response to a call for climate-impact assessments in the 1990 Global Change Research Act, the Assessment was organized by the federal agencies participating in the U.S. Global Change Research Program. Work began in 1997, with various components completed between 2000 and 2002. The assessment included separate teams examining US climate impacts and vulnerability on sub-national regions, sectors, and the nation as a whole, and included participation by roughly two thousand experts and stakeholders. The National Assessment was charged with assessing US impacts of climate variability and change over 25-year and 100-year time horizons. Regional impacts were initially considered in twenty regional workshops, followed by more extended analyses of impacts leading to published assessments for twelve regions, conducted by university-based teams. Sectoral impacts were examined by national teams focusing on agriculture, water, human health, coastal areas and marine resources, and forests. A federal advisory committee, the National Assessment Synthesis Team (NAST), provided intellectual direction for the assessment and synthesized its results in two published reports (NAST 2000, 2001).

The main work of the Assessment was to examine climate impacts. Thus, it needed both climate projections and scenarios of potential future socio-economic conditions over the 21st century, since substantial changes are likely over this period in socio-economic conditions that might influence vulnerability to climate and adaptive capacity.

Emission and Climate Scenarios

For climate scenarios, the Assessment relied predominantly on data and model results previously produced, and conducted additional checking, processing, documentation, and dissemination as needed to make these usable by its study teams. The Assessment encouraged the use of three types of scenarios: historical scenarios produced by extrapolating observed trends or re-imposing historical climate variability or extremes; sensitivity analyses to explore the responses of climate-sensitive systems, with particular emphasis on thresholds defining key vulnerabilities; and global climate model (GCM) simulations of potential future climate conditions to the year 2100.[103]

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

[103] NAST 2001, p. 25.

Of these three approaches, the GCM scenarios were the most precisely specified and the most widely used. The Assessment did not have the resources or time to commission new GCM runs, so relied on model runs completed and published when it began its work. A set of criteria was developed by the NAST for the climate model scenarios to be used in the Assessment. Climate-model scenarios used in the Assessment should, to the greatest extent possible:[104]

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

To ensure timely dissemination, the Assessment chose climate-model scenarios to be used in its analyses in mid-1998. At that time, only two groups had completed runs that met most of the key criteria: the UK Hadley Centre (Model Version 2) and the Canadian Centre for Climate Modeling and Analysis (Model Version 1).[105] These two were consequently chosen as the Assessment's primary climate-model scenarios, which all participating regional and sector analyses were asked to use. The climate sensitivity of these models was 2.5°C (UK Hadley) and 3.6°C (Canadian), lying in the middle of the 1.7 to 4.2°C range of sensitivities represented by models participating in the IPCC Third Assessment.[106]

These two models were limited in their ability to reproduce observed patterns of inter-annual and inter-decadal climate variability, so this was the criterion most weakly met. Other scenarios available at the time from other climate-modeling groups had more serious limitations that made them unusable as standard scenarios for the Assessment. These included unavailability of documented results; projections that stopped short of 2100; non-standard emissions scenarios that made results non-comparable with other models; and failure to treat the

[104] NAST 2001, p. 31-32; MacCracken et al, 2003, p. 1714.

[105] Johns et al. 1997; Boer et al. 1999a, 1999b; MacCracken et al. 2003.

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

day-night cycle explicitly. But because an important part of the analysis conducted by the Assessment was based on quantitative ecosystem models that required not just projected changes in daily-average temperatures, but separate projections of daily highs and lows, this requirement was essential.

For each of these two climate models, only model runs using one emissions scenario were available, and only one ensemble run was used for each.[107] The emissions scenario was IS92a, which represented the middle of the range of IPCC's 1992 scenarios.[108] In addition to greenhouse gases, the scenario included projections of future trends in atmospheric loadings of sulfate aerosols (SO_4), which were assumed to increase sharply through 2050 and then level off for the rest of the 21st century.[109]

The applicability of these two scenarios was tested by checking the models' ability to replicate broad patterns of US climate change over the 20th century when driven by historical greenhouse-gas forcings. Model results were compared against the VEMAP (Vegetation-Ecosystem Mapping and Analysis Project) dataset, a corrected climatic dataset for the 20th century. The VEMAP dataset used statistical methods to interpolate observations to a uniform fine-scale (0.5-degree) grid, fill in missing values, and generate representative daily weather data when only monthly means were available. In addition, it sought to correct for the warm bias present in high-elevation temperature records because observing stations tend to be located in valleys, by adding readings from mountain snow stations. When 20th-century model results were processed using VEMAP algorithms to produce fine-scale data comparable to VEMAP historical observations, they showed reasonable accuracy in reproducing the spatial distribution of average temperatures and century-long temperature trends, but were significantly weaker in replicating observed patterns of precipitation, principally because the spatial distribution of precipitation depends on topographic detail too fine-scale to be captured even by the 0.5-degree VEMAP grid.[110]

With the specified scenario of future emissions, the two climate-model scenarios projected global warming by 2100 of 4.2°C (Canadian) and 2.6°C (Hadley).[111] This projected global warming put these two models at the high end and in the middle, respectively, of the range of warming projected for this emissions scenario by models participating in the IPCC Third Assessment Report.[112] For the continental United States, the two models projected

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

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

[109] See www.usgcrp.gov/usgcrp/nacc/background/scenarios/emissions.html for further detail on emissions scenarios used in the National Assessment.

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

[111] NAST 2001 p. 36, Table 2.

[112] Cubasch and Meehl (2001), Figure 9.5a, p. 541. While the Canadian model lies at the high end, it is not an outlier. The GFDL model (which was more responsive than the Canadian model, with a climate sensitivity of

warming by 2100 of 5.0°C (Canadian) and 2.6°C (Hadley), at the high end and below the middle, respectively, of the range of projections in the IPCC Third Assessment.[113] In their projections of precipitation change over the US, these scenarios both lie at the high end – the Hadley scenario projects the highest precipitation in 2100 and the Canadian the second-highest[114] -- but the Canadian model's greater warming offsets the effect of this precipitation increase on soil moisture, which is projected to decrease over most of the continental United States.[115]

To provide the finer-scale projections required for impact assessment, model-generated projections of monthly climate data were distributed across space (finer points within each model grid-cell) and time (days within the month) following the same finer-scale patterns produced by VEMAP for the observed 20th-century data.[116]

Although only the Hadley and Canadian climate-model scenarios were used throughout the Assessment, several others that met some or all of the Assessment's needs became available during its work. Several region and sector teams were able to use these additional scenarios. In some cases, the additional scenarios allowed groups to strengthen their conclusions. For example, an analysis of future Great Lakes water levels under climate change using eleven climate models found that ten of these showed lower levels and only one higher.[117] In other cases, using multiple models allowed more detailed characterization of uncertainties in future regional changes. For example, the Pacific Northwest team presented distributions of regional temperature and precipitation change in the 2030s and 2090s using four current models and three earlier-generation models.[118]

Despite the Assessment's aim of exploring future climate using three distinct types of scenario, historical scenarios and sensitivity analyses were less extensively used than GCM scenarios and featured less prominently in the Assessment's publications. Two uses of historical climate data – describing historically observed impacts of climate variability, and using observed historical extremes as benchmarks to compare projected future changes – were made by all groups. To support systematic use of historical scenarios, the VEMAP 20th-century dataset described above was provided to all Assessment groups, but no further guidance was provided on how to generate climate scenarios from these historical data, e.g., on what particular historical

4.2 C) projected higher global warming than the Canadian model in this scenario for the first few decades of the century, but only had results through 2060 in time for the TAR.

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

[114] NAST 2001 p. 545, Fig. 8.

[115] NAST 2001 p. 552, Fig. 16 and 18.

[116] NAST 2001, p. 39.

[117] Lofgren et al. 2000; NAST 2001, p. 175.

[118] NAST 2001 p. 256, Fig. 9, from Mote et al 1999, p. 19.

periods to choose or how to use them to assess potential future impacts. Several groups used these historical data to describe the impacts of particular recognized patterns of climate variability, such as ENSO or the Pacific Decadal Oscillation (PDO).[119] Most Assessment groups did not select extreme periods from the historical record as quantitative proxies for potential future climate change, an approach that has been used to create scenarios for impact studies,[120] but many groups did examine past climate extremes in qualitative ways.

The third approach, vulnerability analysis, was the least used in the Assessment. This 'bottom-up' approach involves describing the properties of a climate-sensitive system, specifying some important change or disruption, and asking what climate changes would be required to bring about that disruption and how likely – based on historical data and model projections – such climate changes appear to be. Given the complex dynamics of climate-sensitive systems and models of these systems, and the multiple dimensions of climate on which these can depend, this approach requires a substantial program of new research, analysis, and methodological development[121]. In part because of the intrinsic difficulty of this task – and in part due to management and resource problems – this approach was not pursued in the Assessment. The NAST proposed it, but more tractable approaches to analyzing climate impacts dominated the assessment's work. This remains an important area for further work in development of assessment and modeling methods.

Socio-economic scenarios

As discussed in Section 2.5 above, assessing impacts of future climate change can require specifying not just scenarios of future climate, but also socio-economic characteristics of the future society that will experience the changed climate. Specifying future socio-economic conditions might be necessary for two reasons. First, socio-economic conditions may influence the demands placed on particular resources that are also sensitive to climate change, the value assigned to them, and the non-climatic stresses imposed on them. For example, future flow regimes in river systems will be influenced by upstream demands for municipal and irrigation water use, in addition to the changes caused by climate. Socio-economic scenarios are also needed to assess climate-change impacts on human communities – e.g., economic impacts and their distribution, human health effects, and vulnerability to extreme events – because characteristics of the community interacting with a dynamic climate will strongly influence the community's vulnerability to potential changes and its capacity to adapt.

In contrast to climate scenarios, little prior information or experience was available at the U.S. federal level on constructing scenarios of socio-economic conditions for impact assessment. Consequently, the assessment invested effort in developing methods and procedures for constructing them. A hybrid process was adopted, which was partly centralized and partly decentralized. The centralized component was required because a few socio-economic variables, such as population, economic growth, and employment, are likely to be important in all regions

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

[120] Rosenberg, Easterling et al (the MINK study)

[121] See the AIACC Program, http://www.aiaccproject.org/

and sectors. For these variables, consistent assumptions are needed to allow comparison of impacts across sub-national regions and sectors, and to aggregate from separate regional or sector assessments up to overall national impacts.

A sub-group of the NAST developed three alternative scenarios of these variables at the national level, representing high, medium, and low growth assumptions. Through 2030, these scenarios followed the assumptions of the US Census Bureau high, middle, and low scenarios for fertility and mortality, while employing a wider range of assumed values for net immigration to account for possible illegal immigration.[122] National totals of population, GDP, and employment were then disaggregated among sub-national regions and sectors using a commercial regional economic model.[123] Beyond 2030, the same three variables were projected only at national level, using simple specified annual growth rates chosen to be roughly consistent with the OECD growth rates in the SRES marker scenarios.[124]

The socio-economic scenario process also required a decentralized component because the particular socio-economic characteristics that most strongly influence climate impacts and vulnerability may differ markedly among regions, activities, and resources. For example, the most important factors shaping climate impacts on Great Plains agriculture may be the degree of reliance on irrigation, the crops it is used on, and the technologies used to provide it, while the most important factors shaping coastal-zone impacts may be specific patterns of coastal development, zoning, infrastructure, and local property values. Furthermore, analytic teams with specific expertise and responsibility for assessing regional or sector impacts are likely to know more about what the key socio-economic factors are and what ranges of future values for them are plausible, than will a national group like the NAST. The NAST also judged that decentralized development of socio-economic scenarios was likely to encourage a diverse collection of partial, exploratory analyses from which might emerge an improved understanding of the socioeconomic determinants of impacts and vulnerability.

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

The implementation of this decentralized component of scenario development was weak. With a few exceptions, regional and sector teams did not use the proposed approach. Many teams made no socio-economic projections at all, but rather projected only biophysical impacts based on GCM projections. The Metropolitan East Coast assessment found the socio-economic scenarios were inconsistent with superior local estimates of current population, and so decided not to use them. The teams that did use the socio-economic scenarios used only the aggregate projections of population and economic growth, or in some cases assumed continuation of

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122 Parson et al 2001, p. 102-103.

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

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

present conditions in the assessment period. None used the proposed template for identifying and projecting additional important socioeconomic characteristics.

The limited use of socio-economic scenarios was a key weakness of the National Assessment, which greatly limited its ability to identify key factors likely to shape impacts and vulnerability. More useful assessments of impacts and vulnerability will require more extensive use of socioeconomic scenarios and improved integration of socioeconomic with climatic and environmental scenarios.[125] There were several reasons for this limited use of socioeconomic scenarios in the assessment. Some of the obstacles were managerial, such as inadequate time and resources, and insufficiently clear and timely communication of the proposed approach through the large, cumbersome management structure of the assessment. The proposed approach was only developed by NAST in spring 1998, and presented to team leaders in July 1998, when many teams had their analytic work well underway. Consequently, the time and attention required to implement the approach – including communicating it, persuading and training teams to try it, and working collaboratively between teams and the NAST to test its feasibility and work through problems that arose – were simply not available.

In addition to these managerial obstacles, many Assessment participants were reluctant to use socio-economic scenarios, especially the proposed decentralized approach. Some preferred to avoid any socio-economic projections, implicitly presuming that whenever socio-economic conditions mattered for an impact, relevant conditions in the future would resemble those of the present. Others found the specific contents of the aggregate scenarios or the methods used to produce them suspect, or judged that without social scientists with relevant expertise on their teams they were unable to adequately evaluate the scenarios. Still others objected that the high levels of uncertainty in future socio-economic conditions made any attempt to project conditions more than a few years in the future unacceptably speculative.[126]

Because of the limited use of the socio-economic scenarios, the assessment's experience did not effectively test the potential advantages or pitfalls of the approach. There is a substantial need for further research, development, and testing of new methods, for more time and resources, and for support for provision, integration, and documentation of climate, ecological, and other information such as is being developed under the IPCC TGICA.

Criticisms and Controversies

The National Assessment has been the object of substantial political and scientific controversy. Here, we summarize the major criticisms that pertain to the development and use of scenarios, rather than other aspects of the assessment. Criticisms focused predominantly on the climate scenarios, especially those based on GCMs, probably because these were more precisely defined, widely used in the analyses, and featured in the Assessment's publications. Three criticisms of these were advanced.

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[125] Lorenzoni et al., 2000; Berkhout and Hertin, 2000.

[126] Morgan et al 2005.

The first criticism, widely circulated during 2000, was that the use of non-American climate models to develop climate scenarios was inappropriate and potentially injurious to national interests.[127] While this criticism indicates a dimension of political vulnerability of the assessment, it does not address its technical quality. Since climate models represent the physics of the global atmosphere, they contain no representation of political or economic factors. The Hadley and Canadian global climate models were extensively documented in peer-reviewed scientific literature – and, moreover, were the only models that met the most critical of the Assessment's criteria. That they were developed by scientific groups outside the United States has no significance for their ability to provide scenarios to assess US impacts.

Organizers could have made other choices to limit the political vulnerability shown by this criticism. Choosing US models would have avoided this particular criticism, although at the cost of either weakening the analysis by using scenarios that did not meet the Assessment's needs, or delaying the Assessment a further one-to-two years. In deciding to proceed with non-US models, assessment organizers judged that these costs were too high

The second major criticism was that the two climate-model scenarios used were at the extreme end of available models in their projected climate change. This is partly accurate (see description above). When temperature and precipitation factors are considered together (i.e., high precipitation in some cases may offset the impacts of high temperature), the Canadian scenario lies at the high-impact end – although not an outlier, as other IPCC model projections lie close to it – while the Hadley lies at or somewhat below the middle for most analyses.

The Assessment's organizers and its critics agree that using more models would have been preferable, but the Assessment was limited to these two by its schedule and its technical requirements. Given a limit of only two, there are good reasons that one might choose one scenario in the middle of current projections and one near the top that provides a plausible upper-bound, but such a choice requires care in communicating the significance of the results. Some suggested that presentation of results based on the relatively high Canadian scenario should be more carefully qualified to highlight its position near the top of current projections.[128] Such qualifications require substantial subtlety, however, lest they imply that such results may safely be ignored, when most analyses suggest the full range of future climate-change uncertainty extends both below the Hadley scenario and – in a long, thin tail – above the Canadian.

A related criticism of the climate scenarios focused on the emissions scenario driving them, claiming that it was implausibly high. The issues bearing on choice of emission scenarios are similar to those for choice of climate models. It would be preferable to have a wide and relevant range of emissions scenarios driving an impact assessment – at least for the post-2050 period, since variation in emissions makes little difference in climate projections before then. Using a wide range of emissions scenarios would also allow comparison of projected impacts under high and low emissions futures, and so give insights into what degree of impacts could be avoided by what degree of mitigation effort. But in this assessment, as with the choice of climate models, model runs with this emissions scenario were all that was available. There is no

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

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

clear basis to reject this particular scenario, since IS92a was the scenario most widely used in climate-model runs at the time and it lies near the middle of the range of both the 1992 and the 2001 IPCC scenarios. And there is no support for the claim that this scenario was chosen with the aim of making 21st-century climate change appear as threatening as possible.[129] But while using just two climate models with one emissions scenario was unavoidable in this assessment, it still represented a serious limitation. With more model simulations testing a range of emission scenarios already available, future assessments will be able to remedy this deficiency.

In contrast with the preceding criticisms that the scenarios used in the Assessment understated uncertainty, another criticism focused on the disparities between the two scenarios' projections. Some critics argued that such disparities – e.g., the Canadian scenario projects the Southeastern states becoming much drier than the Hadley model does – show that limitations of present knowledge of regional climate change make any attempt to assess future impacts and vulnerabilities irresponsible.[130] This criticism implies that impact assessment should wait until precise, high-confidence regional climate projections are available. Since a major purpose of the assessment was to represent current uncertainty about climate change and its impacts, such discrepancies between model projections served a valuable purpose, as indications of the uncertainty of projections at the regional scale – particularly when the model disparities had a clear origin, such as differences in projected jet-stream location.

In sum, the National Assessment's use of climate-change scenarios was hampered by the lack of availability of relevant runs, but reflected an adequate attempt to represent the then-understood variation in climate projections for the United States. Future assessments will need to use more climate-model projections – including multiple ensemble runs -- informed by a wider range of relevant emissions scenarios. The Assessment's use of socio-economic scenarios represented a substantial attempt to advance the state-of-the-art of an important element in scenario development and use, although it suffered from lack of time to facilitate its implementation. Future assessments will need to invest substantial resources in developing the state of underlying knowledge, models, and assessment methods for integrating socio-economic considerations into assessments of climate impacts. This includes developing more 'bottom-up' approaches, such as vulnerability analyses, as integral parts of the Assessment.

The experience of the National Assessment raises three issues of greatest significance for future climate-change scenario exercises. First, like several of the experiences reviewed here, it illustrates the difficulty and scale of effort involved in producing scenario-based assessments. Second, the large required start-up effort and time to build the capacity to conduct such an exercise illustrates the great value of sustaining analytic and institutional capacity over time, rather than relying on separate projects. Such continuity of capacity will be necessary to avoid wasteful repetition of start-up efforts, to support accumulation of learning and experience, and to develop and maintaining the required collaborative networks. Finally, the assessment's experience illustrates both the need for consistency in large-scale assessments, and the great

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

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

specificity of information needs within particular impact and adaptation assessments. This combination of centralized and decentralized needs strongly suggests the merit of a cross-scale organizational structure for developing and applying scenarios, such as was attempted but not fully implemented in the National Assessment.

3.3. The UK Climate Impacts Program

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

The 1998 climate scenarios were based on simple transient emissions scenarios similar to the IPCC 1992 scenarios, and runs of the Hadley Center's HadCM2 climate model, the same model used in the US National Assessment.[131] The scenarios provided information only at the model's rather coarse scale, with four grid-cells over the entire UK. Downscaled data were not provided, although the scenarios' documentation noted that finer-scale patterns of variation in current climate data could be used to downscale the data as needed. The four scenarios, called "high", "medium-high", "medium-low", and "low," combined variation in emissions assumptions with variation in assumed climate sensitivity. The medium-high and medium-low scenarios both used the HadCM2 model, with a sensitivity of 2.5°C.[132] The medium-high scenario was forced by a 1% per year equivalent-CO_2 transient scenario, similar to IS92a. The medium-low scenario was forced by a 0.5% per year equivalent-CO_2 transient scenario, similar to the lowest IS92 scenario, IS92d. The high and low scenarios used the same two emissions scenarios, now driving a simpler climate model whose sensitivity was set at 4.5°C for the high scenario and 1.5°C for the low. These scenarios were used in an initial impact assessment focusing predominantly on direct biophysical impacts.[133] The scenarios did not include any explicit statements of probability, although their documentation suggested that the medium-high and medium-low scenarios "in one sense … may be seen as being equally likely," while the high and low scenarios captured part of the tails of the distribution.

The UKCIP's socio-economic scenarios were published in 2001.[134] They drew on the Foresight Program, a broader exercise of the UK Department of Trade and Industry to develop scenarios for long-rang planning in several policy areas, but added further detail in areas relevant to greenhouse-gas emissions and climate impacts. As in several other scenario exercises, scenario developers identified two fundamental uncertainties and combined two alternative

[131] UKCIP 1998.
[132] UKCIP 1998, pg. 13-15.
[133] UKCIP 2000.
[134] UKCIP 2001.

outcomes of each to produce four scenarios. The two core uncertainties they chose were similar to those used in the SRES exercise: social and political values, which varied from an increased focus on individual consumption and personal freedom ("consumerism") to a widespread elevation of concern for the common good ("community"); and governance, which varied from one pole in which authority and power remained concentrated at the national level ("autonomy"), to an opposite pole in which power was increasingly distributed away from national institutions, upward to global institutions, downward to local ones, and outward to non-governmental institutions and civil society ("interdependence"). The two dimensions of uncertainty, values and governance, were assumed independent of each other. Other major uncertainties such as demographic change, the rate and composition of economic growth, and the rate and direction of technological change, were treated largely as consequences of alternative realizations of the two core dimensions of values and governance.[135]

The four scenarios built around these two dimensions of variation were called "National Enterprise", "World Markets", "Local Stewardship", and "Global Sustainability." Each was initially developed as a qualitative narrative of future conditions in UK society intended to apply broadly to both the 2020s and 2050s. Each scenario specified several dozen socio-economic characteristics qualitatively, including multiple aspects of economic development, settlement and planning, values and policy, agriculture, water, biodiversity, coastal zone development, and the built environment.[136]

The implications of each scenario were also realized in projections of multiple quantitative variables, at national scale only. For the 2020s, these provide a great deal of detail, including population, GDP (including the governmental share and the sector split between industry, agriculture, and services), household numbers and average household size, land use and rates of change, total transport and modal split, agricultural production (including such details as chemical and financial inputs, subsidies, yields, and organic area), freshwater supply, demand, and quality, and several indicators of biodiversity and coastal vulnerability. For the 2050s a smaller set of quantitative variables is projected, describing population, GDP, land use, and transport. The plausibility of projections was checked, mainly by comparing projected future rates of change to historical experience. The scenarios were published with a detailed guidance document, which provided suggestions how to use them together with climate scenarios for impact studies.[137]

As of 2005, the socio-economic scenarios had been used in six impact studies.[138] There has been some difficulty applying the national-level scenarios in specific, smaller-scale regions. The most ambitious use has been a preliminary integrated assessment of climate impacts and responses in two regions of England, the Northwest and East Anglia.[139] This study produced four integrated scenarios of regional climate impacts, by pairing each of the four socio-economic scenarios with one climate scenario based on a rough correspondence between the socio-

[135] UKCIP, 2001.
[136] Berkhout et al, 2001.
[137] Berkhout and Hertin 2001.
[138] UKCIP, 2005.
[139] Holman et al 2002.

economic scenario and the IPCC emissions scenario underlying the climate scenario[140] Based on these four scenarios, the study elaborated preliminary regional scenarios corresponding to the four national socio-economic scenarios, and conducted an assessment of coastal-zone impacts and responses using these scenarios and a formal land-use model.[141]

New climate scenarios were produced in 2002, based on the SRES marker scenarios and new versions of Hadley Center climate models. As in 1998 the scenarios were defined as “high”, “medium-high”, “medium-low”, and “low,” but the differences between these now came exclusively from different emissions assumptions, not from climate sensitivity. The high, medium-high, medium-low, and low scenarios were driven by the A1FI, A2, B2, and B1 marker scenarios, respectively. These were used to drive the HadCM3 global climate model (with a grid-scale of 250-300 km), generating climate-change projections for 30-year future periods centered on the decades of the 2020s, 2050s, and 2080s. For a subset of the emissions scenarios and time periods considered, climate projections were processed through a nested hierarchy of three Hadley Center climate models: the HadCM3 model at global scale, the HadAM3H model at intermediate scale, with a grid of about 120 km, and the HadRM3 model for high-resolution climate projections in the UK and Europe, with a grid of about 50 km. This fully nested processing was done for the baseline period (1960-1990), and for the most distant projection period (2070-2100) to produce three ensemble runs for the medium-high (A2) emissions scenario and one for the medium-low (B2). For the other emissions scenarios and the intervening projection periods, results of the global-scale model were downscaled using statistical patterns of fine spatial-scale climate variation derived from full runs using scenario A2. These scenarios were widely distributed and supported through a web-based interface, including map-based graphical display of projected changes in more than a dozen climate indicators on a fine-scale (50 km) grid of the UK.

Several analyses are continuing to use the 2002 climate scenarios in conjunction with the socio-economic scenarios. For example, a 2004 integrated analysis of flood risk and erosion control over a 30-100 year time horizon produced a threat assessment, a set of scenarios of flood risk, and a set of policy recommendations. An evaluation of this study’s effects one year later found that it was being used by several public and private actors to inform decision-making.[142]

The UKCIP has followed a substantially different model from the US National Assessment, based on building a sustained assessment capability rather than a single project. In addition, the central program has less authority over the separate assessments, instead acting more as motivator, resource, and light coordinator. Access to scenarios is to licensed users, of whom there are about 130 – roughly half in universities, the rest about equally split among private sector and all levels of government. Most active users have been national officials responsible for climate-sensitive resources.[143] The program has found it harder to attract serious

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

[141] Shackley et al 2005.

[142] UK Office of Science and Technology 2002.

[143] West and Gawith (2005).

participation from private-sector and local governments, perhaps because they are less accustomed to long planning horizons.

The program has made substantial investment in generating, disseminating, and documenting climate scenarios for impacts users, and making them useful. The jury appears to still be out on whether the level of effort and success is similar for socio-economic scenarios, which have not been either downscaled or repeated. Getting scenarios used is a slow process, but there is evidence that the scenarios produced by this program are starting to be used by decision-makers in support of their practical responsibilities. Although the UK program followed a substantially different organizational model from the US National Assessment, its experience appears to highlight the same issues for future scenario exercises, in particular the importance of continuity of institutional and analytic capacity and the desirability of developing and supporting scenarios via a cross-scale organizational structure that combines centralized and decentralized elements.

3.4. The Millennium Ecosystem Assessment

The Millennium Ecosystem Assessment (MEA) was a large, UN-sponsored assessment of the current status, present trends, and longer-term challenges to the world's ecosystems, including climate change and other sources of stress. Conducted between 2001 and 2005, the MEA sought to assess changes in ecosystems in terms of the services they provide to people and the effects of ecosystem change on human well-being. It also sought to identify and assess methods to mitigate and respond to ecosystem change, for various private and public-sector decision-makers including those responsible for the several international treaties that deal with ecosystems.[144] More than 1350 authors from 95 countries participated in the global assessment's four working groups, and hundreds more in roughly 30 associated sub-global assessments. The assessment's goals were broad, ranging from providing a benchmark for future assessments and guiding future research to identifying priorities for action.[145]

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

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

[145] MEA 2006, pg xii,

All components of the assessment used a common large-scale conceptual framework, which distinguished indirect drivers of ecosystem change, direct drivers, ecosystem indicators, ecosystem services, measures of human well-being, and response options. Direct drivers included direct human perturbations of the environment such as climate change, air pollution, land-use and land-cover change, resource consumption, and external inputs to ecosystems such as irrigation and synthetic fertilizer use, while indirect drivers were underlying socio-economic factors such as population, economic growth, technological change, policies, attitudes, and lifestyles.[146]

The Scenarios working group sought to apply this conceptual framework to long-term trends in ecosystems, looking ahead to 2050 with more limited projections to 2100. They developed the structure of the scenarios in an iterative process, including consultations with potential scenario users and experts in a wide range of decision-making positions around the world.[147] Like several other major scenario exercises, they initially sought to identify two fundamental dimensions of uncertainty in long-term ecosystem stresses, which together would produce four scenarios.[148] For the first dimension, similar to the SRES process, they chose globalization: continuation and acceleration of present global integration trends, versus reversal of these trends to increasing separation and isolation of nations and regions. For the second dimension, in contrast to the broad value-based uncertainties used in the SRES and UKCIP scenarios, they chose one more specifically related to ecosystems: whether responses to increasing ecosystem stresses are predominantly reactive – waiting until evidence of deterioration and loss of services is clear – or predominantly pro-active, taking protective measures in advance of their completely clear need. The combination of two polar values of each of these uncertainties gave four scenarios, summarized in Table 3.4.1.

Table 3.4.1. Millennium Ecosystem Assessment Scenarios

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

The Global Orchestration (global, reactive) scenario presented a globally integrated world with low population growth, high economic growth, and strong efforts to reduce poverty and invest in public goods such as education. In this scenario, society focuses on liberal economic values, follows an energy-intensive lifestyle with no explicit greenhouse-gas mitigation policy, and takes a reactive approach to ecosystem problems.[149] In Order from

[146] MEA 2006, p. 153 (Table 6.1), p. 304 (Table 9.2)
[147] MEA 2006, p. 152.
[148] MEA 2006, Fig 5.2.
[149] MEA 2006, Ch 5.5.1

Strength (regional, reactive) there is also only a reactive approach to ecosystem problems, but this takes place in the context of a fragmented world preoccupied with security and paying less attention to public goods.[150] Population growth is the highest in this scenario, and economic growth is the lowest, particularly in developing countries, and decrease with time. In Adapting Mosaic (regional, proactive), political and economic activity are concentrated at regional ecosystem scale. Societies invest heavily in protection and management of ecosystems, but these efforts are locally organized and diverse. Population growth is nearly as high as in Order from Strength, and economic growth is initially slow but increases after 2020. Finally, TechnoGarden (global, proactive) presents a world that is both focused on ecosystem management and globally connected, with strong development of environmentally friendly technology. Population growth is moderate, and economic growth is relatively high and increasing.[151]

Each scenario was defined in terms of the assessment's overall structure – indirect drivers, direct drivers, etc. – and was initially constructed as a qualitative description, defined principally in terms of indirect drivers. Population and GDP were specified quantitatively, while all other indirect drivers – including social, political, and cultural factors – were qualitative. Population scenarios were derived from the IIASA 2001 probabilistic projections, capturing the middle 50-60% of the distribution, with world population in 2050 ranging and from 8.1 billion (Global Orchestration) to 9.6 billion (Order from Strength).[152] GDP growth was high in Global Orchestration, somewhat lower but recovering after 2020 in TechnoGarden, medium-low in Order from Strength, and initially low but recovering after 2020 in Adapting Mosaic.[153] No statements of probability or likelihood were made about the scenarios.

From the indirect drivers, a more specific and quantified set of direct drivers were developed, using formal models where possible. Species introduction and removal was the only unquantified direct driver.[154] Separate pre-existing models were used of the world energy-economy, greenhouse gas emissions and climate change, air pollution, land-use change, freshwater, terrestrial ecosystems, biodiversity, and marine and freshwater fisheries. The IMAGE 2.2 model generated greenhouse-gas emissions projections similar to the SRES marker scenarios – Global Orchestration was compared to A1B (although somewhat higher), Order from Strength to A2, Adaptive Mosaic to B2, and TechnoGarden to B1.[155] To the extent possible, these quantitative models were used to reason from indirect and direct drivers to ecosystem effects, changes in ecosystem services, and effects on human well-being.[156] In some cases this was achieved by soft-linking models, using outputs from one as inputs to another, but this was limited by different variable definitions, spatial and temporal resolution, and other model

[150] This scenario was originally named "Fortress World" (report of first meeting of MA global modeling group, Jan 7, 2003). The later name reflected participants' judgments that in such a decentralized world preoccupied with security concerns, maintaining global order would require democratic nations to be militarily strong – i.e., it is a world of "realist" international affairs (MEA 2006, p. 133)

[151] MEA 2006, Pg. 131.

[152] MEA 2006, pg. 182.

[153] MEA 2006, pg. 8 (Table S2).

[154] MEA 2006 pg. 304 (Table 9.2)

[155] MEA 2005, p. 315. CO_2 Emissions in 2050: 20.1 GtC in GO, 15.4 in OS, 13.3 in AM, and 4.7 in TG.

[156] MEA 2006, Table S3.

incompatibilities.[157] Not all scenario elements could be modeled quantitatively, so expert judgments were also extensively used. Qualitative scenario process proceeded in parallel with quantitative modeling – elaborating aspects of the scenarios that were not amenable to modeling, filling gaps, and stipulating feedbacks between ecosystem services and human well-being and behavior.[158]

There were attempts to check for consistency between quantitative and qualitative scenario elements through periodic consultations between the two groups. This was particularly important for feedbacks that could not be modeled analytically. Some of these were interactions between direct drivers and ecosystems, but the most difficult occurred in scenarios that assumed strong socio-economic feedbacks and regulating mechanisms. Adapting mosaic, for example, assumed strong feedbacks from new ecosystem observations and knowledge to changes in human behavior that could not be incorporated into the models used. Representing these required allowing qualitative scenario logic to over-ride both the quantitative results and the structure of models. Unfortunately, time limits prevented this consistency checking from being done thoroughly, so remaining unexplored disparities between the qualitative and quantitative representations remained a significant weakness of the scenarios work.[159]

Many of the conclusions developed from the scenarios are common to all four scenarios, while others are common to all except Order from Strength. For example, it is concluded that rapid conversion of ecosystems for use in agriculture, cities and infrastructure will continue, and that habitat loss will continue to contribute to biodiversity loss.[160] Many forms of ecosystem services are projected to increase, however, suggesting the possibility of de-coupling some ecosystem services – although not biodiversity – from ecosystem stresses. Food security is projected to remain out of reach for many people, however. Extreme, spatially diverse changes are projected for freshwater resources, with general deterioration of freshwater services in developing countries under both “reactive” scenarios. Increasing demands for fishery products are projected to increase risks of regional marine fishery collapses.[161] In sum, ecosystem services show mixes of improving and worsening trends in all scenarios except Order from Strength, in which nearly all ecosystem services are projected to be more impaired in 2050 than in 2000.[162] The same three scenarios also suggest that significant changes in policies, institutions, and practices can mitigate some negative consequences of growing pressures on ecosystems, although the required changes are substantial.[163]

In sum, the MEA scenarios project investment substantially more effort in developing rich qualitative and narrative scenarios than the SRES, but also fell short on linking and integrating the qualitative and quantitative components. In part because of the greater elaboration of the qualitative components, this limited coordination resulted in significant

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

[158] Scenarios, Part II, Ch 6.5.5, pg 155

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

[160] Summary chapter.

[161] Scenarios, Table S3.

[162] Id. at 127.

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

inconsistencies and requirements to resolve conflicts between the two components. These inconsistencies arose even with just one model used for several components of the assessment, so the challenges of harmonization between models – and the associated possibility to explore model-structure uncertainty – did not arise. A related problem was that for many factors it was difficult to generate the desired level of variation between scenarios.[164] This raises issues of potential methodological interest, such as how to distinguish robust results from inadvertent convergence of scenario assumptions or failure of model structures to capture the important differences between scenarios, which largely remain to be investigated. Finally, the great breadth of conditions represented in the scenarios, as well as possible concerns with logical circularity between their presumptions and results,[165] makes interpreting the significance of the results difficult.

The experience of this scenario exercise provides a different perspective on some of the same key challenges for future scenarios highlighted by the other activities reviewed. The quite distinct difficulties faced here in attempting to combine quantitative and qualitative scenarios highlight the central importance and the difficulty of developing new methods to integrate these two approaches. In addition, this experience highlights the value of clarity about the intended uses of scenarios, including clarity about whether they are intended to address specific questions or guide decisions, or are focused more on long-term exploration. The risk scenarios becoming less useful due to breadth and vagueness may be particularly acute for scenarios that attempt to capture multiple stresses on some system – even though such multi-stress assessment is repeatedly advocated for climate-change and other forms of environmental assessment.[166]

[164] Report of the First Meeting of the MA Global Modeling Group, 7 Jan 2003; Second Report of the MA Global Modeling Group, 7 March 2003.

[165] This concern is particularly present regarding implications of the assumption that ecosystem management is either proactive or reactive (See, e.g., pg. 240, Ch 8.4.2.1, projected outcomes in Ch 9).

[166] NAST 2001.

4. Issues, Challenges, and Controversies in Climate-Change Scenarios

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

4.1. 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 more sharply the types of decisions that comprise a response to climate change, who makes them, and in what environment – i.e., with what responsibilities, authority, resources, and concerns. These issues carry implications for what benefits scenarios can offer, and how they might be designed and what information they might represent to most effectively provide those benefits. In this section we consider the major concrete decisions that comprise the societal response to climate change. Decisions that pertain to assessment, modeling, and research are considered in Section 4.2. Since development of the decision agenda for climate change remains at a relatively early stage, this discussion must be somewhat hypothetical, extending from rather thin current practice to reasonable speculation about future decisions and likely information needs.

A basic fact about climate-change decision-making is that there is no single global climate-change decision-maker. Because the dynamics of climate change operate on multiple spatial scales from the local to the global, it is not subject to unitary or coordinated decision-making. Rather, a large number of 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.

In Section 2 we described climate-change decisions using the conventional dichotomy of mitigation versus adaptation. To consider potential contributions of scenarios in more detail, we propose a three-way division of these decisions based on three types of decision-maker, dividing them into three groups, whom we call *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, and can be distinguished from each other by the nature of their 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.

National officials' responsibilities are the broadest, and the most likely to be explicitly identified as related to climate change. They develop national policies on greenhouse-gas emissions, including both regulations and incentives that influence emissions directly, and policies to 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, and not limited to mitigation and adaptation: to the extent that other responses such as geoengineering are considered, or design of systems and institutions for assessment, it will mostly be national officials, acting domestically or negotiating internationally, who make those decisions. They are also responsible for overall national welfare, including not just the environmental effects of their decisions but also other national interests such as economic prosperity and security, so their climate-change decisions may be linked with these other responsibilities.

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. These 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 and more specific in spatial scale or sectoral 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 will strongly influence society's ability to control greenhouse-gas emissions and consequently the effectiveness and cost of mitigation policies. 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 in some cases be vulnerable to climate change and its impacts, the largest climate-related threats or opportunities for this group are likely to come not from climate change itself, but from climate-change policies, particularly national mitigation policies, as well as other market and regulatory decisions that will determine the outcomes of private mitigation activities.

At greatly varying levels of precision and specificity depending on the state of relevant knowledge, scenarios can present two types of information to support decisions by these 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 generality, the three types of decision-makers differ substantially in the 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. Their needs from scenarios are consequently likely to be quite different as well.

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," that is not present in scenarios for impacts and adaptation. Because mitigation policies seek to reduce future emissions by altering the socio-economic drivers of 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, which 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.

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. These may be among the most important factors determining the consequences of national mitigation policies. 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 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.[167]

Scenario Needs: Impacts and Adaptation Managers

Of the three, impacts and adaptation managers are the group for whom the most effort has been made to provide useful scenarios, and the most has been achieved. To assess the threats and opportunities they face and evaluate responses, these decision-makers 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 their decisions must respond, so scenarios of climate-change stresses can be constructed independently of assessment of potential decisions, without concern for feedbacks by which the decisions may require modifying the conditions specified in the scenario.

Particular decision-makers' needs will be highly specific in the variables they require, and their time and space scale and resolution. A planner of water-management infrastructure may need monthly or finer-scale rain and snow projections over their watershed; a designer of coastal infrastructure may need probabilistic projections of specific characteristics related to sea level, storm intensity and frequency, storm surge, or saltwater intrusion. But in their climatic elements, these information needs all rest on a common core of scenarios of global climate change 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 adopt 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 information and documentation are transferred accurately.

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[167] Morita et al 2001; CCSP SAP 2.1a.

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 and support for related decisions. In addition, for many if not most areas of impacts, there are likely to be important interactions between climate change and other changes and stresses affecting decision-making over the same time period, requiring scenarios of multiple stresses that represent potential climate change in the context of other important and linked dimensions of change, such as population growth and development.

Scenario Needs: Energy Resource and Technology Managers

The consequences of decisions by energy and technology managers will predominantly be influenced by the mitigation policies in effect, nationally and internationally, over the lifetime of the relevant investments. Consequently, these actors will most benefit from scenarios that explore alternative policy regimes and their consequences for the value of energy and technology assets. 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 in scenarios. Scenarios of emissions, climate change, and impacts, are largely background information for these actors – factors that only matter for decisions via their likely influence on policy stringency, and so that do not need to be explicitly represented in scenarios. These actors may be in a position to exercise some influence over policy, but they do not make it and their influence is unlikely to be so strong that climate-policy scenarios would have to incorporate feedbacks from their own advocacy efforts.

Unlike the other two types of decision-makers we have distinguished, these actors are likely to be in competitive relationships 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 these actors use scenarios to help inform their planning and decision-making, they may consequently choose to produce them privately. As for the other types of decision-makers, these specialized scenarios could be based on general scenarios of global emissions and climate change. Several prominent emissions scenarios including SRES have explicitly excluded consideration of mitigation policies. When these are included, they have typically been formulated at a high level of abstraction and generality. The most specific exploration of mitigation policies in scenarios have been in exercises such as post-SRES and 2.1a that have identified trajectories consistent with various levels of atmospheric stabilization, but these have not posed the questions about what stringency, timing, and form of mitigation policies are plausible or likely.

Representing Decisions in Scenarios

A serious challenge that arises in attempts to develop scenarios to support all types of decision concerns how to represent decisions within scenarios – a challenge that is often referred to as “reflexivity.” To avoid scenarios that are either circular or contradictory, 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, just like well understood biophysical or economic processes. In the more likely event that others' choices cannot be confidently predicted, they might be represented as uncertainties – again, just like an uncertain biophysical or economic process. As with all uncertainties, how to treat them depends on judgments of their importance for the users' decisions: if they are of the highest importance, 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 as exogenous uncertainties.

The representation of decisions by scenario users is fundamentally different. Since these are assumed to be under the users' control and the scenarios are intended to inform their choice, these should not be represented as exogenous uncertainties within the scenarios. Rather, alternative choices should be stipulated independently from the scenarios. Users can then explore their implications under challenges and boundary conditions imposed by scenarios that include representation of the most important uncertainties. 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 mitigation assumptions.

For global climate scenarios, the question of how to represent decisions arises most acutely in deciding how to represent mitigation decisions. Following the general reasoning above, treatment of these should depend on what type of decisions is being informed. In climate scenarios to inform impact assessments and related decisions, scenario users are not considering mitigation decisions and likely have little influence over them, so emissions scenarios should include assumptions about the likely or plausible range of mitigation efforts. In estimating this range the possibility must be considered that it may be truncated if sustained rapid emissions growth generates future political pressure for aggressive mitigation – e.g., due to increasing signs of climate change, alarming projections of future change, or other environmental harms from rapid expansion of coal or synthetic fuels.

It is not assured that such a negative-feedback mechanism will 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 unwittingly create lock-ins to 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 perceived as unnecessary. This negative-feedback mechanism will 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 developed 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 these are on the agenda. Consequently, while extreme emissions futures should be excluded in scenarios for impacts based on negative mitigation-policy feedbacks, these should not be excluded when assessing mitigation decisions. If scenarios that truncate high-emissions futures based on assumed stringent mitigation efforts are used to support a decision that stringent mitigation is not necessary, the decision is based, contradictorily, on the presumption of the contrary decision. If the scenarios are to inform mitigation decisions, these decisions must be considered explicitly, not presumed in the underlying logic of the scenario.

This argument is complicated by the fact that no single actor controls emissions and mitigation strategy, either over the whole world or over the entire time horizon considered. National officials choose only for their own nations in the near term. Even when they negotiate global mitigation, they only act for the near term. They may view their responsibilities to include long-term planning and institutional design for future mitigation as well, but their successors will decide whether to continue, strengthen, or otherwise change mitigation measures adopted today, or adopt new ones. 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 or in the absence of a 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, perhaps based on the assumption that increased wealth or technological prowess will make it easy for them to do so. 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. Whatever assumption about future policy decisions is made for purposes of developing scenarios, however, actual current policy should seek to develop institutions and procedures that allow future adaptations in response to changes in knowledge and capabilities.

To summarize the current state of scenario use for mitigation and adaptation decisions, the importance of connecting the two is widely recognized and their use is growing, but not much is yet realized or fully developed. There is a large gap between, on the one hand, the widely recognized value that scenarios could provide to climate-change decisions and the aspirations of those producing scenarios 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. This rapid increase 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 about present knowledge and uncertainty. The major scenario exercises discussed in this report fall into this category, including the IPCC emissions and climate scenarios, the US and UK assessments of climate impacts, and the Millennium Assessment scenarios.

BOX 4.1.1:
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.[168]

The MEC assessment laid the foundation for agencies in the region to address climate change and consider both adaptation and mitigation responses. The assessment began with a regional workshop in

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

April, 1998 involving about 150 participants, including representatives of public agencies at the municipal, regional, state, and federal levels as well as climate researchers from the region. The workshop provided direction for the subsequent assessment, conducted by sector teams of researchers and officials from public agencies responsible for the study sectors. Teams developed regional scenarios of climate change and sea level rise based on the downscaled climate-model scenarios provided by the US National Assessment, plus two additional scenarios based on projection of recent regional climate trends and historical extreme events. The MEC scenarios were used to project climate-change impacts on beach nourishment, 100 and 500-year flood heights, wetland aggregation and loss, adequacy of the water supply system under droughts and floods, illnesses from acute air-pollution episodes, and peak energy loads. These impact projections in turn were used for preliminary assessment of adaptation strategies and policies.

Following the MEC Assessment, the New York Climate and Health Project developed updated climate scenarios for the region in consultation with an Advisory Board of public and private stakeholders and scientists. This study further analyzed public health impacts, focusing specifically on the effects of ozone air quality and extreme heat events. The updated climate scenarios used the IPCC A2 and B2 emissions scenarios driving a global climate model and a regional climate model to create down-scaled scenarios for the region. These were augmented with newly developed scenarios of future regional land use and population growth based on the IPCC A2 and B2 storylines, to support modeling and analysis of public-health impacts.

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 between regional researchers and the agency that manages the water system. The Task Force is using 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 model-based 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, based on collapse of the West Antarctic and Greenland ice sheets and modification of the thermohaline circulation. DEP is using results of the Task Force study 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.

These activities provide 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. That stakeholders have been willing to support and participate in three separate phases of these activities, and that NYCDEP has decided to incorporate them into a strategic planning exercise, provides clear evidence of the practical utility of the exercises.

Box 4.1.2.
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 U.S. Gulf of Mexico coast in the 20th century illustrated in Figure 1.[169] In southeastern Louisiana, where the local rate of land surface subsidence is as high as 2.5 cm per year, rise in local "relative sea level" may be the most important factor in the rapid loss of coastal zone wetlands that has occurred over the past several decades.[170]

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

The ecosystem modeling team working for the State of Louisiana and the U.S. Army Corps of Engineers in the aftermath of the 2005 hurricane season is presently integrating accelerated sea level rise scenarios into planning exercises that will aid federal and state agencies in evaluating restoration alternatives[172]. 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[173]. Sea level rise scenarios are also being used by transportation experts to assess the impacts of climate change and variability on the Gulf Coast transportation sector (CCSP Product 4.7). For this assessment of transportation impacts, a sea level rise simulation model developed by the U.S. Geological Survey generates scenarios of sea level change using over a dozen different AOGCMs and 6 different SRES emission scenarios. An example of the sea level rise scenarios developed for this assessment is presented in figure 2.

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

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

[169] Gosselink, 1984; Williams *et al*., 1999; Burkett *et al*. 2005.
[170] Shinkle and Dokka 2004; Barras *et al*., 2003.
[171] U.S. Army Corps of Engineers, 2005.
[172] http://www.clear.lsu.edu/clear/web-content/index.html
[173] 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.

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.

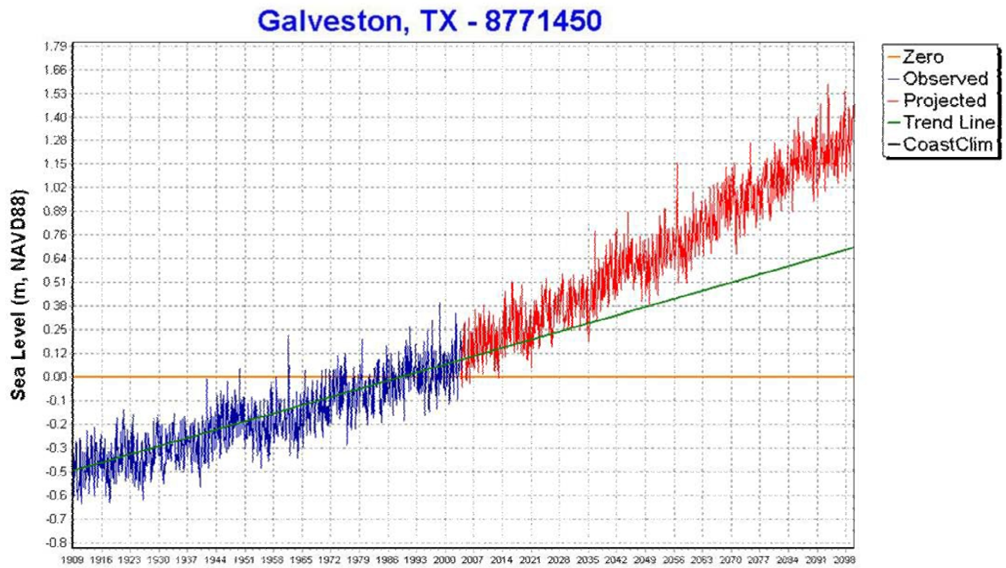

Figure 4.1.1. Output from a Gulf Coast sea level rise scenario tool
Source: Tom Doyle, USGS, Lafayette, Louisiana.

BOX 4.1.3.
Scenarios in the California Water Plan

The California Department of Water Resources produces an updated California Water Plan every five years. The plan assesses and 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.” (Plan home page).

Prior plans through 2000 had only constructed a single future scenario. The 2005 plan represented a major advance, in that it 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 one presenting higher and lower increases in the demands on California’s water resources. The report of the 2005 plan includes a discussion of global climate change and the potential challenges it poses to water supply and demand in California, but climate change is not 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 plan updates. In parallel with development of the three principal scenarios in this plan update, DWR sponsored development of several analytic tools and models to begin developing the capacity for more sophisticated 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.[174] It is planned to incorporate these climate-change scenarios explicitly in development of 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 specific 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 Program 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. But however essential these efforts at coordination around scenarios may be, their implementation has not been wholly satisfactory in practice. In part, this weakness has reflected management issues rather than the use of the scenarios themselves. 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. These are important tasks that need planning and resources to ensure proper execution.

Scenarios used in large-scale assessments can also make other contributions, by virtue of the prominent dissemination that a major assessment provides. They may, for example, be used as inputs to planning or decision-support processes that did not participate in the original

[174] California DWR 2005, Pg 4-32.

assessment, or were not even considered by the producers of the scenarios or the assessment. In such use, they may gain a more direct connection to decision-making than they had in their original production or use. Such derivative uses appear to be especially likely for scenarios of global emissions and the model-based climate scenarios based on them, because these types of scenarios are one required input, directly or with additional subsequent analysis and assessment, to many different decisions by diverse actors. Examples of such uses are the widespread citation of IPCC scenarios in research announcements of opportunity and climate-relevant decisions being undertaken by many private firms. Because potential users differ widely in their specific needs for scenario-based information, such derivative uses would require that the origin and meaning of the scenarios, in terms of underlying reasoning and assumptions, treatment of uncertainty, and assumptions about baselines and the degree of mitigation effort underlying emissions scenarios, be conveyed clearly, explicitly, and simply.

Scenarios can also contribute to the broad framing of public and policy debate on the issue. This effect may be especially pronounced for scenarios produced as part of a large, prominent, official assessment, because the assessment gains prominence and because scenarios can provide compact, salient results that can be the most widely noted, reported, and recalled pieces of information from an assessment.

In this role, scenarios become prominent in policy debates in which many contending views and interests are present – views and interests related to climate change, potential responses to it, or other linked issues. In such a setting, scenarios inevitably become political objects, in two senses. They are subject to political forces that seek to influence their development, and political reactions to them once developed. 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 – including the political sponsors of the scenario exercise or assessment – may seek to bias scenarios' content to help advance their policy preferences or their broader political objectives. This does not mean that scenarios should not have normatively determined content. It is not possible to eliminate normative biases in scenarios, and even predominant normative influence in a scenario can be useful if it is explicit. For example, scenarios can be constructed to examine what kinds of futures are both desirable and attainable, or to posit a highly desirable future and work through feasible paths to reach it.

But these uses are distinct from scenarios constructed to characterize uncertainty about future conditions for strategic planning, risk analysis, and assessment. Scenarios better serve these applications if they focus on likely or plausible futures, including those that pose sharp decision-making challenges, rather than desirable ones. When scenarios in such uses present a desired state – as the SRES scenarios all showed various degrees of North-South income convergence – this can weaken subsequent uses, since certain undesirable or unjust futures that might represent significant risks are not considered.

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

Other political pressures come onto scenarios in the broader use, debate, and criticism that they are subject to 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 know habits of conventional thinking and excessive confidence.

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

In global change scenarios, these conflicts and opportunities for bias arise most acutely over emissions scenarios. Since much of the uncertainty about climate change beyond 2050 comes from uncertainty in future emissions trends, actors with strong policy preferences can highlight emissions scenarios that lend support to their view. 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 lowest-emission scenarios to suggest that no action to limit emissions is warranted. Both these tactics – highlighting either the top or bottom of a wide range of possibilities to support your preferred policy – are easy to employ. Because scenarios are used when knowledge of causal processes is weak, it is easy to make any scenario you wish to highlight appear salient and likely, even if it is extreme. It is equally easy to probe inside the details of any scenario you wish to denounce to find inconsistent or implausible implications, particularly when a scenario is rich in detail.

But while political actors may have legitimate reasons to highlight one extreme scenario or another, it is not appropriate for any such scenario to dominate assessment or consideration of decisions. Claiming that only a single scenario is plausible – especially one near the top or bottom of the present range – is claiming to predict the future, moreover that the future will be extreme relative to present understanding. Such claims can be readily dismissed. Claims that a particular scenario is *implausible* cannot be so readily 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 much too confident the future will extend recent trends.[175] The threshold any single scenario must pass is that it appear plausible or instructive enough 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. In constructing a set of scenarios, the range of conditions they represent should encompass 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 or another does not necessarily impugn the credibility even of a single scenario, certainly not a whole set, because scenarios cannot be consistent in every underlying detail.

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 be incorporated into decisions of which scenarios merit continuing analysis, which ones can be dropped due to appearing increasingly implausible, and what type of new ones raising issues or outcomes not previously considered need to be added. One major basis for updates in scenarios will be policies and targets adopted, which can set a baseline to focus further deliberations. Perfect attainment of targets and success of policies should not be assumed, 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?

Box 4.2.1.
Scenarios of Ozone Depletion in International Policy-making[176]

Emission scenarios of CFCs and other ozone-depleting chemicals exercised substantial influence on policy debates over control of these chemicals to protect the ozone layer. Until the early 1980s, these policy debates used a convention to project future ozone losses that was originally adopted as a simplifying research assumption: constant emissions forever. Projections were stated in terms of the

175 Smil 2006; Greenberger et al 1983.
176 This example drawn from Parson (2003).

resultant equilibrium ozone loss. This convention has obvious advantages for research, similar to those of simple standard greenhouse-gas scenarios such as doubled-CO_2 equilibrium in climate models. It was a simple way to standardize model input assumptions, allowing exploration of scientific and modeling uncertainties without the confounding effect of different emissions assumptions. Moreover, because this convention made no claim to realism, it avoided distracting atmospheric-science debates with arguments over whether one emissions projection or another was more realistic. But while the resultant calculations of steady-state ozone loss were not projections of realistic future trends, they were frequently mistaken as such.

The question of what future emissions trends were likely only became a prominent point of 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 aerosol spray propellants, their largest use, and declined further in the recession of the early 1980s. It was widely argued that further restrictions were unnecessary because CFCs' major markets were saturated and further growth was highly unlikely. The resumption of sharp growth in 1983 undermined this claim, making it clear for the first time that managing the ozone risk required considering scenarios of CFC growth as well as steady-state and decline. How much emissions might grow and what it 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 several other types of emissions 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% per year would lead to large losses.

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

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

Box 4.2.2.
Climate-Change Scenarios for the Insurance Industry

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

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 for losses due to 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 the new 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, they 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 the 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, either by increasing the probability of severe events or the correlation among them.

There have been two public exercises using 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 a scenario of CO_2 stabilization at 550 ppm. Using highly simplified assumptions about changes in the distribution of storm wind speeds under climate change, the analysis calculated changes in losses due to US hurricanes, Japanese typhoons, and European windstorms associated with each emissions scenario using Cat models. No other impacts of climate change, and no changes in the socio-economic conditions that determine exposures, were considered. Consequences of each scenario were calculated for average insurance losses, extreme insurance losses, reserve requirements, and risk premiums.

The second scenario exercise, conducted by Harvard Medical School researchers with sponsorship by Swiss Re and UNDP, used two scenarios of 21st-century climate change to examine potential impacts on human and ecosystem health, and associated economic costs, not limited to the insurance industry.

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

The first scenario has increases in property losses and business interruptions following recent trends, emergence of new types of health-related losses, and increasing difficulty in underwriting. The combined effect of increased losses, pressure on reserves, inflation of constructions costs after disasters, and rising costs of risk capital result in a gradual decline in insurance profitability. As commercial insurability declines and cash-short governments (already providing flood and crop insurance) are unable to assume new risks, more climate-related losses are shifted back to individuals and businesses.

The second scenario is qualitatively similar but more severe. There are substantial increases in both average losses and variability, leading to large premium increases and withdrawal of insurers from many markets. As a result, many developments whose financing is contingent on insurance are left stranded, particularly along coastlines. As many insurance firms succumb to mounting losses, those remaining establish strict limits on coverage, shifting 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 public policies to reduce greenhouse-gas emissions and prepare for climate change, and providing support for changed regulations allowing 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 4.2.3.
Scenarios of Climate Impacts in the Columbia River Basin

Researchers at the University of Washington, in conjunction with the US National Assessment, studied climate impacts on the Columbia River system, which is the primary source of energy and irrigation water for the Northwest states and one of the most intensively managed river systems in the world.[177] The project examined the response of annual and seasonal flows both to existing patterns of climate variability, and to projected 21st century climate change.

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

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

Assessing the impacts of these flow changes requires assumptions about trends in demand for various water uses and how the system is managed. The group used a model of reservoir operations that calculated the combined effects of specified flow changes and various alternative system-operation rules on the reliability of different water-management objectives, such as electrical generation, flood control, irrigation supply, and preserving flows for salmon. Under historical climate variability, all these

[177] Mote et al 2004; Payne et al 2004.

objectives can achieve high reliability in high-flow years (i.e., in the cool phase of ENSO or PDO), but conflict between them occurs in low-flow (warm) years, when only one top-priority objective can be maintained at or near 100% reliability and other uses suffer substantial risks of shortfall. Alternative operating rules distribute this shortfall risk among uses.

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

In this analysis, scenarios helped to illustrate interactions between management decisions and climate change and variability, and to explore opportunities and limits for adaptation through management changes alone, with no change in infrastructure or larger-scale policies. This analysis has not been incorporated into any operational decisions, but has been integrated into the Fifth Conservation Plan issued by the Northwest Power and Conservation Council.[178] 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.

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

Scenario exercises are collaborative activities that need to be managed. As discussed in Section 1, scenario exercises involve numerous managerial decisions, such as how participants are chosen, which jobs are assigned and how these jobs fit together, how disagreements are resolved, and how much time and money is dedicated to the exercise. These matters can be decisive for the success of a scenario exercise, but in many cases the challenges and tradeoffs they pose are fairly obvious. For example, scenario exercises need sufficient time to build a team, research scenario components, consult repeatedly with users, and disseminate results but the necessary time is often not available, so various compromises are required. Adding participants expands the expertise and the range of perspectives 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 between groups. Accepting external direction on a scenario exercise increases the likelihood that the scenarios are seriously considered by external decision-makers, but also increases the risk that scenarios are perceived as biased or simply reflecting conventional wisdom. These issues pose significant challenges and call for judgment and skill in their resolution, but they apply to any collaborative analytic activity and are not in any way unique to scenario exercises.

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

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

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

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

But climate change scenarios are typically developed for a much more diverse set of users and stakeholders. This is particularly the case for scenarios produced for 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[179]" – are an enormous group, diverse in their interests and responsibilities. Potential stakeholders may be difficult to identify, and may have conflicting interests in the construction and use of scenarios. With users so diverse, scenarios may be limited to broad, exploratory purposes, such as signaling how serious the issue is or providing indirect input to many actors' decisions.

Under these conditions, the factors determining the most useful nature and extent of stakeholder participation are much more complex than in homogeneous-user scenario exercises. Certain users and uses may be clearly identified, such as the analysts and modelers who need scenarios as inputs to subsequent analyses, e.g., climate modelers who need input from emissions scenarios or impact assessors who need input from climate scenarios. Here, the case for close collaboration of users in scenario development is strong. These users may have highly specific scenario needs, including such prosaic factors as the format, resolution, and medium of the output, which scenario developers need to understand and meet. This may require one-time consultation, or ongoing interactions if the needs change. More intensive interaction may be required when users' specific needs are hard for scenario producers to meet. For example, climate modelers may 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. In this case, detailed consultation is needed to ensure that the two groups understand each others' needs and capabilities in enough detail.

The provision of climate-scenario data to support impact assessments is more difficult. Narrowly targeted impact assessments (e.g., one sector or resource in one region) can benefit from intensive stakeholder involvement in scenario production. This would allow an assessment team to draw on special expertise about local resources and processes and to connect to relevant decision-makers. This is clear, for example, for coastal managers considering the establishment or revision of setback lines for coastal-zone construction as sea level rises (McLean et al., 2001), or rangeland managers considering the purchase of conservation lands or easements for the purpose of providing migration corridors. But scenarios are more typically produced to serve not just one specific impact assessment but many, particularly within large-scale assessments like the IPCC. In contrast to climate modelers, these stakeholders are numerous and diverse in their disciplinary foundations, methods, and tools, and operate at scales much smaller than global. Their data needs are likely to have some commonalities, but substantial differences. Involving a representative collection of users in scenario production is likely still productive, but variance in users' needs makes the questions of stakeholder participation complex. A large and reasonably representative group will need to be involved, as well as a range of disciplinary and modeling experts, while keeping the total size of the scenario team manageable. Moreover, choosing representatives to participate is not likely to be straightforward. Users may lack expertise in each others' data needs, or their needs may be distinct or even in conflict.

The larger and more diverse in preferences and values the potential users and stakeholders for a scenario exercise are, the more difficult it is to figure out which of them should be involved in scenario production, and in what capacity. There is some value in having

[179] CCSP 2003, p. 112.

people with practical responsibilities related to climate change involved, rather than just researchers, if only to provide a general sense of the usability of data and analysis in supporting real decisions. As with more focused user groups, the general case for stakeholder involvement is strongest in the initial scoping and design of a scenario exercise, and in the evaluation of scenarios for relevance, practicality, and addressing key concerns. The case for stakeholder involvement is less strong in the actual work of background research, analysis, and modeling to generate and quantify specific scenarios.

Can a scenario process be completely open? 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. This tension poses challenges for design of processes of representation and consultation in scenario development, on which further progress is needed.

Box 4.3.1.
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 on controlling sulfur emissions. Among many differences between the programs they took sharply different approaches to involving stakeholders, and differed strongly in how effectively they informed decision-making.

The US National Acid Precipitation Assessment Program (NAPAP) was created in 1980 as a 10-year, $570-million research program to study all aspects of acid deposition: emissions, atmospheric transport and deposition, impacts, and economic analysis of alternative control strategies.[180] Managed by a committee of six lead government agencies and supported by a full-time staff office, the program involved roughly 2,000 researchers.[181] Although charged to conduct both scientific research and assessment, NAPAP strongly emphasized scientific discovery over policy relevance in its allocation of resources, selection of questions, and scheduling of activities.[182] Its assessment report was extremely opaque on the origin and interpretation of its scenarios, and did not use them to integrate across the multiple disciplinary domains of the issue or characterize the implications of alternative policies. Moreover, NAPAP released its assessment report several months after passage of the 1990 Clean Air Act Amendments adopted new acid-rain controls, although some commentators have noted that scientific participants and assessment staff contributed to the policy debate through prior informal exchanges with policy-makers.[183] Overall, NAPAP is regarded as having succeeded as a research program, but fallen critically short of providing useful information for decision making.

[180] NAPAP, 1982; Herrick, 2004.
[181] Herrick, 2004.
[182] Roberts, 1991; Cowling, 1992; Russell, 1992.
[183] Perhac, 1991; Roberts, 1991; Patrinos, 2000.

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 for monitoring and modeling acid emissions, transport, deposition, and impacts (EMEP). In contrast to NAPAP, EMEP focused more on assessment than research. It was specifically established to inform the policy process, and closely linked to it.[184] Scientific models of components of the acid-rain issue were chosen for their ability to contribute to a simplified integration of the problem, while 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 models was the RAINS model, developed by a research team 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 policymakers in the negotiation of sulfur-control agreements under the Convention, and had substantial influence over the distribution of controls adopted.[185]

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 EMEP 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

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

The global change scenarios discussed in this report must be communicated to multiple audiences with diverse interests and information needs. Although the specifics of what must be communicated will vary from case to case, any communication of scenario-based information to a large diverse public audience is likely to require certain common elements. Just as uncertainty is central to scenario exercises, it is central to the problem of effectively and responsibly communicating scenarios. Whatever decisions are made in resolving these issues must be reflected in the communication of scenarios to those outside the scenario development group. For example, scenario outputs should acknowledge the unavoidable elements of subjective judgment in developing scenarios, and scenario developers should be prepared to explain and

[184] Gough et al 1998.
[185] Levy 1995.

defend the judgments they made. Where particular scenarios were constructed to have specific meanings – e.g., a reference case, a plausible worst-case, or the exploration of a particular causal process taken to its extreme – these should be clearly conveyed, including whatever degree of specificity in conveying judgments of likelihood that has been decided. A particularly important distinction to communicate clearly is between scientific uncertainty and scenario uncertainty, e.g., requiring explicit statements of when and how scenarios change (such as the reduced projections of future SO_2 emissions in the 2001 IPCC scenarios), and clear explanations of the effects of such changes. Scenarios' 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.

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

In large and complex assessments such as the IPCC and US National Assessment, communication of scenarios and underlying information both to various groups within the assessment and to potential outside users can pose managerial challenges. In USNA, climate scenarios and other related information were provided to participating assessment teams in several formats (e,g., tabular summaries, models, graphic representations), through websites backed up with workshop presentations. In the IPCC, the Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA) was established in 1997 to facilitate distribution of climate scenario data, model results, and baseline and scenario information on other environmental 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).[186]

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

[186] 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.

estimates of natural variability.[187] In Figure 4.4.1, 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.

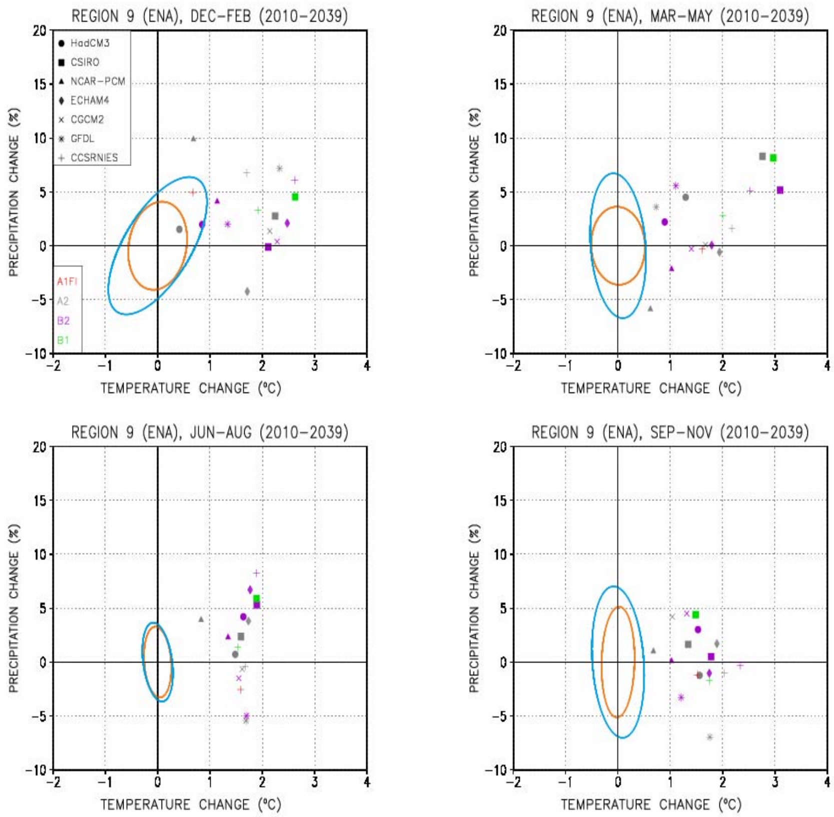

Figure 4.4.1. Regional scattergram for eastern North America, 2040-2069. The x-axis shows temperature changes in °C, the y-axis precipitation changes in percent. Each point shows one model's projection under one emissions scenario. A point's color denotes the corresponding emissions scenario, its shape the corresponding model (per legend, lower left of figure). Ovals show 95% confidence bounds for natural 30-year climate variability, calculated from unforced 1000-year runs of the models CGCM2 (orange) and HadCM3 (blue). Points outside the ellipses indicated projected climate change significantly outside the range of natural variability, most frequently due to changes in temperature rather than precipitation.[188]

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

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

[188] IPCC DDC, ipcc-ddc.cru.uea.ac.uk/sres/scatter_plots/regional_galleries/region_plots9/index.html, Figures downloaded February 16, 2006.

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 than this" or "lower than this"), and which fall in the middle of the range.

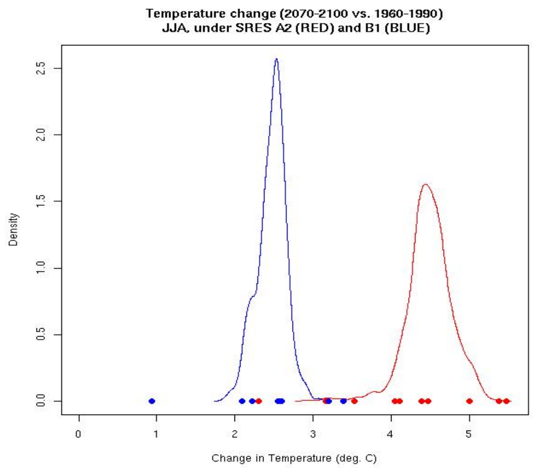

Figure 4.4.2.   Constructed probability distributions of model-simulated temperature change in 2070-2100 compared to historical temperature (1960-1990) in the Gulf Coast region, using 19 climate models with the SRES A2 (red) and B1 (blue) scenarios. Each point along the x axis represents a different model run.

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

4.5. 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. Since scenarios usually specify multiple characteristics of an assumed future, whether as multiple elements of a narrative or multiple quantitative variables, it is necessary to consider carefully how well these elements fit together. There are complexities and difficulties that 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, poses risks to the validity and usefulness of the scenarios.

Certain simple elements of internal consistency in scenarios are unproblematic. Elements of a scenario, for example, should avoid gross contradictions in view of well established knowledge about the behavior of biophysical or socio-economic systems. Similarly, elements of scenarios should not inadvertently move far outside the bounds of historical experience or presently recognized causal processes. Such inadvertently implausible assumptions can arise, for example, when multiple elements of a scenario are specified independently without cross-checking; e.g., independent end-year specifications of a region's population and GDP without checking the 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 between regions. Only when extreme or unprecedented outcomes are inadvertent should they necessarily be avoided, however. Intentionally presenting future conditions that initially seem implausible, with an explanation of how they could in fact arise, can be a valuable contribution to risk assessment, by broadening decision-makers' expectations of what ranges of future developments are plausible.

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

Expressed in probabilistic terms, statements about internal consistency may be interpreted as claims that a scenario is more likely to occur than some set of hypothetical alternatives; that is, a claim that the particular alignment of factors in the chosen scenario, or ones similar to it, is more likely than other alignments that were not chosen. One might, for example, claim that a scenario with rapid economic growth and growth in energy use was more internally consistent than one in which the economy grew rapidly but energy use did not. But where do these perceptions of greater or lesser likelihood come from, and how valid are they? In some cases there might be a well-founded theory or model that says certain outcomes tend to be related. Alternatively, some explicit analyses might connect the claim to some 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, identifying additional bodies of research and scholarship that can be brought to bear, etc. While the use of subjective judgments and deliberative processes cannot be avoided in scenario development, they pose significant risks of error and bias that are well established in empirical research on judgment and decision-making; e.g., excessive influence of articulate or charismatic individuals, re-affirmation of unfounded conventional wisdom, insufficient adjustment away from arbitrary initial characterizations (anchoring), etc.[189] While there are many devices and methods available to help identify and limit the influence of such processes, continual vigilance is required – just because a scenario looks consistent does not mean that it is – and success at avoiding these can never be guaranteed.

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 jointly specified in a scenario. In global-change applications of scenarios, integration typically refers to a more specific type of breadth. In the case of integrated-assessment models, an integrated scenario would specify all major components of the causal chain of global-change issues, typically multiple dimensions of emissions and their socio-economic drivers, climate, impacts of climate change, and possibly certain forms of 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 the risks of inconsistency and contradiction as the breadth and integration of 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 external (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, it is frequently the case that multiple models are 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

[189] Slovic et al 1976.

ones they calculate endogenously. In this case, some variables must be specified exogenously for some models, but are calculated endogenously by others.

This creates various problems for consistency. In general, when scenario exercises are conducted in this way, there will be some elements for which distinct, inconsistent specifications are provided – some of which are assumed and others which 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.[190] Less obvious is that it may be equally fruitless to define scenarios in terms of GDP and energy consumption trajectories and to force multiple models to reproduce these. Some models may include these variables as exogenous inputs, but other models may produce these variables as the endogenous result of a variety of parameters and structural assumptions, including productivity factors, elasticities of substitution in production, and assumptions about the rate and mechanisms of technological progress. For this reason, multi-model exercises such as the Energy Modeling Forum usually avoid strong coordination of inputs, instead seeking to harmonize a few of the most essential and commonly used inputs.[191] If a multi-model exercise is to be pursued, the most useful approach would be to make common assumptions about the variables that are furthest back in the causal chain. However, given the wide variation in model structures, achieving model harmonization will remain a challenge.

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

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[190] 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.

[191] Weyant and Hill 1999.

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. This approach does not suppress uncertainty, but confounds model uncertainty with parameter uncertainty. It may be preferable to cross exogenous inputs with models to produce a larger number of scenarios from which subsets can be extracted as needed, perhaps organizing these as a nested hierarchy of scenarios similar to the SRES 6 marker scenarios, 40 SRES scenarios, and hundreds of scenarios in the literature review.

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 that have 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 distinctions between alternative narrative scenarios correspond more closely to variation of model structure than to variation of parameters, because they reflect different basic assumptions about how the world works. Better integrating the two approaches will require developing ways to connect narrative scenarios to model structures, rather than merely to target values for a few variables that models are then asked to reproduce. This has not happened because scenario exercises have not had the capability or resources to direct new model development, or to induce modelers to undertake substantial structural changes to 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 analysis of decisions under uncertainty, and what challenges are posed in how uncertainty is represented. It also addresses several important debates about how to treat uncertainties.

In most scenario exercises, uncertainty is represented not in a single scenario, but in variation among multiple scenarios considered together.[192] 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, how, and how specifically measures of likelihood are assigned.

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 cas is so simple that many scholars and practitioners argue it should not be considered a scenario at all.[193] Still, even this simple and extreme case raises significant issues. We begin here and then move to more complex cases.

If we also assume 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 looking for 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 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 are no longer simply inputs to an analytic exercise but become descriptions of potential future states that must be communicated directly or indirectly to decision-makers for their reflection and

[192] 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.

[193] E.g., Wack 1986, in this case, the scenario is just a "quantification of a clearly recognized uncertainty".

deliberation. Second, if distributions of important uncertain quantities are unknown, it is necessary to exercise judgment of how 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.

Of course, 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 subjective elements. Despite this unavoidable element of subjectivity, 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.

Projections 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.

Subjective bias is a major risk in all scenarios, 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.[194] 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.[195] 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 communicating scenarios to users – even in the extreme case that the scenario only specifies values of one quantitative variable – limited time, resources, and attention usually require that only a few discrete values or time-paths are specified, not a complete distribution. Scenario developers must consequently decide how many scenarios to provide and how to space them.

How many scenarios to provide will rest 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, while still keeping the process manageable. If the use made of each scenario is expensive – e.g., running a large model or spending the time of busy senior people – 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 forty scenarios produced by the SRES process, only six (initially four) were highlighted as “marker” scenarios, while most subsequent analyses used just two or three.[196]

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

[194] Morgan and Keith 1996.
[195] Kahnemann and Tversky 1974; Wallsten and Whitfield 1986.
[196] Scenarios A2 and B1, sometimes augmented with A1B.

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 is predictably small.

One must also consider how far out in one or both tails of the distribution a set of scenarios should go. Empirical research practice typically draws ranges for unknown quantities to capture 90 to 95 % probability, but there may be good reasons to go further in constructing scenarios. Possibilities further out might be important enough, in their consequences or their effect on preferred decisions, that they must be considered despite their low probability. Assessments and policy in both regulation of health and safety risks and national security, for example, routinely focus on highly consequential risks of a much smaller probability than 1%.

It is often suggested that an important condition of a set of scenarios is that they "span the literature" of prior scenarios or projections of the same quantities. While one should be cautious about a set of scenarios spanning a much narrower range than published estimates of the same quantities, there may be good reasons for a wider or different range, or even in some cases for a narrower range. Scenarios are not scientific research: a published scenario may have been constructed to serve various purposes other than 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 development process, depending on the relationship between their intended purposes. Moreover, previously published scenarios can be highly self-referential, since many published analyses use prominent prior scenarios as inputs to a new study, or examine a new model by forcing it to reproduce some prior scenario. For all these reasons, previously published scenarios are better regarded as one input to the judgment of developers of new scenarios than an authoritative picture of present knowledge that new scenarios must follow.

4.6.3. 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.[197] Large-scale bifurcations may also arise from breakthroughs in energy technology. Such possibilities are typically not captured either in historical data or models, as they represent changes in the structure of causal relations that render both invalid.

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 whether and how to consider these uncertainties consequently turns on the balance between their probability – which is believed to be low but not

[197] NRC 2002.

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 five-meter sea level rise over this century – and the well-identified mechanism by which such a rise could occur – may suggest the importance of explicitly considering a scenario involving loss of one of the major continental ice masses. But including such a scenario runs the risk that users will assign a much higher probability to it than is appropriate either because of its vividness and extremity, or because they presume that developers' decision to include the scenario meant they assigned high probability to it. When such a scenario is included, scenario developers have a serious responsibility to communicate, loudly and consistently, that its status is different from the others.

A further challenge in representing large-scale or discrete changes in scenarios is that there might be many such possibilities, all of them high-consequence but believed low-probability. Including any one may mislead both by exaggerating its probability and by suppressing the possibility of others (the "unknown unknowns"). 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 highlight a 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, representing alternative resolutions of multiple uncertainties – but still with the constraint that only a few scenarios can be produced and used – it is necessary to decide which uncertainties are represented. Even when scenarios include only multiple quantitative variables, it is no longer possible for a few scenarios to span all corners of the joint distribution of these variables. Rather, they must combine variations in ways that are most illuminating and important for the purpose at hand, massively reducing the dimensionality of the problem to make it intelligible for users. In addition, increasingly detailed and realistic scenarios often specify characteristics that are qualitative, or described less precisely than 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,[198] 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 more than for simple quantitatively described scenarios, it is normally only possible to produce a few such rich scenarios in any activity. Typical configurations include two or three outcomes on one fundamental uncertainty; four scenarios, produced by jointly varying two realizations of two uncertainties that are presumed independent; or one scenario that continues familiar trends and dynamics, combined with one or two that pose fundamental changes.

Formal uncertainty reasoning states that as the number of characteristics specified in a scenario increases, the likelihood of the scenario decreases, because it represents the joint occurrence of a larger collection of events. Yet this approach, like any responsible use of scenarios, must imply certain claims of likelihood. Every scenario included must be deemed likely enough to merit the resources and attention spent on developing and analyzing it. This applies even to extreme-event scenarios that are intentionally constructed to 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.

These two points – that probability must decline as scenario complexity increases, and that any successful use of scenarios must imply the judgment of developers and users that they are likely enough to merit consideration – might appear to pose a contradiction. The contradiction can be avoided – as can the conclusion that rich multivariate scenarios must be arbitrary and of vanishingly small likelihood – in either of two ways. First, if scenario designers in fact succeed at identifying a few deep structural uncertainties that strongly condition outcomes on many other characteristics in a scenario, then the richness of a scenario description need not

198 Shell International 2003.

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. On the other hand, there will often be no way to further test these judgments, and it is in principle possible that the proliferation of additional detail in scenarios – even detail that developers and users recognize is crucial for determining valued outcomes and preferred choices – is arbitrary or erroneous.

A second route to resolving the contradiction and building up sufficient basis for confidence in the likelihood of detailed scenarios lies in the precision with which scenario characteristics are specified. In rich multivariate scenarios, many characteristics are often specified diffusely: economic growth may be merely “high” or “low”, rather than stating a particular value. Even when a characteristic is stated quantitatively, its specific value may be regarded as merely illustrative of a range of similar values; e.g., GDP growth might be set at 4% because a user needs a numerical model input, but it is understood to represent a broad swath of similar values that all count as “high” growth. Interpreted in this way, a multivariate description may remain likely enough to merit examination – and indeed, a modest number of scenarios may exhaust the set of potential futures that matter for the issue at hand. Here one is not assigning likelihood to the precise numerical assumptions used to flesh out the details of a scenario, but rather to cover a broad range of possible future conditions that resemble that scenario more than the other scenarios in the set.

4.6.5 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 normally avoided. After the scenarios were published, several critics argued that since the most prominent and important outputs of the scenarios were the projections of greenhouse-gas emissions under the six marker scenarios, it was natural – and essential for development of rational climate-change policy – to describe the distribution of emissions in probabilistic terms. For example, how likely are 2100 emissions to lie above the 30 GtC of scenario A2? Below the 5.2 GtC of B1? Should the range spanned by the SRES scenarios be understood to comprise 90% of all probability? 99%? All of it?

Developers of the SRES scenarios stood by their initial decision not to quantify probabilities. Since the controversy only became prominent long after the decision had been made by a writing team no longer in operation, it would have been virtually impossible for the group to retrospectively assign such probabilities. But rather than rely on this argument of managerial infeasibility alone, SRES organizers offered a vigorous substantive defense of their initial decision. 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 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.

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

In this simpler case, there are several strong arguments for being explicit about these probabilities. Stating probabilities explicitly organizes current knowledge about possible outcomes, and allows comparative risk assessment between scenarios and explicit exploration of risk-reducing strategies.[199] Sophisticated decision-makers whose choices depend on uncertainty in these variables need probability information about possible values, not just a set of alternative values, to evaluate choices – whether their approach to decision-making is expected-value, risk-averse, or robust. Moreover, when such scenarios are presented without probability judgments, users will attach their own, often via simple heuristic devices that may misrepresent the developers' understanding. Many subsequent users of the SRES emissions scenarios, for example, have simply assumed the probabilities they needed to conduct further assessments, using such simple devices as counting scenarios or assuming a uniform distribution over the entire range. It is clear that the next major emissions scenario exercise, whether done under IPCC auspices or within the larger community, will have to explicitly confront the need to make more definitive probability statements. Since scenario developers are better informed to do this than others, this is likely to become their responsibility.

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

For richer and more complex scenarios, three principled arguments are advanced against seeking to assign probabilities. First, some argue that for the type of events represented in rich, complex scenarios, probabilities cannot be sensibly estimated. At its root, this represents a healthy recognition of the severe methodological problems in aggregating expert judgments – although there are elicitation techniques that go some distance to addressing these. For high-stakes public policy issues, declining to state probabilities and instead letting users assign their

[199] Webster 2003.

own might be viewed as deference to democratic legitimacy or as a recognition that it is more appropriate for the decision makers to make the determination as to the weights of the various futures foreseen by the experts. The contrary argument is that the group developing scenarios presumably has the best access to the expert knowledge needed to make these probability judgments. The real issue here may well be the divide between the creators and users of scenarios, since the large number of relevant creators and users prevents the close face to face interplay that would allow a joint process to determine the likelihoods.

The second argument against assigning probability is that the massively large multivariate space of possibilities from which scenarios are drawn, and the vague and qualitative way that some scenario characteristics are specified, make it impossible to coherently define the boundaries of the outcome space to which probabilities are being assigned. In other words, there is no way to clearly define the interval "between" one scenario and another; and if probability is attributed to a lump of possibilities around a scenario rather than to the interval between them, is it not possible to define clearly the boundaries of the lump to which the probability is assigned. 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 common ground between users and creators. Here, even if assigning a precise numerical probability is judged too difficult, less precise likelihood measures such as "higher versus lower", or "roughly equal" could be assigned. In some applications where scenarios are intended to capture all the uncertainty of concern to the decision-maker – i.e., scenarios are intended to be mutually exclusive and collectively exhaustive – there may even be a reasonable basis for numerical probability.

A third objection to assigning probabilities to socio-economic characteristics such as emissions scenarios is that of "reflexivity" – the concern that since the purpose of scenarios is to inform decision-making, any probability judgment will be rendered invalid because of changes in behavior influenced by the statement of the scenario and its probability assignment. We have addressed this concern in some detail in Section 4.1 in discussing the representation of decisions within scenarios, in particular in the distinction we have drawn between how mitigation decisions should be treated in scenarios to inform mitigation decisions, and to inform impacts or adaptation-related decisions. We might only add here that as applied to global emissions, this concern would require extreme influence by scenarios on their users' behavior and extreme influence by these scenario users on global emissions. The concern might apply more seriously for scenarios are prepared in close consultation with national mitigation policy-makers, but this is an example of the type of scenario use for which we judge explicit attempts to assign probabilities to be less valuable. In any case, it is not clear that concerns about reflexivity should specially afflict the attempt to assign probability to scenarios describing future behavior, rather than rendering any scenario of human behavior invalid.

A final 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 some merit, but only to the extent that it accurately describes how these scenarios will be used. Quantitative assignment of probabilities to scenarios when high-stakes decisions are implicated is clearly difficult and contentious, as the SRES controversy illustrates. Even if this argument correctly characterizes how scenarios are used, 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 that refers to 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), weakest for complex multivariate scenarios with substantial qualitative or narrative elements. The controversy over probabilities in SRES reflected in part different perceptions of what type of scenarios these were. SRES initially followed a storyline-based process and rejected quantification of probabilities on that basis. Subsequent efforts, however, consisted predominantly of developing quantitative emissions projections and neglected further development of the storylines. Moreover, many users perceived the scenarios as consisting principally of their emissions projections, and were not much interested in the under-developed storylines that lay behind them. The controversy over quantitative probability in this case may suggest that, to the extent that quantitative projections are a major output of a scenario exercise, developers may have responsibility to go further in characterizing the likelihood of the resultant emissions intervals than would be appropriate for the more complex underlying storylines.

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

BOX 4.6.1
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 strategic-planning consulting firm expert in scenario methods, to develop a scenario of potential national-security implications of abrupt climate change. ONA conducts assessments on diverse issues of potential national security significance. This request was stimulated by widespread scientific interest at the time in potential abrupt climate change, particularly from shifts in North Atlantic circulation, and more specifically by a 2002 report on the topic by the National Academy of Sciences.[200] Several scientific papers had reported new evidence of rapid climate shifts in the past, and recent observed changes in Atlantic circulation and salinity that some scientists thought might indicate impending larger disruption.[201]

GBN staff developed the scenario by reviewing scientific literature and informally consulting with climate and ocean scientists.[202] They reviewed three past climate events – the cool period in the North Atlantic region of 1300 – 1850 called the "little ice age"; a Century-long period of stronger cooling about 8,200 years ago; and the "Younger Dryas", a rapid re-cooling of nearly 9 °F in the North Atlantic region that occurred 12,700 years ago and lasted 1,300 years[203] -- and decided to base their scenario on the one of intermediate severity, the 8,200-year event. 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.[204]

For their future abrupt-change scenario, the authors constructed a path of climate change to reach conditions like those during the 8,200-year event by 2020. The path to reach these conditions involved rapid warming through 2010, as high as 4 – 5 °F per decade in some regions,[205] 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 of extreme changes in multiple world regions, but contend that this is defensible and useful for an exercise focused on sketching the nature of challenges posed by a plausible worst case.[206]

The socio-economic and security implications of the climate scenario were developed judgmentally, in consultation with ONA. For the first 10 years, the authors project incremental changes, 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

[200] NRC, 2002.

[201] See, e.g., Dickson et al, 2002, Hansen et al, 2001, Gagosian, 2003.

[202] Global Business Network, 2004.

[203] Woods Hole Oceanographic Institute, 20?? ("abrupt change" brochure), Alley 2000.

[204] Alley et al, 1997.

[205] Note that these regional projections are 5 - 10 times faster than the IPCC projected global-average rate of warming over the 21st century.

[206] GBN, pg 7; Schwartz interview; GBN Press Release, "Abrupt Climate Change", February 2004, at www.gbn.com/ArticleDisplayServlet.srv?aid=26231

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 EU, 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 and its reports published in February 2004 and reported in Fortune Magazine the same month.[207] Several weeks later, the London Observer claimed to have obtained the report secretly, and used its extreme scenario to criticize US refusal to join the Kyoto Protocol.[208] Subsequent news coverage took up the theme that the report was secret or suppressed, suggesting the reason was that its extreme scenario called for more urgent action on climate change.[209] In the resultant controversy, DOD stated – accurately – that the report did not represent US policy, but was merely a speculative study by a consultant. The controversy subsided after a few weeks, and interest and concern about the possibility of abrupt change – although not of this precise character – have continued to grow.[210]

This scenario is a sketch of an abrupt climate-change event. There is little fine-scale detail about the hypothesized changes or the underlying reasoning, and no attempt to suggest how likely or unlikely the described event it. It seeks to provide a preliminary answer to the question, what might the worst case look like? Such questions are more often posed to scenarios 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. It would seem likely that many climate-change decision-makers could benefit from such upper-bound scenarios too, but this exercise is the only example of an extreme or 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 at risk of misunderstanding or misrepresentation. Attempting to manage these risks through secrecy appears risky and 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.

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

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

[209] San Francisco Chronicle, "Pentagon-Sponsored Climate Report Sparks Hullabaloo in Europe", February 25, 2004; The Providence Journal, "Pentagon report plans for climate catastrophe", March 3, 2004.

[210] E.g., Alley 2004 cites it as a useful worst-case assessment.

5. Conclusions and Recommendations

This section presents our conclusions regarding the present state of development and use of scenarios for climate-change applications, and some recommendations for specific changes or initiatives to advance current practice to make scenarios more useful.

Before doing so, we briefly reprise some key definitional points, because uses of the term scenarios are so divergent. We have defined scenarios as descriptions of future conditions produced to inform decision-making under uncertainty. This definition distinguishes scenarios from assessments, models, decision analyses, and other decision-support activities. As descriptions of potential future conditions, scenarios can serve as inputs to such activities, but are not identical to these, and not alternatives to them.

We have also distinguished scenarios from other types of future statements intended to inform decisions, such as projections, predictions, and forecasts. Relative to these, scenarios tend to be more multivariate (but still schematic), tend to be developed in groups, and tend to presume lower predictive confidence. The last condition is the case in part because scenarios tend to be used in situations where the basis for forecasting is less established because of deeper uncertainties, or for situations that pertain to further in the future beyond the range for which there is high confidence in specific projections, even contingent ones.

Having distinguished scenarios from these related activities, we consider a broad set of scenarios of diverse characteristics and uses, including simple and complex, various combinations of quantitative and qualitative, and positive and normative. Unless stated otherwise, our conclusions and recommendations pertain to this whole set. Where we intend them to apply to only certain types or uses of scenarios, we state this explicitly.

5.1 Use of Scenarios in Climate-Change Decisions

Scenarios can make valuable contributions to climate-change decision-making. Many of the decisions that will comprise the societal response to climate change – whether mitigation, adaptation, or some other form of response – involve high stakes, deep uncertainties, and long time horizons. Scenarios can make valuable contributions to these decisions by structuring present knowledge and uncertainty, prompting critical examination of present assumptions and practices, stimulating new insights, identifying key pitfalls or opportunities, or providing a framework for the assessment of particular decisions. For some decisions, that involve irreversible near-term commitment to choices whose consequences extend over a horizon involving substantial uncertainties, some form of scenario-based reasoning may be essential.

There is a big gap between the use of scenarios in current practice and their potential contributions. Despite this evident value and capability, many climate- related decisions that could benefit from scenarios (e.g., many decisions regarding long-term management and investments in climate-sensitive areas such as freshwater systems or coastal zones) are not using them. Indeed, many such decisions are still being made without considering climate change at all. Conversely, many exercises producing climate-change scenarios have only weak and indirect connections to practical decisions related to climate-change mitigation or adaptation.

Interest in considering and using climate-change scenarios is sharply increasing. There appears to be a rapid increase in interest now underway in considering climate-change scenarios in diverse decision and planning processes. This trend is strongest for planners and decision-makers concerned with climate-change impacts and adaptation. The trend reflects the combined effects of advanced in scientific understanding of climate change, maturation of models and analytic tools, and increased recognition of the potential importance of climate change by decision-makers. Given the high general concern about climate change and the advance of background scientific knowledge, we expect this trend to continue, for these and other types of decisions.

Scenarios of global emissions and resultant climate change are required by many diverse climate-related decision-makers. Although climate-change decision-makers and their particular needs from scenarios are highly diverse, many will need scenarios of global emissions and resultant climate change and many more will need information that depends upon these. Commonly provided scenarios of these types can serve these needs of extremely diverse decision-makers, provided they are presented with enough transparency and documentation about their underlying reasoning and assumptions.

Beyond global climate forcings and resultant climate changes, decision-makers' needs from climate-change scenarios are highly diverse. Different climate-change decision-makers will have greatly differing information needs from scenarios, in the factors and variables included, the time and spatial scale at which they are provided, and the breadth and interpretation of uncertainty represented. One dimension on which these needs can be distinguished is the type of decision-maker: national officials, impacts and adaptation managers, and technology and energy managers. The means for meeting these additional needs will likely be diverse too. Some will call for additional, separate capabilities.

Impacts and Adaptation Managers are a major group of scenario users with distinct information needs. Impacts and adaptation managers – including both national officials and others responsible for more specific domains of impact – will need climate-change scenarios, driven by specified global emissions scenarios, to provide information about potential climate-related stresses on their areas of responsibility. In addition, they will need climate, environmental, and socio-economic information specific to their area of responsibility, at the appropriate spatial and temporal scale. Meeting these needs will require both easy access to centrally produced climate scenario information and associated tools and support, and development of decentralized capabilities for developing and applying additional scenario-related information. Although not identical, many of these specific information needs are likely to be similar in character for many particular locations and types of impact.

Meeting information needs for impacts and adaptation may require a cross-scale organizational structure. The combination of centralized and decentralized information needs suggest the desirability of a cross-scale organizational structure – a linked network of institutions at the international, national, and sub-national level – for providing scenario-related information. Such a structure would combine central provision of nationally or globally consistent climate and socio-economic scenarios; decentralized elaboration of these with variables and characteristics especially required for particular impact analysis or drawing on superior local knowledge; and provision of tools and resources to allow modification of regional socio-economic scenarios and elaboration of new ones within loose larger-scale consistency constraints, to address specific regional capabilities and concerns.

Scenarios for Impact and Adaptation Managers should be based on emissions assumptions that presume a likely range of mitigation interventions, now and in the future. The emissions assumptions underlying scenarios for impacts managers should be based on the likely range of future global emissions trajectories, including explicit assumptions about what degrees of further mitigation effort are likely over time. This will typically imply a narrower range of emission futures than is considered in scenarios to support mitigation decisions.

Mitigation Policy-Makers are also a major group of climate-change scenario users with distinct needs. Most mitigation policy-makers are national officials making national policy and participating in international negotiations, but this group also includes sub-national officials when they share mitigation responsibilities or undertake mitigation initiatives. Serious mitigation initiatives are likely to represent major policy innovations and carry significant risks of many kinds, including the effectiveness and cost of the policies but also their effects on government budgets, competitiveness of particular industries, opportunities for national technological capabilities, etc. Decision-makers considering such policies will need scenarios of global and national emissions trends, resultant climate change, and aggregate impacts. In addition, they will need to consider many factors specific to their jurisdiction – e.g., national policies, institutions, economic structure, technological capabilities, and the detailed structure of national emissions – and information about the relevant policy and bargaining environment for their choices, including alternative scenarios of other nations' mitigation strategies and various degrees of implementation and compliance with international mitigation decisions.

Scenarios for mitigation decisions should include a wide range of baseline emissions assumptions and not pre-judge the likely level of mitigation effort. In contrast to scenarios for impacts and adaptation decisions, those used for mitigation decisions should not estimate the likely level of mitigation effort. Rather, mitigation decisions should consider the full range of potential mitigation choices on the agenda, defined relative to baseline assumptions that, as much as possible, reflect only efforts already enacted or committed, including a range of reasonable assumptions about implementation and compliance. This will typically imply a wider range of emissions futures than is considered in scenarios used to support impacts and adaptation decision-making.

Mitigation Decision-Makers can use target-driven scenarios for backcasting. Mitigation decision-making may also benefit from scenarios that impose explicit future environmental targets such as limits on emissions or atmospheric concentrations, together with assumptions about policy and implementation elsewhere, and reason backwards to explore alternative paths to, and implications and requirements of, attaining that goal, including feasibility, costs, and tradeoffs. These must be defined in ways relevant to the level of decision-making being informed, i.e., alternative national targets to inform national policy-making, in the broader context of alternative global baselines or global targets.

Mitigation decisions will require scenario development capacity at the national level. While core scenarios of global emissions and climate-change can provide a partial input into mitigation decisions, the scope and specificity of additional information needs for these decisions suggests the need for additional elaboration of relevant scenarios at the national level (or sub-national, if mitigation decisions are being considered there), generated in consultation with policy-makers.

Energy Resource and Technology Managers are a third major group of climate-change scenario users with distinct needs. Energy resource and technology managers concerned with private responses to mitigation policy primarily need scenarios that represent alternative policy regimes. Emissions and climate change underlie these as influences on policy decisions, but do not capture the most important uncertainties for these decision-makers. While many actors may wish to generate these scenarios privately to keep their assumptions and analyses confidential, there may also be value in multi-party collaborative scenario-building exercises in which today's policy-makers and corporate planners jointly examine what range of policy, economic, and energy regimes is plausible or likely in 30 years.

5.2 Use of Scenarios in Climate-Change Assessments

Large-scale, official assessments are the major use for scenarios at present, and are likely to remain an important use. Large-scale, official assessments represent the most prominent demand for climate-related scenarios at present, and are likely to remain major users, particularly for coordinated scenarios of global emissions and resultant climate-change.

Within assessments, scenarios are principally used to support further analysis, modeling, and assessment. When scenarios are used in assessments, some users are clearly identified: e.g., climate modelers are major users of emissions scenarios, while impacts assessors and modelers are major users of climate-change scenarios. Users of these types have specific needs from scenarios, and close consultation is possible between scenario producers and users to meet these needs. Substantial progress has been made in providing useful scenarios for these groups, at both the national and international level. These efforts should be continued and expanded.

The presentation of scenarios in assessments leads to many additional uses, not foreseen. Scenarios presented in large-scale assessments gain prominent dissemination that results in their being put to many uses their developers did not foresee. Scenarios should strive for maximal clarity of documentation and transparency about underlying reasoning and assumptions, to improve the ease of use and reduce the risk of misunderstanding in such derivative uses, although they cannot anticipate all information needs of an open-ended set of diverse potential uses.

In assessments, scenarios can be an effective issue-framing device. Also because of their prominent dissemination, scenarios presented in major assessments can exercise substantial influence over the framing of policy discussions, or provide simple, widely used metrics of the seriousness of the issue. They may consequently exercise broad influence over many decisions that depend upon such an aggregate perception of seriousness. The expectation of such influence further heightens the responsibility for transparency in the production of scenarios.

Scenarios contain unavoidable elements of judgment in both their production and use. Although they draw on relevant data, knowledge, and analysis, scenarios contain unavoidable elements of judgment. This puts serious responsibilities onto scenario developers, and also means that there is no authoritative way to resolve arguments over whether a scenario is plausible or not. When a wide enough range of potential futures is considered, some scenarios are likely to draw criticism, in part motivated by opposition to their foreseeable implications for action. Any scenario can be attacked as unreasonable, speculative or unlikely, and close enough scrutiny of any scenario can usually reveal inconsistencies, but these do not provide sufficient basis for excluding a scenario from consideration. Indeed, scenarios designed to represent extreme events, or to lie near an end of a presently judged distribution, should by definition appear unlikely. The most productive response to such criticisms lies in transparency about the process, reasoning, and assumptions used to produce scenarios, which can both shift arguments to underlying uncertainties that are worth arguing about, and help limit biases in the production of scenarios.

5.3 A Sustained Capacity for Scenarios

CCSP should provide resources to support a new capacity for producing, analyzing, supporting, and updating scenarios of global emissions and resultant climate change. Because scenarios of global emissions and resultant climate change are needed directly or indirectly for so many diverse uses, there is strong value in centralized, coordinated provision of these. A capacity should be created to stimulate, produce, analyze, and disseminate global emissions and climate-change scenarios, and to periodically evaluate and update them in light of new knowledge, experience, and decision needs.

Several institutional models would be feasible for this capacity. It could be US-based or international. It could be a government office, a non-governmental organization, or a collaborative multi-party network. And it could do any or all of producing scenarios itself, convening activities to produce scenarios with broader participation, or receiving and reviewing scenarios produced by others.

Several criteria would have to be met, however, for this capacity to be effective:

> ***Adequate sustained resources.*** The capacity must build and maintain a sophisticated analytic capability, and develop skills and institutional memory regarding prior experiences, successes, and failures. This requirement precludes the scenarios capacity being a series of *ad hoc* one-time activities or a part-time burden imposed on people and organizations with other full-time responsibilities.

> ***Connections with outside expertise, analysis, models.*** The capacity needs to build and maintain close collegial connections with outside networks of researchers and analysts in

multiple fields of expertise, including emissions modelers, climate scientists and modelers, impacts researchers, and resource managers – including collaboration with parallel international and national efforts, including scenario projects established to serve more specific needs.

Insulation from political control. For the scenarios and analyses based on them to be perceived as credible by their diverse users, the capacity needs enough insulation from political control, at both the national or international level, to prevent scenarios from becoming proxies for conflict over preferred near-term policies, and to allow exploration of the implications of alternative futures that represent plausible risks but that some major political actors would find objectionable.

Maximum transparency. The capacity must strive for maximal transparency regarding inputs, models, assumptions, and reasoning employed in developing scenarios, as well as any significant disagreements that arose and how they were resolved and any remaining weaknesses recognized by the developers. The broader and more diverse the collection of intended uses and users, the more crucial is transparency of the scenario-production process – because different users may require scenarios produced using different underlying assumptions, and they must be able to track the underlying logic to exercise this choice. This would enhance credibility in the scenario-development process. While calls for such transparency are widely made, experience suggests it is difficult to achieve, particularly for such matters as disagreements or recognized weaknesses that may risk professional embarrassment. Still, achieving more transparency and more widely informed debate on such matters is essential for advancing scenario methods.

A mandate to support development of methods and models. Attempts to characterize emissions trends and the socio-economic factors driving them have repeatedly had to consider new issues, identify newly relevant data sources, and develop and test new modeling capabilities. High-priority methodological challenges beyond model and data development also arise frequently, such as the current need for better methods to integrate qualitative and quantitative aspects of scenarios. A major contribution of this centralized scenarios capacity can be to support exploration, development, critical examination, and testing of such methods, and dissemination of results and lessons learned.

Authority for effective coordination and quality control. The capacity needs authority to provide effective coordination of scenarios for transparency, consistency (e.g., of units, formats, etc.), and quality control. A weak "clearinghouse" for scenarios that lacks authority to critically scrutinize scenarios, request changes, and grant or withhold some status or benefit (e.g., resources, publication, certification, or inclusion in some process) based on a judgment of acceptable standards being met is not an adequate model.

5.4 Characteristics of 'core' emissions and climate scenarios

Scenarios should be global in scope and century-scale in time horizon. Core emissions and climate scenarios should be global in scope; should specify all major climate-relevant emissions and other human perturbations, as well as their underlying socio-economic drivers;

and should extend over time horizons of at least 100 years, including some with horizons of 200-300 years, to support assessments of long-term vulnerability to sea-level rise.

Several distinct logical types of emissions scenarios should be developed. Socio-economic and emissions scenarios should include some combination of alternative baselines, alternative levels of incremental stringency of mitigation effort, and specified future targets to support backcasting and feasibility analysis.

Emissions scenarios should be based on diverse socio-economic futures. Emissions and associated socio-economic scenarios should explore a wider range of potential socio-economic and policy futures than has been done, including explicit examination of the implications of varying patterns of mitigation effort. What would the world look like if emissions grow strongly for several decades with little control effort, then we shift to stringent mitigation efforts? What if part of the world makes a lot of effort and part makes very little? What if development stagnates in major world regions? Considering such varied future histories is crucial for considering long-term risks and opportunities from major mitigation choices.

Scenarios should reflect various explicit degrees of coordination. Scenarios provided should reflect explicit variation in the degree and type of coordination, including for example, a) provision of a few standard scenarios to meet the needs of downstream models and analyses for coordinated inputs in intercomparison exercises (i.e., standard emissions scenarios for climate-model comparison, standard climate scenarios for impact model comparison); b) scenarios generated using multiple models with common exogenous inputs, for exploration of uncertainties related to model structure, and; c) non-standardized scenarios produced at the initiative of researchers and modelers seeking to explore alternative assumptions or meet specific user needs – provided these meet basic standards of quality control, transparency, and documentation.

Global socio-economic and emissions scenarios should include and link qualitative and quantitative components. Global scenarios of emissions and the socio-economic variables underlying them should include qualitative and narrative scenario components, as well as quantitative projections of emissions and underlying socio-economic drivers, and should include a sustained analytic effort to integrate qualitative and quantitative components. The qualitative, narrative elements can provide a vehicle for exploration of major historical uncertainties with large implications for global emissions and climate change; provide a coherent logical structure that ties together quantitative assumptions on multiple variables; and provide guidance for extension of scenarios through elaboration of additional detail. Gaining these benefits will require much more sustained effort to integrate quantitative models of emissions and their socio-economic determinants with qualitative and narrative scenarios, to iterate between them, and to critically examine each in light of the other, than has been made in climate-change scenario exercises thus far.

Emission scenarios should connect narratives to model structures, not parameter values. These efforts should strive to connect alternative qualitative narratives to alternative logical structures of quantitative models, not just alternative parameter values. Alternative quantifications conditioned on the same narrative storyline and associated basic causal logic can provide insight into uncertainty in key parameters such as GDP and emissions, conditional on the broad historical conditions defined by the storyline, provided model quantifications are not harmonized on these outputs.

Centrally provided scenarios of global emissions and climate change cannot provide all information needed for either mitigation or adaptation decisions at national or smaller scale. Information needs for decision-making at national or smaller spatial scale, whether for adaptation or mitigation, may be finer-scale and more detailed than can be provided by the global-scale scenarios capacity, for both climate and socio-economic information. For emissions and socio-economic information, the global capacity can provide scenarios of world trends in emissions, socio-economic conditions, and the large-scale pattern of policy response elsewhere that can serve as background information to be elaborated or modified by national scenario processes. For climate information, the global capacity can provide access to climate-model output, plus access and support for statistical methods or finer-scale modeling tools for producing required finer-scale data for particular impact and adaptation applications.

5.5 Scenario Process: Developer-User Interactions

In general, there are benefits in collaboration between scenario developers and users, particularly at the beginning and ending stages of a scenario exercise. There is always value in close communication and collaboration between the developers and intended users of scenarios, although the most appropriate means of realizing this vary substantially among scenario exercises. User engagement is most important in the initial scoping and design of a scenario exercise, and in the evaluation and application of the scenarios generated. The value of user engagement in the detailed middle stages of scenario development, quantification, elaboration, and checking, depends on the precise conditions.

The value of such interactions, and the ease of achieving them, are likely to be greater when scenario users are few in number, clearly identified, and similar in their interests and perspectives. When the set of users for scenarios is clearly identified, relatively small, and homogenous, there is the strongest case for close and intensive collaboration between users and developers throughout the process. When potential users are numerous and diverse, such intensive engagement may be infeasible, and various structured processes for consultation, representation, and information exchange are needed. While progress has been made in new methods to increase the numbers participating in scenario exercises, further development of such methods is needed.

5.6 Communication of Scenarios

Effective communication of scenarios is essential, including the means to reach audiences of diverse interests and technical skills. Scenarios must be communicated effectively to their potential users, including both technical and non-technical audiences. In addition to the contents or outputs of scenarios, communication must include associated documentation, tools, and support for their use. Various methods should be used to promote broad dissemination of scenario information; for instance, presentations, reports, websites, and centralized data distribution centers. To facilitate user understanding of results, various methods should be used to communicate numerical and technical information, including multiple tabular, summary, and graphical formats, ideally with user-interactive capabilities.

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

5.7 Consistency and Integration in Scenarios

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

In scenario exercises that use multiple models to explore potential future conditions, model inputs should be controlled for consistency, rather than model outputs. Use of multiple models in parallel to produce alternative descriptions of future conditions can improve understanding of uncertainties, if models are run under consistent assumptions about exogenous inputs. Forcing convergence of outputs among multiple models suppresses model variation, including variation from alternative causal structures, that could provide valuable information about uncertainties. Temptation to seek a spurious increase in credibility by forcing convergence of multiple model outputs should be resisted. The appropriate treatment of quantities that are exogenous in some participating models and endogenous in others can vary case by case. In general, however, forcing multiple models to convergent values of such variables is not desirable.

An important exception to the advice not to control for consistency in model outputs is that such control can be valuable in exercises that specify common output targets for policy evaluation. For example, consistent emissions constraints are needed in order to explore implications of alternative atmospheric concentration stabilization levels.

Transparency in reporting model differences, assumptions, and reasoning can help to overcome the presence of some inconsistencies in scenario generation. Ideally, multiple scenarios in an exercise should differ from each other only on those issues that are intentionally chosen to distinguish them, and be consistent on all other factors. This is not always possible, particularly when scenarios are generated using different models. In this case, it is particularly important to pursue maximal transparency about the models, assumptions, and reasoning underlying each scenario – perhaps by publishing diagnostic reports that include discussion of points of weakness, uncertainty, and disagreements and the means used to resolve them.

5.8 Treatment of Uncertainty in Scenarios

More explicit characterization of probability judgments should be included in some future scenario exercises than has been practiced so far. The advantages of assigning explicit characterization of probability to scenarios – or their consequences for a few key variables – are likely in our judgment to outweigh their disadvantages. Such specification should be pursued to a greater degree than has been done in major global-change scenario exercises to date.

Including explicit probability judgments is likely to be more useful when key variables are few, quantitative outcomes are needed, and potential users are numerous and diverse. The case for assigning explicit confidence or probability measures is strongest when scenarios' most salient components are quantitative projections of a few key variables, such as emissions or average temperature change over the globe or some region, because the technical barriers to assigning probabilities are least severe in this case. The case is strongest when a primary purpose of the scenario exercise is to provide inputs to other quantitative assessment activities, or to inform decisions that primarily depend on one or a few key quantitative variables, because these are situations in which at least some users are likely to require probability judgments. The case is strongest when the set of potential scenario users and uses is large and heterogeneous, because this situation provides the least opportunity for informal or implicit communication of judgments of importance or confidence based on intense, sustained collaboration between scenario developers and users.

Including explicit probability judgments is likely to be less useful when scenarios specify multiple characteristics, including prominent narrative or qualitative components; when the purpose of a scenario exercise is sensitivity analysis or heuristic exploration; and when potential users are few, similar, and known. When scenarios are primarily construed as rich, qualitative narratives that present major alternative historical and socio-economic trajectories, the technical obstacles to explicit probability assignment are greatest and the confidence in scenario developers' subjective probability assignments is likely to be lowest. When the primary purpose of a scenario exercise is stimulate critical or creative thought, or to conduct sensitivity analysis to probe the limits of a subsequent model or analysis or a proposed robust decision strategy, or to explore ways of meeting a specified output target, explicit probability assignment provides little or no benefit. When users are few, homogeneous, and specifically identified, they or their proxies can be intensively involved in the scenario generation exercise, allowing effective informal communication of developers' judgments of relevant probabilities without requiring explicit formal statements. Alternatively exercises with such intensive collaboration can support dialogs that engage scenario users in the potentially illuminating exercise of assigning and discussing their own probability judgments, rather than imposing that responsibility exclusively on the researchers or analysts developing scenarios.

The centralized capacity we propose should endeavor to provide probability estimates for global emissions and climate-change scenarios. The global emissions and climate-change scenarios produced by our proposed capacity should include explicit probability assignments to ranges of their few key quantitative outputs, including global emissions and global-average temperature change (conditional on specific underlying assumptions), because of the large and diverse set of users to whom these are targeted. Emissions and climate scenarios should typically present several paths that span a wide range of judged uncertainty, e.g., 95% to 99%. In making these judgments, the distribution of previously produced or published scenarios provides one source of guidance but is not authoritative, because these are not independent and may have been developed for different questions and purposes.

Providing explicit probability and likelihood statements allows users to choose whether to use them or not. Some users may choose to use these explicitly in their subsequent analysis or decision support, others may use them only to help decide which scenarios to use, while still others may appropriately choose to disregard them entirely. Users may choose to use a different group of scenarios or a different subset of the uncertainty range due to differences in risk aversion, differences in the scope of their decision authority, or differences in assumptions about decisions by other actors, present or future.

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

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