

Global-Change Scenarios

Their Development and Use

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

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Executive Summary

2

A scenario is a description of potential future conditions produced to inform decision-making under uncertainty. Scenarios can help inform decisions that involve high stakes and poorly characterized uncertainty, which may thwart other, conventional forms of analysis or decision support. Originally developed to study military and security problems, scenarios are now widely used for strategic planning and assessment in businesses and other organizations, and increasingly used to inform planning, analysis, and decision-making for environmental issues including climate change.

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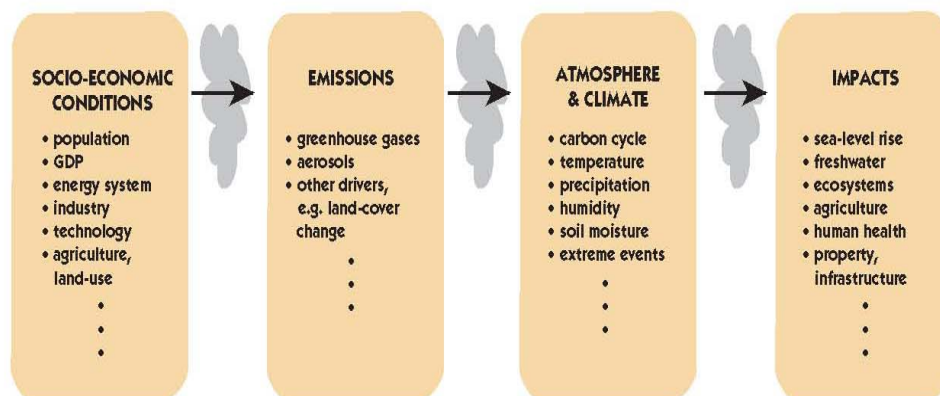
Scenarios can serve many purposes. They can help inform specific decisions, or can provide inputs to assessments, models, or other decision-support activities when these activities need specification of potential future conditions. They can also provide various forms of indirect decision support, such as clarifying an issue’s importance, framing a decision agenda, shaking up habitual thinking, stimulating creativity, clarifying points of agreement and disagreement, identifying and engaging needed participants, or providing a structure for analysis of potential future decisions.

16 *Scenarios for Climate Change: Five Types*

17

Developing a scenario exercise involves many design choices, of which the most important involve choosing the few key uncertainties to represent in alternative scenarios. Five types of scenarios have been developed to address different aspects of the climate-change issue, which are distinguished by where they fall along a simple linear causal chain extending from the socio-economic determinants of greenhouse-gas emissions through the impacts of climate change as shown in Figure ES-1. (This figure does not represent the complete causal structure of the climate issue, which has many linkages and feedbacks. Rather, this simple structure only illustrates how scenarios have been used to fit within the simplest and most prominent causal pathway of the issue.)

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

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1
2 *Emissions Scenarios for Climate Simulations:* Emissions scenarios state future paths of
3 greenhouse-gas emissions or other climate perturbations. A major use of these is to provide
4 needed inputs to climate models. Such scenarios may specify simple arbitrary perturbations
5 of emissions or concentrations (e.g., doubling atmospheric CO₂), or time-paths reflecting
6 specified assumptions for evolution of socio-economic drivers such as population, economic
7 growth, and technological change.

8
9 *Emissions Scenarios for Exploring Alternative Energy/Technology Futures:* Another use of
10 emissions scenarios involves specifying an environmental or emissions target, arbitrarily or
11 based on normative or political goals, to examine what patterns of socio-economic change,
12 energy resources, and technology development are consistent with the target and/or what
13 interventions might be needed to meet it. Such scenarios have examined conditions for
14 stabilizing atmospheric CO₂ concentration at various levels, and the implications of
15 stabilizing radiative forcing for multi-gas reduction strategies.

16 *Climate-Change Scenarios:* Climate scenarios specify potential future climate conditions to
17 inform assessments of impacts, vulnerabilities, and adaptation options, and inform decision-
18 making for adaptation or mitigation. They can be produced by arbitrary perturbation of
19 present conditions, by using climates from elsewhere or the past as a proxy for potential
20 future climate in a given location, or by climate-model simulations driven by some specified
21 scenario of future emissions.

22 *Scenarios of Direct Biophysical Impacts, e.g., Sea Level Rise:* Scenarios can specify
23 alternative trajectories for some important form of climate impact that influences many other
24 impacts. For example, scenarios of sea level rise can capture the most important impact
25 pathways in many coastal regions, including the large uncertainties associated with potential
26 loss of continental ice sheets in Greenland and Antarctica.

27
28 *Multivariate Scenarios for Impact Assessment:* Assessing climate-change impacts requires
29 not just considering climate in isolation, but other linked changes and stresses including both
30 environmental and socio-economic trends. The factors that influence particular impacts and
31 vulnerabilities are likely to be widely variable, and may include demographic, economic,
32 technological, institutional, and cultural characteristics. Consequently, scenarios may have to
33 be generated in an exploratory manner in the context of attempting to assess specific local
34 and regional impacts.

35 *Scenarios for Climate Change: Major Examples*

36 The report reviews four major exercises producing or using scenarios for climate-change
37 applications. The Intergovernmental Panel on climate Change (IPCC) has produced three sets of
38 scenarios of 21st-century greenhouse-gas emissions, of which the most ambitious and important
39 were produced for the Special Report on Emissions Scenarios (SRES) between 1997 to 1999.
40 SRES produced four qualitative storylines on which six “marker” scenarios were based – one
41 model quantification of each storyline plus two technological variants of one storyline that
42 stressed fossil-intensive and low-carbon energy supply technologies, each produced by a

1 different energy-economic model. Other models' replications of each other's marker scenarios
2 plus a few additional explorations yielded 40 scenarios in total. These scenarios highlighted
3 several insights, including the ability of alternative paths with similar emissions in 2100 to differ
4 widely in their interim pathways and thus in atmospheric concentrations; the ability of alternative
5 technological assumptions alone to generate as wide a range of emissions futures as substantially
6 divergent socio-economic pathways; and the fact that similar emissions paths can come from
7 widely different combinations of underlying socio-economic factors and so pose distinct
8 mitigation problems. A widely publicized critique of the SRES scenarios alleged over-
9 estimation of future emissions growth due to the metric used to compare incomes in rich and
10 poor nations, but this was later found to be insignificant. More serious and illuminating
11 challenges associated with these scenarios concerned how to balance and integrate qualitative
12 and quantitative scenarios; how to use and how much to coordinate multiple models to generate
13 the most useful insights; and whether, when, and how it is appropriate to assign explicit
14 probability judgments to alternative scenarios or associated ranges of quantitative variables.

15 The U.S. National Assessment was a comprehensive assessment of potential impacts of
16 climate change and variability on the United States, focusing on major regions and sectors
17 (agriculture, water, human health, coastal areas and marine resources, and forests). The
18 Assessment needed scenarios of 21st-century US climate and socio-economic changes. For
19 climate scenarios, it relied principally on climate-model scenarios produced by the UK Hadley
20 Centre and the Canadian Centre for Climate Modeling and Analysis, each driven by a single
21 emissions scenario, with statistical downscaling based on detailed local conditions and present
22 patterns of fine-scale climate variation. Other proposed types of climate scenario, including
23 historical scenarios and inverse methods to probe for key vulnerabilities, were less used. For
24 socio-economic scenarios, a novel approach was proposed that combined specified scenarios for
25 a few key national-level variables such as population and economic growth, and a common
26 process to elaborate and document additional socio-economic assumptions as needed for specific
27 regional and sector analyses. The Assessment was criticized for relying on just two climate-
28 model runs and one emissions scenario, although these choices were dictated by time limits and
29 availability of climate-model runs. Limited use was made of the socio-economic approach,
30 principally due to time limits and communication problems.

31 The UK Climate Impacts Program provides common datasets, tools, and support,
32 including scenarios, for climate-impact assessments for UK regions and sectors by researchers
33 and stakeholders. The program produced climate scenarios in 1998 and 2002, all based on the
34 Hadley Centre climate models, and socio-economic scenarios in 2001. The program stresses
35 building a sustained assessment capability by acting as a motivator, resource, and light
36 coordinator with little central authority over separate assessments. The reliance on climate
37 scenarios from just one family of climate models may pose risks of incomplete representation of
38 key uncertainties.

39 The Millennium Ecosystem Assessment (MEA) examined the status, present trends, and
40 longer-term challenges to the world's ecosystems, including climate change and other stresses.
41 One of the assessment's four working groups constructed scenarios of global ecosystems to 2050
42 and beyond, largely independently of the group examining current status and trends. All

1 assessment components used a common conceptual framework, which distinguished indirect
2 drivers of ecosystem change (e.g., population and economic growth, technological change,
3 policies and lifestyles), direct drivers (e.g., climate change, air pollution, and land-use and land-
4 cover change), ecosystem indicators, ecosystem services, measures of human well-being, and
5 response options. The Scenarios group applied this framework to characterizing potential
6 ecosystem stresses in 2050, with more limited projections to 2100. The four scenarios were
7 based on two dimensions of uncertainty: degree of globalization, and predominance of proactive
8 vs. reactive response to ecosystem stresses. The qualitative storylines underlying these scenarios
9 were more richly developed than in other climate-change scenario exercises. Concerns with
10 these scenarios pertained to the degree of integration and consistency between qualitative and
11 quantitative scenario components; risks of logical circularity within scenarios; and unexplained
12 similarity of projected ecosystem effects among scenarios.

13 *Scenarios for Climate Change: Challenges and Controversies*

14 *Scenarios and Decisions*

15 Scenarios can inform climate-change mitigation and adaptation decisions, but most uses
16 so far have had relatively indirect connections to such decisions. Although there is no single
17 global climate-change decision-maker, scenarios can inform the many decision-makers with
18 diverse responsibilities that will affect and be affected by climate change. Three groups of
19 decision-makers with distinct information needs can be distinguished: mitigation policy-makers,
20 who are mostly but not exclusively national officials; impacts and adaptation managers,
21 including national officials and others who are responsible for particular climate-sensitive assets,
22 resources, or interests; and energy resource and technology managers, who include owners,
23 developers, and investors in energy resources and energy-related capital stock and new
24 technologies.

25 A key issue in creating scenarios for all decision-makers is how to represent decisions
26 within scenarios. In general, decisions by the scenario user should be explicitly examined
27 relative to baseline conditions specified in scenarios, while decisions by others outside their
28 control should be treated like any exogenous uncertainty. The issue is most important in the
29 treatment of mitigation decisions: scenarios to inform mitigation should allow explicit
30 examination of the entire relevant range of mitigation decisions, while scenarios to inform
31 impacts and adaptation should specify the likely range of mitigation efforts – usually yielding a
32 narrower range of emissions futures than is considered in scenarios to inform mitigation.

33 *Scenarios in Assessments and Policy Debates*

34 In climate-change assessments, scenarios can provide required inputs to other parts of the
35 analysis and help to organize multiple components of the assessment. When scenarios are used
36 in a prominent assessment, they may subsequently be adopted in planning or decision-support
37 processes outside the original assessment. Scenarios can also help frame public and policy
38 debate, in part by providing an aggregate metric of the issue's severity. They consequently may
39 gain prominence in contentious policy debates, and so become subject to political attempts to
40 influence their content and political criticism based on their perceived implications for policy

1 action. The unavoidable judgments underlying construction of scenarios provide opportunity for
2 partisan efforts to make scenarios policy prescriptive, and for claims that only certain scenarios
3 are plausible (e.g., high or low-emissions scenarios, depending on the critic's motivation). These
4 claims are unavoidable, since scenarios represent key uncertainties bearing on high-stakes policy
5 decisions, but such attempts to restrict scenarios should be resisted, principally through
6 prominent communication of the reasoning, assumptions, and treatment of particular
7 uncertainties underlying scenarios.

8 *Scenario Development Process: Expert-Stakeholder Interactions*

9 Scenario exercises must decide how and how much to involve scenario users and
10 stakeholders in scenario development. In other fields where users are clearly identified,
11 relatively small and homogeneous, close, intensive collaboration between scenario developers
12 and users or their representatives is desirable. Although the advantages of close user
13 involvement also apply to scenarios for climate change, the number and diversity of potential
14 users of these scenarios, who may not be clearly identified and may have contending material
15 interests in the scenarios' content or use, call for delicate decisions of participation and
16 representation to keep scenarios tuned to practical users' needs while keeping the development
17 process small enough to be manageable.

18 *Communication of Scenarios*

19 Climate change scenarios must be communicated to multiple audiences with diverse
20 interests and information needs. In addition to the scenarios' content, sufficient information
21 must be provided about the process and reasoning by which the scenarios were developed, to
22 allow users to scrutinize the underlying data, models, and reasoning, judge their confidence in
23 the scenarios, and have opportunities to critique the scenarios and suggest alternative approaches.
24 Effective communication can help engage a broad user community in updating and improving
25 scenarios. Open communication of the decisions, assumptions, and uncertainties underlying
26 scenarios is likely both to increase users' confidence that the scenarios have reasonably
27 represented current knowledge and key uncertainties, and help them develop alternatives if they
28 are unconvinced.

29 *Consistency and Integration in Scenarios*

30 Scenarios should strive for internal consistency. At one level, this means avoiding clear
31 contradictions with well established knowledge, and not moving inadvertently outside bounds of
32 historical experience – although such sharp departures from experience may be useful if pursued
33 intentionally to examine low-probability risks or broaden decision-makers' perceptions.
34 Perceptions of internal consistency or coherence in scenarios ultimately rest on subjective
35 judgments, which pose well known risks of bias if not carefully structured and controlled.
36 Potential inconsistencies grow when scenario exercises use multiple models and attempt to
37 harmonize them, particularly when some key quantities are externally specified for some models
38 and calculated within others. Attempting to avoid such inconsistency by standardizing model
39 outputs, however, can carry more serious risks by obscuring interpretation of results and
40 precluding use of model variation to illuminate uncertainty. Attempts to connect qualitative and

1 quantitative aspects of scenarios have been particularly challenging for pursuit of consistency.
2 Different narrative scenarios often reflect different assumptions about how the world works,
3 which correspond more closely to different model structures than to parameter variation. Better
4 integrating the two approaches will require developing ways to connect narrative scenarios to
5 model structures, rather than merely to target values for a few variables that models are then
6 asked to reproduce.

7 *Treatment of Uncertainty in Scenarios*

8 A scenario exercise can represent a few key uncertainties by variation among scenarios.
9 Extreme economy is required in choosing which uncertainties to represent, what variation
10 including potential extremes is represented for each, and how they are combined in a manageable
11 number of scenarios. Complex narrative scenarios pose special problems in representing and
12 communicating uncertainty, which are usually addressed by seeking underlying structural
13 uncertainties – e.g., deep societal trends such as globalization or values shifts – that are judged to
14 influence many other factors of concern. The most prominent controversy in treatment of
15 uncertainty in scenarios has concerned whether or not to explicitly assign probabilities to
16 scenarios or associated ranges of quantitative outcome variables. The debate rests in part on
17 different views of the typical contents of scenarios, since subjective probabilities can readily be
18 assigned to ranges of one or two quantitative variables. Explicit probability assignment in such
19 simple cases offers clear benefits for assessing alternative choices, and avoids the risk of users
20 assigning their own, perhaps less informed, probability judgments. Assigning probabilities to
21 rich multivariate scenarios, particularly if these include narrative elements, is much more
22 problematic, since there is no clearly defined interval “between” such scenarios and their
23 boundaries are not clearly defined.

24 ***Conclusions and Recommendations***

25 *Use of Scenarios in Climate-Change Decisions*

- 27 • Scenarios can make valuable contributions to climate-change decision-making. There is
28 a big gap between the use of scenarios in current practice and their potential
29 contributions, but interest in using scenarios is increasing.
- 30 • Scenarios of global emissions and resultant climate change are required by many diverse
31 climate-related decision-makers, but beyond these variables decision-makers’ needs from
32 climate-change scenarios are highly diverse.
- 33 • Impacts and adaptation managers, including both national officials and others responsible
34 for more specific domains of impact, need climate-change scenarios, driven by specified
35 global emissions scenarios, to represent potential climate-related stresses on their areas of
36 responsibility, plus other environmental and socio-economic information at appropriate
37 scales. Their combined needs for centrally produced climate scenario information,
38 associated tools and support, and a capability to develop and apply additional scenario
39 information related to their responsibilities, suggests the need for a cross-scale
40 organizational structure to provide scenario information.

- 1 • Mitigation policy-makers, who are mainly but not exclusively national officials, need
2 scenarios of global and national emissions trends, resultant climate change, and aggregate
3 impacts. In addition, they need scenario information about the potential policy
4 environment for their choices, including alternative scenarios of other nations' mitigation
5 strategies, international mitigation decisions, and implementation and compliance. In
6 some cases, they can usefully employ target-driven scenarios for backcasting analysis.
7 Mitigation decisions require scenario development capacity at the national level.
- 8 • Scenarios for mitigation decisions should include a wide range of baseline emissions
9 assumptions and should not pre-judge the likely level of mitigation effort, while scenarios
10 for impact and adaptation managers should be based on emissions assumptions that
11 include the range of mitigation interventions they judge likely.
- 12 • Energy resource and technology managers, who are mainly private-sector actors,
13 primarily need scenarios that represent alternative policy regimes over the 30 to 50-year
14 time horizons relevant for investment and technology-development decisions. Scenarios
15 of emissions and climate change may provide background, but do not capture the most
16 important uncertainties for these decision-makers.

17 *Use of Scenarios in Climate-Change Assessments*

- 18 • Large-scale, official assessments are the main present use of scenarios, and will likely
19 remain a major use. Scenarios in assessments mostly support further analysis, modeling,
20 and assessment. They can also help frame the climate issue for public and policy-makers.
21 Presentation of scenarios in assessments leads to additional unforeseen uses.
- 22 • Scenarios contain unavoidable elements of judgment in their production and use. This
23 makes them vulnerable both to attempts at bias and to partisan attack. The most
24 productive response lies in transparency about the process, reasoning, and assumptions
25 used to produce scenarios, which can both help limit bias in scenario production and
26 focus subsequent argument on underlying uncertainties.

27 *What should centrally provided emissions and climate scenarios look like?*

- 28 • Centrally provided scenarios of emissions and resultant climate change should be global
29 in scope, with major climate-relevant emissions and other perturbations specified at least
30 for major world regions. They should have a time horizon of a century or longer, with
31 interim results at roughly decadal resolution.
- 32 • Centrally provided scenarios of global emissions and climate change can help inform
33 mitigation and adaptation decisions at national and sub-national scale, but these also
34 require additional information at national or smaller scale.
- 35 • Emissions scenarios of several types are needed to serve diverse uses, including
36 alternative baselines, alternative levels of incremental stringency of mitigation effort, and
37 specified future targets to support backcasting and feasibility analysis. Some emissions
38 scenarios should be coupled to explicit scenarios of wide-ranging alternative socio-
39 economic futures, but this is not necessary for all uses. Scenarios should reflect various
40

1 explicit degrees of coordination, including simple fully standardized scenarios for
2 evaluating and comparing downstream models, multi-model scenarios using common
3 input assumptions, and non-standardized scenarios to explore alternative assumptions or
4 meet specific user needs.

- 5 • Some scenarios of socio-economic conditions should include qualitative and quantitative
6 elements and sustained analytic efforts to link the two. These elements can provide a
7 vehicle to explore major historical uncertainties with large implications for climate
8 change and vulnerability; provide a logical structure to connect assumed trajectories for
9 multiple variables; and provide guidance to other analysts or users to extend scenarios by
10 elaborating additional detail. Alternative qualitative and narrative elements should be
11 linked not just to alternative parameter values in quantitative models, but also to
12 alternative forms of causal relations and model structures.

13 14 *Scenario Process: Developer-User Interactions*

- 15 • There is value in close collaboration between scenario developers and users, particularly
16 at the beginning and ending stages of a scenario exercise.
- 17 • The ease of achieving such collaboration and its value are likely to be greater when
18 scenario users are clearly identified, few in number, and similar in their interests and
19 perspectives.

20 21 *Communication of Scenarios*

- 22 • Scenarios must be communicated effectively to their potential users, including both
23 technical and non-technical audiences. In addition to scenario contents, communication
24 should include associated documentation, tools, and support.
- 25 • Scenario communication must include transparent disclosure of underlying assumptions,
26 models, and reasoning, including explicit identification of the major uncertainties
27 represented in each scenario. Such transparency is necessary to support the credibility of
28 scenarios, to alert potential users to conditions under which they might wish to use or
29 modify them, and to inform criticism and improvement of scenarios.

30 31 *Consistency and Integration in Scenarios*

- 32 • Any scenario should be internally consistent in its assumptions and reasoning, to the
33 extent this can be established.
- 34 • In scenario exercises that use multiple models to explore potential uncertainties in future
35 conditions, consistency between models should be pursued primarily through
36 coordination of inputs, not outputs, except when coordinated outputs represent common
37 goals for policy evaluation.
- 38 • Transparency in reporting scenario and model differences as well as underlying
39 assumptions and reasoning can help mitigate the effects of inconsistencies among
40 scenarios.

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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. Means available to express these judgments are of widely varying specificity, ranging from agreed terminology to explicitly quantified probability distributions. All such judgments should include explicit acknowledgement of their inevitable subjective elements, and appropriate caveats.
- Explicit probability judgments are easiest to produce and least controversial in scenarios generated using quantitative models of climate change or specific impact domains. These can be conditioned on specific assumptions for socio-economic inputs such as emissions, and can represent explicitly and quantitatively the effects of specified variation in initial conditions or unknown parameter values. These devices are also available, although in less widespread use, in economic models used to project emissions.
- Including explicit probability judgments is likely to be most useful when key variables are few, quantitative outcomes are needed, and potential users are numerous and diverse. It is likely to be least useful when scenarios specify multiple characteristics including prominent qualitative elements; when the purpose is sensitivity analysis or heuristic exploration; and when potential users are few, similar, and known.
- Because of their large and diverse set of potential users, centrally provided scenarios of global emissions and climate change should attempt to include some explicit probability judgments for ranges of key quantitative outputs, including global emissions and global-average temperature change. These should span a wide range of judged uncertainty on these variables, e.g., 95 to 99 percent. Providing such explicit likelihood statements lets users choose whether to use them or not.
- Scenario exercises should give more attention to low-probability, high-consequence extreme cases, such as loss of a major continental ice sheet or changes in meridional ocean circulation. With these, it is especially crucial to be explicit and transparent about the reasoning and assumptions underlying each scenario, including developers' judgments of relative likelihoods.

Expanding and Sustaining Capacity for Production and Use of Scenarios

- Present scenario capacity is inadequate. To help fulfill these presently unmet needs, the CCSP should establish a program to:
 - Commission scenarios for use in assessments and decision-support activities.
 - Disseminate scenarios with associated documentation, tools, and guidance materials.
 - Commission various groups to evaluate scenarios and their applications and to develop improved methods.
 - Archive results and documentation related to all these tasks, to provide historical perspective and institutional memory for future scenario-related activities.

- 1 • Several conditions in the design and management of this new program would be required
2 to ensure its effectiveness.
- 3 • The program should build and maintain strong connections with outside relevant
4 expertise, and analytic and modeling capability.
- 5 • The program should integrate and balance goals and criteria related to scientific and
6 technical quality, and those related to utility and relevance to users.
- 7 • The program should be insulated from political control.
- 8 • The program should strive for maximum transparency in its own activities, in
9 addition to demanding it from activities it supports.
- 10 • The program will require the authority and resources necessary to articulate and
11 promulgate standards for transparency, consistency, and quality control.
- 12 • The program will require adequate sustained resources.
13

1 **Introduction**

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

10 Scenarios are used to support planning and decision-making when issues have deep or
11 poorly characterized uncertainty and high stakes, often accompanied by long time horizons.
12 These conditions apply to the major decisions of how to respond to global climate change. As
13 scientific research advances our knowledge of the climate’s present state and trends, its patterns
14 of variability, and its responses to external forcings, we are gaining an increasingly clear view of
15 risks that may be realized late this century or beyond. These future risks are linked to near-term
16 socio-economic trends and decisions in both public and private sectors. Some near-term
17 decisions – such as investment in long-lived capital equipment, new resources, or new
18 technologies in the energy sector – can influence long-term trends in the emissions contributing
19 to climate change. Other near-term decisions – such as investment in long-lived capital
20 equipment in water resources, infrastructure, or coastal development – can influence how
21 adaptable and how vulnerable future society will be to the impacts of climate change.

22 Although such decisions are being made now, making them responsibly requires
23 considering their potential consequences over the longer term, including associated uncertainties.
24 This requires thinking about the future conditions that will shape their consequences, not just
25 next month or next year but 10, 30, 50, or 100 years in the future – longer periods than the
26 horizon of conventional methods of planning or analysis.² Attempting to describe potential
27 future conditions over this long time horizon presents a seeming paradox. On the one hand,
28 conditions this far in the future, and the factors and actors that may influence them, are deeply
29 uncertain.³ On the other hand, we have a great deal of knowledge that can help make informed
30 assumptions about future conditions, even over such long horizons. This includes well-
31 established scientific knowledge about physical, chemical, and biological processes; more
32 weakly, relatively well-established causal mechanisms in economics, sociology, and politics; and
33 more weakly still, certain seemingly robust empirical patterns of historical change in population,
34 economics, and technology. All of these give some guidance to support judgments about future
35 conditions that are more or less likely, virtually certain, or virtually impossible. In some ways
36 we might be highly confident that the future will resemble the present, e.g., in the radiative
37 properties of atmospheric trace gases. In others, we might judge it likely that future conditions
38 will lie within some envelope extrapolated from present and past trends, e.g., in projecting rates
39 of change in fertility, mortality, or labor productivity. Still other areas, such as the development

² Morgan et al 1998.

³ Lempert et al 2006.

1 and social consequences of major technological advances, or large-scale political events such as
2 wars, political realignments, or epidemics, may hold more fundamental uncertainties, which
3 might be adequately represented as larger uncertainty bounds on known quantities or
4 discontinuities, or other changes that lie outside what we can presently imagine.

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

10 Early climate-change debates mainly concerned scientific questions such as whether and
11 how the climate is changing, how much change is caused by human activities, and how sensitive
12 the climate system is. Scenarios did not figure prominently in these debates. But as advancing
13 climate science has increasingly shifted the debate from confirming and describing the climate-
14 change problem toward deciding what to do about it, the need for long-term decision-support
15 tools like scenarios has increased, as have the scrutiny and criticism these have attracted.⁴ In a
16 contentious public-policy area like climate change, controversy over scenarios is to be expected:
17 scenarios are a method to structure and communicate the most important uncertainties, and
18 conflicting judgments about uncertainties are a major source of disagreements over what to do.
19 Consequently, we expect the trend of scenarios' increasing prominence and contentiousness to
20 continue – particularly for emissions scenarios, since these are the relevant metric of human
21 environmental burden and the point of most contested proposed intervention.

22 In this report, we try to cast some light on current and coming debates over climate-
23 change scenarios. These debates presently exhibit basic confusion about the definition,
24 purposes, and potential used of scenarios. We aim to provide clarification and practical advice to
25 two related audiences: those conducting assessments or analyses that develop or use scenarios;
26 and those commissioning, using, and interpreting such assessments or analyses. For the first
27 group, we seek to provide an organized summary of relevant experience in similar efforts,
28 discussion and clarification of key choices and challenges, and – to the extent present knowledge
29 allows – practical guidance about pitfalls, challenges, and opportunities in particular approaches.
30 For the second group, we seek to provide guidance on what to ask for, how and how much to
31 participate in its production, how to interpret the results, and what questions to ask.

32 Because the charge of this report is unlike those of other Synthesis and Assessment
33 products, the approach we have taken to producing it is necessarily different as well. We were
34 tasked with reviewing, interpreting, and evaluating experience with scenario methods in global
35 climate change applications. This is not a narrowly focused question, and there is not a well-
36 developed scientific literature on which we can draw for answers. While we have reviewed the
37 existing literature on scenarios, most of it concerns scenarios in other decision domains than
38 global climate change. In addition, we have examined several major scenario exercises in global-
39 change applications. In this, we have drawn on published materials, both from the exercises

⁴ E.g., See, e.g., Lomborg, Michaels, Castles and Henderson 2003a, 2003b, UK House of Lords.

1 themselves and from commentary and criticism, as well as documentary materials and records,
2 interviews with participants and users, and the experience and judgments of team members.

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

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

1 *1. Scenarios, their Characteristics and Uses*

3 *1.1 Defining Scenarios*

4 A scenario is a description of potential future conditions, developed to inform decision-
5 making under uncertainty. The decisions in question can be by individuals, groups,
6 organizations, or governments, and may pertain to any subject matter. While many writers on
7 scenarios give no explicit definition, others have offered a wide range of definitions, often
8 substantially more complex and restrictive than this one. The published definitions gathered in
9 Box 1.1 give a sense of both the broad commonalities among many analysts' conceptions and the
10 significant differences among them.

Box 1.1. Scenarios: a Sampling of Published Definitions.

13 A scenario is a coherent, internally consistent, and plausible description of a possible
14 future state of the world.⁵

15 A scenario is a story that describes a possible future. It identifies some significant events,
16 the main actor and their motivations, and it conveys how the world functions. Building
17 and using scenarios can help people explore what the future might look like and the likely
18 challenges of living in it.⁶

19 Scenarios are images of the future, or alternative futures. They are neither predictions nor
20 forecasts. Rather, each scenario is one alternative image of how the future might unfold.
21 A set of scenarios assists in the understanding of possible future developments of
22 complex systems. Some systems, those that are well understood and for which complete
23 information is available, can be modeled with some certainty, as is frequently the case in
24 the physical sciences, and their future states predicted. However, many physical and
25 social systems are poorly understood, and information on the relevant variables is so
26 incomplete that they can be appreciated only through intuition and are best
27 communicated by images and stories. Prediction is not possible in such cases.⁷

28 A climate scenario is a plausible representation of future climate that has been
29 constructed for explicit use in investigating the potential impacts of anthropogenic
30 climate change. Climate scenarios often make use of climate projections (descriptions of
31 the modeled response of the climate system to scenarios of greenhouse gas and aerosol
32 concentrations), by manipulating model outputs and combining them with observed
33 climate data.⁸

34 [Scenarios] are created as internally consistent and challenging descriptions of possible
35 futures. They are intended to be representative of the ranges of possible future

⁵ IPCC TAR WG2, p. 149.

⁶ Shell International 2003.

⁷ IPCC SRES, pg. 62.

⁸ IPCC TAR WG1, p. 741.

1 developments and outcomes in the external world. What happens in them is essentially
2 outside our own control.⁹

3 Scenarios are coherent, internally consistent and plausible descriptions of possible future
4 states of the world, used to inform future trends, potential decisions, or consequences.
5 They can be considered as a convenient way of visioning a range of possible futures,
6 constructing worlds outside the normal timespans and processes covering the public
7 policy environment.¹⁰

8 Scenarios are plausible, challenging, and relevant sets of stories about how the future
9 might unfold. They are generally developed to help decision-makers understand the wide
10 range of potential futures, confront critical uncertainties, and understand how decisions
11 made now may play out in the future. They are intended to widen perspectives and
12 illuminate key issues that might otherwise be missed or dismissed. The goal of
13 developing scenarios is often to support more informed and rational decision-making that
14 takes both the known and the unknown into account.¹¹

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

32 Over the past few decades, the use of scenarios has moved outside the realm of military
33 and diplomatic activity. Beginning with strategic planning at the Royal Dutch/Shell oil

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.

1 company,¹⁵ scenarios are now widely used for strategic planning, analysis, and assessment by
2 businesses and other organizations. They have also figured increasingly prominently in
3 planning, analysis, and policy debate for long-term environmental issues, in particular global
4 climate change. Because the total body of experience with scenarios provides useful insights
5 into their use in any particular domain, this section elaborates the meaning, characteristics, and
6 potential uses of scenarios in general. The next section turns to their specific use for global
7 environmental issues.

8 *Distinguishing Scenarios from Assessments, Models, and Analyses*

9 Confusion is widespread in discussions of scenarios, because their form and usage are
10 highly diverse, and because writers' uses of the term are often imprecise and occasionally
11 contradictory. Scenarios must be distinguished, on the one hand, from the various types of
12 assessment, decision support, or analyses that often use scenarios; and, on the other hand, from
13 other types of statements about future conditions, such as predictions, projections, or forecasts.

14 An assessment is any process that reviews and synthesizes scientific or other expert
15 knowledge to provide information of relevance to policy or decision makers.¹⁶ The most
16 common methods of assessment are deliberations of expert panels and formal models, but other
17 methods combine human deliberations with formal analysis or modeling, including war games of
18 other simulation games, policy exercises, political-military exercises, constructing future
19 histories, back-casting, and others.¹⁷ These methods may use specifications of potential future
20 conditions – i.e., scenarios – as inputs to or components of their work. Scenarios may even be
21 essential for some of these methods. For example, a war or crisis gaming exercise needs a
22 scenario to specify the nature of the threat or crisis, while a formal model used to represent future
23 development of some issue of concern needs a scenario to specify future values of those inputs
24 not explicitly calculated within the model. But these methods are broader than and distinct from
25 scenarios. For example, models do not need scenario-based inputs when used to reconstruct past
26 conditions or study causal processes.

27 The distinction between assessments and scenarios is perhaps clearest in conventional
28 assessments based on deliberations of expert panels, such as the Intergovernmental Panel on
29 Climate Change (IPCC), US National Assessment, or Millennium Assessment.¹⁸ Such
30 assessments often construct representations of future development of an issue, usually based on
31 formal models. These representations require scenario-based inputs and may produce outputs
32 that are themselves used as scenarios in other activities. But the scenario-related activities are
33 frequently not the central focus of the overall assessment, which may examine many additional
34 things, e.g., the state of knowledge in particular scientific areas, the status of and trends in
35 particular environmental conditions, the evidence attributing particular environmental changes to

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, US National Assessment, MEA.

1 human inputs, or particular policy-relevant scientific questions. Assessments may also include
2 evaluations of proposed actions or proposed criteria for conducting such evaluations. Scenarios
3 thus may provide required inputs to assessments, but are distinct from them.

4 *Distinguishing Scenarios from Projections, Predictions, and Forecasts*

5 Scenarios must also be distinguished from other types of statements about the future,
6 such as predictions, projections, and forecasts. All of these satisfy the basic definition above:
7 they are descriptions of potential future conditions whose primary purpose in most cases is to
8 support decisions. How can scenarios be distinguished? Examining the ways scenarios are used
9 and discussed by practitioners and researchers suggests four characteristics that distinguish them
10 from other types of future statements. Although these characteristics are not essential, they are
11 all more likely to be present in scenarios than in other types of future statement, so they help to
12 sharpen and delimit the definition of a scenario.

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

20 Second, scenarios are schematic: that is, they are multidimensional but not without limit.
21 Scenarios do not seek to describe potential future conditions with complete precision or detail.
22 Rather, they highlight essential characteristics and processes with enough detail that
23 knowledgeable observers perceive them as realistic and relevant, but not so much as to distract
24 from large-scale patterns. Indeed, one potential use of scenarios is to stimulate creative thinking
25 and insights, for which they must leave something to the imagination. How much detail and
26 precision is appropriate is a judgment that depends on the particular application.

27 Third, scenarios usually come in groups. To be a useful tool to inform decision-making
28 under uncertainty, scenarios must represent uncertainty. This is most often done by providing
29 multiple scenarios, each presenting an alternative realization of uncertain future conditions.¹⁹
30 The number of scenarios depends on the application. Scenario exercises usually use between
31 two and seven, depending on the stakes of the issue, the resources invested in the exercise, and
32 the depth of analysis devoted to each scenario. The most frequently proposed numbers are three
33 or four.

34 Finally, scenarios tend to claim less confidence than other types of future statements.
35 Although different authors' usage is not consistent, "prediction" and "forecast" usually denote
36 statements for which the highest confidence is claimed. "Projection" denotes a less confident
37 statement, which may have some specified confidence level and may be explicitly contingent on

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.

1 specified assumptions about other future conditions. Calling a future statement a “scenario”
2 usually implies still less confidence and more associated contingencies. Any use of a scenario
3 for serious planning or analysis does, however, presume some minimal threshold of likelihood.
4 The situation described must be judged likely enough to merit attention, and to justify expending
5 resources and effort to study its implications and potential responses to it. There may also be a
6 time ordering among these three types of statements – predictions or forecasts tend to describe
7 nearer-term futures and scenarios longer-term futures – but there are exceptions, and the meaning
8 of near-term and long-term depend on the particular context.

9 ***1.2. Creating a Scenario Exercise: Key Characteristics and Choices***

10 Beyond these general characteristics, scenarios vary greatly in their use, production, and
11 contents. Extensive scholarly effort has gone into providing alternative scenario taxonomies.²⁰
12 Scenarios can be distinguished, for example, by whether they present a snapshot of a future state
13 or a dynamic account of changes over time to reach that state; by their degree of complexity; by
14 the relative balance of deliberation and intuition versus formal analysis used in producing them;
15 or by their temporal and spatial scale. The set of characteristics on which scenarios could be
16 sorted is long and open-ended, so we make no attempt to provide an exhaustive list. Instead, we
17 summarize the main dimensions of scenario variation in the form of a list of potentially open-
18 ended design choices.

19 *Variation among Scenarios: Three Basic Dimensions*

20 Three dimensions of variation, concerned with the purpose of a scenario exercise, have
21 far-reaching implications for its design and use and so merit separate discussion. First, the
22 intended use of a scenario exercise can vary from the more predictive to the more exploratory or
23 heuristic. It is of course a fundamental error to take a scenario’s illustrative description of
24 potential future conditions as a confident prediction of what will actually happen – in our
25 terminology, to take a scenario as a projection or even a prediction.²¹ Still, a scenario must be
26 judged likely enough to merit the attention of busy people. Exploratory uses of scenarios may
27 presume only this low threshold, yet have great value. For example, scenarios can be used to
28 probe and challenge the mental models, thought habits, and unrecognized assumptions of
29 decision-makers; to clarify points of agreement and disagreement; to identify and engage needed
30 participants; to provide a preliminary structure for advance analysis of potential future decisions;
31 or to seek insights into unrecognized opportunities, risks, causal linkages, or uncertainties.²²
32 Such insights can arise not just from examination of uncertainties, but also from meticulous
33 critical examination of future factors that are essentially certain, e.g., strongly determined
34 demographic trends such as the aging of industrialized-country populations, or even of present
35 conditions whose significance has been overlooked.²³ Still, the predictive confidence accorded

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

²¹ Several such errors are collected and discussed in Bracken 1977 and Brewer 1990.

²² Brewer 1990.

²³ Shell International 2001, 2003. For example, in a 1960s crisis exercise on a Soviet invasion of Iran, one participant realized the local supply of jet fuel available to support a rapid US response was ten times larger than

1 to scenarios is a matter of degree: carefully developed scenarios that are judged to have captured
2 the most important uncertainties may claim some moderate degree of confidence, and reasonable
3 distinctions may be drawn between scenarios that represent conventional versus surprising
4 futures, best and worst cases, etc.

5 A related dimension of variation among scenario exercises is their proximity to decision-
6 making.²⁴ Scenario exercises may involve actual decision-makers and seek to directly advise a
7 specific, identified, near-term decision, but more frequently their relationship to concrete
8 decisions and decision-makers is indirect. Scenarios may be used for risk assessment,
9 contingency planning, identification of potential threats or actions to be considered, or early
10 characterization of a poorly understood issue. In such applications, exploratory uses dominate.
11 Scenario exercises that are closer to decisions with significant stakes operate under very different
12 requirements, usually driven by specific user needs. Their uses tend to be more predictive –
13 constrained by limits of available knowledge – so they might be expected, for example, to
14 provide more explicit and complete characterization of major uncertainties. They are also likely
15 to be more integrated with methods to evaluate alternative choices and identify preferred ones.

16 A third basic dimension of variation concerns whether scenarios are defined primarily
17 normatively, on the basis of their perceived desirability or undesirability, or primarily on the
18 basis of their perceived plausibility or likelihood. Although all scenarios include both positive
19 and normative elements, it is important to keep as clear as possible which elements are included
20 based on perceived likelihood or plausibility and which because of perceived desirability or
21 undesirability. The most frequent use of explicitly normative scenarios involves constructing
22 some hypothetical future state primarily on the basis of its desirability. Such a future might be
23 constructed to embody participants' general intuitions about desirable social trends, or to achieve
24 specific environmental, development, or other goals.²⁵ The scenario exercise then consists
25 primarily of “back-casting” – attempting to construct paths that connect present conditions to the
26 specified future conditions, to examine the feasibility of the target, and identify costs, tradeoffs,
27 and conditions associated with meeting it.²⁶ Similarly, one can posit an undesirable future state
28 and then reason through conditions associated with avoiding it. This approach is sometimes
29 proposed to reduce the risks of hidden bias in construction of scenarios which, like any decision
30 support tool, can be misused to provide support for a decision already made for other reasons,
31 rather than to inform a decision not yet made. By bundling normative assumptions into the

had been thought, because kerosene – an acceptable substitute – was used for domestic cooking and heating (Schelling 1964).

²⁴ This dimension is presented by Van Notten et al 2003 as “exploration” versus “decision support.”

²⁵ 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, or the scenarios of the Global Scenario Group, which included some defined by specified trends and others back-cast from normatively specified targets for 2050 (Kemp-Benedict et al 2002, Raskin et al 2002).

²⁶ Robinson 1982, 2003.

1 future target state or boundary conditions, analysts hope to reduce their penetration into the
2 subsequent instrumental reasoning about actions and conditions to reach the target.²⁷

3 *Developing Scenarios: Main Dimensions of Choice*

4 Table 1.1 extends the preceding discussion, summarizing the main areas of variation and
5 choice involved in constructing a scenario exercise. This is a highly simplified representation of
6 a complex set of choices. In any particular scenario exercise some of these choices may be made
7 by default, without explicit consideration, perhaps because the preferred choice is obvious in
8 context. Although we present these choices in simple sequential order, this is not necessary:
9 choices might be made in some other order, or iteratively adjusted. But while the process and
10 sequence of choices may be idealized, the set of choices is not: creating a scenario requires
11 explicit or implicit choices on all these dimensions.
12

13
14 **Table 1.1** *Idealized Sequence of Major Choices in Scenario Development.*

- 15
- 16 ■ Main focus, framing, users, question(s) to be addressed
- 17 ■ Process and participation
- 18 ■ Key uncertainties to explore: how many, over what range
- 19 ■ Narrative, quantitative, or both
- 20 ■ Level of complexity (number of quantitative variables, detail of narrative)
- 21 ■ Specific variables and factors to specify
- 22 ■ Time horizon and spatial extent
- 23 ■ Temporal and spatial resolution
- 24

25 The most basic choices in developing scenarios, which include the three dimensions of
26 variation called out above, involve identifying the main focus of the exercise: what issues are to
27 be addressed or what decisions informed, for whom? The decision to conduct a scenario-based
28 exercise does not necessarily imply that these matters are clearly understood. The closer a
29 scenario exercise is to concrete decisions, the more likely it is that these definitional issues will
30 be understood clearly, in part through discipline on the process imposed by the involvement of
31 decision-makers. But most often, the coupling of scenarios to decisions is relatively weak.²⁸ In
32 some applications (e.g., corporate strategic planning, responding to a novel military threat) the
33 relevant decision-makers may be clearly identified at the outset, but the issues to be addressed
34 and relevant choices may not be. In other applications, scenarios may be developed to address
35 some broad issue or concern (e.g., climate change, emerging infectious diseases, or terrorism),
36 but the potential users and decisions to be informed might both be unspecified. But whether
37 relationship of a scenario exercise to decisions is near or far, direct or indirect, clear

²⁷ This approach does not preclude such misuse: if a goal is strongly desired, scenarios are at risk of conscious or unconscious bias to make it look easy. Japanese war-games of the Battle of Midway provide striking examples (Bracken 1977).

²⁸ 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.

1 understanding of its focus and purpose is important, and infrequently achieved: many scenario
2 exercises muddle through with vagueness, confusion, or disagreement regarding the focus,
3 purpose, and intended user of the exercise. Clarifying the overall focus of a scenario exercise
4 may require broad consultations or scoping workshops involving many potentially interested
5 decision-makers, other stakeholders, and analysts and researchers.

6 A second basic set of decisions concerns the process by which scenarios are developed.
7 Like the focus of the exercise, decisions about the process of developing scenarios often receive
8 little thought, or are not even explicitly recognized as choices, but are nonetheless highly
9 consequential. What expertise must be included to ensure the scenarios adequately reflect the
10 best available scientific knowledge, data, and models? What decision-makers, stakeholders, or
11 their surrogates must be involved to keep the scenarios relevant, plausible, and credible? For
12 scenario exercises that must integrate knowledge from diverse domains, individual participants'
13 knowledge, flexibility, and imagination can be as important as the disciplines or stakeholder
14 groups they represent. How intensively, for how long, and by what means will participants
15 interact? Will the process be open to outside observers or participants? How and when will
16 feedback on the scenarios be sought, and how will it be used? How and to whom will results be
17 communicated? And crucially, how will the process be led, and how will disagreements be
18 resolved? With good leadership, resolving differences in a scenario exercise can be less arbitrary
19 and more illuminating than in other group tasks; when disagreements persist after careful
20 examination, they can be treated as important uncertainties to be retained as alternative
21 scenarios, not suppressed by picking a winner, splitting the difference, or retreating to vague
22 language. Whatever process is chosen, a series of substantive choices must be made about what
23 goes into the scenarios. The most important of these concern what key uncertainties will be
24 explored, and how much richness and detail should be included in scenarios to illuminate these.

25 What uncertainties are to be explored, and how? Many dimensions of uncertainty may be
26 relevant to the issue being examined, but only a few can be examined explicitly in any scenario
27 exercise. Defining these is a crucial choice that shapes much of what follows in a scenario
28 exercise. For those uncertainties judged most important, alternative outcomes are usually
29 represented in alternative scenarios. For example, scenarios might present high and low-growth
30 futures, or alternative forms that a competitive threat might take. Other uncertainties judged less
31 crucial are usually suppressed by presenting a single "best guess" or "reference case." The few
32 key uncertainties chosen can be represented in the number and character of scenarios, depending
33 on the intended use. A particular uncertainty might be represented by high and low values of
34 some quantity, or by a reference case supplemented with high and/or low variants. If two or
35 more uncertainties interact, they can be represented by scenarios that combine different
36 outcomes of each: in the simplest form, two interacting uncertainties can be represented by four
37 scenarios, often illustrated by a two-by-two matrix.²⁹ Several alternative scenarios might seek to
38 span a plausible range for some key quantitative variable, or present distinct qualitative outcomes
39 for a single uncertainty, e.g., three types of competitive threat, or three political futures for a
40 region in turmoil. Alternatively, scenarios can represent plausible extreme or "worst-case"
41 scenarios, to assess the robustness of decisions or strategies.

²⁹ Alternative interpretations of this matrix structure are discussed in van't Klooster and van Asselt 2006.

1 How rich and complex should each scenario be? Defining scenarios as we have, as
2 multivariate but synoptic, still leaves a wide range of levels of complexity to choose from. At
3 one extreme, scenarios may specify time-paths for just a few quantitative variables, or even just
4 one. Such scenarios are common, e.g., in applications such as analyzing a firm’s profitability
5 under alternative scenarios for oil prices, or projecting tax revenues under alternative scenarios
6 of productivity growth and inflation, often in a standard “high, middle, low” format. A scenario
7 can accommodate more complexity by projecting additional quantitative variables, but as the
8 number of variables increases, so also does the need for an organizing principle or gestalt to tie
9 them together in a non-arbitrary way.

10 At the other extreme, the core of a set of scenarios can be a set of rich, coherent
11 narratives, an approach frequently called the Shell approach.³⁰ Each narrative, described
12 principally in text, reflects a distinct conception of how the world might develop with a
13 persuasive underlying causal logic. A narrative scenario can stand alone but may also include
14 specifications of important quantitative variables, e.g., of population or economic growth,
15 consistent with the broad causal logic underlying the scenario. The narrative provides the
16 context and explanatory logic that tie together the time-paths of quantitative variables, although
17 particular time-paths are regarded as illustrating, not defining, the scenario – i.e., a different
18 scenario would present substantially different time paths or relationships among them.

19 The choice of how rich and complex to make scenarios has far-reaching implications for
20 the process of developing the scenarios, what can be done with them, and the uses they can
21 serve. The two extreme approaches imply large differences in how uncertainty is treated, what
22 aspects of the problem receive attention, and the relationship between scenarios and their users,
23 which we discuss for climate-change scenarios in Section 4. Richer and more complex scenarios
24 require more time and effort to develop, whether based on quantitative models, narratives, or
25 both. Complex narrative-based scenarios may require many person-months of development to
26 become realistic, relevant, and persuasive, with consistent relationships among scenario
27 elements. In return for the extra effort, this approach allows great flexibility in the way potential
28 futures are described. Narratives can convey different aspects of a future situation with varying
29 degrees of salience or specificity, and they can compactly convey the tone or character of a
30 future situation by allusion, where a precise specification would appear arbitrary or labored. The
31 narrative approach avoids limiting the defining characteristics of a scenario to any particular set
32 of pre-specified variables, but attempts to be alert to a wide range of potentially important
33 characteristics and mechanisms of causal influence. Proponents of this approach argue that a
34 coherent narrative at the core of a scenario is necessary to avoid arbitrariness in specifying
35 multiple variables, and to make the exercise useful to decision-makers: “Most scenarios merely
36 quantify alternative outcomes of obvious uncertainties (for example, the price of oil may be \$20
37 or \$40 a barrel in 1995). Such scenarios are not helpful to decision makers”.³¹

38 The remaining substantive choices in specifying a scenario follow from the preceding
39 large-scale choices. They include specifying the time horizon and spatial extent of the scenarios;

³⁰ Van der Heijden 1996; Wack 1985a, 1985b; Schwartz 1991; Shell International 2003.

³¹ Wack 1985a, p. 74.

1 deciding the particular elements to include,; and the temporal and spatial resolution at which
2 scenario outputs are stated. Decisions about temporal resolution (e.g., hourly to multi-decadal)
3 and spatial resolution (e.g., regional, national, continental scales) are particularly important when
4 – as is often the case in global-change applications – scenarios are produced or used by
5 quantitative models. Such models may have very precise requirements for the specification and
6 resolution of inputs and outputs, creating the possibility for serious mismatches between what
7 users need or expect, and what scenario developers feel comfortable and competent providing.

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

12 13 ***2. Scenarios in Global-Change Analysis and Decision Support***

14 Analysts have tried to develop scenarios to support understanding of and decision-
15 making for global environmental issues, beginning with the global models of the mid-1970s and
16 early assessment of acid rain and stratospheric ozone in the late 1970s to early 1980s.³² The
17 reasons for using scenarios in global change are similar to those that apply in other decision
18 domains: high-stakes decisions that must be made under deep uncertainty about the conditions
19 that will determine their consequences, the values at stake, or the relevant set of choices and
20 actors. As in other domains, well-designed scenario exercises can provide a structure for
21 assessing alternative choices and help focus on the nature of the issue, the relevant choices and
22 actors, the values that might be at stake, and the types of research or analysis that might help
23 clarify preferred choices.

24 For climate-change applications, scenario exercises have been conducted and sponsored
25 by governments, international organizations, non-governmental organizations, and collaborative
26 groups. While these have been diverse in form, details, and purposes, they have tended to focus
27 more on heuristic and exploratory uses than on supporting specific decisions. The boundaries of
28 the climate-change issue are not sharply defined, however: climate change implicates and
29 connects to many other areas of policy, including energy, agriculture, hazard protection, and
30 broad questions of economic development. Consequently, there is substantial uncertainty about
31 what all the relevant decisions, decision-makers, and potentially affected values are. While some
32 decisions are clearly of primary relevance to climate change, many other decisions that appear to
33 be connected have not yet incorporated consideration of climate change or even recognized the
34 connection. Reflecting these fuzzy boundaries of the issue, scenario exercises developed for
35 climate change have overlapped with other exercises primarily focused on ecosystems, energy,
36 and broad issues of world development. The fuzziness of the climate issue's definition increases

³² See, e.g., Meadows et al 1972, Barney et al 1982; summary of early ozone assessments in Parson 2003; summary history of scenarios in global-change applications in Swart et al, 2004. What was the earliest scenario work in global change depends, of course, on how the boundaries of global change are defined. Kahn and Wiener (1967) might be considered an early example.

1 the challenge of developing useful scenarios, but also increases the potential value of well-
2 crafted and executed scenario exercises.

3 The decisions most directly related to climate change are conventionally sorted into two
4 categories, mitigation and adaptation.³³ Mitigation consists of actions that reduce the human
5 perturbations of the climate system, by reducing net anthropogenic greenhouse-gas emissions.
6 Adaptation consists of actions to reduce the harm or increase the benefit from climate change
7 and its impacts. Despite uncertainty about the precise decision agenda, we can identify in
8 general terms the type of information scenarios might provide that would be useful to each type
9 of decision.

10 Scenarios can help inform adaptation decisions by characterizing the nature and severity
11 of relevant potential impacts; identifying key vulnerabilities, particularly those that might not
12 otherwise have been recognized; identifying research or monitoring priorities that might give
13 advance warning about impacts, particularly acute vulnerabilities; expanding the perceived set of
14 potential responses; and providing a framework for evaluating alternative adaptation measures.
15 They may also help to clarify the time structure of relevant decisions, identifying those near-term
16 decisions that might have important but under-recognized connections to future impacts and
17 vulnerability.

18 Similarly, scenarios can help inform mitigation decisions by characterizing the potential
19 impacts of climate change and their severity, since these provide the motivation for mitigation.
20 But, in addition, mitigation decisions can benefit from information about potential emissions
21 trends, which determine the nature of the challenge of limiting emissions; about potential
22 pathways of the extraction and depletion of current energy resources and development of new
23 ones; and about potential pathways of technological development. Mitigation decisions may also
24 benefit from scenarios representing potential policy context in which they are made.

25 To date, most climate-related uses of scenarios have not examined decisions directly, but
26 have been embedded in larger exercises of assessment, modeling, or characterization of the issue.
27 These uses have included formal integrated-assessment models,³⁴ comprehensive assessments
28 conducted by multi-disciplinary expert bodies (e.g., IPCC), and more narrowly focused
29 assessment exercises targeting specific aspects of the climate-change issue. In these uses,
30 scenarios represent components of the climate-change issue that are required inputs to an
31 assessment or model.

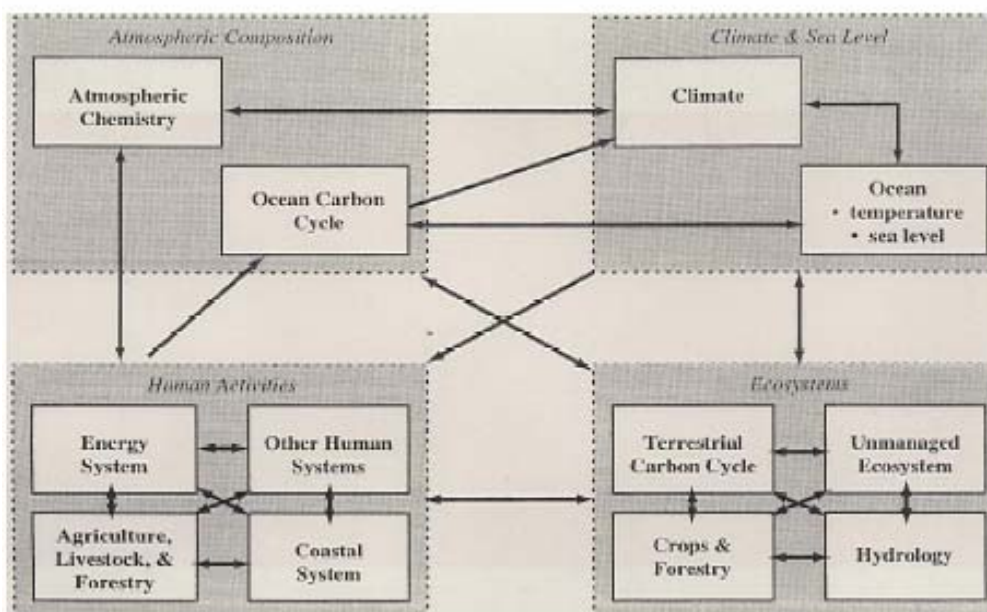
32 The causal logic of the climate-change issue is complex, including multiple two-way
33 causal links and feedbacks between socio-economic, geophysical, and ecological systems.
34 Integrated-assessment models seek to represent many of these linkages and feedbacks explicitly:
35 Figure 2.1 shows a typical example of the “wiring diagrams” that illustrate the increasingly
36 dense linkages and feedbacks represented in these models. But while such diagrams might be

³³ 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.

³⁴ Weyant et al 1996; Parson and Fisher-Vanden 1997.

1 taken to indicate that all relationships are represented explicitly within the model – endogenously
 2 – this is not the case. All models of the climate-change issue rely on scenarios to specify some
 3 future quantities exogenously, and in virtually all cases, scenario-specified inputs are not
 4 modified to account for results of the subsequent analysis: i.e., they are truly exogenous, and the
 5 causal logic does not close.

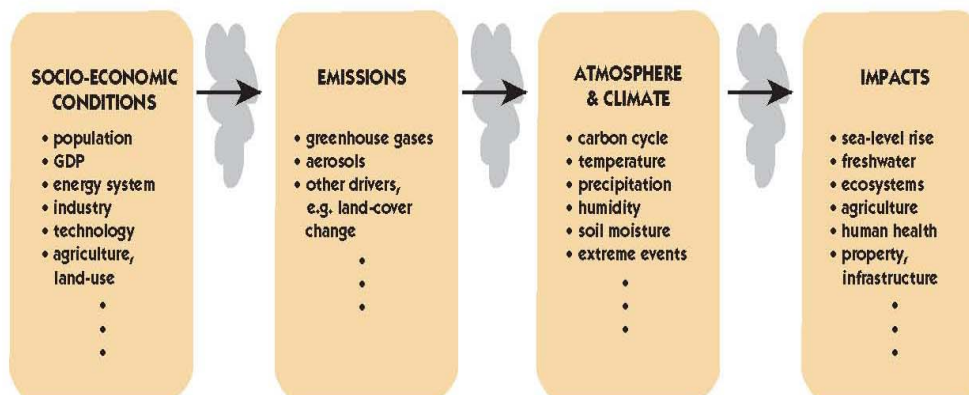
6 When scenarios are used to specify exogenous inputs to a model of some aspect of the
 7 climate-change issue, the causal logic of the analysis can be greatly simplified from that shown
 8 in Figure 2.1. Instead, the logic can be represented by a simple linear structure that extends from
 9 human activities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



16
 17 **Figure 2.1: Wiring Diagram for Integrated Assessment models of climate change.**
 18 (Source: Weyant et al, 1996, IPCC 1995 WG3)

19 This linear logical structure allows a simple, practical categorization of five types of
 20 scenarios that have been developed for the climate-change issue. These types are defined by
 21 what quantities they specify, and what primary area of analysis they provide input to. Their
 22 differences can be represented by where they cut the causal chain in Figure 2.2, with the scenario
 23 specifying quantities lying on one side of the cut, and the assessment or other activity using the
 24 scenario lying on the other side. The next five subsections discuss these five types of climate-
 25 change-related scenarios in turn.

1



2

3 *Figure 2.2: Anthropogenic climate change: Simplified linear causal chain*

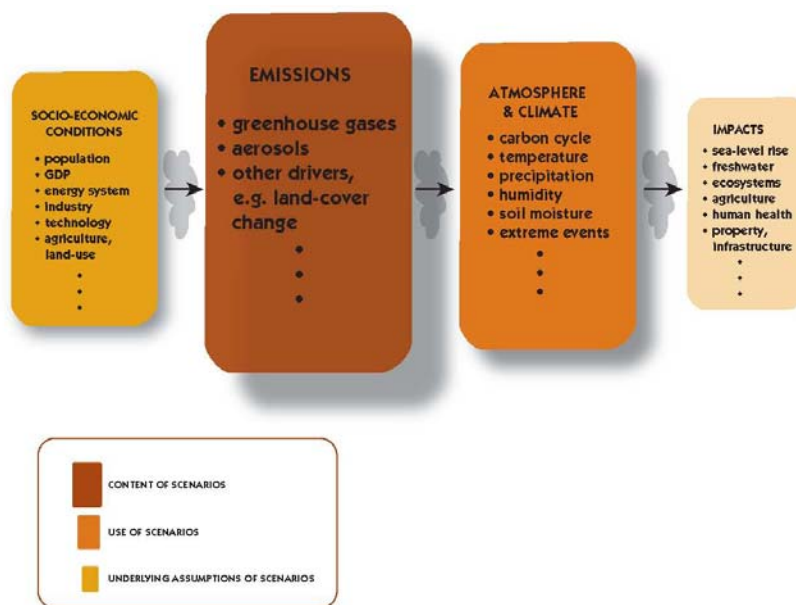
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5 **2.1. Emissions Scenarios for Future Climate Simulations**

6 Scenarios of greenhouse-gas emissions, sometimes including other human perturbations
7 such as land-use change, are the best known type of climate-change related scenario. Emissions
8 scenarios provide required inputs to model calculations of future climate change, as shown in
9 Figure 2.3. As the focus and intended use of climate-model studies has shifted over time, so has
10 the role of emissions scenarios. Early research studies examined the climate system's response
11 to potential (rather than projected) emissions inputs in individual model studies or standardized
12 model comparisons. In such exercises, the purpose of a scenario is to provide a known,
13 consistent perturbation big enough to generate an informative model response. Such scenarios
14 must be standardized, so differences between model runs can be traced to scientific uncertainties
15 and model differences, but they can be simple and arbitrary, making no claim to being realistic.
16 The earliest such scenarios showed a "step-change" increase in atmospheric concentration of
17 CO₂ from its pre-industrial value, to either two or four times that value.³⁵ Models' equilibrium
18 responses to doubled CO₂ provided a standard benchmark of model responsiveness, which has
19 remained around the range of 1.5 to 4.5°C for more than 20 years. This range of modeled
20 equilibrium responses to a standardized perturbation does not predict actual climate changes
21 under human perturbations, although it has often mistakenly been taken as such.

22

³⁵ e.g., Manabe and Wetherald 1967; Manabe and Stouffer, 1979.



1
2
3 **Fig 2.3: Emissions Scenarios for Climate Simulations**
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5 The next generation of climate-model studies, beginning in the early 1990s, specified a
6 time-path of atmospheric concentrations rather than a one-time perturbation. These studies for
7 the first time allowed comparison of models' transient responses, including the rate of change.
8 They still used a simple, highly idealized standard scenario, most frequently a 1 percent per year
9 increase in atmospheric concentration, expressed as CO₂-equivalent. Only two such transient
10 simulations had been conducted by the first IPCC assessment (1990),³⁶ but by the time of the
11 second assessment (1996), most modeling groups had produced at least one.

12 Since the mid-1990s, climate modelers have increasingly sought to produce realistic
13 pictures of how the climate may actually change, requiring a new approach to emissions
14 scenarios. Scenarios must now present well-founded judgments or guesses of actual future
15 emissions trends and their consequences for atmospheric concentrations. The required emissions
16 scenarios have been constructed either by extrapolating recent emissions trends, or particularly
17 for energy-related CO₂, representing emissions in terms of underlying drivers such as population,
18 economic growth, and technological change and projecting these drivers using some combination
19 of modeling and trend extrapolation. Driven by such scenarios, climate models for the first time
20 can claim to be reasonable estimates of how the climate might actually change. In addition,
21 comparisons using multiple models and emissions scenarios have allowed partitioning of
22 uncertainty in future climate change into roughly equal shares attributed to uncertainty in climate
23 science and models, and in emissions trends.³⁷ These comparisons have also allowed estimation
24 of the climate-change benefits from specified emissions reductions.

³⁶ Washington and Meehl 1989, Manabe, Souffer, Spelman, and Bryan 1991.

³⁷ Cubash et al 2001.

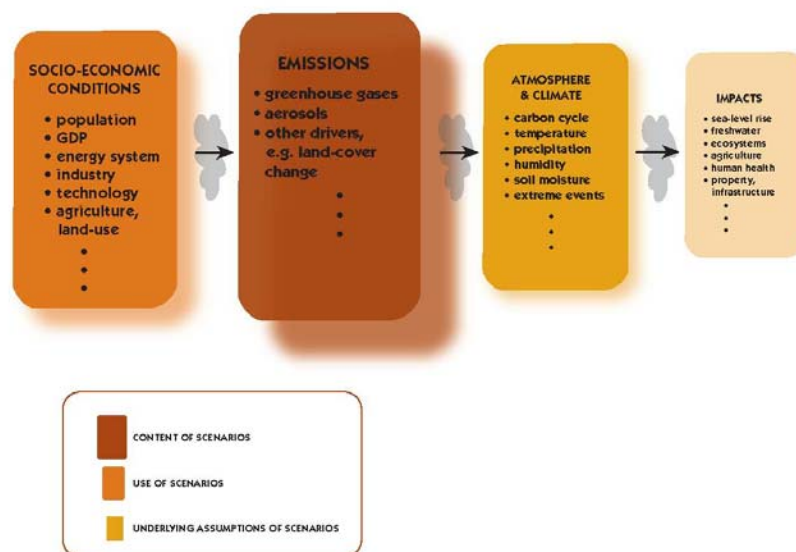
1 As this shift occurred, advances in climate models – e.g., improved representations of
2 atmospheric aerosols, tropospheric ozone, and atmosphere-surface interactions – produced
3 mismatches between emissions scenarios and the input needs of climate models. For example,
4 climate models now require emissions of several types of aerosols and reactive gases (principally
5 the ozone precursors, hydrocarbons, CO and NO_x), explicit estimates of black carbon and
6 organic carbon, and some disaggregation of different types of volatile organic compound (VOC)
7 emissions. Moreover, because these emissions act locally and regionally rather than globally,
8 they must be specified at the spatial scale of a model grid-cell, about 150 sq. km. Models of
9 atmospheric chemistry and transport then use these emissions to generate the concentrations and
10 radiative forcings used by the climate model. Since emissions scenarios often do not provide the
11 required detail, climate modelers meet these input needs through various *ad hoc* approaches.

12 Changes in standard emissions scenarios pose challenges for maintaining comparability
13 with past model results. For example, the IPCC's IS92 scenarios projected that future SO₂
14 emissions would roughly double, then stabilize, while the later SRES scenarios projected sharp
15 decreases, giving 2100 emissions about one quarter the IS92 value. This change caused
16 significant increases in projected warming that were not due to any changed scientific
17 understanding. To help maintain backward comparability, many climate-model groups have
18 continued to run simulations using older standardized scenarios, to provide benchmarks for
19 comparisons both among current models and between current and previous-generation models.

20 ***2.2. Emissions Scenarios for Exploring Alternative Energy and Technology*** 21 ***Futures***

22 In addition to providing needed inputs to climate models, emission scenarios have also
23 been produced to examine alternative socio-economic, energy, and technological futures, as
24 shown in Figure 2.4. As in Figure 2.3 the content of the scenario is emissions, but the scenario is
25 now used to examine the socio-economic implications of alternative emission paths, which lie
26 upstream or to the right in the causal chain. A scenario specifying a particular emissions time-
27 path can be used to explore what patterns of demographic and economic change, energy resource
28 availability, and technology development are consistent with that trajectory. Alternatively,
29 scenarios can be used to examine what changes in policies, technologies, or other factors would
30 be required to shift emissions from some assumed baseline onto a specified lower path, and to
31 estimate the cost of such a shift. To be used in this way, an emissions scenario might be
32 specified arbitrarily, or might specify some environmental target based on normative criteria as
33 discussed in Section 1.2. Such scenarios have been most frequently used to examine emissions
34 trajectories that stabilize atmospheric CO₂ concentrations at specified levels. More recent
35 exercises have instead taken stabilization of radiative forcing as the target, to examine the role of
36 non-CO₂ greenhouse gases in meeting stabilization goals.³⁸

³⁸ EMF 21 and 23; CCSP SAP 2.1a.



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Fig 2.4: Emissions Scenarios for Energy/Technology Futures

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An important early example is the WRE scenarios, which presented emissions pathways that stabilized atmospheric CO₂ concentration at five levels, ranging from 450 to 1000 ppm.³⁹ Developed heuristically from 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.

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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 studied 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-CO₂ gases and carbon sequestration in mitigation targets and policies.⁴⁰

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In a recent scenario exercise of this type sponsored by the CCSP, three modeling teams constructed separate reference-case scenarios to examine the implications of stabilizing radiative forcing at levels roughly corresponding to CO₂ concentrations of 450, 550, 650, and 750 ppm. They examined the energy system, land-use, and economic implications of moving to stabilization. This project explored the role of multiple gases and alternative multi-gas control

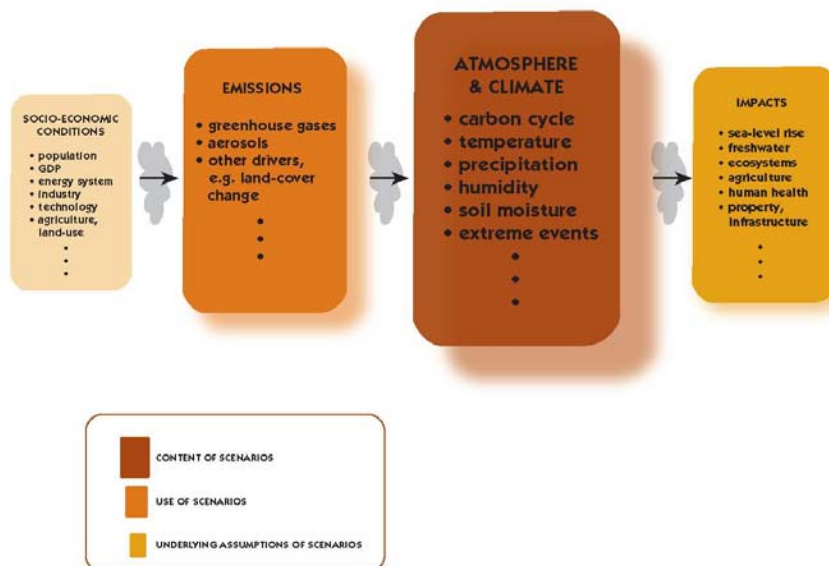
³⁹ Wigley, Richels, and Edmonds 1997.

⁴⁰ 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.

1 strategies, in pursuing atmospheric stabilization. These scenarios may also provide a basis for
 2 future analyses by the CCSP, the Climate Change Technology Program (CCTP), or others.⁴¹

3 **2.3. Climate Change Scenarios**

4 Climate scenarios describe potential future climate conditions. They are used to provide
 5 inputs to assessments of climate-change impacts, vulnerabilities, and associated options for
 6 adaptation, and to inform decision-making related to either adaptation or mitigation. Depending
 7 on their specific use, climate scenarios may include multiple variables, such as temperature,
 8 precipitation, cloudiness, humidity, and winds. They may describe these at spatial scales ranging
 9 from the entire globe, through broad latitude bands, large continental and sub-continental
 10 regions, to climate model grid-cells or finer scales. They may project these at time resolutions
 11 ranging from annual or seasonal averages to daily or even finer-scale weather.⁴²



12

13 **Fig 2.5: Climate-Change Scenarios**

14 Three major types of climate scenarios are distinguished by how they are produced:
 15 incremental scenarios, analog scenarios, and climate-model scenarios.⁴³ Incremental scenarios
 16 change current conditions by plausible but arbitrary amounts. For example, a region's
 17 temperature might be warmed by 2, 3, or 4°C from present conditions, or its precipitation
 18 increased or decreased by 5, 10, or 20 percent. Such adjustments can be made to annual or
 19 seasonal averages, to finer-period measurements of current conditions, or to the variability of
 20 temperature or precipitation over days, months, or years.⁴⁴ Like the simple emissions scenarios
 21 used for climate-model comparisons, incremental climate scenarios are simple to produce but

⁴¹ CCSP Synthesis and Assessment Product 2.1a.

⁴² IPCC – TGCIA 1999; Barrow et al, 2004..

⁴³ Mearns et al 2001.

⁴⁴ e.g., Mearns et al 1992, 1996; Semenov and Porter 1995.

1 make no claim to represent actual future conditions. They are used for initial exploratory studies
2 of climate impacts and to test the sensitivity of impact models.

3 Analog climate scenarios represent potential future climates by the observed climate
4 regime at another place or time. A spatial analog imposes the climate of one location on another,
5 e.g., representing the potential climate of New York in the 2050s by that of Atlanta today or that
6 of Illinois in the 2050s by that of Kansas today.⁴⁵ A temporal analog imposes climate conditions
7 observed in the past, in the historical record or earlier paleoclimatic observations, e.g., using the
8 hot, dry period of the 1930s to study impacts of potential future hot, dry climates.⁴⁶ Like
9 incremental scenarios, analog climate scenarios are more useful for exploratory studies of the
10 climate sensitivity of particular resources or systems than for projecting likely impacts. While
11 they represent climate states that are known to be physically possible, they are limited as
12 representations of potential future states since they do not consider the changes in greenhouse-
13 gas concentrations that are the principal driver of climate change.

14 Climate-model scenarios use computers to produce a physically consistent representation
15 of the movement of air, water, energy, and radiation through the atmosphere. Climate models,
16 also called General Circulation Models or GCMs, approximate this calculation by dividing the
17 atmosphere into thousands of grid-cells, roughly 150 sq km in today's models, with a dozen
18 vertical layers, treating conditions as uniform within each cell and representing finer-scale
19 processes by numerical relationships, called "parameterizations," that are defined at the scale of
20 a grid cell. Climate models are used to study the present climate and its responses to past
21 perturbations like variation in the sun's output or volcanic eruptions, and to construct scenarios
22 of future climate change under any specified scenario of emissions and other disturbances.

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

36 Just as modeling future climate change requires specification of future emissions trends,
37 assessments of future climate-change impacts require specification of future climate change.
38 Data from a climate-change scenario might be used as input to impact assessments of freshwater
39 systems, agriculture, forests, or any other climate-sensitive system or activity. Impact studies

⁴⁵ e.g., Kalkstein 1992.

⁴⁶ e.g., Rosenberg et al, 1993.

1 can use various methods, including quantitative models such as hydrologic and crop models,
2 threshold analyses that examine qualitative disruptions in the behavior of climate-sensitive
3 systems, or expert judgments that integrate various pieces of scientific knowledge.

4 As with all scenarios, the usefulness of climate scenarios depends on how well they meet
5 users' information needs. The highly specific climate-data needs of impact analyses may not
6 readily be provided by climate-model outputs, or may include results of whose validity climate
7 modelers are not confident. For example, a common need of impact analyses is for data at
8 substantially finer scales than the relative coarse grid of a climate model, which might have only
9 60 to 100 cells over the continental United States. One advantage of incremental and analog
10 scenarios is that they can typically provide data at substantially finer scales. "Downscaling"
11 techniques seek the benefits of model-based scenarios – physical realism and explicit emissions-
12 scenario drivers – and data at finer scales. The two major approaches are statistical downscaling
13 and nested regional modeling.⁴⁷ Statistical downscaling involves estimating statistical
14 relationships between large-scale variables of observed climate, such as regional-average
15 temperature, and local variables such as site-specific temperature and precipitation.⁴⁸ These
16 relationships are then assumed to remain constant under global climate change. A nested
17 regional climate model provides an explicit physical representation of climate for a specific
18 region, including local factors such as mountain ranges, complex coastlines, and surface
19 vegetation patterns, with initial and boundary conditions provided by a GCM. Regional climate
20 models can provide projections at scales as small as 10 to 20 km. Although downscaled results
21 are anchored to local features with well-understood climatic effects, downscaling introduces
22 uncertainties beyond those already present in climate-model results.⁴⁹

23 ***2.4. Scenarios of Direct Biophysical Impacts: Sea Level Rise***

24 Although climate-change scenarios can provide inputs to studies of any impact, scenarios
25 can also be constructed of particularly important forms of impact, such as sea level rise – one of
26 the more costly and certain consequences of climate warming.⁵⁰ Changes in global mean sea
27 level as the climate warms can be calculated using a GCM with a coupled ocean and atmosphere,
28 which can simulate the transfer of heat to the ocean and the variation of ocean temperature with
29 depth. To construct sea level rise scenarios for particular coastal locations, model-derived
30 projections of global mean sea level rise must be combined with projections of local subsidence
31 or uplift of coastal lands, as well as local tidal variations derived from historical tide-gauge data.

32 Sea level rise will increase circulation and change salinity regimes in estuaries, threaten
33 coastal wetlands, alter shorelines through increased erosion, and increase the intensity of coastal
34 flooding associated with normal tides and storm surge. Scenarios of sea level rise are
35 consequently needed to assess multiple linked impacts on coastal ecosystems and settlements. In
36 specific locations, these impacts will depend on many characteristics of coastal topography,

⁴⁷ Giorgi et al 2001.

⁴⁸ Wilby and Wigley 1997.

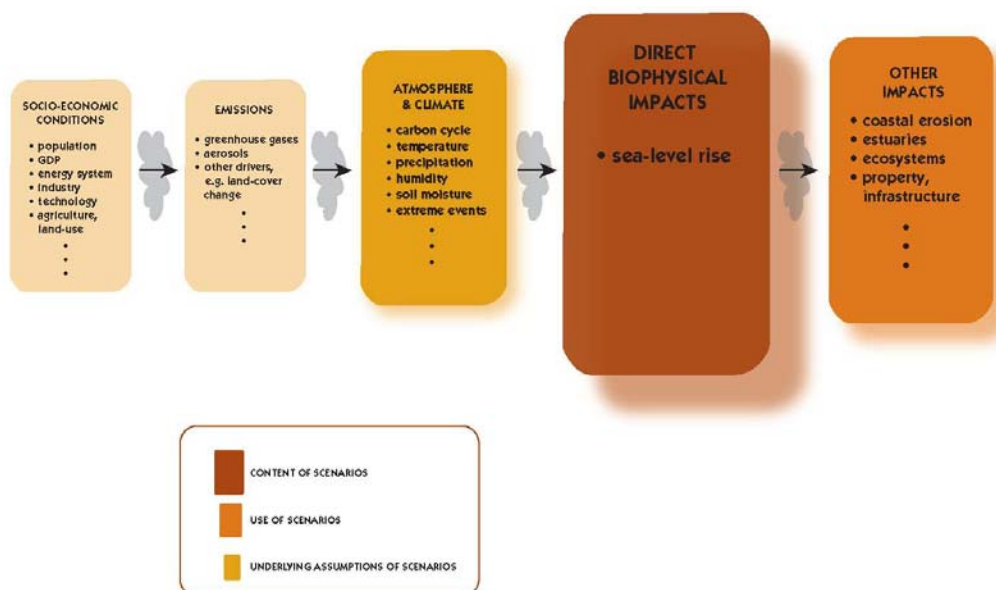
⁴⁹ Mearns et al 2001, Giorgi et al., 2001.

⁵⁰ IPCCa 2001.

1 ecosystems, and land use – e.g., coastal elevation and slope, rate of shoreline erosion or
 2 accretion, tide range, wave height, local land use and coastal protection, salinity tolerance of
 3 coastal plant communities, etc. – in addition to local sea level rise.⁵¹

4 In addition to its gradual impacts, sea level rise is subject to large uncertainties from the
 5 potential loss of continental ice sheets in Greenland and West Antarctica. The consequences of
 6 these events for global sea level rise are well known because they can be calculated quite
 7 precisely from the volume of the ice sheets – roughly 7 meters rise from complete loss of the
 8 West Antarctic Ice Sheet and 5 meters from Greenland – but the probabilities of these events and
 9 their likely speed of occurrence are both highly uncertain. One recent study has suggested a
 10 probability of a few per cent that the West Antarctic Ice Sheet will contribute an additional one
 11 meter per century beyond that calculated from gradual warming.⁵²

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

16 There are several reasons to call out sea level rise from other climate-change impacts to
 17 be represented in separate scenarios. First, sea level rise is a powerful driver of other forms of
 18 climate-change impact, probably the most important driver of impacts in coastal regions. Since
 19 it is a direct physical impact of climate change that can be described precisely and compactly, a
 20 sea level rise scenario is an efficient way to transmit the most important information about
 21 climate change to coastal impact assessments. Moreover, since sea level rise does not depend on
 22 socio-economic processes and cannot be significantly influenced by human actions (other than
 23 by limiting climate change itself), it may be reasonably to treated as exogenous for purposes of

⁵¹ Burkett et al. *In Press*.

⁵² Vaughan and Spouge 2002.

1 impact assessment. For all these reasons, sea level rise is a good proxy for the most important
2 causal routes by which climate change will affect coastal regions.

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

10 ***2.5. Multivariate Scenarios for Assessing Impacts, Adaptation, and Vulnerability***

11 Many potentially important impacts of climate change cannot be adequately assessed by
12 considering only how the climate might change. These impacts require multivariate scenarios
13 that include climate change and other characteristics likely to influence impacts. This is the case,
14 for different reasons, for both ecosystems and socio-economic systems, although the nature of
15 the multivariate scenarios that are required – i.e., the number and identity of the characteristics
16 that must be specified – will vary widely among particular impacts.

17 Ecosystems are affected by climate change, but also by many other changes in
18 environmental conditions that are influenced by human activities, such as nitrogen and sulfur
19 deposition, tropospheric ozone and smog, and changes in erosion, runoff, loadings of other
20 pollutants, land use, land cover, and coastal-zone characteristics. Consequently, realistic
21 assessments of potential future impacts on ecosystems require specifying the most important
22 forms of human-driven stresses jointly, not just climate.⁵³

23 In addition, many important forms of climate-change impact depend not just on climate
24 change, its direct biophysical impacts such as sea level rise, and perhaps other forms of
25 environmental stress, but also on the nature of the society on which these climate and other
26 environmental changes are imposed – e.g., how many people there are; where and how they live;
27 how wealthy they are; how they gain their livelihoods; and what types of infrastructure,
28 institutions, and policies they have in place.⁵⁴

29 Assessment of climate impact on ecosystems that are intensively managed for human use,
30 such as agriculture, managed forests, rangelands, and hydrologic systems, must consider human
31 management as a factor in impacts. The non-climatic factors that influence these management
32 decisions – e.g., changes in market conditions, technologies, or cultural practices – must be
33 considered for inclusion in scenarios if they are sufficiently important in mediating climate
34 impacts.

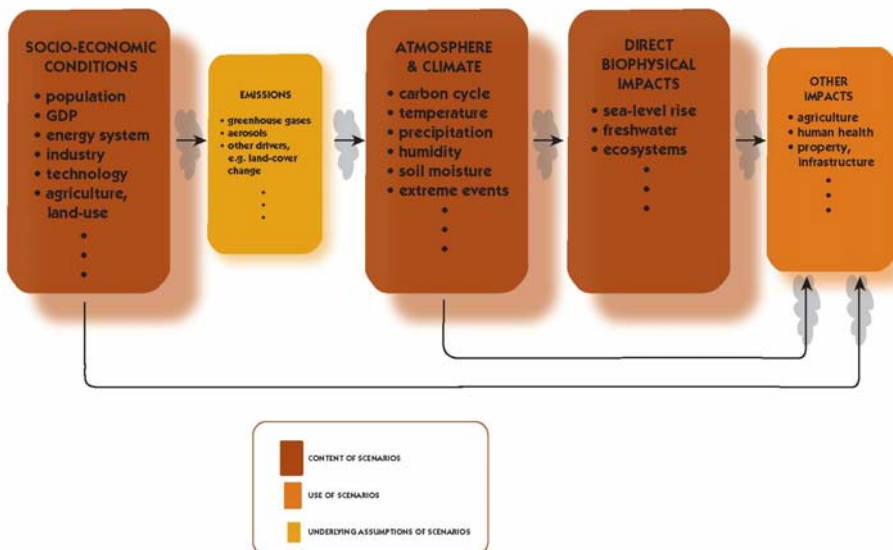
35 In other domains, socio-economic factors can mediate climate impacts by influencing
36 vulnerability and adaptive capacity. No general model of the socio-economic determinants of
37 adaptive capacity exists. Important factors are likely to vary across specific types of impact,

⁵³ Millennium Ecosystem Assessment 2005.

⁵⁴ Parson et al 2001, 2003. Arnell et al 2004.

1 locations, and cultures, and may include many demographic, economic, technological,
 2 institutional, and cultural characteristics.

3



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6 **Figure 2.6: Multivariate Scenarios for Impact Assessment**

7 Some socio-economic characteristics that are likely to be relevant for many impact
 8 assessments – e.g., the size and sometimes the age structure of population, the size and
 9 sometimes the sector mix of GDP – are normally generated in the course of producing emissions
 10 scenarios. Consequently, when current emissions scenarios exist for the region for which an
 11 impact assessment is being conducted, it makes sense to strive for consistency with them.⁵⁵
 12 Even for these variables, however, there may be significant problems of incompatible spatial
 13 scale. Impact assessments often examine smaller spatial scales than emissions projections, so
 14 may need these socio-economic data at finer scale than is available. Downscaling future socio-
 15 economic projections has proved challenging thus far. There is no generally accepted method
 16 for doing so, and several research groups are exploring development of alternative methods.⁵⁶

17 In contrast to the few clearly identified aggregate characteristics needed to construct
 18 emissions scenarios, the socio-economic factors that most strongly shape adaptive capacity and
 19 vulnerability for particular impacts may be detailed, subtle, and location-specific. It may not
 20 even be clear what characteristics are most important before doing a comprehensive analysis of
 21 potential causal pathways shaping impacts. The most important characteristics may interact
 22 strongly with each other or with other economic or social trends, or may not be readily
 23 quantifiable. All these factors make the development of socio-economic scenarios for impact
 24 assessment a much more difficult endeavor than constructing emissions scenarios.

⁵⁵ Berkhout et al 2001, citing UNEP 1994 guidelines.

⁵⁶ Toth and Wilbanks 2004. Pitcher 2005.

1 Because scenarios are schematic, not all factors that might be important for impacts can
2 be included. Details are typically not included or treated as merely illustrative. But particular
3 details, which cannot be identified in advance, may be crucial determinants of vulnerability to
4 climate impacts.⁵⁷ Impact assessments have responded to this dilemma in two broad ways.⁵⁸
5 First, constructing scenarios of relevant socio-economic conditions has been delegated to local or
6 regional teams with expertise in the impacts being assessed, subject to constraints to maintain
7 consistency with other assessments. Second, since local or regional scenario groups may not
8 have access to all knowledge relevant to understanding the main determinants of impacts, more
9 open-ended approaches have been employed – e.g., exploratory analyses that iterate between
10 considering particular characteristics that might be important, examining their implications for
11 impacts using the data and models available, then re-assessing what variables are most
12 important.

13 This section has sketched a typology of global-change scenarios, and identified major
14 types of decision-makers who might use global-change scenario-based information. The next
15 section turns to current experience with global-change scenarios, summarizing the development,
16 contents, and uses of four major exercises. Informed by these cases plus additional short
17 scenario examples presented in text boxes, Section 4 will summarize and discuss the major
18 challenges for making and using scenarios that are raised by this experience, providing the basis
19 for the conclusions and recommendations presented in Section 5.

20

⁵⁷ Berkhout et al 2002.

⁵⁸ Berkhout et al 2001; Parson et al 2001.

1 **3. Review of Major Climate-Change Scenario Exercises**

2 In this section, we review experience to date developing and using scenarios for global
 3 climate change applications. Because little literature on these activities yet exists, our selection
 4 of cases has inevitably been both limited by time and resources at our disposal, and reliant in part
 5 on the knowledge and experience of team members. We discuss four exercises in detail, in an
 6 attempt to cover the largest-scale and most important activities. Section 3.1 reviews the IPCC
 7 emission scenarios, with particular detail on the most recent and important exercise, the *Special*
 8 *Report on Emissions Scenarios* (SRES). Section 3.2 considers the US National Assessment,
 9 which developed and used scenarios of climate and socio-economic conditions. Section 3.3
 10 considers the UK Climate Impacts Program, which has also both developed and used scenarios,
 11 following a different approach from the US National Assessment. Section 3.4 reviews the
 12 ambitious scenario-generating exercise conducted as part of the Millennium Ecosystem
 13 Assessment, in which climate change was one of several dimensions of stress considered on
 14 global ecosystems.

15 For each exercise, we consider only the development and use of scenarios, rather than
 16 examining the larger assessment processes of which the scenarios were part. We consider how
 17 the scenarios were developed, including both methods of reasoning and managerial process; how
 18 and by whom they were used; and subsequent evaluations, when these are available. General
 19 issues and challenges that emerge from these experiences are discussed in Section 4.

20 To provide more illustrative variation, we also provide shorter summaries of eight
 21 additional scenario activities, some of them related to the four we consider in detail. Presented in
 22 text boxes throughout Section 4, these are intended to provide additional information to highlight
 23 particular issues. We have particularly sought experiences that illuminate potential relationships
 24 between scenarios and decision-making.

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

28 **3.1. IPCC Emissions Scenarios**

29 Since its establishment in 1989, the IPCC has organized three exercises to develop scenarios of
 30 greenhouse-gas emissions, of increasing scale and complexity. For its first report, IPCC's
 31 Working Group 3 on "Response Strategies" included a sub-group on emissions scenarios. Four
 32 scenarios were produced but little used in this assessment because of time limits and because,
 33 with one exception, only doubled-CO₂ equilibrium climate-model runs were available at the
 34 time.⁵⁹ The next exercise produced six new scenarios, called IS92a through IS92f. These were
 35 the first global emissions scenarios with a full suite of greenhouse gases and at least some
 36 explicit calculation underlying each. The IS92a scenario, one of the central scenarios in this
 37
 38

⁵⁹ The scenarios were mentioned in a 1-page Appendix to the Working Group 1 report. The one non-equilibrium run available was a preliminary transient run using 1% annual CO₂ concentration increase. See Mitchell et al (1990) and Bretherton et al (1990), both in Houghton, Jenkins, and Ephraums (1990).

1 group, was used in climate-model comparisons conducted for the 1996 IPCC assessment, along
2 with the simpler transient scenario of 1 percent annual increase in equivalent-CO₂ concentration
3 and further equilibrium runs.⁶⁰
4

5 The third and most ambitious IPCC scenario process was established in 1997, and
6 worked for two years to produce the *Special Report on Emissions Scenarios* (SRES).⁶¹ In part,
7 this process was established in response to two widely circulated criticisms of the IS92 scenarios.
8 The first of these criticized the 1992 scenarios for inconsistency with other published scenarios
9 of energy and carbon intensity for major world regions; failing to reflect important recent trends,
10 including the collapse of the Soviet Union and increasing restrictions on sulfur emissions
11 worldwide; relying inappropriately on a single model; and only being useful as climate-model
12 inputs, not for other purposes such as mitigation studies or supporting climate-change
13 negotiations.⁶² The second criticized the IS92a scenario for assuming increasing divergence in
14 the per capita emissions of industrialized and developing regions, arguing that this represented a
15 strong bias in favor of already developed regions.⁶³

16 In response, the 1996 plenary session of the IPCC requested a new set of emissions
17 scenarios. These new scenarios were to improve treatment of sulfur aerosols and emissions from
18 land-use change, and were not to rely on a single model or expert team, but instead to draw on
19 the existing literature and invite any group with relevant expertise to participate in an “open
20 process.”⁶⁴ They were also charged to serve more uses than climate-model inputs, such as
21 supporting impact analyses, but to assume no new climate-policy interventions. Although not
22 explicitly in the terms of reference, it was also clearly understood that the scenarios would
23 address the criticism of the IS92 scenarios by focusing on convergent development paths
24 between North and South.

25 In January 1997 the IPCC established a writing team, including members of several
26 energy-economic modeling groups and experts in related areas such as population, technological
27 change, and scenario development methods. The process ran under tight time pressure to
28 provide preliminary scenarios by early 1998 for climate-model runs in the IPCC Third
29 Assessment.

30 Prior scenarios were compiled in a web-based database,⁶⁵ and any researcher was invited
31 to submit new ones. By mid-1998 the database contained more than 400 scenarios. Most of
32 these projected only energy-related CO₂ emissions, but they were highly diverse in their
33 coverage and resolution, the variables included, and their methodologies. The usefulness of
34 these scenarios in constructing new ones was limited by several weaknesses, however. Many

⁶⁰ 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.

⁶¹ Nakicenovic *et al*, 2000.

⁶² 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.

⁶³ Parikh 1992.

⁶⁴ SRES report Terms of Reference, Appendix I, p. 324.

⁶⁵ Morita and Lee 1998, cited SRES p. 79.

1 were incomplete, lacked documentation of inputs, or made inconsistent assumptions. Few
2 included sulfur or land-use emissions, which were specifically requested of the new scenarios.
3 Many were unclear on whether they assumed mitigation efforts, while the new scenarios were
4 instructed to exclude them. Consequently, the development of new scenarios had to proceed
5 largely independently of the collection of existing scenarios through the literature review and
6 open process.

7 Early on, participants decided to use narrative scenarios in addition to quantitative
8 models, and to include experts in this approach on the writing team. This decision drew on
9 recent successes using such scenarios for energy and environmental applications,⁶⁶ and
10 responded to the charge to make the scenarios more integrated and more broadly useful.
11 Participants in an April 1997 workshop chose two key uncertainties to explore in the scenarios:
12 whether world values would mainly stress economic prosperity or balance economic and
13 ecological concerns (labeled “A” vs. “B” scenarios); and whether the organization of economies
14 and institutions would continue shifting toward global integration, or reverse and move toward
15 regional fragmentation (labeled “1” vs. “2” scenarios).⁶⁷

16 Combined, these gave four scenarios, which were sketched in preliminary terms at the
17 workshop. In the A1 (economic, global) scenario, economic growth and inter-regional income
18 convergence continue strongly worldwide – all developing countries grow like Japan and Korea
19 from the 1950s to the 1980s – while world population peaks at 9 billion by 2050. Rapid
20 innovation yields many advanced energy sources, while acid rain and other local and regional
21 environmental problems are aggressively controlled. In contrast, the A2 (economic, regional)
22 scenario has higher population growth, lower economic growth with more continuing regional
23 disparities, slower innovation, and weaker international institutions. B1 (ecological, global) has
24 low population growth, moderate economic growth with strong convergence, and strong
25 reductions in per capita energy use, mostly through higher efficiency, while B2 has intermediate
26 population growth, low economic growth with weaker convergence, and moderate improvements
27 in energy efficiency and development of non-carbon energy sources.⁶⁸ The storylines were
28 elaborated in short text descriptions with some preliminary numbers attached in Fall 1997.⁶⁹

29 Modeling teams were asked to produce initial quantifications of these scenarios in fall
30 1997, to match specified 2100 target values within 10 percent. In February 1998, the preliminary
31 quantitative targets were re-confirmed and modelers asked to continue work on quantifications,
32 now including a breakdown of economic output into four world regions.⁷⁰ In April, one model’s
33 quantification was chosen as a “marker scenario” for each of the four scenarios – a particular
34 scenario that would provide the basis for interim reporting to climate modelers, some of whose
35 results other participating models would be asked to replicate.

⁶⁶ E.g., the IEC and WBCSD scenario exercises.

⁶⁷ Minutes, Lead Authors Meeting, Paris, 13-15 April, 1997.

⁶⁸ Arnell et al 2004. Minutes, Lead Authors Meeting, Paris, 13-15 April, 1997.

⁶⁹ Minutes, informal modelers meeting, Berkeley, Feb 7-8.

⁷⁰ Draft minutes, Berkeley meeting, Pg 4.

1 **Table 3.1.1 Target Values for 2100 in Initial Scenario Quantifications**
 2

SCENARIO	A1B	A2	B1	B2
Population	7.1	15.1	7.1	10.4
GDP (trillion)	\$530	\$250	\$340	\$235
Final Energy (EJ)	~1,700	870	770	950
Model for Marker scenario	AIM	ASF	IMAGE	MESSAGE

3
 4 Source: Minutes of Laxenburg meeting, 2-3 July 1998.

5 These interim marker scenarios were used to provide emissions scenarios to climate
 6 models participating in the IPCC third assessment. An IPCC climate modelers' meeting in June
 7 1998 agreed to use SRES scenarios and asked for three cases, central emissions, stabilization,
 8 and high emissions.⁷¹ The writing team initially discussed meeting this request by identifying
 9 scenarios corresponding to each of these requested cases,⁷² but decided to provide only the
 10 marker scenarios and recommend that all four be used without identifying any as "central."

11 The marker scenarios also provided the basis for coordination of subsequent scenario
 12 development. Up to this point, there had been substantial discrepancy between different models'
 13 quantifications of the same scenarios, particularly at regional level. With the adoption of the
 14 markers, other groups were asked to replicate (within 5 – 10 percent) the marker results on
 15 population, GDP, and final energy for the four world regions, for 2100 and several interim
 16 years.⁷³ Achieving this requested replication posed significant challenges for modelers.⁷⁴

17 With a further year of work, modeling teams produced a total of 40 scenarios that were
 18 retained in the report, of which 26 replicated one of the marker scenarios. Although a few of the
 19 14 non-replicates reflected a model's inability to match the results of a marker scenario, most
 20 were produced because a modeling team intentionally sought to explore alternative assumptions.
 21 For example, the A1 scenario, which originally balanced fossil and non-fossil energy sources,
 22 was augmented by variants with different assumptions about fossil resources and non-fossil
 23 technology development, giving widely divergent emissions paths stressing coal, gas, and non-
 24 fossil energy technology. Modifications of the scenario set continued until late in the process.
 25 For example, it was decided in October 1998 to drop several B variants with explicit mitigation,

⁷¹ Laxenburg minutes report results of IPCC Scoping Meeting, Bonn, 29 June – 1 July 98.

⁷² 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 SO₂ profiles), and B1 or an A1 variant called AIR a stabilization case (at about 550 ppm) (Laxenburg July 1998 report, pg 1).

⁷³ Because markers were produced by different models with different time steps, the interim years to be harmonized differed for each scenario.

⁷⁴ 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).

1 including one stabilization scenario.⁷⁵ At the final IPCC approval meeting, it was decided at the
2 request of the Saudi delegation to reduce the two fossil-intensive variants of A1 to one, a variant
3 of the gas-intensive scenario which was renamed A1FI (for “fossil-intensive”).⁷⁶

4 *Significance and Use*

5 The SRES scenarios have been the most comprehensive, ambitious, and carefully
6 documented emissions scenarios produced to date. They represented a substantial advance from
7 prior scenarios, and contributed to assessments and subsequent research on climate impacts and
8 responses. The SRES scenarios formed the basis for climate-model comparisons in the IPCC
9 Third Assessment (2001) and continuing work in the Fourth Assessment. Most subsequent
10 climate-model work has used only a few of the marker scenarios – typically A2 and B2,
11 sometimes with A1B added. SRES scenarios also provided baselines for analysis of mitigation
12 scenarios in the Third assessment.⁷⁷

13 Several significant insights were illuminated by the SRES scenarios.

- 14 ■ Scenarios with similar emissions in 2100 can follow markedly different paths in the
15 interim, giving wide differences in cumulative emissions and concentrations.
- 16 ■ Technology and energy-resource assumptions can strongly perturb future emissions,
17 even with constant socio-economic assumptions. For example, the three A1 variants
18 show that changing these assumptions alone can generate as wide a range of
19 emissions futures as substantial variation of demographic and economic futures.
- 20 ■ Highly distinct combinations of demographic, socio-economic, and energy-market
21 conditions can produce similar emissions trajectories, suggesting that a particular
22 emissions trajectory can pose very different types of mitigation problems, depending
23 on what combination of driving factors underlies the emissions.

24 *Criticisms and Controversies*

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

28 *Assigning Explicit Probabilities*

29 The SRES team decided at the outset to make no probabilistic statements about the
30 scenarios. Their report used great care in its language to avoid any suggestion that one scenario

⁷⁵ 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).

⁷⁶ A1FI was the gas-intensive scenario, A1G, with revisions to methane emissions and additional non-CO₂ gases added from the A1 run of the MESSAGE model.

⁷⁷ Morita and Robinson, 2001 (WG3, TAR)

1 might be more central or more likely than any other.⁷⁸ This decision was consistent both with
2 standard practice in developing narrative scenarios, and with the instruction in their terms of
3 reference not to favor any model.⁷⁹

4 They were sharply criticized for this decision.⁸⁰ Critics argued that there were no
5 technical obstacles to assigning probabilities to emissions ranges bounded by the marker
6 scenarios; that scenario developers must have made probabilistic judgments in generating and
7 evaluating the scenario quantifications and that not making these judgments explicit would
8 withhold relevant information; and that if scenario developers decline to assign probabilities,
9 others who are less informed will do so. Indeed, many probabilistic emissions calculations have
10 been produced since the SRES, using various methods such as assigning uniform or other
11 specified distributions over the emissions range of the marker scenarios, counting scenarios lying
12 in specified intervals in the larger SRES set, unbundling and recombining alternative values of
13 the drivers underlying SRES emissions figures, or sampling over parameter distributions within a
14 single model. In response to these criticisms, SRES authors argued that attempting to assign
15 probabilities to scenarios would require assigning joint distributions to the underlying driving
16 factors, and that this would lead to an explosion of combinatoric possibilities over which any
17 attempt to assign probabilities would be spurious and arbitrary.⁸¹

18 The situation of the SRES scenarios is in fact more nuanced than the arguments of either
19 their authors or critics would suggest. It may well be unhelpful to assign probabilities to rich,
20 multidimensional narrative scenarios, yet still useful to assign interval probabilities when
21 scenarios principally represent uncertainty in one or two quantitative variables. And while the
22 SRES scenarios began their lives like the former type of storyline scenario, they finished more
23 like the latter. For many users, the scenarios *are* their projections of greenhouse-gas emission
24 trends. When they are viewed in this way, a potential user may reasonably ask, how likely are
25 emissions to be higher than this – a distinct and better-posed question than, what is the
26 probability of an A1 world? The uncertainty issue has no clear resolution in this case, and poses
27 hard design problem for scenarios and assessments more broadly. Although the SRES exercise
28 has raised this controversy most explicitly to date, the problem is a general one that any scenario
29 exercise must confront. We discuss it further in section 4.6.

30 *Exchange Rates: PPP versus MER*

31 The most prominently publicized criticism of SRES focused on the fact that all but one of
32 the participating models compared GDP across regions using market exchange rates (MER),
33 instead of the more correct purchasing-power parity (PPP) approach. PPP comparisons correct
34 for price differences among countries, providing a more accurate comparison of real incomes.
35 Because lower-income countries have lower price levels, MER-based comparisons overstate the
36 income gap between rich and poor countries.

⁷⁸ E.g., Minutes of London meeting, March 1999.

⁷⁹ Washington DC (April 29-30 1998), draft minutes, pg. 6.

⁸⁰ Schneider 2001, Pittock et al 2001.

⁸¹ Grubler and Nakicenovic, 2001.

1 In a series of letters to the IPCC chairman and several subsequent publications, two
2 critics argued that the use of MER caused SRES scenarios to over-estimate future income growth
3 in developing countries (because they over-estimated the initial income gap), and consequently
4 to over-estimate future emissions growth. Their criticism was widely circulated and repeated by
5 prominent climate-change skeptics.⁸²

6 But while using MER does overstate future income growth, it does not necessarily follow
7 that future projections of emissions growth are also overstated. MER is universally recognized
8 as a flawed measure of income, whose use in global-change scenarios is only justified by better
9 availability of current and historical data, and the fact that international emissions trades in any
10 future mitigation regime will likely be made at market exchange rates. But changing the
11 measure of income also changes the relationship between income and such physical quantities as
12 energy and food consumption, which determine emissions. Consequently, while MER overstates
13 future income growth in poor countries, it also overstates future reductions in energy and
14 emissions intensity. These opposing errors are likely to be similar in size, in which case any
15 error in emissions projections from using MER will be small.⁸³

16 A related, more serious concern is that in response to criticisms that the IS92 scenarios
17 were biased to favor the North, all SRES scenarios assumed varying degrees of real income
18 convergence between North and South. But an exercise to construct potential climate-change
19 futures may need to consider less optimistic and less desirable futures in which some currently
20 poor regions fail to solve the development problem. Not considering less fortunate futures,
21 including ones that might challenge the adequacy of current responses, institutions, and decision-
22 making capacity, may limit scenarios' usefulness in supporting long-term risk assessment and
23 planning for the societal response to climate change.

24 *Under-Development of Narrative Scenarios*

25 Although the SRES storylines were produced first and featured prominently in
26 publications, they remained underdeveloped and underused throughout the process. In part due
27 to time pressure, in part due to the predominance of quantitative modelers in the process, little
28 attention was given to further development of the storylines once initial quantifications were
29 established and modeling work began. Nor was significant effort devoted to integration and
30 cross-checking between storylines and quantitative scenarios, although a major purpose of the
31 narratives was to give coherent structure to quantifications.⁸⁴ Concerns raised about the
32 storylines included lacking specification of characteristics other than those needed to generate
33 emissions; imbalance between the storylines, with A1 much more developed than the others and
34 B2, the least developed, likely to be heavily used as the median scenario for emissions; apparent
35 inconsistencies within A2; and lack of clarity regarding the distinctions between A2 and B2 – a
36 serious enough concern that merging them was repeatedly considered until late in the process.⁸⁵

⁸² Castles and Henderson, 2003a, 2003b; the Economist, 2003a, 2003b; Michaels, 2003.

⁸³ Nakicenovic et al, 2003; McKibben et al, 2004; Holtmark and Alfsen, 2005; Manne and Richels, 2005; Grubler et al, 2004.

⁸⁴ Beijing minutes, pg 10.

⁸⁵ Bilthoven draft minutes, p. 7-8; Berkeley draft minutes, pg. 6; DC draft minutes.

1 Moreover, participants disagreed over the meaning of some of the scenarios, as indicated
2 by the persistent difficulty they had in agreeing on descriptive names.⁸⁶ These names were
3 dropped late in the project, in the context of a broad retreat from attempting to flesh out the
4 storylines. That so little integration of qualitative and quantitative components was achieved in
5 spite of serious and persistent efforts suggests the magnitude of the analytical and
6 methodological challenges involved.

7 *Harmonizing Scenarios, Interpreting the Results*

8 Scenario exercise that use multiple models can coordinate them in several ways:
9 choosing one or a few illustrative scenarios as coordinating devices for subsequent analyses, as
10 was done with the SRES marker scenarios; fixing values of a small set of exogenous inputs to
11 multiple models, to characterize resultant uncertainties and examine their origins through
12 focused model intercomparisons; or fixing key outputs as targets, to reason backwards and
13 examine requirements for achieving them.

14 Choosing a few quantitative variables as the initial link between storylines and models
15 makes these variables serve as a framework to capture the storylines' basic logical structure.
16 Although these choices are not obvious, the variables chosen here appear reasonable. But the
17 causal structure of a model will not generally mirror the presumed causal logic of a narrative, so
18 a model cannot be expected to calculate values for other variables that flesh out the storyline
19 logic. Moreover, the few key variables so chosen may not be exogenous inputs for every model
20 used in the subsequent quantification. Of the three variables specified in the SRES process, only
21 population was exogenous for all participating models. Because GDP and final energy were
22 endogenous for some or all participating models, matching their specified values required
23 manipulating other internal model characteristics. Once one model run was chosen as the marker
24 for each scenario, subsequent attempts by other models to replicate the results posed the same
25 problem more acutely, since more outputs were specified at this point.

26 The problems associated with attempting to harmonize model outputs are related to the
27 under-development of narrative scenarios and limited integration of qualitative and quantitative
28 components. The storylines were associated with relatively restrictive numerical targets even
29 though the storylines did not develop the richness or coherence that would carry implications for
30 additional characteristics. The preliminary targets were only slightly modified throughout the
31 project, despite subsequent discovery of significant problems. For example, the UN 1998
32 population projections, with substantial reductions in projected fertility, were completed while
33 the scenario development work was underway but not incorporated.⁸⁷

34 *Clarity about Uses, involving Users:*

⁸⁶ 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.

⁸⁷ Bilthoven minutes, p. 11.

1 The SRES scenarios were charged with serving other uses beyond driving climate
2 models, but given little guidance on what specific additional uses or users to serve, or how the
3 scenarios might best serve them, neither of which is obvious.⁸⁸ Providing climate-model inputs
4 remained the most prominent and most clearly specified use, as well as the only use that had an
5 early deadline. But climate modelers were not involved in the scenario development process,
6 and their needs and SRES capabilities diverged. A September 1997 briefing identified the
7 principal needs of climate modelers as haste and greater emissions detail.⁸⁹ They wanted
8 separate emissions trajectories for major greenhouse gases, not just CO₂-equivalent, including
9 regional detail for some emissions such as sulfur – even suggesting that it would be desirable to
10 have sulfur emissions disaggregated by stack height, to distinguish dispersed emissions from
11 large point sources. Although SRES provided gridded sulfur data by post-processing model
12 outputs, in most cases the emissions included and their spatial detail (not to mention stack
13 height) were limited by the capabilities and structures of participating models.

14 Representatives of other potential uses were even less involved in the process.
15 Supporting assessment of mitigation strategies was largely deferred to the post-SRES scenarios
16 prepared for the IPCC Third Assessment Report, although ambiguity about the degree of
17 mitigation effort implied by some SRES scenarios complicated that task. Impact and
18 vulnerability assessments depend on diverse small-scale socio-economic and ecological factors
19 that a global exercise centered on energy-economic models cannot provide.⁹⁰ For the population
20 and economic projections that were provided in the course of generating emissions scenarios, the
21 key issue for impacts and adaptation was the degree of spatial detail provided. For consistency
22 among scenarios, and to avoid base-year discrepancies with national and regional datasets, SRES
23 scenario results were reported only for four large world regions. Greater regional detail was
24 available from individual models, but with inconsistent regional boundaries. Providing the
25 greater regional detail desired for impact assessments would generate discrepancies between the
26 global-model results represented in scenarios and the more detailed data and projections
27 available at national and regional levels.⁹¹ Developing valid methods to downscale socio-
28 economic scenario information and integrate it with national and regional datasets remains a key
29 challenge for producing useful scenarios for impact assessment.⁹²

30 In sum, the SRES experience raised four issues of greatest significance for subsequent
31 attempts to develop more useful climate-change scenarios: methods for developing and using
32 narrative scenarios and integrating them with quantitative model results; the desirability of and
33 appropriate methods for characterizing probabilities associated with scenarios; alternative modes
34 for coordinating use of multiple models and their implications for the interpretation and use of
35 scenarios; and relationship between scenario exercises and their users, including the need for
36 clarity about specific intended uses, appropriate methods for engaging users in scenario

⁸⁸ Alcamo et al, 1995.

⁸⁹ Bilthoven draft minutes, p. 5.

⁹⁰ See, e.g., discussion with Mike Hulme on behalf of TGICA, DC draft minutes, April 1998, pg. 9.

⁹¹ January 1998, meeting with Richard Moss, WG2 Technical Support Unit, in Berkeley minutes.

⁹² Pitcher 2005.

1 development, and how to improve utility of scenarios when not all potential user groups are
2 specifically identified. These are discussed in Sections 4 and 5.

3 ***3.2. The US National Assessment***

4 The U.S. National Assessment was the most comprehensive attempt to date to assess
5 climate impacts on the United States over the 25-year and 100-year horizons, and to consider
6 both major sub-national regions and sectors.⁹³ Responding to a requirement in the 1990 Global
7 Change Research Act, the National Assessment was organized by federal agencies participating
8 in the U.S. Global Change Research Program. Work began in 1997, with various components
9 completed between 1999 and 2003. Regional impacts were initially considered in 20 regional
10 workshops, followed by more extended analyses of impacts, leading to published assessments for
11 12 regions, conducted by university-based teams. Sectoral impacts were examined by national
12 teams focusing on agriculture, water, human health, coastal areas and marine resources, and
13 forests. A federal advisory committee, the National Assessment Synthesis Team (NAST),
14 provided direction for the assessment and synthesized its results in two published reports (NAST
15 2000, 2001). Roughly two thousand experts and stakeholders participated.

16 As an assessment focused on climate impacts, the National Assessment needed both
17 climate scenarios and scenarios of potential future socio-economic conditions over the 21st
18 century, since substantial changes are likely over this period in socio-economic conditions that
19 might influence vulnerability to climate and adaptive capacity.

20 ***Emission and Climate Scenarios***

21 For climate scenarios, the National Assessment relied predominantly on data and model
22 results previously produced. Study teams conducted additional checking, processing,
23 documentation, and dissemination as needed to make these usable. The assessment encouraged
24 the use of three types of climate scenarios: historical scenarios produced by extrapolating
25 observed trends or re-imposing historical climate variability or extremes; an inverse approach
26 using sensitivity analyses to explore the responses of climate-sensitive systems, with particular
27 emphasis on thresholds defining key vulnerabilities; and climate model simulations of future
28 climate conditions.⁹⁴

29 Of these three approaches, the climate-model scenarios were the most precisely specified
30 and the most widely used. The National Assessment did not have the resources or time to
31 commission new climate model runs, so had to rely on those completed and published when it
32 began its work. A set of criteria was developed by the NAST for the climate model scenarios to

⁹³ 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.

⁹⁴ NAST 2001, p. 25. Note that although it is arguable whether the inverse approach involves scenarios by the definition we have adopted here (because it does not stipulate specified future climate conditions, but attempts to identify them from presumed thresholds or breakpoints), we are following the usage of the NAST reports in calling these approaches three types of scenarios.

1 be used in the assessment. Climate-model scenarios used in the assessment should, to the greatest
2 extent possible.⁹⁵

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

19 To ensure timely dissemination, the National Assessment chose climate-model scenarios
20 to be used in its analyses in mid-1998. At that time, only two groups had completed runs that met
21 most of the key criteria: the UK Hadley Centre (Model Version 2) and the Canadian Centre for
22 Climate Modeling and Analysis (Model Version 1).⁹⁶ All participating regional and sector teams
23 were asked to use these scenarios. The climate sensitivity of these models was 2.5°C (UK
24 Hadley) and 3.6°C (Canadian), lying in the middle of the 1.7 to 4.2°C range of sensitivities
25 represented by models participating in the IPCC Third Assessment.⁹⁷

26 These two models were limited in their ability to reproduce observed patterns of inter-
27 annual and inter-decadal climate variability. But other climate-model runs available at the time
28 failed to meet essential requirements of the ecosystem models that were the basis for an
29 important part of the assessment: availability of documented results, projections to 2100,
30 standard/comparable emissions scenarios, and explicit treatment of the day-night cycle.

31 For these two climate models, model runs using only one emissions scenario were
32 available, and only one ensemble run was used for each.⁹⁸ The emissions scenario was IS92a,

⁹⁵ NAST 2001, p. 31-32; MacCracken et al, 2003, p. 1714.

⁹⁶ Johns et al. 1997; Boer et al. 1999a, 1999b; MacCracken et al. 2003.

⁹⁷ Cubasch and Meehl 2001, Table 9.1, pp. 538-540, and Table 9A.1, p. 577.

⁹⁸ 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.

1 which represented the middle of the range of IPCC's 1992 scenarios.⁹⁹ In addition to greenhouse
2 gases, the scenario included atmospheric loadings of sulfate aerosols (SO₄), which were assumed
3 to increase sharply through 2050 and then level off for the rest of the 21st century.¹⁰⁰

4 The applicability of these two scenarios was tested by checking the models' ability to
5 replicate broad patterns of US climate change over the 20th century when driven by historical
6 greenhouse-gas forcings. Model results were compared against the VEMAP (Vegetation-
7 Ecosystem Mapping and Analysis Project) dataset, a corrected climatic dataset for the 20th
8 century. This comparison showed reasonable accuracy in reproducing the spatial distribution of
9 average temperatures and century-long temperature trends, but significantly weaker reproduction
10 of observed patterns of precipitation, mainly because the spatial distribution of precipitation
11 depends on topographic detail too fine-scale to be captured even by the 0.5-degree VEMAP
12 grid.¹⁰¹

13 With the specified scenario of future emissions, the two climate-model scenarios
14 projected global warming by 2100 of 4.2°C (Canadian) and 2.6°C (Hadley).¹⁰² These
15 projections were at the high end and in the middle, respectively, of the range of warming
16 projected for this emissions scenario by models participating in the IPCC Third Assessment
17 Report.¹⁰³ For the continental United States, the two models projected warming by 2100 of
18 5.0°C (Canadian) and 2.6°C (Hadley), at the high end and below the middle, respectively, of the
19 range of projections in the IPCC Third Assessment.¹⁰⁴ In their projections of precipitation
20 change over the United States, these scenarios both lay at the high end – the Hadley scenario
21 projected the highest precipitation in 2100 and the Canadian the second-highest¹⁰⁵ – but the
22 Canadian model's greater warming offset the effect of this precipitation increase on soil
23 moisture, which was projected to decrease over most of the continental United States.¹⁰⁶

⁹⁹ 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.

¹⁰⁰ See www.usgcrp.gov/usgcrp/nacc/background/scenarios/emissions.html for further detail on emissions scenarios used in the National Assessment.

¹⁰¹ VEMAP members 1995; Kittel et al 1995, 1997.

¹⁰² NAST 2001 p. 36, Table 2.

¹⁰³ Cubasch and Meehl (2001), Figure 9.5a, p. 541. While the Canadian model lies at the high end, it is not an outlier. The GFDL model (which was more responsive than the Canadian model, with a climate sensitivity of 4.2 C) projected higher global warming than the Canadian model in this scenario for the first few decades of the century, but only had results through 2060 in time for the TAR.

¹⁰⁴ 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.

¹⁰⁵ NAST 2001 p. 545, Fig. 8.

¹⁰⁶ NAST 2001 p. 552, Fig. 16 and 18.

1 Although only the Hadley and Canadian climate-model scenarios were used throughout
 2 the assessment, several others that met some or all of the assessment’s needs became available
 3 during its work. Several region and sector teams were able to use these additional scenarios. In
 4 some cases, the additional scenarios allowed groups to strengthen their conclusions. For
 5 example, an analysis of future Great Lakes water levels under climate change using eleven
 6 climate models found that ten of these showed lower levels and only one higher.¹⁰⁷ In other
 7 cases, using multiple models allowed more detailed characterization of uncertainties in future
 8 regional changes. For example, the Pacific Northwest team presented distributions of regional
 9 temperature and precipitation change in the 2030s and 2090s using seven GCMs.¹⁰⁸

10 Despite the National Assessment’s aim of exploring future climate using three distinct
 11 types of scenario, historical scenarios and sensitivity analyses were less extensively used than
 12 GCM scenarios and featured less prominently in the assessment’s publications. Two uses of
 13 historical climate data – describing observed impacts of climate variability and using observed
 14 historical extremes as benchmarks to compare projected future changes – were made by all
 15 groups. To support systematic use of historical scenarios, the VEMAP 20th-century dataset was
 16 provided to all groups, but no further guidance was provided on how to generate climate
 17 scenarios from these historical data, e.g., on what periods to choose or how to use them to assess
 18 potential future impacts. Several groups used these historical data to describe the impacts of
 19 particular recognized patterns of climate variability, such as ENSO or the Pacific Decadal
 20 Oscillation (PDO).¹⁰⁹ Many groups examined past climate extremes, but only in qualitative
 21 ways; most did not follow the approach, taken in some previous impact studies, of using
 22 historical extreme periods as quantitative proxies for potential future climate.¹¹⁰

23 The third approach, vulnerability analysis, was the least used in the National Assessment.
 24 This “inverse” approach involves describing the properties of a climate-sensitive system,
 25 specifying some important change or disruption, and asking what climate changes would be
 26 required to bring about that disruption and how likely – based on historical data and model
 27 calculations – such climate changes appear to be. Given the complex dynamics of climate-
 28 sensitive systems and models of these systems, and the multiple dimensions of climate on which
 29 these can depend, this approach requires a substantial program of new research, analysis, and
 30 methodological development¹¹¹. In part because of the intrinsic difficulty of this task – and in
 31 part due to management and resource problems – this approach was not pursued. The NAST
 32 proposed it, but more tractable approaches to analyzing climate impacts dominated the
 33 assessment’s work. This remains an important area for further work in development of
 34 assessment and modeling methods.

35 *Socio-economic scenarios*

¹⁰⁷ Lofgren et al. 2000; NAST 2001, p. 175.

¹⁰⁸ NAST 2001 p. 256.

¹⁰⁹ E.g., Southeast analysis of ENSO dependence of hurricanes; Pacific Northwest examination of impacts of ENSO and PDO on forests, fish, and water. **REFS?**

¹¹⁰ Rosenberg *et al*, 1993.

¹¹¹ See the AIACC Program, <http://www.aiaccproject.org/>

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

13 In contrast to climate scenarios, little prior information or experience was available on
14 constructing scenarios of socio-economic conditions for impact assessment. Consequently, the
15 assessment developed new methods, using an approach that combined centralized and
16 decentralized elements. Centralization was needed because a few variables, such as population,
17 economic growth, and employment, are likely to be important in all regions and sectors. For
18 these, consistent assumptions are required to allow comparison of impacts across regions and
19 sectors, and to aggregate from separate assessments up to overall national impacts. A NAST
20 sub-group developed high, medium, and low-growth scenarios of these variables at the national
21 level. These followed the US Census Bureau high, middle, and low scenarios for fertility and
22 mortality through 2030, but assumed a wider range of values for net immigration to account for
23 possible illegal immigration.¹¹² Over this period, national population, GDP, and employment
24 were disaggregated among regions and sectors using a commercial regional economic model.¹¹³
25 Beyond 2030, national projections of these variables followed OECD growth rates in the SRES
26 marker scenarios.¹¹⁴

27 Decentralization was also needed because the particular socio-economic characteristics
28 that most strongly influence climate impacts and vulnerability may differ among regions,
29 activities, and resources. For example, major socio-economic determinants of climate impacts
30 on Great Plains agriculture may include the crops grown, the extent of irrigation, and the
31 technologies used to provide it, while the main determinants of coastal-zone impacts may be
32 patterns of coastal development, zoning, infrastructure, and local property values. The NAST
33 judged that those assessing regional or sector impacts were likely to know more about such
34 factors than a central body. Consequently, to support decentralized scenario development, the
35 NAST proposed a consistent template for assessment teams to follow in creating their own
36 scenarios. Teams were asked to identify two socio-economic factors they judged most important
37 for their impacts of concern; to identify a range of these factors to represent roughly 90 percent
38 confidence; and to create socio-economic scenarios by combining high and low values of these
39 factors, plus middle or best-guess values if they so chose.

¹¹² Parson et al 2001, p. 102-103.

¹¹³ Terleckyj 1999a, 1999b.

¹¹⁴ The high-growth scenario was roughly comparable with A1, medium with B1, and low with A2 and B2.

1 Implementation of socio-economic scenarios in the National Assessment was weak. Few
2 assessment teams used the proposed approach. Many made no socio-economic projections at all,
3 but rather projected only biophysical impacts based on GCM results. One assessment team
4 found the socio-economic scenarios were inconsistent with superior local estimates of current
5 population, and so decided not to use them.¹¹⁵ The teams that did use the socio-economic
6 scenarios used only aggregate projections of population and economic growth, or in some cases
7 assumed continuation of present conditions in the assessment period. None used the proposed
8 template for identifying and projecting additional important socioeconomic characteristics.

9 Several factors contributed to this limited use of socioeconomic scenarios. In addition to
10 various managerial and communication problems, many participants were reluctant to use socio-
11 economic scenarios, especially the proposed decentralized approach. Some preferred to avoid
12 any socio-economic projections, implicitly presuming either that socio-economic conditions did
13 not matter for impacts, or that those that did matter would remain similar to present conditions.
14 Others objected to specific contents of the scenarios or the methods used to generate them, or
15 judged that their team lacked the expertise required to evaluate them. Still others objected that
16 uncertainties in future socio-economic conditions made any attempt to construct scenarios for
17 more than a few years in the future unacceptably speculative.¹¹⁶ Consequently, while the
18 assessment attempted to advance scenario methods, weak implementation of these methods
19 limited its ability to identify key vulnerabilities. More useful assessments of impacts and
20 vulnerability will require more extensive use of socioeconomic scenarios, improved integration
21 of socioeconomic with climatic and environmental scenarios, and substantial further investment
22 in development and testing of new methods.¹¹⁷

23 *Criticisms and Controversies*

24 The National Assessment was the object of substantial political and scientific
25 controversy. Here, we summarize the major criticisms that pertain to the development and use of
26 scenarios. Criticisms focused predominantly on the climate scenarios, especially those derived
27 from GCMs, probably because these were more precisely defined, widely used in the analyses,
28 and featured in the assessment's publications. Three criticisms of these were advanced.

29 The first, widely circulated during 2000, was that the use of non-American climate
30 models for climate scenarios was inappropriate and potentially injurious to national interests.¹¹⁸
31 While this criticism indicates a dimension of political vulnerability of the assessment, it does not
32 address its technical quality. Since climate models represent the physics of the global
33 atmosphere, they contain no representation of political or economic factors. The Hadley and
34 Canadian global climate models were extensively documented in peer-reviewed scientific
35 literature – and, moreover, were the only models that met the most critical of the assessment's
36 criteria. That they were developed by scientific groups outside the United States has no
37 significance for their ability to provide scenarios to assess US impacts. Using US models would

¹¹⁵ The Metropolitan East Coast assessment, CITE.**

¹¹⁶ Morgan et al 2005.

¹¹⁷ Lorenzoni et al., 2000; Berkhout and Hertin, 2000.

¹¹⁸ Congressional Record, June 16, 2001, Statements of Senators Hagel (pg. S5292) and Craig (Pg. S5294).

1 have avoided this criticism, but at the cost of either weakening the analysis by using scenarios
2 that did not meet the assessment's needs, or delaying the work by one to two years. In deciding
3 to proceed with non-US models, assessment organizers judged that these costs were too high.

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

10 The National Assessment's organizers and its critics agreed that using more models
11 would have been preferable, but the assessment was limited by its schedule and its technical
12 requirements. Given a limit of only two, there can be good reasons to choose one scenario in the
13 middle of current projections and one near the top that provides a plausible upper-bound, but the
14 significance of the results must then be communicated with great care. Some critics suggested
15 that presentation of results based on the relatively high Canadian scenario should be more
16 carefully qualified to highlight its position near the top of current projections.¹¹⁹ Such
17 qualifications must be crafted very subtly, however, lest they imply these results may safely be
18 ignored, when most analyses suggest the full range of future climate-change uncertainty extends
19 both below the Hadley scenario and – in a long, thin tail – above the Canadian.

20 A related criticism of the climate scenarios claimed that the emissions scenario driving
21 them was implausibly high. The issues bearing on choice of emission scenarios are similar to
22 those for choice of climate models. It would be preferable to have a wide and relevant range of
23 emissions scenarios driving an impact assessment – at least for the post-2050 period. Using a
24 wide range of emissions scenarios would also allow comparison of projected impacts under high
25 and low emissions futures, and so give insights into what degree of impacts could be avoided by
26 what degree of mitigation effort. Model runs with this emissions scenario were all that were
27 available, however. Moreover, there is no clear basis to reject this particular scenario, since it
28 was the scenario most widely used in climate-model runs at the time and lies near the middle of
29 the range of both the 1992 and the 2001 IPCC scenarios. Finally, there is no support for the
30 claim that this scenario was chosen with the aim of making 21st-century climate change appear as
31 frightening as possible.¹²⁰ But while using just two climate models with one emissions scenario
32 was unavoidable in this assessment, it still represented a serious limitation. With more model
33 simulations testing a range of emission scenarios already available, future assessments will be
34 able to remedy this deficiency.

35 In contrast with the preceding criticisms that the scenarios used in the assessment
36 understated uncertainty, another criticism focused on the disparities between the two scenarios'
37 projections. Some critics argued that such disparities – e.g., the Canadian scenario projects the
38 Southeastern states becoming much drier than the Hadley model does – show that our limited
39 knowledge of regional climate change makes any attempt to assess future impacts and

¹¹⁹ MIT Integrated Assessment project, comments on National Assessment, Aug 11, 2000, p. 15

¹²⁰ Michaels, 2003, p. 171-192.

1 vulnerabilities irresponsible.¹²¹ This criticism implies that impact assessment should wait until
2 precise, high-confidence regional climate projections are available. Since a major purpose of the
3 assessment was to represent current uncertainty about climate change and its impacts, such
4 discrepancies between model projections served a valuable purpose, as indications of the
5 uncertainty of projections at the regional scale – particularly when the model disparities had a
6 clear origin, such as differences in projected jet-stream location.

7 In sum, the National Assessment’s use of climate-change scenarios was hampered by the
8 lack of available relevant runs, but reflected an adequate attempt to represent then-understood
9 variation in climate projections for the United States. Future assessments will need to use more
10 climate-model projections – including multiple ensemble runs -- informed by a wider range of
11 relevant emissions scenarios. The National Assessment attempted to advance the state of the art
12 in using socio-economic scenarios, but achieved only limited success in implementing its plans.
13 Future assessments will need to invest substantial resources in developing the state of underlying
14 knowledge, models, and assessment methods for integrating socio-economic considerations into
15 assessments of climate impacts. This includes further development of novel approaches to link
16 climate and socio-economic scenarios, such as the proposed “inverse” approach to vulnerability
17 analysis.

18 The experience of the National Assessment raises three significant issues for future
19 climate-change scenario exercises. First, like several of the experiences reviewed here, it
20 illustrates the difficulty and scale of effort involved in producing scenario-based assessments.
21 Second, the large required start-up effort and time to build the capacity to conduct such an
22 exercise illustrates the great value of sustaining analytic and institutional capacity over time,
23 rather than relying on separate projects. Such continuity of capacity will avoid wasteful
24 repetition of start-up efforts, support accumulation of learning and experience, and develop and
25 maintain the required collaborative networks. Finally, the assessment’s experience illustrates
26 both the need for consistency in large-scale assessments, and the great specificity of information
27 needs within particular impact and adaptation assessments. This combination of centralized and
28 decentralized information requirements suggests the need for a cross-scale organizational
29 structure for developing and applying scenarios, including scenarios of both climate and socio-
30 economic conditions.

31 **3.3. The UK Climate Impacts Program**

32
33 The UK Climate Impacts Program was established in April 1997 as one element of a
34 broad program of scientific research, assessment, and support for policy-making on climate
35 change. The UKCIP supports research and analysis of impacts for particular regions, sectors,
36 activities in the UK. The program provides common datasets and tools, as well as ongoing
37 support to university researchers and organized stakeholder groups in all regions of the UK. As
38 part of its role in stimulating, supporting, and coordinating decentralized and stakeholder-driven

¹²¹ 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.)

1 impact analyses, the UKCIP has produced and disseminated three sets of scenarios: climate
2 scenarios in 1998 and 2002, and socio-economic scenarios in 2001.

3 The 1998 climate scenarios provided information only at the rather coarse scale of the
4 Hadley Centre's HadCM2 climate model, with four grid-cells over the entire UK. Four
5 scenarios, called "high," "medium-high," "medium-low," and "low," combined variation in
6 emissions assumptions with variation in assumed climate sensitivity. The medium-high and
7 medium-low scenarios both used the HadCM2 model, with a sensitivity of 2.5°C.¹²² The
8 medium-high scenario was driven by a 1 percent per year equivalent-CO₂ transient scenario,
9 similar to IS92a. The medium-low scenario was driven by a 0.5 percent per year equivalent-CO₂
10 transient scenario, similar to the lowest IS92 scenario, IS92d. The high and low scenarios used
11 the same two emissions scenarios driving a simpler climate model, whose sensitivity was set at
12 4.5°C for the high scenario and 1.5°C for the low. These scenarios were used in an initial impact
13 assessment focusing predominantly on direct biophysical impacts.¹²³ The scenarios did not
14 include any explicit statements of probability, although their documentation suggested that the
15 medium-high and medium-low scenarios "in one sense ... may be seen as being equally likely,"
16 while the high and low scenarios captured part of the tails of the distribution. Nor did they
17 include any potential extreme climate events such as those associated with large changes in the
18 North Atlantic circulation.

19 The UKCIP's socio-economic scenarios drew on the Foresight Program, a broader
20 exercise of the UK Department of Trade and Industry to develop scenarios for long-rang
21 planning in several policy areas, with additional detail in areas relevant to greenhouse-gas
22 emissions and climate impacts.¹²⁴ As in several other scenario exercises, developers identified
23 two fundamental uncertainties and combined two alternative outcomes of each to produce four
24 scenarios. The two core uncertainties they chose were similar to those used in the SRES
25 exercise: social and political values, which varied from an increased focus on individual
26 consumption and personal freedom ("consumerism") to a widespread elevation of concern for
27 the common good ("community"); and governance, which varied from authority and power
28 concentrated at the national level ("autonomy"), to power increasingly flowing to global
29 institutions, downward to local ones, and outward to non-governmental institutions and civil
30 society ("interdependence"). The two dimensions of uncertainty, values and governance, were
31 assumed to be independent of each other. Other major uncertainties such as demographic
32 change, the rate and composition of economic growth, and the rate and direction of technological
33 change, were treated largely as consequences of alternative realizations of the two core
34 dimensions of values and governance.¹²⁵

35 The four scenarios built around these two dimensions of variation were called "National
36 Enterprise," "World Markets," "Local Stewardship," and "Global Sustainability." Each was
37 initially developed as a qualitative narrative of future conditions in UK society intended to apply
38 broadly to both the 2020s and 2050s. Each scenario specified several dozen socio-economic

¹²² UKCIP 1998, pg. 13-15.

¹²³ UKCIP 2000.

¹²⁴ UKCIP 2001.

¹²⁵ UKCIP, 2001.

1 characteristics qualitatively, including multiple aspects of economic development, settlement and
2 planning, values and policy, agriculture, water, biodiversity, coastal zone development, and the
3 built environment.¹²⁶

4 Each scenario was also realized in projections of multiple quantitative variables, at
5 national scale only. For the 2020s, these provided detail on population, GDP (including the
6 governmental share and the sector split between industry, agriculture, and services), household
7 numbers and average household size, land use and rates of change, total transport and modal
8 split, agricultural production (including such details as chemical and financial inputs, subsidies,
9 yields, and organic area), freshwater supply, demand, and quality, and several indicators of
10 biodiversity and coastal vulnerability. For the 2050s a smaller set of quantitative variables was
11 projected, describing population, GDP, land use, and transport. The plausibility of projections
12 was checked, mainly by comparing projected future rates of change to historical experience. The
13 scenarios were published with a detailed guidance document, which provided suggestions how to
14 use them together with climate scenarios for impact studies.¹²⁷

15 As of 2005, the socio-economic scenarios had been used in six impact studies.¹²⁸ There
16 has been some difficulty applying the national-level scenarios in specific, smaller-scale regions.
17 The most ambitious use has been a preliminary integrated assessment of climate impacts and
18 responses in two regions of England, the Northwest and East Anglia.¹²⁹ This study produced
19 four integrated scenarios of regional climate impacts, by pairing each of the four socio-economic
20 scenarios with one climate scenario based on a rough correspondence between the socio-
21 economic scenario and the IPCC emissions scenario underlying the climate scenario¹³⁰ Based on
22 these four scenarios, the study elaborated preliminary regional scenarios corresponding to the
23 four national socio-economic scenarios, and conducted an assessment of coastal-zone impacts
24 and responses using these scenarios and a formal land-use model.

25 Four new climate scenarios were produced in 2002, based on the SRES marker scenarios
26 and new versions of Hadley Center climate models. These new scenarios differed only in their
27 emissions assumptions, not climate sensitivity. The high, medium-high, medium-low, and low
28 scenarios were driven by the A1FI, A2, B2, and B1 marker scenarios, respectively. These were
29 used to drive the HadCM3 global climate model (with a grid-scale of 250-300 km), generating
30 climate-change projections for 30-year future periods centered on the decades of the 2020s,
31 2050s, and 2080s. For some emissions scenarios and time periods, climate projections were
32 processed through a nested hierarchy of three Hadley Center climate models: the HadCM3
33 model at global scale, the HadAM3H model at intermediate scale, with a grid of about 120 km,
34 and the HadRM3 model for high-resolution climate projections in the United Kingdom and
35 Europe, with a grid of about 50 km. This nested processing was done for the baseline period
36 (1960-1990), and for the most distant projection period (2070-2100) to produce three ensemble

¹²⁶ Berkhout et al, 2001.

¹²⁷ Berkhout and Hertin 2001.

¹²⁸ UKCIP, 2005.

¹²⁹ Holman et al 2002.

¹³⁰ 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).

1 runs for the medium-high (A2) emissions scenario and one for the medium-low (B2). For the
2 other emissions scenarios and the intervening projection periods, results of the global-scale
3 model were downscaled using statistical patterns of fine spatial-scale climate variation derived
4 from full runs using scenario A2. These scenarios were widely distributed and supported
5 through a web-based interface, including map-based graphical display of projected changes in
6 more than a dozen climate indicators on a fine-scale (50 km) grid of the United Kingdom.

7 Several analyses are continuing to use the 2002 climate scenarios in conjunction with the
8 socio-economic scenarios. For example, a 2004 integrated analysis of flood risk and erosion
9 control over a 30-100 year time horizon produced a threat assessment, a set of scenarios of flood
10 risk, and a set of policy recommendations. An evaluation of this study's effects one year later
11 found that it was being used by several public and private actors to inform decision-making.¹³¹

12 The UKCIP, in contrast to the US National Assessment, has built a sustained assessment
13 capability. In addition, the central program has less authority over the separate assessments,
14 instead acting more as motivator, resource, and light coordinator. Access to scenarios is to
15 licensed users, of whom there are about 130 – roughly half in universities, the rest about equally
16 split among private sector and all levels of government. Most active users have been national
17 officials responsible for climate-sensitive resources, with less participation from the private
18 sector and local governments.¹³²

19 The program has invested in generating, disseminating, and documenting useful climate
20 scenarios for impacts users. The jury appears to still be out on whether the level of effort and
21 success is similar for socio-economic scenarios, which have not yet been either downscaled or
22 repeated. Getting scenarios used is a slow process, but the scenarios produced by this program
23 are starting to be used by decision-makers in support of their practical responsibilities. A
24 significant limitation of the program, however, is its exclusive reliance on just one family of
25 climate models. This may pose risks of under-estimating future climate uncertainty and over-
26 confidence in assessments of potential climate impacts and responses. Although the UK
27 program followed a substantially different organizational model from the US National
28 Assessment, its experience highlights some of the same issues for future scenario exercises, in
29 particular the importance of continuity of institutional and analytic capacity and the desirability
30 of developing and supporting scenarios using an organizational structure that combines
31 centralized and decentralized elements.

32 **3.4. The Millennium Ecosystem Assessment**

35 The Millennium Ecosystem Assessment (MEA) was a large, UN-sponsored assessment
36 of the current status, present trends, and longer-term challenges to the world's ecosystems,
37 including climate change and other sources of stress. Conducted between 2001 and 2005, the
38 MEA sought to assess changes in ecosystems in terms of the services they provide to people and

¹³¹ UK Office of Science and Technology 2002.

¹³² West and Gawith (2005).

1 the effects of ecosystem change on human well-being. It also sought to identify and assess
2 methods to mitigate and respond to ecosystem change, for various private and public-sector
3 decision-makers including those responsible for the several international treaties that deal with
4 ecosystems.¹³³ More than 1350 authors from 95 countries participated in the global assessment's
5 four working groups, and hundreds more in about 30 associated sub-global assessments. The
6 assessment's goals were broad, ranging from providing a benchmark for future assessments and
7 guiding future research to identifying priorities for action.¹³⁴

8 Results of the global assessment were presented in a March 2005 synthesis report, and in
9 additional volumes presenting the output of the assessment's four working groups, "Current
10 State and Trends," "Scenarios," "Policy Responses," and "Multi-Scale Assessments." The
11 current state and trends group examined ecosystem trends over the past 50 years and projections
12 to 2015; the scenarios group took a longer view to 2050 and beyond. Because of time
13 limitations, the work of these two groups proceeded largely independently.

14 All components of the assessment used a common large-scale conceptual framework,
15 which distinguished indirect drivers of ecosystem change, direct drivers, ecosystem indicators,
16 ecosystem services, measures of human well-being, and response options. Direct drivers
17 included direct human perturbations of the environment such as climate change, air pollution,
18 land-use and land-cover change, resource consumption, and external inputs to ecosystems such
19 as irrigation and synthetic fertilizer use. Indirect drivers included underlying socio-economic
20 factors such as population, economic growth, technological change, policies, attitudes, and
21 lifestyles.¹³⁵

22 The Scenarios working group sought to apply this conceptual framework to long-term
23 trends in ecosystems, looking ahead to 2050 with more limited projections to 2100. They
24 developed the structure of the scenarios in an iterative process, including consultations with
25 potential scenario users and experts in a wide range of decision-making positions around the
26 world.¹³⁶ Like several other major scenario exercises, they initially sought to identify two basic
27 dimensions of uncertainty in long-term ecosystem stresses, which together would produce four
28 scenarios.¹³⁷ For the first dimension, like SRES they chose globalization: continuation and
29 acceleration of present global integration trends, versus reversal of these trends to increasing
30 separation and isolation of nations and regions. For the second dimension, in contrast to the
31 broad value-based uncertainties used in the SRES and UKCIP scenarios, they chose one more
32 specifically related to ecosystems: whether responses to increasing ecosystem stresses are
33 predominantly reactive – waiting until evidence of deterioration and loss of services is clear – or
34 predominantly proactive, taking protective measures in advance of their clear need. The
35 combination of two polar values of each of these uncertainties yielded four scenarios,
36 summarized in Table 3.4.1.

¹³³ E.g., the Convention on Biological Diversity, the Convention to Combat Desertification, the Convention on Migratory Species and the Ramsar Convention on Wetlands.

¹³⁴ MEA 2006, pg xii.

¹³⁵ MEA 2006, p. 153 (Table 6.1), p. 304 (Table 9.2)

¹³⁶ MEA 2006, p. 152.

¹³⁷ MEA 2006, Fig 5.2.

Table 3.4.1. Millennium Ecosystem Assessment Scenarios

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

3 The Global Orchestration (global, reactive) scenario presented a globally integrated
4 world with low population growth, high economic growth, and strong efforts to reduce poverty
5 and invest in public goods such as education. In this scenario, society focuses on liberal
6 economic values, follows an energy-intensive lifestyle with no explicit greenhouse-gas
7 mitigation policy, and takes a reactive approach to ecosystem problems.¹³⁸ In Order from
8 Strength (regional, reactive) the reactive approach to ecosystem problems takes place in a
9 fragmented world preoccupied with security and less attentive to public goods.¹³⁹ This scenario
10 exhibits the highest population growth and lowest economic growth, particularly in developing
11 countries, and decreasing with time. In Adapting Mosaic (regional, proactive), political and
12 economic activity are concentrated at regional ecosystem scale. Societies invest heavily in
13 protection and management of ecosystems in locally organized and diverse efforts. Population
14 growth is nearly as high as in Order from Strength, and economic growth is initially slow but
15 increases after 2020. Finally, TechnoGarden (global, proactive) presents a world that is both
16 focused on ecosystem management and globally connected, with strong development of
17 environmentally friendly technology. Population growth is moderate, and economic growth is
18 relatively high and increasing.¹⁴⁰

19 Each scenario was initially constructed as a qualitative description. Population and GDP
20 were specified quantitatively, while all other indirect drivers – including social, political, and
21 cultural factors – were qualitative. Population scenarios were derived from the IIASA 2001
22 probabilistic projections, capturing the middle 50-60 percent of the distribution, with world
23 population in 2050 ranging from 8.1 billion (Global Orchestration) to 9.6 billion (Order from
24 Strength).¹⁴¹ No statements of probability or likelihood were made about the scenarios.

25 From the indirect drivers, a more specific and quantified set of direct drivers was
26 developed, using formal models where possible. Species introduction and removal was the only

¹³⁸ MEA 2006, Ch 5.5.1

¹³⁹ 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)

¹⁴⁰ MEA 2006, Pg. 131.

¹⁴¹ MEA 2006, pg. 182.

1 unquantified direct driver.¹⁴² Separate pre-existing models were used of the world energy-
2 economy, greenhouse gas emissions and climate change, air pollution, land-use change,
3 freshwater, terrestrial ecosystems, biodiversity, and marine and freshwater fisheries. To the
4 extent possible, these quantitative models were used to reason from indirect and direct drivers to
5 ecosystem effects, changes in ecosystem services, and effects on human well-being.¹⁴³ In some
6 cases this was achieved by soft-linking models, using outputs from one as inputs to another, but
7 this was limited by different variable definitions, spatial and temporal resolution, and other
8 model incompatibilities.¹⁴⁴ Not all scenario elements could be modeled quantitatively, so expert
9 judgments were also extensively used. The qualitative scenario process proceeded in parallel
10 with quantitative modeling – elaborating aspects of the scenarios that were not amenable to
11 modeling, filling gaps, and stipulating feedbacks between ecosystem services and human well-
12 being and behavior.¹⁴⁵

13 The groups attempted to check for consistency between quantitative and qualitative
14 scenario elements through periodic consultations, particularly for feedbacks that could not be
15 modeled analytically. Some of these were interactions between direct drivers and ecosystems,
16 but the most difficult occurred in scenarios that assumed strong socio-economic feedbacks and
17 regulating mechanisms. Adapting Mosaic, for example, assumed strong feedbacks from new
18 ecosystem observations and knowledge to changes in human behavior that could not be
19 incorporated into the models used. Representing these required allowing qualitative scenario
20 logic to override both the quantitative results and the structure of models. Unfortunately, time
21 limits prevented this consistency checking from being done thoroughly, so unexamined
22 disparities between qualitative and quantitative aspects of the scenarios remained a significant
23 weakness.¹⁴⁶

24 Many of the conclusions developed from the scenarios are common to all four scenarios,
25 while in others Order from Strength is the exception. An example conclusion is that rapid
26 conversion of ecosystems for use in agriculture, cities, and infrastructure will continue, and that
27 habitat loss will continue to contribute to biodiversity loss.¹⁴⁷ However, if ecosystem services
28 increase as projected, some ecosystem services – although not biodiversity – may be decoupled
29 from ecosystem stresses. Food security is projected to remain out of reach for many people.
30 Extreme, spatially diverse changes are projected for freshwater resources, with general
31 deterioration in developing countries under both “reactive” scenarios. Increasing demands for
32 fishery products are projected to increase risks of regional marine fishery collapses.¹⁴⁸ In sum,
33 ecosystem services show mixes of improving and worsening trends in all scenarios except Order
34 from Strength, in which nearly all ecosystem services are projected to be more impaired in 2050

¹⁴² MEA 2006 pg. 304 (Table 9.2)

¹⁴³ MEA 2006, Table S3.

¹⁴⁴ Summary chapter of Synthesis Report, Table S2; Ch 6.5.5, p. 155.

¹⁴⁵ Scenarios, Part II, Ch 6.5.5, pg 155

¹⁴⁶ Carpenter, Dec 9 2005; Zurek, Dec 12, 2005.

¹⁴⁷ Summary chapter.

¹⁴⁸ Scenarios, Table S3.

1 than in 2000.¹⁴⁹ The same three scenarios also suggest that significant changes in policies,
2 institutions, and practices can mitigate some negative consequences.¹⁵⁰

3 In sum, the MEA scenarios project invested substantially more effort in developing rich
4 qualitative and narrative scenarios than the SRES, but also fell short on integrating qualitative
5 and quantitative components. In part because of the greater elaboration of the qualitative
6 components, this limited coordination resulted in significant inconsistencies and requirements to
7 resolve conflicts between the two components. These inconsistencies arose even with just one
8 model used for several components of the assessment, so the challenges of harmonization
9 between models – and the associated possibility to explore model-structure uncertainty – did not
10 arise. A related problem was that for many factors it was difficult to generate the desired level of
11 variation between scenarios.¹⁵¹ This raises issues of potential methodological interest, such as
12 how to distinguish robust results from inadvertent convergence of assumptions or model
13 structures, which remain to be investigated. Finally, the great breadth of conditions represented
14 in the scenarios, as well as possible concerns with logical circularity between their presumptions
15 and results,¹⁵² make interpreting the significance of the results difficult.

16 The experience of this scenario exercise provides a different perspective on some of the
17 same key challenges for future scenarios highlighted by the other activities reviewed. The quite
18 distinct difficulties faced here in attempting to combine quantitative and qualitative scenarios
19 highlight the central importance and the difficulty of developing new methods to integrate these
20 two approaches. In addition, this experience highlights the value of clarity about the intended
21 uses of scenarios, including clarity about whether they are intended to address specific questions,
22 guide decisions, or explore long-term conditions. The risk of scenarios becoming less useful due
23 to breadth and vagueness may be particularly acute for scenarios that attempt to capture multiple
24 stresses on some system – even though such multi-stress assessment is repeatedly advocated for
25 climate-change and other forms of environmental assessment.¹⁵³

26

¹⁴⁹ Id. at 127.

¹⁵⁰ www.millenniumassessment.org/en/global.scenarios.aspx

¹⁵¹ 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.

¹⁵² 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).

¹⁵³ NAST 2001.

4. Challenges and Controversies in Scenarios for Climate Change

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

4.1. Scenarios and Decisions

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

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

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

1 scenarios providing structured information and assumptions about the values at stake, the
2 available choices, and their consequences under alternative climate-change futures.

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

14 Impacts and adaptation managers have responsibility for particular assets, resources, or
15 interests that might be sensitive to climate change. They must decide how to anticipate, prepare
16 for, and respond to the threat, minimize its harm, and maximize any associated benefit. They
17 may be private or public actors – e.g., owners or managers of long-lived assets such as ports or
18 water-management facilities; managers of lands, forests, or protected areas; emergency
19 preparedness or public health officials; officials making zoning or coastal development policy; or
20 firms in insurance or financial markets who may bear secondary risks from impacts or seek to
21 develop new instruments to exchange these risks. Unlike national officials, these actors'
22 decisions are purely *responses* to climate change, realized or anticipated: they have little
23 influence over how the climate will change. Their responsibilities will often connect with the
24 impacts-related responsibilities of national officials, but are narrower in scale or scope. Impacts
25 and adaptation managers would be concerned not with aggregate climate-change impacts on the
26 United States, but with more specific impacts such as those on seasonal flows and water-
27 management operations on the Upper Mississippi.

28 Energy resource and technology managers include developers and operators of fossil or
29 non-fossil energy resources, investors in long-lived energy-dependent capital stock such as
30 electrical utilities, and researchers, innovators, and investors in new energy-related technologies.
31 These decision-makers are mostly but not exclusively in the private sector. Their decisions may
32 have consequences that interact with various processes operating over multiple time-scales, from
33 short-term market responses, to decadal-scale processes of investment, resource development
34 and depletion, and penetration of new technologies, to century-scale processes of climate
35 change.¹⁵⁴ These actors' decisions will strongly influence society's ability to control
36 greenhouse-gas emissions. This group also includes energy consumers such as firms or public
37 agencies considering mitigation actions in their own operations. While their areas of
38 responsibility may be vulnerable to climate change and its impacts, the largest climate-related
39 risks for this group are likely to come not from climate change itself, but from climate-change
40 policies: national mitigation policies, and other market and regulatory decisions that shape the
41 outcomes of private mitigation activities.

¹⁵⁴ Shell International 2001; Davis 2003.

1 At greatly varying levels of precision and specificity, scenarios can present two types of
2 information to support decisions by these three types of actors. Scenarios can represent potential
3 future developments that may threaten decision-makers' interests or values, call for decisions, or
4 challenge conventional thinking and practices. And they can provide a structure to assess
5 potential consequences of alternative decisions for things that matter to the decision-maker.
6 Beyond this generalization, the three types of decision-makers will differ substantially in the
7 specific types of information they need, the time horizons of their decisions, and the type and
8 extent of causal connections between their decisions and the conditions specified in scenarios.

9 *Scenario Needs: National Officials*

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

19 In their responsibilities for national mitigation policy, national decision-makers will also
20 need information about the aggregate impacts of climate change, since the more severe climate
21 impacts are likely to be, the greater the justification and likely political support for mitigation
22 measures. But mitigation decisions also require additional information – including projections of
23 future emissions in the absence of explicit mitigation efforts, and the consequences of alternative
24 mitigation policies, in their effects on emissions, their cost, and their implications for other
25 dimensions of national interest.

26 These needs introduce a dimension of complexity into mitigation scenarios, sometimes
27 called “reflexivity.” Because mitigation policies seek to reduce future emissions by altering the
28 socio-economic drivers of emissions growth, the analysis of mitigation policies and their
29 consequences must be coupled to the causal logic of emissions scenarios. Whereas climate
30 scenarios can be treated as exogenous when assessing adaptation decisions, emissions scenarios
31 cannot be treated as exogenous in assessing mitigation decisions. Any emissions scenario
32 embeds some assumptions about mitigation policies, which may have to be changed to assess
33 particular mitigation policies. This effect will be strongest when emissions projections and
34 mitigation options are being considered at the same spatial scale, e.g., national mitigation
35 policies are being assessed relative to national emissions projections. The effect of national
36 mitigation strategies on global emissions will be weaker: no nation controls global emissions
37 trends, and the effects of small nations' mitigation strategies on global trends can be very small.

38 Scenarios to inform mitigation decisions are also likely to require considering alternative
39 assumptions about the policy context in which these decisions are made. The effects of national
40 mitigation strategies – including how much they reduce national emissions, as well as their costs
41 and other consequences – will depend on the economic, technological, and policy context,

1 including related decisions by other major nations, individually and through international
2 coordination. Assumptions about the policy context will be less important in scenarios to inform
3 international mitigation decisions, since when decisions are globally coordinated there is no
4 “elsewhere” – but alternative assumptions about nations’ degrees of compliance and form of
5 implementation of international commitments may still be needed.

6 Scenarios of emissions, climate change, and impacts inform mitigation decisions by
7 helping to characterize the potential severity of climate change and therefore how important it is
8 to control emissions. This support is indirect, serving primarily to elevate or moderate the
9 general level of concern on the issue. More focused work on mitigation has been done using
10 constructed scenarios of limited emissions, often aiming at stabilizing atmospheric
11 concentrations at various levels, and examining the configurations of technology, energy
12 resources, and economic and population growth that are consistent with the specified scenario.
13 Some studies have used quantitative models to estimate costs of such scenarios, relative to an
14 assumed baseline emissions scenario.¹⁵⁵

15 *Scenario Needs: Impacts and Adaptation Managers*

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

23 Particular decision-makers’ needs will be highly specific in the variables they require,
24 and their time and space scale and resolution. A planner of water-management infrastructure
25 may need monthly or finer-scale rain and snow projections over a watershed; a designer of
26 coastal infrastructure may need probabilistic projections of sea level, storm intensity and
27 frequency, storm surge, or saltwater intrusion. But in their climatic elements, these information
28 needs all rest on a common core of scenarios of global climate change and emissions drivers.
29 This dual structure of information – highly particular climate variables, based on a set of
30 common “core scenarios” – suggests a cross-scale organizational structure for providing scenario
31 information: commonly produced scenarios of climate change and other components requiring
32 consistency, specialized expertise, or high-cost resources; development of decentralized
33 capabilities in impact assessments to adopt these core scenario elements and develop assessment-
34 specific extensions; and close communication between these groups to ensure that useful
35 variables are generated and saved, and that data and documentation are transferred accurately.

36 This is the area of climate-related decisions for which the provision of information from
37 climate-change scenarios is most advanced. Still, further progress is needed in the development
38 and use of scenarios of socio-economic conditions, and in creation of methods and tools to
39 augment centrally provided scenario information with information tailored to specific impact. In

¹⁵⁵ Morita et al 2001; CCSP SAP 2.1a.

1 addition, many impacts-related decisions will require scenarios of climate change in the context
2 of other linked stresses and changes.

3 ***Scenario Needs: Energy Resource and Technology Managers***

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

13 Unlike the other two types of decision-makers, these actors are likely to compete with
14 each other. If, for example, they are investors allocating research effort between higher and
15 lower-emitting energy sources, those who better anticipate future policy will benefit relative to
16 those who do worse. If they use scenarios, they may consequently choose to produce them
17 privately, perhaps coupled with other analyses to generate practical guidelines for investments.¹⁵⁶
18 As for the other types of decision-makers, these specialized scenarios could be based on general
19 scenarios of global emissions and climate change. Published scenarios produced to date on the
20 climate-change issue, however, have not considered mitigation policies with the specificity
21 necessary to inform these actors' decisions.

22 ***Representing Decisions in Scenarios***

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

35 Representing decisions by the scenario users is fundamentally different. Since the
36 scenarios are intended to inform these decisions, alternative choices should not be represented as
37 exogenous uncertainties but be stipulated independently from the scenarios. Users can then
38 explore their implications under conditions imposed by scenarios, including representation of

¹⁵⁶ Ged Davis, personal communication. (posted expert review comments).

1 major uncertainties. Various degrees of coupling can be required between the logic of scenarios
2 and the analysis of consequences of the users' decisions. In scenarios for impacts, these can
3 usually be separate; in scenarios for mitigation, they may have to be closely coupled, since
4 emissions scenarios may change under alternative assumptions about mitigation decisions.

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

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

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

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

40 Moreover, national officials act only for their own nations in the near term, even when
41 they negotiate global mitigation. They may make choices for long-term planning and

1 institutional design for future mitigation as well, but it is their successors who will decide
2 whether to continue, strengthen, or otherwise change measures adopted today. From the
3 perspective of current national officials, mitigation decisions by other nations and in the future
4 fall between the two cases discussed above: they are not controlled by the scenario user, but can
5 be influenced to some degree. For policy choices by other nations, national officials may need to
6 be advised in two modes, reflecting their dual responsibilities to make national policy and to
7 negotiate international agreements. In the latter capacity, alternative approaches to global
8 mitigation strategy should be represented as choices. But when they consider national decisions
9 separate from globally coordinated strategy, relevant decisions of other major nations should be
10 represented as uncertainties. This may require use of two distinct types of scenarios to advise
11 development of different aspects of national mitigation policy.

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

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

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

34 Mitigation decisions at the national and international level have taken scenarios into
35 account indirectly. Most scenarios have been constructed to provide inputs to assessments,
36 models, or other analyses. This has included serving as inputs to the production of other types of
37 scenarios, which then describe other potential future conditions that depend on those specified in
38 the scenario, as for example a model-based climate scenario depends on inputs from an
39 emissions scenario. While these uses can be characterized as supporting decisions (i.e.,
40 decisions about assessments, modeling, and research), their connection to concrete decisions of
41 mitigation and adaptation is indirect, achieved through contributions such as supporting strategic
42 planning and risk assessment, providing advance analysis for potential future decisions,

1 exploring plausible extreme cases, helping to characterize and prioritize key uncertainties, or
2 educating decision-makers or the public. This description applies to the major scenario exercises
3 discussed in this report, including the IPCC emissions and climate scenarios, the US and UK
4 assessments of climate impacts, and the Millennium Assessment scenarios.
5

6 **BOX 4.1.1:**

7 ***Scenarios for Climate-Change Adaptation in the New York Metropolitan Region***
8

9 Three linked activities – the Metropolitan East Coast (MEC) assessment of the US National Assessment,
10 the New York Climate and Health project (NYCHP), and the New York City Department of
11 Environmental Protection (NYCDEP) Task Force on Climate Change – have used or are using scenarios
12 to assess impacts of climate change on the New York Metropolitan Region, identify areas of
13 vulnerability, and inform regional planning and decision-making.¹⁵⁷
14

15 The MEC assessment began with a regional workshop in April 1998, involving about 150 participants,
16 including public agencies at all levels of government as well as climate researchers. The subsequent
17 assessment was conducted by sector teams of researchers and officials from agencies responsible for the
18 study sectors. Teams developed regional scenarios of climate change and sea level rise based on the
19 downscaled climate-model scenarios provided by the US National Assessment, plus two additional
20 scenarios based on extrapolation of recent regional climate trends and historical extremes. The scenarios
21 were used to project climate-change impacts on beach nourishment, 100 and 500-year flood heights,
22 wetland aggregation and loss, adequacy of the water supply system under droughts and floods, illnesses
23 from acute air-pollution episodes, and peak energy loads. These impact projections were used for
24 preliminary assessment of adaptation strategies and policies.
25

26 Following the MEC Assessment, the NYCHP created updated regional climate scenarios in consultation
27 with an expert-stakeholder Advisory Board. This study further analyzed public health impacts, focusing
28 on air quality and extreme heat events. The updated climate scenarios used the IPCC A2 and B2
29 emissions scenarios driving global and regional climate models to create downscaled scenarios for the
30 region. These were augmented with newly developed scenarios of future regional land use and
31 population growth based on the IPCC A2 and B2 storylines.
32

33 In response to the widespread public attention received by the MEC Assessment Report, the
34 Commissioner of the NYCDEP established the Climate Change Task Force, a collaboration among
35 regional researchers and the agency that manages the water system. The Task Force uses the latest
36 climate-model simulations from the IPCC Fourth Assessment Report, as well as additional global and
37 regional climate models, to develop new regional scenarios. These will include probability distributions
38 of average and extreme temperature and precipitation change, as well as sea level rise. The Task Force is
39 also developing qualitative scenarios of extreme sea level rise in the region. DEP is using these results to
40 develop a comprehensive adaptation strategy for the New York City water system, including assessment
41 of many specific adaptation options, that considers both uncertainties in future climate change and
42 managerial factors such as the time horizon of different adaptation responses and capital turnover cycles.
43

44 This is a successful example of scenario-based assessment of climate impacts and adaptation options.
45 The scenarios are connected with the concrete responsibilities and concerns of stakeholders, who were

¹⁵⁷ Rosenzweig and Solecki, 2001; Kinney et al., 2005; Rosenzweig et al., 2005.

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

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 (Figure 4.1).¹⁵⁸ In southeastern Louisiana, where the local rate of land surface subsidence is as high as 2.5 cm per year, rise in local "relative sea level" may be the most important factor in the rapid loss of coastal zone wetlands over the past several decades.¹⁵⁹

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.¹⁶⁰ This assumption sharply contrasts with the IPCC projections, which state that the global average rate of sea level rise in the 21st century may increase 2- to 4-fold over that of the 20th. Such increases will exacerbate wetland losses throughout the Gulf Coast region and obstruct restoration plans that do not take account of likely increases in water levels and salinity.

The ecosystem modeling team working for the State of Louisiana and the U.S. Army Corps of Engineers is presently integrating accelerated sea level rise scenarios into planning exercises that will aid federal and state agencies in evaluating restoration alternatives.¹⁶¹ 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.¹⁶² Sea level rise scenarios are also being used to assess the impacts of climate change and variability on the Gulf Coast transportation sector. To assess transportation impacts, a sea level rise simulation model developed by the U.S. Geological Survey generates scenarios of sea level change using over a dozen GCMs and six SRES emission scenarios.

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

¹⁵⁸ Gosselink, 1984; Williams *et al.*, 1999; Burkett *et al.* 2005.

¹⁵⁹ Shinkle and Dokka 2004; Barras *et al.*, 2003.

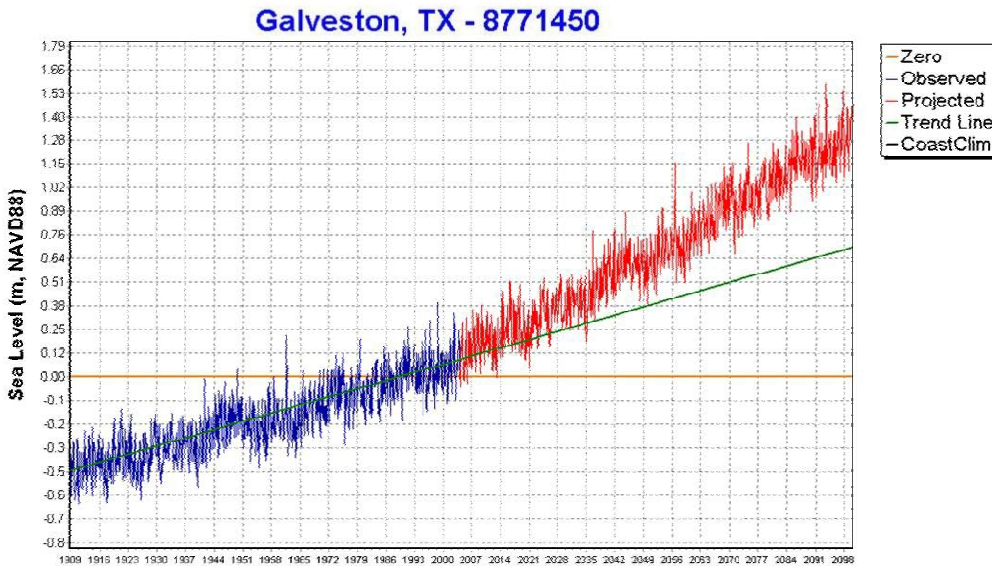
¹⁶⁰ U.S. Army Corps of Engineers, 2004.

¹⁶¹ <http://www.clear.lsu.edu/clear/web-content/index.html>

¹⁶² 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.

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



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Figure 4.1. 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 (DWR) produces an updated California Water Plan every five years. The plan projects water supplies and demands, and evaluates current and proposed demand-management programs and supply investments, to “provide a framework for water managers, legislators, and the public to consider options and make decisions regarding California’s water future.”¹⁶³

In contrast to prior plans that constructed only one future scenario, the 2005 plan explicitly considered uncertainty in supply and demand projections. Three alternative scenarios of supply and demand conditions were constructed through 2030: one extending current trends in population and economic growth, agricultural production, environmental restrictions on water use, and water conservation occurring without policy initiatives (e.g., through equipment replacement, technological change, and revised building codes); and two presenting higher and lower increases in demands. The report of the

¹⁶³ Water Plan home page.

1 2005 plan discusses global climate change and the potential challenges it poses to water supply and
2 demand in California, but climate change is not explicitly represented in the plan's three scenarios.

3
4 In addition to adopting these scenarios, the State of California is developing data and analytic capacity to
5 enrich the treatment of uncertainty and climate change in future plans. In parallel with development of
6 the three principal scenarios in this plan update, DWR sponsored development of several analytic tools to
7 strengthen the treatment of uncertainty in future plans. In addition, the California Climate Change
8 Research Center with co-sponsorship from DWR is developing fine-scale regional climate-model
9 scenarios to support analysis of climate-change impacts on water resources.¹⁶⁴ The DWR plans to
10 incorporate these climate-change scenarios explicitly in the next plan update in 2010.

11 ***4.2. Scenarios in Assessments and Policy Debates***

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

25 In a broad assessment including many teams considering separate questions of climate-
26 change, impacts, mitigation, and adaptation, simple coordinating devices are needed to make
27 teams' work comparable and allow synthesis to produce aggregate conclusions. Emissions
28 scenarios are natural devices to provide such coordination, both because emissions hold the
29 clearest near-term opportunities for intervention, and because they have clear and recognized
30 connections both directions in the causal chain, to every aspect of the climate-change issue.
31 These efforts to use scenarios as broad coordinating devices have not been wholly satisfactory in
32 practice, however, in part due to management issues. To serve as coordinating devices, scenarios
33 must be developed and disseminated early in the process, preferably before the work of
34 assessment teams even begins. Moreover, they must be documented with detailed information
35 about the process and reasoning used to generate them, including explicit identification of
36 underlying assumptions and supporting data, models, and arguments. In practice, timely,
37 detailed, and transparent dissemination of scenario information has rarely been achieved.

38 Scenarios used in large-scale assessments can also make other contributions that are
39 related to the prominent dissemination a major assessment receives. They may, for example, be
40 used as inputs to planning or decision-support processes that were not part of the original

¹⁶⁴ California DWR 2005, Pg 4-32.

1 assessment. In such use, they may gain a more direct connection to decision-making than they
2 had in their original production or use. Scenarios of global emissions and the model-based
3 climate scenarios based on them especially lend themselves to such derivative uses, informing
4 many different decisions by diverse actors.

5 Scenarios in prominent assessments can also contribute to the framing of public and
6 policy debates. In this role, scenarios inevitably become political objects, in two senses. They
7 are subject to political forces that seek to influence their development, and political reactions to
8 them once developed. These pressures pose challenges and risks that differ quite markedly from
9 those that apply in using scenarios to inform decision-making, where we tend to assume a greater
10 degree of commonality of knowledge, perspective, and interest in the process among participants
11 and some group of relatively well-defined users.

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

22 Other political pressures come onto scenarios in the broader use, debate, and criticism
23 that they encounter after release. For impartial support of policy decisions, scenarios should
24 fairly present knowledge and uncertainty about potential variation on important dimensions.
25 This typically requires consideration of a wide range of potential futures – often a wider range
26 than relevant decision-makers might initially think plausible, due to well know habits of
27 conventional thinking and excessive confidence.

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

37 In global change scenarios, these conflicts and opportunities for bias arise most acutely
38 over emissions scenarios. Since much of the uncertainty about climate change beyond 2050
39 comes from uncertainty in future emissions trends, actors with strong policy preferences can
40 highlight emissions scenarios that lend support to their view. Those who advocate aggressive
41 mitigation may highlight the highest-emissions scenarios to emphasize the elevated risk of

1 climate change that would follow. Those who oppose mitigation may highlight the lowest-
2 emission scenarios to suggest that no action to limit emissions is warranted. Both these tactics –
3 highlighting either the top or bottom of a wide range of possibilities to support a preferred policy
4 – are easy to employ. Because scenarios are used when knowledge of causal processes is weak,
5 it is easy to make any scenario you wish to highlight appear salient and likely, even if it is
6 extreme. It is equally easy to probe inside the details of any scenario you wish to denounce to
7 find inconsistent or implausible implications, particularly when a scenario is rich in detail.

8 But while political actors may have legitimate reasons to highlight one extreme scenario
9 or another, it is not appropriate for any such scenario to dominate assessment or consideration of
10 decisions. A claim that only a single scenario is plausible – especially one near the top or bottom
11 of the present range – is a claim to predict the future, which can be readily dismissed. Claims
12 that a particular scenario is *implausible* cannot be so easily dismissed, however, since scenarios
13 represent only the imperfect judgment of the team that produced them. Leaving aside scenarios
14 that violate clear principles of science (e.g., one whose energy assumptions violate the laws of
15 thermodynamics) or economics (e.g., one that presumes a large new capital stock in a few
16 decades without the investments needed to create it), it is possible to construct pictures of the
17 next century so extreme or unprecedented that most observers would agree they do not merit
18 serious consideration. But short of such an extreme – which describes no global-change scenario
19 discussed here or known to us – claims that a broad class of potential futures is implausible
20 should have to pass a high hurdle. Identifying specific extreme or implausible elements within a
21 scenario does not suffice to make this case, since virtually any scenario will be found to contain
22 these if scrutinized closely enough. Nor does identifying ways that a scenario of future change
23 diverges from some established trend or pattern, since established trends can and do change.

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

35 In subsequent revisions as knowledge advances, scenarios can continue to play their role
36 coordinating assessments and framing policy debates with more focus and less arbitrariness.
37 Continuing research and analysis might come to identify some scenarios as severe in their
38 consequences and others as inconsequential, or might revise the initial characterization of the
39 determinants and feasibility of particular scenarios, including suggesting that some are too
40 unlikely to merit serious consideration. These judgments can feed into decisions about

¹⁶⁵ Smil 2006; Greenberger et al 1983.

1 continuing analysis of scenarios: which ones can be dropped and what new ones should be
 2 added. One major basis for updates in scenarios will be policies adopted, which can set a
 3 baseline to focus further deliberations. Perfect attainment of targets and success of policies
 4 should not be assumed, but scenarios can focus subsequent debate by posing such questions as
 5 “What if we just meet this target; what if we fall short by this much; and what if we exceed it by
 6 this much, or adopt these additional measures?”

7
 8 **Box 4.2.1.**

9 ***Scenarios of Ozone Depletion in International Policy-making***¹⁶⁶

10
 11 Emission scenarios of chlorofluorocarbons (CFCs) and other ozone-depleting chemicals substantially
 12 influenced policy debates over control of these chemicals to protect the ozone layer. Until the early
 13 1980s, these policy debates used a convention to project ozone losses that originally served as a
 14 simplifying research assumption: constant emissions forever. This convention has obvious research
 15 benefits, like the simple doubled-CO₂ equilibrium scenarios used in climate models. It standardized input
 16 assumptions, allowing exploration of scientific and modeling uncertainties without the confounding effect
 17 of different emissions assumptions. Moreover, this convention made no claim to realism, and so avoided
 18 distracting arguments over whether one emissions projection or another was more realistic. Nevertheless,
 19 the resultant calculations were frequently mistaken for projections of realistic future trends.

20
 21 The question of what future emissions trends were likely only became prominent in policy debates around
 22 1983. World CFC production had dropped nearly a third in the late 1970s due to both regulatory and
 23 market-driven reductions in their largest use, aerosol spray propellants, and declined further in the early
 24 1980s recession. It was widely argued that further restrictions were unnecessary—CFCs’ major markets
 25 were saturated and further growth was highly unlikely. The resumption of sharp growth in 1983
 26 undermined this claim, making it clear for the first time that managing the ozone risk required considering
 27 scenarios of CFC growth as well as steady-state and decline. How much emissions might grow and what
 28 it would mean for the atmosphere remained highly controversial, however.

29 Emissions of other chemicals complicated the picture. Advances in stratospheric chemistry showed that
 30 future ozone loss depended not just on CFCs, but also on emissions of several other gases, including
 31 carbon dioxide, methane, and nitrous oxide. But the knowledge and computing capacity to credibly
 32 model interactions among all these pollutants only began to appear in the early 1980s. In 1984, a major
 33 scientific assessment conducted the first standardized comparison of multiple stratospheric models using a
 34 few simple scenarios of emissions trends for CFCs and other chemicals. This exercise had the striking
 35 result that under a wide range of trends in other emissions, constant CFC emissions would lead to only
 36 very small ozone losses, while CFC growth above about 1 percent per year would lead to large losses.

37
 38 This result, together with resumed growth in CFC production, had a powerful effect in breaking the
 39 deadlock in international negotiations that had persisted since the mid-1970s. Although not the only
 40 factor that mattered, this result was crucial in persuading long-standing opponents of CFC controls to
 41 accept limits on their future growth. This decisively shifted the agenda for the subsequent negotiations
 42 that in 1987 yielded agreement on the Montreal Protocol, which cut CFCs by 50 percent.
 43

¹⁶⁶ This example drawn from Parson (2003).

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

5
6 **Box 4.2.2.**

7 ***Climate-Change Scenarios for the Insurance Industry***

8
9 The insurance and reinsurance industries face large financial risks from climate change. These are
10 present in many business lines, but the clearest risk is in insurance for property damage from weather-
11 related events, especially windstorms and floods.

12
13 In the past two decades, weather-related insurance losses have increased rapidly. By some estimates
14 losses have doubled, even controlling for population and insured value – a much faster increase than that
15 in losses from non-weather events. Climate change is likely to increase insurance risks in multiple ways,
16 increasing the frequency and severity of loss events and also their correlation. Historically based pricing,
17 which is often required by regulations or market conditions, can compound insurers' vulnerability by
18 preventing them from anticipating and adapting to a changed risk environment.

19
20 Insurance companies do not use scenarios of future climate change in pricing decisions, because property
21 and casualty contracts are written for short periods, usually one year. Since 1992's Hurricane Andrew,
22 these have mostly been priced using historically based Catastrophic Event Risk Models (Cat models).
23 These estimate losses using a simulated distribution of storm conditions based on historical experience,
24 together with estimates of the durability of insured property. While future climate change poses no risk
25 for these short-term pricing decisions, insurers are concerned that climate change may already have
26 invalidated the historical distributions on which these models are based, by increasing either the
27 probability of severe events or the correlation among them.

28
29 Two published exercises have used climate-change scenarios to explore longer-term risks to the insurance
30 industry. The first, conducted for the Association of British Insurers in June 2005, examined potential
31 impacts of climate change on the costs of extreme weather events (both insured and total economic costs)
32 under the six SRES marker scenarios, as well as IS92a and CO₂ stabilization at 550 ppm. The analysis
33 calculated changes in losses due to US hurricanes, Japanese typhoons, and European windstorms.

34
35 The second scenario exercise, conducted by Harvard Medical School researchers with sponsorship by
36 Swiss Re and the United Nations Development Program, used two scenarios of 21st-century climate
37 change to examine potential impacts on human and ecosystem health, and associated economic costs, not
38 limited to the insurance industry. The two climate scenarios both assumed CO₂ doubling by
39 approximately mid-century, one with continued incremental climate changes and one with hypothesized
40 nonlinear impacts and abrupt events. The exercise examined potential changes in infectious and water-
41 borne diseases, asthma, agricultural productivity, marine ecosystems, freshwater availability, and natural
42 disasters including heat waves and floods. The analysis was based primarily on qualitative judgments.

43
44 The first scenario showed increased property losses and business interruptions relative to recent trends,
45 emergence of new types of health-related losses, and increasing difficulty in underwriting. The second
46 scenario was qualitatively similar but more severe, with substantial increases in both average losses and
47 variability leading to large premium increases and withdrawal of insurers from many markets, particularly

1 along coastlines. As many insurance firms succumbed to mounting losses, those remaining established
2 strict limits on coverage, shifting more exposure back to individuals and businesses.

3
4 Neither of these exercises was connected to any specific, near-term business decision faced by insurance
5 companies. Both could serve longer-term decision-making, however, including planning for reserve
6 accumulation, providing supporting analysis for advocating mitigation and adaptation policies, and
7 providing support for changed regulations to allow more flexible pricing of risks experiencing long-term
8 increases. Such exercises can also serve to inform firms' long- term risk-avoidance strategies, including
9 decisions to exit certain areas of business.

10
11
12 ***Box 4.2.3.***
13 ***Scenarios of Climate Impacts in the Columbia River Basin***

14
15 In conjunction with the US National Assessment, researchers at the University of Washington studied
16 climate impacts on the Columbia River system, which is the primary source of energy and irrigation water
17 for the Northwest states and one of the most intensively managed river systems in the world.¹⁶⁷ The
18 project examined the response of annual and seasonal flows both to existing patterns of climate
19 variability, and to projected 21st century climate change.

20
21 The study projected climate change through 2050 using eight climate models driven by one emissions
22 scenario (1 percent per year CO₂ concentration increase), which on average projected 2.3°C regional
23 warming by the 2040s with precipitation increases of 10 percent in winter and a few percent in summer.
24 In the Columbia, these changes are projected to increase flows in winter (because there is more winter
25 precipitation and more of it falls as rain) and to decrease flows in summer (because there is less snowpack
26 and it melts earlier in the spring). The impact of summer decreases is likely to be substantially more
27 serious than that of winter increases. Because the Columbia is a snowmelt-dominated system, winter
28 flows could double or even triple and remain below the present spring peak.

29
30 Assessing the impacts of these flow changes requires assumptions about water demands and system
31 management. The study used a reservoir operations model that calculated the combined effects of flow
32 changes and alternative system-operation rules on the reliability of different water-management
33 objectives, such as electrical generation, flood control, irrigation supply, and preserving flows for salmon.
34 Under historical climate variability, all these objectives can achieve high reliability in high-flow years
35 (i.e., in the cool phase of ENSO or PDO), but conflict between them occurs in low-flow (warm) years,
36 when only one top-priority objective can be maintained at or near 100% reliability and other uses suffer
37 substantial risks of shortfall. Different operating rules distribute this risk among uses.

38
39 Under the projected climate and flows of the 2040s, this model showed a pattern of competition between
40 uses similar to but additional to what already prevails in low-flow years, suggesting increases in already
41 sharp conflict among uses over flow allocations. One objective could be maintained near full reliability,
42 but other uses suffered reliability losses up to 10 percent from the changed climate in addition to effects
43 of continued climate variability.
44

¹⁶⁷ Mote et al 2004; Payne et al 2004.

1 In this analysis, scenarios helped to illustrate interactions between management decisions and climate
2 change and variability, and to explore opportunities and limits for adaptation through management
3 changes alone, with no change in infrastructure or larger-scale policies. This analysis has not been
4 incorporated into any operational decisions, but has been integrated into the Fifth Conservation Plan
5 issued by the Northwest Power and Conservation Council.¹⁶⁸ More detailed assessment of climate-
6 change impacts would require extending this analysis to include projected changes in water demands,
7 both through direct climate effects and through scenarios of regional economic and population growth,
8 allowing a more realistic assessment of potential effects of new water-management investments and
9 changes in large-scale policies to alter water demand, balance competing uses, or improve coordination
10 among the multiple organizations involved in managing the river system.

11 12 ***4.3. The process of developing scenarios: Expert-stakeholder interactions***

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

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

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

¹⁶⁹ See, e.g., Chess and Purcell 1999; EPA 2001; Gregory and McDaniels 2005; Holling 1978; NRC 1996; Renn et al 1995.

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

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

19 But climate change scenarios typically serve larger and more diverse sets of users and
20 stakeholders. This is especially true for scenarios produced in large-scale, official assessments
21 such as the IPCC or US National Assessment. Climate-change stakeholders – defined by the
22 CCSP as “individuals or groups whose interests (financial, cultural, value-based, or other) are
23 affected by climate variability, climate change, or options for adapting to or mitigating these
24 phenomena¹⁷¹” – are an enormous group, diverse in their interests and responsibilities.

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

35 Other users, however, may be numerous, diverse in their disciplinary foundations,
36 methods, and tools, and not clearly identified. Their information needs may have some
37 commonalities but substantial differences. They may even have points of conflicting interest in
38 the construction and use of scenarios. The general case for stakeholder involvement remains
39 strong with such diverse users, especially in the initial design of a scenario exercise, and in the

¹⁷⁰ McLean et al., 2001.

¹⁷¹ CCSP 2003, p. 112.

1 evaluation and refinement of scenarios for relevance, practicality, and utility. In principle, the
2 required approach is to involve a reasonably diverse and representative group of users and
3 stakeholders, as well as an appropriate range of disciplinary and modeling experts, while keeping
4 the size of the scenario team manageable. But the judgments about participation and
5 representation needed to carry out this approach in any particular scenario exercise will be
6 complex and challenging.

7 Can a scenario process be completely open? In political settings, some insulation from
8 users may be needed to insure consistency across participating models and analyses. Whatever
9 approach to stakeholder participation is adopted, numbers must be kept manageable. Despite
10 recent progress in scenario methods allowing a substantial increase in the number of participants,
11 there are still practical limits. Although requirements for expertise external to the core scenario
12 team increase with scenario complexity, a scenario process is unlikely to work with a hundred
13 people in the room. A few scenario processes have engaged much larger numbers of
14 participants, but these have greatly reduced the complexity of the scenario-creation process by
15 limiting it to specifying inputs to a single interactive model, or have involved large numbers of
16 participants in independent, parallel sessions interacting with a computer-based model or
17 scenario construction system.¹⁷² These tensions between representational realism, participation,
18 and managerial feasibility pose challenges for design of processes of representation and
19 consultation in scenario development, on which further progress is needed.
20

21 ***Box 4.3.1.***

22 ***Scenarios in Acid-Rain Assessments: Two Approaches***

23
24 Two programs, one in the United States and one in Europe, developed scenarios in integrated-assessment
25 models of acid rain to inform policy decisions over sulfur emissions. Among many other differences, the
26 two programs differed strongly in their approaches to involving stakeholders, and in their effectiveness at
27 informing decision-making.
28

29 The US National Acid Precipitation Assessment Program (NAPAP) was created in 1980 as a 10-year
30 program to study all aspects of acid deposition: emissions, transport and deposition, impacts, and control
31 strategies.¹⁷³ Managed by a committee of six government agencies and supported by a full-time staff
32 office, the program involved roughly 2,000 researchers.¹⁷⁴ Although charged to conduct both scientific
33 research and assessment, NAPAP strongly emphasized research.¹⁷⁵ Its assessment report was opaque on
34 the origin and interpretation of its scenarios, and did not use the scenarios to integrate across the issue or
35 examine implications of alternative policies. Overall, NAPAP is regarded as having succeeded as a
36 research program, but fallen critically short in providing useful information for decision making.
37

38 An alternative approach to acid-rain assessment was taken in Europe as part of the policy debates under
39 the Convention on Long-Range Transboundary Air Pollution (LRTAP). The core of this assessment was
40 a cooperative program to monitor and model acid emissions, transport, deposition, and impacts. In

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

¹⁷³ NAPAP, 1982; Herrick, 2004.

¹⁷⁴ Herrick, 2004.

¹⁷⁵ Roberts, 1991; Cowling, 1992; Russell, 1992.

1 contrast to NAPAP, this program focused more on assessment than research, being specifically
2 established to inform the policy process.¹⁷⁶ Scientific models of components of the acid-rain issue were
3 chosen to contribute to a simplified integration of the problem; scenarios of emissions and controls were
4 chosen in consultation with officials, in an attempt to replicate the policy alternatives under consideration.
5

6 The culmination of this pursuit of simple, accessible, and policy-relevant analyses was the RAINS model,
7 developed at the International Institute for Applied Systems Analysis (IIASA) in Austria. As a result of
8 its flexibility, ease of use, and relevance to policies under consideration, the RAINS model was used
9 extensively by policy-makers in the negotiation of sulfur-control agreements under the Convention, and
10 had substantial influence over the controls adopted.¹⁷⁷
11

12 The contrast in approach and outcome between these two programs suggests the potential value of close
13 interaction between experts and stakeholders in producing scenarios, at least when the stakeholders are
14 relatively expert officials responsible for a specific set of decisions. In the European case, such close
15 interaction helped to ensure the credibility of baseline emissions scenarios and the relevance of proposed
16 control scenarios, despite the diverse and sometimes contending interests of the participating officials.
17 The contrast between the two programs also suggests that there can be significant tradeoffs between
18 scientific and assessment objectives in programs that seek to integrate the two activities.
19

20 **4.4. Communication of Scenarios**

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

27 Although specific needs will vary from case to case, any communication of scenario-
28 based information to a large diverse public audience is likely to require a few common elements.
29 First, in addition to the scenarios' content, enough information should be provided about the
30 process and reasoning by which the scenarios were developed. This allows users and
31 stakeholders to understand and critique scenarios, and to determine their own levels of
32 confidence. Second, scenarios developers should identify the uncertainties considered. A
33 particularly important distinction to communicate clearly is between scientific uncertainty and
34 scenario uncertainty, including explicit statements of when and how scenarios change (e.g., the
35 reduced SO₂ projections in the IPCC SRES scenarios), and clear explanations of the effects of
36 such changes. Third, related to uncertainty, developers should acknowledge the unavoidable
37 elements of subjective judgment in developing scenarios, and be prepared to explain and defend
38 the judgments they made. Fourth, when particular scenarios were constructed to have specific
39 meanings – e.g., a reference case, a plausible worst-case, or the exploration of a particular causal
40 process taken to its extreme – these should be clearly conveyed. Fifth, if scenario developers
41 have articulated any indicators of the confidence they place on scenarios or distributions of

¹⁷⁶ Gough et al 1998.

¹⁷⁷ Levy 1995.

1 associated variables, this information and any supporting reasoning should also be made
2 available.

3 Scenarios' communication strategy should attempt to steer users away from certain
4 common pitfalls, such as choosing one scenario and treating it as a highly confident prediction,
5 or taking the range spanned by a set of scenarios as encompassing all that can possibly happen.
6 An effective strategy of communicating scenarios and their underlying reasoning can help to
7 engage users in the process of updating and improving scenarios. Providing transparency rather
8 than claiming authoritative status for scenarios is likely to increase users' confidence that the
9 scenarios have reasonably represented current knowledge and key uncertainties. It also provides
10 users with the tools to develop alternative representations if they are unconvinced.

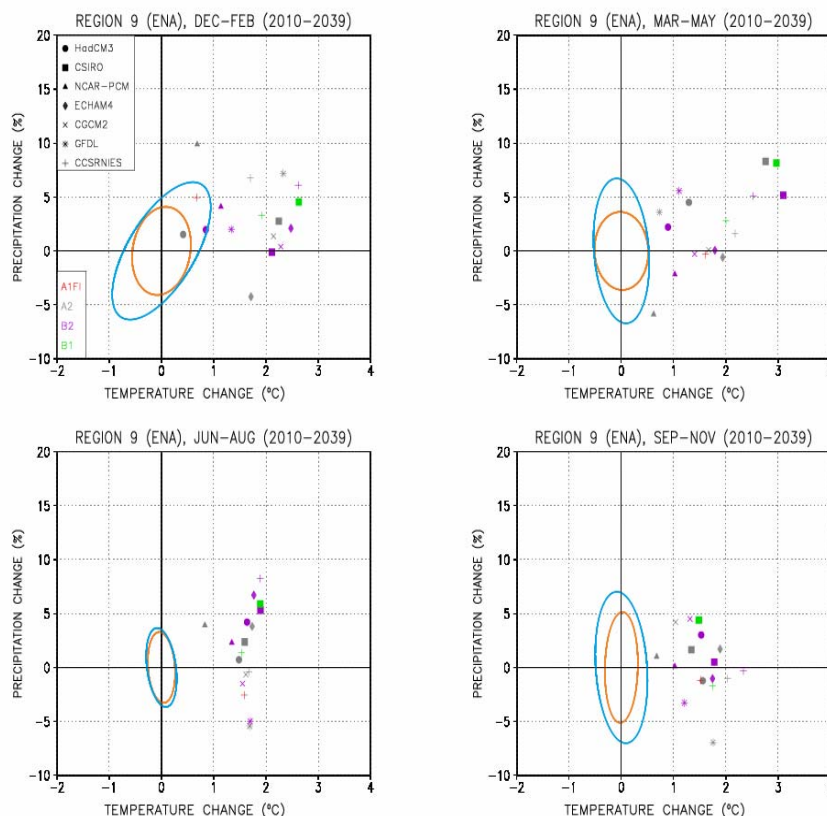
11 In large and complex assessments such as the IPCC and US National Assessment,
12 communication of scenarios and underlying information both to various groups within the
13 assessment and to potential outside users poses representational and managerial challenges.
14 Scenario exercises have experimented with various visual techniques for conveying complex
15 information in vivid and understandable form, including landscape representations, maps, and
16 pictures, as well as various graphical and tabular formats.¹⁷⁸ In the US National Assessment,
17 climate scenarios and other related information were provided to participating assessment teams
18 in several formats (e.g., tabular summaries, models, graphic representations), through websites
19 backed up with workshop presentations. In the IPCC, the Task Group on Data and Scenario
20 Support for Impact and Climate Analysis (TGICA) was established in 1997 to facilitate
21 distribution of climate scenario data, model results, and baseline and scenario information on
22 other environmental and socio-economic conditions, for use in climate impact and adaptation
23 assessments. Data, scenarios, and supporting information are distributed over the internet by the
24 IPCC Data Distribution Center (DDC).¹⁷⁹

25 To compactly communicate uncertainty in climate scenarios, the TGICA and several
26 national scenario efforts have developed various graphical methods, including scattergrams
27 showing the range of projected temperature and precipitation changes generated by several
28 climate models using four SRES marker scenarios, and comparing these projected changes to
29 estimates of natural variability.¹⁸⁰ In Figure 4.4.1, each data point represents one climate-model
30 projection associated with a given SRES emissions scenario. Efforts to develop similarly
31 compact representations of the distribution of scenarios for extremes as well as annual and
32 seasonal averages are underway.

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

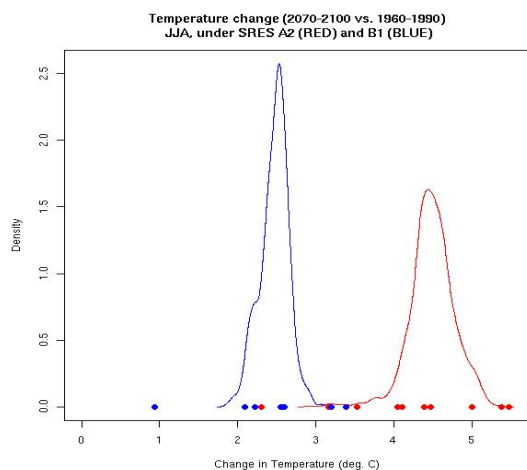
¹⁷⁹ Information on the TGICA is at ipcc-wg1.ucar.edu/wg1/wg1_tgica.html. The DDC is jointly operated by the UK Climatic Research Unit and the Deutsches Klimarechenzentrum, with several mirror sites around the world. Data are provided via the web or CD-ROM. All data distributed are in the public domain.

¹⁸⁰ Ruosteenoja *et al.*, 2003; Mearns and Tibaldi _____



1
 2 Figure 4.4.1. Regional scattergram for eastern North America, 2040-2069. The x-axis shows temperature changes
 3 in °C, the y-axis precipitation changes in percent. Each point shows one model’s projection under one emissions
 4 scenario. A point’s color denotes the corresponding emissions scenario, its shape the corresponding model (per
 5 legend, lower left of figure). Ovals show 95 percent confidence bounds for natural 30-year climate variability,
 6 calculated from unforced 1000-year runs of the models CGCM2 (orange) and HadCM3 (blue). Points outside the
 7 ellipses indicated projected climate change significantly outside the range of natural variability, most frequently due
 8 to changes in temperature rather than precipitation. (Source: Ruosteenoja *et al.*, 2003)

9 To help users select climate scenarios for impact assessments, an alternative to
 10 summarizing climate-model scenarios in such scattergrams is to combine various climate-model
 11 results using statistical methods to construct explicit probability distributions for important
 12 climate variables. Figure 4.4.2 shows one such method, which assigns weights to model results
 13 based on their bias in simulating the current climate (smaller biases are assigned higher weight)
 14 and their correspondence with other model results (outliers are assigned lower weights). This
 15 method compactly communicates multiple model results, clearly conveying which ones fall at
 16 the top and bottom of the distribution (“unlikely to be higher/lower than this”), and which fall in
 17 the middle of the range.
 18



1
2 Figure 4.4.2. Constructed probability distributions of model-simulated temperature change in 2070-2100 compared
3 to historical temperature (1960-1990) in the Gulf Coast region, using 19 climate models with the SRES A2 (red) and
4 B1 (blue) scenarios. Each point along the x axis represents a different model run.

5 This current focus on collections and intercomparisons of model-based projections with
6 various emission scenarios represents a new approach for communicating scenario-driven model
7 output to users engaged in assessment and adaptation activities. It has enabled users to consider
8 a broader range of emission scenarios and climate models than was feasible in the US National
9 Assessment and previous IPCC assessments. It allows users to consider all available model and
10 scenario combinations to span the literature, or to select only scenarios that exceed some
11 threshold of interest or fall within some specified probability range. Future assessments should
12 benefit from this type of multi-model, multi-scenario approach, which allows users more
13 effective and informed choice over scenarios to consider.

14 ***4.5. Consistency and Integration in Scenarios***

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

22 Certain elements of internal consistency in scenarios are unproblematic, such as avoiding
23 gross contradictions with well known principles of behavior of biophysical or socio-economic
24 systems, and not inadvertently moving far outside the bounds of historical experience.
25 Inadvertently implausible assumptions can arise, for example, when multiple elements of a
26 scenario are specified without cross-checking; e.g., end-year specifications of a region’s
27 population and GDP without checking the implied growth rate in GDP per capita, or specifying
28 energy-related emissions trajectories without checking what they imply for resource availability.
29 Avoiding these pitfalls requires thorough cross-comparisons of related values with each other, of
30 terminal values with implied time-trends in the intervening period, and of values within and

1 between regions. Scenario developers should not always and necessarily avoid extreme or
2 unprecedented outcomes, however. Presenting extreme or seemingly implausible future
3 conditions *intentionally*, with an explanation of how they could in fact arise, can contribute to
4 several of the major purposes of scenarios, e.g., shaking up habitual thinking and broadening
5 expectations of what future developments are plausible.

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

13 Expressed in probabilistic terms, statements about internal consistency may be
14 interpreted as claims that alignments of factors similar to those in the scenario are more likely
15 than other, dissimilar alignments. One might, for example, claim that a scenario with rapid
16 growth and both the economy and energy use is more internally consistent than one in which the
17 economy grew rapidly but energy use did not. But where do these perceptions of greater or
18 lesser likelihood come from, and how valid are they? In some cases a well-founded theory or
19 model might say that certain outcomes tend to be related. Alternatively, explicit analyses might
20 connect the claim to underlying assumptions that are open to scrutiny and criticism. But in the
21 absence of such transparent foundations for judgments of what scenario conditions are consistent
22 and what are not, these claims can only rest on more diffuse judgments by scenario developers,
23 refined and tested through various deliberative processes – e.g., arguing about the claims,
24 working through their implications relative to those of alternative specifications, identifying
25 additional bodies of research and scholarship that can be brought to bear, etc.

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

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

39 More likely, an integrated scenario would be constructed by combining exogenous
40 assumptions about some elements with model-calculated values for others. This approach does
41 not avoid increasing risks of inconsistency and contradiction as a scenario is expanded,

1 particularly when multiple models are used. Since models embody specific, quantitative causal
2 relations among variables, they do not require – or indeed allow – all variables to be specified.
3 Scenarios provide only those exogenous inputs that the model does not produce. These scenario-
4 based inputs should be consistent with each other, but to a lesser extent than the precise standard
5 that defines consistency in a scenario. These exogenous inputs, together with model results, can
6 jointly comprise a scenario that is generated for some alternative use.

7 Consistency problems grow when scenario exercises involve multiple models and
8 attempts are made to achieve model harmonization. When scenarios are constructed partly out
9 of exogenous inputs provided by a scenario (made consistent as much as possible through
10 qualitative or intuitive causal reasoning) and partly out of models, multiple models are often
11 used. Using multiple models in parallel can allow for more extensive exploration of causal
12 relations, and helps to characterize uncertainty in scenarios since different models embody
13 different representations of causal processes. It may also enhance the credibility of the process.
14 But models of the same broad set of phenomena – e.g., models of the economy and energy sector
15 – frequently differ in which variables they require as exogenous inputs and which ones they
16 calculate endogenously. In this case, some variables must be specified exogenously for some
17 models, but are calculated endogenously by others.

18 This creates various problems for consistency. In general, when scenario exercises are
19 conducted in this way, some elements are assumed and others are model-calculated. Attempting
20 to avoid this poses even more serious problems, however. It is not usually possible to arbitrarily
21 perturb the exogenous input variables so all inputs and outputs match across all models, since
22 such perturbations will influence other variables in the model. Consequently, avoiding these
23 inconsistencies will require manipulating internal relationships within models to make their
24 outputs match the specified values, given the common inputs. But such reverse-engineering of
25 internal model relationships to match specified outputs, in addition to being exceedingly
26 cumbersome and arbitrary, can corrupt the internal logic of models, obscure the interpretation
27 and significance of results, and make it impossible to use model variation to illuminate
28 uncertainty.

29 For example, in an exercise to generate non-intervention scenarios of potential future
30 emissions, little insight is likely to be gained from defining scenarios in terms of the resulting
31 emissions and forcing the different models to generate these emissions targets.¹⁸¹ It may be
32 equally fruitless to define scenarios in terms of GDP and energy consumption trajectories and to
33 force multiple models to reproduce these. For this reason, multi-model exercises such as the
34 Energy Modeling Forum usually seek to harmonize only a few of the most essential and
35 commonly used inputs.¹⁸² When multiple models are used to generate scenarios, the most useful
36 way to pursue consistency may be to develop common assumptions for the variables furthest

¹⁸¹ 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.

¹⁸² Weyant and Hill 1999.

1 back in the causal chain, but the wide variation of model structure can make even this approach
2 to harmonization challenging.

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

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

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

27 There are good reasons to combine narrative with quantitative approaches, as scenario
28 exercises have increasingly sought to do. But the connection between qualitative and
29 quantitative aspects of global-change scenarios has been inadequate, diminishing the usefulness
30 of the exercises due to inconsistencies within each type of scenario and between the two types.
31 This problem has partly been due to limited time and resources, but has also reflected substantive
32 difficulties in linking the two types of scenario that have not been understood or managed well.
33 Narrative scenarios typically specify deep structural characteristics like social values and the
34 nature of institutions, which are associated with structural characteristics of models such as the
35 determinants of fertility trends, labor-force participation, savings and investment decisions, and
36 substitutability in the economy. Consequently, the differences among alternative narrative
37 scenarios, reflecting different basic assumptions about how the world works, correspond more
38 closely to variation of model structure than to variation of parameters. Better integrating the two
39 approaches will require developing ways to connect narrative scenarios to model structures,
40 rather than merely to target values for a few variables that models are then asked to reproduce.
41 This has not happened because scenario exercises have not had the capability or resources to
42 direct new model development, or to induce modelers to undertake substantial structural changes

1 to their models. This would require substantial efforts, including getting modelers to interact
2 with scenario exercises in a new way, but might hold more promise for allowing scenarios to
3 usefully inform discussions about large-scale policy choices for mitigation and adaptation.

4 ***4.6. Treatment of Uncertainty in Scenarios***

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

10 In most scenario exercises, uncertainty is represented not in a single scenario, but in
11 variation across several scenarios considered together.¹⁸³ The choices to be made in deciding
12 how to represent uncertainty include the following:

- 13 • What characteristics are varied
- 14 • By how much these characteristics are varied, separately and together (e.g., should
15 extreme values of multiple characteristics be combined, or extremes of some combined
16 with the middle cases of others)
- 17 • How many scenarios to create and consider together
- 18 • What description, documentation, or other information is attached – including whether
19 and how specifically measures of likelihood are assigned.

20 ***4.6.1. Uncertainty in simple quantitative projections: basic approaches***

21 How these choices are made and their implications for scenario use and effectiveness are
22 closely related to the large-scale decisions in designing a scenario exercise outlined in Section
23 2.1. In particular, the role of uncertainty in a scenario exercise is strongly linked to scenario
24 complexity, richness, and use. In the simplest case, a scenario exercise may be dominated by a
25 single quantitative variable, so all uncertainty could be represented by alternative future levels or
26 time-paths of that variable. This case is so simple that many scholars and practitioners argue it
27 should not be considered a scenario at all.¹⁸⁴ Still, even this simple and extreme case raises
28 significant issues. We begin here and then move to more complex cases.

29 If we also assume that the probability distribution is known, the situation reduces to a
30 formal exercise in analysis of decision-making under uncertainty. Given a known set of choices
31 and outcomes of each choice under each uncertain outcome, alternative choices can be evaluated
32 by formal methods such as seeking the best outcome on average or under some risk-averse
33 valuation scheme, or seeking robust strategies. This decision-analytic approach can be extended

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

¹⁸⁴ E.g., Wack 1986, states that such a scenario is just a “quantification of a clearly recognized uncertainty”.

1 to situations of a few uncertain variables with a known joint distribution, multiple decision-
2 makers who evaluate outcomes differently, or (with somewhat more difficulty) decision makers
3 with different probability distributions.

4 Further relaxation of these simplifying assumptions moves us toward activities that are
5 more widely recognized as scenario exercises. First, if a scenario exercise is addressed to more
6 than just a few decision-makers with known choice sets and outcome valuations, scenarios can
7 no longer simply be inputs to an analytic exercise, but rather become descriptions of potential
8 future states that must be communicated directly or indirectly to decision-makers for their
9 reflection and deliberation. Second, if distributions of important quantities are unknown, it is
10 necessary to exercise judgment regarding how to draw on relevant knowledge to construct and
11 describe alternative future values of the quantities, and how to represent these values to users
12 with a manageable number of scenarios.

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

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

35 Estimating output distributions based on assumed distributions of uncertain input
36 parameters does not capture all uncertainty of importance for assessment and decision-making.
37 The input probability distributions are not known with certainty, nor are the structural
38 assumptions that determine the mapping of inputs onto outputs within any particular model.
39 Uncertainty analysis can embrace this additional level of uncertainty, sometimes called “meta-
40 uncertainty,” by stepping up one more level of abstraction – considering not just uncertain
41 quantities, but uncertainty about their uncertainty, or alternatively, probability distributions over
42 probability distributions of unknown quantities. Methods to represent and process such meta-

1 uncertainty mirror those used for first-order uncertainty. This is an active area of research, but
2 its importance for assessment methods and their application is unclear. This level of abstraction
3 increases the difficulty of communicating scenarios and their underlying reasoning transparently
4 and comprehensibly to non-specialists. Moreover, since any step of analysis represents an act of
5 potentially fallible judgment, taking the step to meta-uncertainty still does not capture all
6 possible uncertainty. It is not clear whether, for purposes of constructing and using scenarios,
7 the explicit separation of uncertainty in outcomes from uncertainty in probability distributions
8 brings more benefit than could be gained from simple heuristic guidance to assume distributions
9 are wider than initially seems necessary.

10 Subjective bias is a major risk in all scenarios, which can be reduced but not eliminated
11 through use of existing data and formal modeling. Judgment is an essential element in
12 constructing scenarios, both to apply relevant data and models when these are available, and to
13 build future descriptions using less formal methods when they are not. The expert judgments
14 supporting such less formal projections may be better founded than mere uninformed
15 speculation, since there is typically much relevant knowledge available beyond what is explicitly
16 captured in present datasets and models. Approaches to developing expert-judgment based
17 projections vary widely in their structure and formality, from simply asking one or more experts
18 to state their best estimate of some unknown quantity, to highly structured elicitation exercises
19 that provide multiple cross-checked estimates of the same quantity.¹⁸⁵ Such methods must attend
20 to risks of overconfidence and bias, which are well documented in experts as well as laypeople.
21 Carefully designed elicitation protocols can reduce the effects of such biases, e.g., by prompting
22 experts to broaden their estimates of uncertain quantities, but cannot eliminate them.¹⁸⁶ An
23 additional challenge to these methods is that there is no generally accepted method for selecting
24 or aggregating estimates from multiple experts.

25 **4.6.2. How many scenarios, over what range?**

26 In communications of scenarios, limited time, resources, and attention usually require
27 that only a few discrete values or time-paths are specified, not a complete distribution. Scenario
28 developers must decide how many scenarios to provide and how to space them.

29 How many scenarios to provide rests on a judgment of the value provided by each
30 additional point from the underlying distribution relative to the burden of producing and using
31 each new scenario. If the use made of each scenario is expensive – e.g., consuming large
32 quantities of time of busy senior people, or running a large model – then the number of scenarios
33 that can be adequately treated may be very few. The 1992 IPCC scenario exercise provided six
34 separate scenarios, of which nearly all subsequent analyses used just one or two. Of the forty
35 scenarios produced by the SRES process, only six (initially four) were highlighted as “marker”
36 scenarios, while most subsequent analyses used just two or three.¹⁸⁷

¹⁸⁵ Morgan and Keith 1995.

¹⁸⁶ Tversky and Kahnemann 1974; Wallsten and Whitfield 1986.

¹⁸⁷ Initially A2 and B2 were most widely used. More recent work has used A2 and B1, sometimes with A1B.

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

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

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

26 It is often suggested that an important condition of a set of scenarios is that they “span the
27 literature” of prior scenarios or projections of the same quantities. While one should be cautious
28 about a set of scenarios spanning a much narrower range than published estimates of the same
29 quantities, there may be good reasons for a wider or different range, or even in some cases for a
30 narrower range. A published scenario may have been constructed to serve various purposes
31 other than providing an independent new estimate of a quantity of interest. Previous scenarios
32 developed to serve some particular purpose may or may not be relevant to a new scenario
33 exercise, depending on the relationship between their intended purposes. Moreover, previously
34 published scenarios can be highly self-referential, since many published analyses use prominent
35 pre-existing scenarios as inputs to a new study, or examine a new model by forcing it to
36 reproduce some pre-existing scenario. For all these reasons, previously published scenarios are
37 better regarded as one input to the judgment of developers of new scenarios than an authoritative
38 picture of present knowledge that new scenarios must follow.

39 ***4.6.3. Bifurcations and major state changes***

40 While many uncertainties may be treated as a continuous range of possible values, some
41 uncertainties may capture large-scale bifurcations or abrupt changes. For climate change,

1 potential abrupt changes include melting of major continental ice sheets or shifts to some new
2 mode of ocean circulation.¹⁸⁸ Large-scale bifurcations may also arise from breakthroughs in
3 energy technology. Such possibilities are typically not captured in either historical data (because
4 they are by assumption novel), or models (because they would represent a change in the causal
5 structure represented in models).

6 Abrupt changes can pose particular challenges for deciding the number and range of
7 scenarios to include in an assessment or decision-support exercise, either because their
8 consequences are so extreme or because they would fundamentally change our understanding of
9 how the system operates. The decision of whether and how to consider these uncertainties
10 consequently turns on the balance between their probability – which is believed to be low but not
11 well characterized – and their high consequences, which must be evaluated relative to the
12 scenarios' intended use. This will be a particularly difficult choice when only a few scenarios
13 are being generated. For example, in a coastal impacts assessment the enormous consequences
14 of the difference between a half-meter and a five-meter sea level rise over this century – and the
15 well-identified mechanism by which such a large rise could occur – may suggest the importance
16 of explicitly considering a scenario involving loss of one of the major continental ice masses.
17 But including such a scenario runs the risk that users will assign it a much higher probability
18 than is appropriate, either because of its vividness and extremity or because they presume that
19 developers' decision to include the scenario meant that they assigned high probability to it.
20 When such a scenario is included, scenario developers have a serious responsibility to
21 communicate, loudly and consistently, its different status.

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

30 ***4.6.4. Uncertainty in Multivariate or Qualitative Scenarios***

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

35 The most basic of these is that with multiple dimensions of variation in scenarios, it is
36 necessary to decide which uncertainties are represented. Even when scenarios include only
37 multiple quantitative variables, it is no longer possible for a few scenarios to span all corners of
38 the joint distribution of these variables. Rather, they must combine variations in ways that are
39 most illuminating and important for the purpose at hand, massively reducing the dimensionality

¹⁸⁸ NRC 2002.

1 of the problem to make it intelligible for users. In addition, increasingly detailed and realistic
2 scenarios often specify characteristics that are qualitative, or described less precisely than
3 cardinal variables. For example, alternative scenarios might specify that current trends of
4 globalization increase, stagnate, or reverse, or that decision-making capacity on climate change
5 increases or decreases. Such characteristics may be judged crucial to include because they may
6 be among the most important drivers of preferred choices or consequences of concern.

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

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

22 This approach, formalized in the Shell scenarios method,¹⁸⁹ involves two steps: first
23 identifying a small number of fundamental uncertainties and a small set of alternative
24 realizations of each; and then, elaborating additional future characteristics associated with each
25 realization through both qualitative reasoning to fill in a narrative, and assembly of data and
26 model results to build a parallel quantitative description to the extent this is judged useful.
27 Repeated, critical iteration between the qualitative and quantitative elements is conducted, to
28 bring additional relevant knowledge and expertise to bear and to check for consistency.

29 Even rich narrative multivariate scenarios must imply certain claims of likelihood. Every
30 scenario included must be deemed likely enough to merit the resources and attention spent on
31 developing and analyzing it. This applies even to extreme-event scenarios that are intentionally
32 constructed to capture the low-probability tail of the distribution, since even they must be
33 perceived likely enough to merit time and attention given their severity. Since users would reject
34 any scenario that they persistently judged too implausible to consider, when decision-makers
35 find a scenario exercise useful, it validates developers' judgment that each scenario was likely
36 enough to consider.

37 In a purely mathematical sense, any one specific rich multivariate scenario must be
38 arbitrary and of vanishingly small probability. There are, however, ways in which it may be
39 reasonable to assign non-zero probabilities to multivariate scenarios. First, if scenario designers

¹⁸⁹ Shell International 2003.

1 in fact succeed at identifying a few deep structural uncertainties that strongly condition outcomes
2 on many other characteristics in a scenario, then the richness of a scenario description need not
3 imply that it is vanishingly unlikely. Whether this is true or not is a judgment to be made by
4 scenario developers and users in each application. If they are sufficiently careful in their
5 development and critical examination of scenarios, their judgment may well be correct. But
6 there will often be no way to further test these judgments, so it is of course possible that the
7 proliferation of additional detail in scenarios – even detail that developers and users recognize is
8 crucial for determining valued outcomes and preferred choices – is arbitrary or erroneous.

9 A second way in which rich, detailed scenarios may be judged sufficiently likely to
10 consider concerns the precision with which scenario characteristics are specified. In rich
11 multivariate scenarios, many characteristics are often specified diffusely: economic growth may
12 be merely “high” or “low”, rather than stating a particular value. Even when a characteristic is
13 stated quantitatively, its particular value may be treated as merely illustrative of a range of
14 similar values; e.g., annual GDP growth might be set at 4 percent because a user needs a
15 numerical model input, but it is understood to represent a broad range of similar values that all
16 count as “high” growth. Interpreted in this way, a multivariate description may remain likely
17 enough to merit examination – and indeed, a modest number of scenarios may exhaust the set of
18 potential futures that matter for the issue at hand. Here one is not assigning likelihood to the
19 precise numerical assumptions used to flesh out the details of a scenario, but rather to a thick
20 slice of future conditions that resemble that scenario more than the other scenarios in the set.

21 ***4.6.5 The Debate over Quantifying Probabilities***

22 A major debate in the use of global-change scenarios has concerned whether or not to
23 specify quantitative probabilities associated with scenarios. This debate is central to the meaning
24 and use of scenarios, and has been sharpest over the IPCC’s SRES scenarios. Developers of the
25 SRES scenarios decided at the outset of their process that they would make no attempt to assign
26 probabilities to scenarios, in part because they were adopting the Shell approach of developing
27 scenarios from storylines, in which quantitative probabilities are usually avoided. After the
28 scenarios were published, several critics argued that since the most prominent and important
29 outputs were the projections of emissions under the six marker scenarios, it was natural – and
30 essential for development of rational climate-change policy – to describe the distribution of
31 emissions in probabilistic terms. For example, how likely are 2100 emissions to lie above the 30
32 GtC of scenario A2 or below the 5.2 GtC of B1? Should the range spanned by all forty SRES
33 scenarios be understood to comprise 90 percent of all probability? 99 percent? All of it?

34 Developers of the SRES scenarios stood by their initial decision not to quantify
35 probabilities. Since the controversy only became prominent long after the decision had been
36 made by a writing team no longer in operation, it would have been virtually impossible for the
37 group to retrospectively assign such probabilities. But rather than rely on this argument of
38 managerial infeasibility alone, SRES organizers offered a vigorous substantive defense of their
39 initial decision. This defense relied in part on the statement that the six marker scenarios were
40 all “equally sound,” without providing any guidance regarding what this meant other than
41 explicitly denying that it meant “equally likely.” Describing each of the six marker scenarios as
42 “equally sound” represents the entirely reasonable case that in the developers’ judgment these all

1 needed to be considered seriously –without making any further judgment as to their likelihood.
2 While clearly frustrating to those wanting to use the scenarios as a basis for policy, the result is
3 entirely consistent with the IPCC mandate to do assessment, but not to reach policy conclusions.

4 This debate, however, will continue and rests in part on different conceptions of the
5 meaning, and typical contents of a scenario. The simpler the contents of scenarios, the more
6 readily they lend themselves to explicit quantification of probabilities. When scenarios consist
7 only of alternative time-paths of a single quantitative variable, or one such variable is of
8 predominant importance, it is straightforward and sensible to understand the intervals between
9 those time-paths to have probabilities associated with them and there are several strong
10 arguments for being explicit about these probabilities. First, stating probabilities allows
11 comparative risk assessment between scenarios and explicit exploration of risk-reducing
12 strategies.¹⁹⁰ Second, sophisticated decision-makers whose choices depend on uncertainty in
13 these variables need probability information about possible values, not just a set of alternative
14 values, to evaluate choices – whether their approach to decision-making is based on expected
15 values, risk-aversion, seeking robust strategies, or some other approach. Finally, when such
16 scenarios are presented without probability judgments, users may attach their own, often via
17 simple heuristic devices that may misrepresent the developers’ understanding. For example,
18 many subsequent users of the SRES emissions scenarios have simply assumed the probabilities
19 they needed to conduct further assessments, using such simple devices as counting scenarios or
20 assuming a uniform distribution over the entire range.

21 Opponents of explicit quantification of probabilities do not dispute that such probabilities
22 can coherently be assigned to simple scenarios in one or two quantitative variables. Rather, they
23 raise principled objections to the appropriateness of attempting to quantify probabilities for more
24 complex scenarios, particularly those involving socio-economic conditions, as well as practical
25 objections to the use of probabilities even in the case of simple quantitative scenarios.

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

30 First, some argue that the large multivariate space of possibilities from which such
31 scenarios are drawn, and the vague and qualitative way that some scenario characteristics are
32 specified, make it impossible to coherently define the boundaries of the outcome space to which
33 probabilities are being assigned. There is no way to clearly define the interval “between” one
34 scenario and another; and if probability is attributed to a slice of possibilities around each
35 scenario rather than to the intervals between them, is it not possible to define clearly the
36 boundaries of the slice to which the probability is assigned. To the extent that scenarios describe
37 different types of worlds, which are distinguished from each other by alternative resolution of a
38 few key uncertainties – e.g., high or low growth, high or low globalization – where the location
39 of the boundary is not precisely specified, it may be difficult to create a shared understanding of
40 these boundaries between users and creators. But if assigning a precise numerical probability is

¹⁹⁰ Webster 2003.

1 judged too difficult in these cases, less precise descriptions such as “highly likely”, “more
2 likely”, “less likely,” or “roughly equal” could be assigned. In some applications where
3 scenarios are intended to capture all the uncertainty of concern to the decision-maker – i.e.,
4 scenarios are intended to be mutually exclusive and collectively exhaustive – there may even be
5 a reasonable basis for numerical probability.

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

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

36 Finally, some argue that probabilities cannot be known, or even sensibly estimated, for
37 socio-economic futures – perhaps because socio-economic processes and mechanisms are
38 intrinsically less knowable than biophysical ones, perhaps due to the unpredictable effects of
39 human creativity and leadership, and perhaps because causation does not operate in the human
40 domain as it does in the bio-physical domain. Although these arguments raise deep
41 philosophical questions, as a practical matter probabilistic projections are routinely done in some
42 socio-economic domains, including projections of population and economic growth, but not, or

1 not well, in others, such as projecting technological innovation. Provided the basic concept of
2 subjective probability is accepted, weaker knowledge and deeper uncertainties can be
3 accommodated by broadening the relevant uncertainties rather than declining to make
4 probabilistic judgments, but the question remains of whether the resultant broad uncertainty
5 ranges are meaningful or operationally useful.

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

13 An additional practical argument against quantifying probabilities is that attempting to do
14 so may represent a distraction that uses time, generates conflicts, and is of little value to scenario
15 users. Whether this is indeed the case, however, is in part a judgment to be made by scenario
16 users, not developers. Opponents of quantified probability argue that users typically only need
17 scenarios to pass some probability threshold. Beyond this threshold, they will seek robust
18 choices that yield acceptable outcomes under all possibilities, so further refinement of
19 probability serves no purpose. This argument has merit, but only to the extent that it accurately
20 describes how these scenarios will be used. Quantitative assignment of probabilities to scenarios
21 when high-stakes decisions are implicated is clearly difficult and contentious, as the SRES
22 controversy illustrates. Even if this argument correctly characterizes how scenarios are used,
23 users might still be able to profitably exploit more detailed probability information if it were
24 available – although one must also consider the risk that non-technical users might somehow be
25 more likely to misunderstand scenarios with explicit probability judgments attached (perhaps by
26 taking a stated probability distribution as the “true” distribution) than to misunderstand a simple
27 collection of scenarios presented with no such probability information (perhaps by taking the
28 range presented to embrace the totality of all possibilities). It is also possible that engaging
29 scenario users in an attempt to assign probabilities, even only illustratively, could both draw on
30 relevant knowledge of uncertainties that they possess more than scenario developers, and provide
31 a valuable device to probe and sharpen their understanding of the situation. Any argument that
32 refers to the information needs of specific users becomes less persuasive as the set of potential
33 uses and users, and the likely diversity of their information needs, grow larger.

34 Overall, we find the arguments in favor of quantifying probabilities to be strongest for
35 scenarios whose major outputs are projections of one quantitative variable (or very few), and
36 weakest for complex multivariate scenarios with substantial qualitative or narrative elements.
37 The controversy over probabilities in SRES reflected in part different perceptions of what type of
38 scenarios these were. SRES initially followed a storyline-based process and rejected
39 quantification of probabilities on that basis. Subsequent efforts, however, consisted
40 predominantly of developing quantitative emissions projections and neglected further
41 development of the storylines. Moreover, with a few significant exceptions, subsequent
42 applications of the scenarios have principally used their emissions figures, sometimes together

1 with population and GDP, and made little or no use of the under-developed storylines that lay
2 behind them. The controversy over quantitative probability in this case suggests that when
3 quantitative projections are a major output of a scenario exercise, developers may have a
4 responsibility to go further in characterizing the likelihood of the resultant emissions intervals
5 than would be appropriate for the more complex underlying storylines.

6 Moreover, even for rich narrative scenarios, the arguments against rendering probability
7 judgments are strongest when the exercise is produced for a small number of users with similar
8 responsibilities and concerns. In such a setting, intensive interaction between scenario
9 developers and users can provide whatever additional detail about, or confidence in, the
10 scenarios that users may require to benefit from the scenarios. When scenarios serve potential
11 users who are more numerous and diverse, however, such intensive interaction is not possible.
12 As a result, the theoretical value of explicit likelihood judgments increases. To the extent that
13 future global-change exercises continue to strengthen their qualitative aspects and the integration
14 between qualitative and quantitative – valuable directions for future efforts – they should still
15 seek to move further toward explicit characterization of likelihood than has been done thus far.
16

17 ***BOX 4.6.1***

18 ***The Global Business Network Abrupt Climate Change Exercise***

19 In 2002, the Office of Net Assessments (ONA), a small strategic planning office in the Office of
20 the US Secretary of Defense, asked the Global Business Network (GBN), a consulting firm expert in
21 scenario methods, to develop a scenario of potential national-security implications of abrupt climate
22 change. This request was stimulated by widespread scientific interest at the time in abrupt climate
23 change, particularly shifts in North Atlantic circulation, including a 2002 report by the National Academy
24 of Sciences.¹⁹¹ In addition, several scientific papers had reported changes in Atlantic circulation and
25 salinity that some scientists thought might indicate impending larger disruption, as well as new evidence
26 of rapid climate shifts in the past.¹⁹²

27 GBN staff developed the scenario by reviewing scientific literature and informally consulting
28 with climate and ocean scientists.¹⁹³ They reviewed three past climate events of diverse severity and
29 decided to base their scenario on the one in the middle, the century-long period of strong cooling 8,200
30 years ago. Coming after an extended warm period, this event brought cooling of about 5 °F over
31 Greenland, with cold and dry conditions extending around the North Atlantic basin and substantial drying
32 in mid-continental regions of North America, Eurasia, and Africa.¹⁹⁴

33 For their future abrupt-change scenario, the authors constructed a path of climate change to reach
34 these conditions by 2020. The pathway involved rapid warming through 2010, as high as 4 – 5 °F per
35 decade in some regions,¹⁹⁵ followed by a rapid turn to cooling around 2010, as melting in Greenland

¹⁹¹ NRC, 2002.

¹⁹² See, e.g., Dickson et al, 2002, Hansen et al, 2001, Gagosian, 2003.

¹⁹³ Global Business Network, 2004.

¹⁹⁴ Alley et al, 1997.

¹⁹⁵ Note that these regional projections are 5 - 10 times faster than the IPCC projected global-average rate of warming over the 21st century.

1 freshens the North Atlantic and substantially shuts down the thermohaline circulation. By 2020,
2 hypothesized conditions have approached those of the 8,200-year event – cooling of 5 °F in Asia and
3 North America and 6 °F in Europe, with widespread drying in major agricultural regions and
4 intensification of winter storm winds. The authors acknowledge that the scenario pushes the boundaries
5 of what is plausible, both in the rapidity of changes and in the simultaneous occurrence of extreme
6 changes in multiple world regions. They contend that this is defensible and useful, however, for an
7 exercise focused on sketching the nature of challenges posed by a plausible worst case.¹⁹⁶

8 The socio-economic and security implications of the climate scenario were developed
9 judgmentally, in consultation with ONA. Incremental changes are projected for the first 10 years, with
10 general increase in environmental stresses and approximate maintenance of present disparities between
11 rich and poor countries. After 2010, catastrophic cooling in Europe and drying of major agricultural
12 regions worldwide brings widespread shortages of food, due to decreased agricultural production; of
13 water, due to shifted precipitation patterns; and of energy, due to shipping disruptions from increased sea
14 ice and storminess. These shortages produce 400 million migrants over the period 2010-2020, as
15 desperate scarcity generates violent conflict in Europe, Asia, and the Americas. Extending their
16 speculation on security implications into the 2020s, the authors hypothesize widespread southward
17 migration of Europeans and near-collapse of the EU, sustained conflict in East and Southeast Asia
18 including struggles between China and Japan over access to Russian energy supplies, and increasing
19 political integration of a fortress North America to manage security risks and refugee flows.

20 ***Controversy and Criticism***

21 The project was completed in October 2003, its report published in February 2004 and reported in
22 *Fortune Magazine* the same month.¹⁹⁷ A few weeks later, the *London Observer* claimed to have obtained
23 the report secretly and used the scenario to criticize US refusal to join the Kyoto Protocol.¹⁹⁸ Subsequent
24 news coverage took up the theme that the report was secret or suppressed, and suggested the reason was
25 that the scenario called for more urgent action on climate change.¹⁹⁹ In the resultant controversy, DOD
26 stated – correctly – that the report did not represent US policy, but was merely a speculative consultant’s
27 study. Although the controversy subsided after a few weeks, interest and concern about the possibility of
28 abrupt climate change, although not of this precise character, have continued to grow.²⁰⁰

29 This scenario is a sketch of an abrupt climate-change event, with little fine-scale detail about the
30 hypothesized changes or underlying reasoning and no attempt to suggest how likely or unlikely such an
31 event is. Rather, it seeks a preliminary answer to the question, what might the worst case look like? Such
32 questions are more often posed in security studies than other fields, because of the unique nature of
33 responsibilities of military organizations – responding to diverse, novel, unknown threats with extremely
34 high cost of failure. Many climate-change decision-makers could likely benefit from such upper-bound

¹⁹⁶ GBN, pg 7; Schwartz interview; GBN Press Release, “Abrupt Climate Change”, February 2004, at www.gbn.com/ArticleDisplayServlet.srv?aid=26231

¹⁹⁷ Stipp 2004. (released, January 26, 2004)

¹⁹⁸ 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,

¹⁹⁹ 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.

²⁰⁰ E.g., Alley 2004 cites it as a useful worst-case assessment.

1 scenarios too, but this exercise is the only example of a worst-case scenario produced for climate change.
2 Major official assessments have focused overwhelmingly on average or best-guess projections.

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

1 **5. Conclusions and Recommendations**

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

5 Before doing so, we briefly reprise some key definitional points, because uses of the term
6 scenarios are so divergent. We have defined scenarios as descriptions of future conditions
7 produced to inform decision-making under uncertainty. This definition distinguishes scenarios
8 from assessments, models, decision analyses, and other decision-support activities. Scenarios
9 may be developed and used in conjunction with these – for example, scenarios can provide
10 descriptions of potential future conditions used as inputs to such activities – but are not identical
11 to these, and not alternatives to them.

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

19 Having distinguished scenarios from these related activities, we consider a broad set of
20 scenarios of diverse characteristics and uses, including simple and complex scenarios,
21 quantitative and qualitative scenarios as well as various combinations of the two, and scenarios
22 whose primary use and interpretation is positive or normative. Where we intend our conclusions
23 and recommendations to apply to only certain types or uses of scenarios, we state this explicitly.
24 Unless stated otherwise, they pertain to all types of global-change scenarios we are considering.

25 **5.1 Use of Scenarios in Climate-Change Decisions**

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

35 **There is a big gap between the use of scenarios in current practice and their potential**
36 **contributions.** Despite this evident value and capability, many climate- related decisions that
37 could benefit from scenarios (e.g., many decisions regarding long-term management and
38 investments in climate-sensitive areas such as freshwater systems or coastal zones) are not
39 using them. Indeed, many such decisions are still being made without considering climate

1 change at all. Conversely, many climate-change scenarios have only weak and indirect
2 connections to practical decisions related to climate-change mitigation or adaptation.

3 ***Interest in considering and using climate-change scenarios is sharply increasing.*** There is
4 increasing interest in considering climate-change scenarios in diverse decision and planning
5 processes. This trend is strongest for planning and decisions concerned with climate-change
6 impacts and adaptation. The trend reflects advances in scientific understanding of climate
7 change, gradual maturation of models and analytic tools, and increasing recognition by
8 decision-makers of the potential importance of climate change. Given the high general
9 concern about climate change and the advance of background scientific knowledge, we
10 expect this trend to continue, and to broaden to other types of climate-related decisions.

11 ***Scenarios of global emissions and resultant changes in atmospheric trace-gas***
12 ***concentrations and climate are a core requirement shared by many diverse climate-related***
13 ***decisions.*** Although climate-change decision-makers and their particular information needs
14 are highly diverse, many will need scenarios of global emissions and resultant climate
15 change, and many more will need information that depends on these. Consistent scenarios of
16 global emissions and climate change, provided centrally at the national or international level,
17 can serve these diverse needs – if they are presented with enough transparency and
18 documentation of their underlying reasoning and assumptions.

19 ***Beyond global emissions and resultant climate change, decision-makers' needs from***
20 ***scenarios are highly diverse.*** Different climate-change decision-makers will have highly
21 variable needs from scenarios, in the factors and variables included, the time and spatial scale
22 at which they are provided, and the nature of uncertainties represented. The means for
23 meeting these additional needs will likely be diverse too. Some will call for separate,
24 specialized scenario production capabilities. A major distinction in scenario-related needs
25 can be drawn between mitigation policy-makers (who are mostly but not exclusively national
26 officials), impacts and adaptation managers, and energy resource and technology managers.

27 ***Impacts and adaptation managers are a major type of scenario users with distinct***
28 ***information needs.*** Impacts and adaptation managers – including both national officials and
29 others responsible for more specific domains of impact – need climate-change scenarios,
30 driven by specified global emissions scenarios, to provide information about potential
31 climate-related stresses on their areas of responsibility. In addition, they need other
32 environmental and socio-economic information specific to their areas of responsibility, at
33 appropriate spatial and temporal scales. Meeting these needs will require both easy access to
34 centrally produced climate scenario information and associated tools and support, and
35 development of decentralized capabilities for developing and applying additional scenario-
36 related information. Many of these specific information needs are likely to be similar in
37 character, although not identical, for many particular locations and types of impact.

38 ***Meeting information needs for impacts and adaptation requires a cross-scale***
39 ***organizational structure.*** These decisions' combination of centralized and decentralized
40 information needs suggests the need for a linked network of institutions at national and sub-
41 national levels to develop scenarios. Such a structure would combine central provision of

1 globally consistent emissions and climate change scenarios; decentralized elaboration of
2 these scenarios with additional variables required for regional impacts and adaptation
3 analyses; and provision of tools and resources to support development and use of scenarios.

4 ***Scenarios for impact and adaptation managers should be based on emissions assumptions***
5 ***that include a likely range of mitigation interventions, now and in the future.*** The
6 emissions assumptions underlying scenarios for impacts managers should be based on the
7 likely range of future global emissions trajectories, including explicit assumptions about what
8 degrees of further mitigation effort are likely over time. This will typically imply a narrower
9 range of emission futures than is considered in scenarios to support mitigation decisions.

10 ***Mitigation policy-makers are a major type of scenario users with distinct needs.*** Mitigation
11 policy-makers are usually officials who make national policy and participate in international
12 negotiations, but this group also includes sub-national officials when they share mitigation
13 responsibilities or undertake mitigation initiatives. Serious pursuit of greenhouse-gas
14 mitigation will require major policy innovations that carry significant risks of many kinds,
15 including the effectiveness and cost of the policies but also their effects on government
16 budgets, competitiveness of particular industries, opportunities for national technological
17 capabilities, etc. Decision-makers considering such policies will need scenarios of global
18 and national emissions trends, resultant climate change, and aggregate impacts. In addition,
19 they will need to consider many factors specific to their jurisdictions – e.g., national policies,
20 institutions, economic structure, technological capabilities, and the detailed structure of
21 national emissions – and information about the policy environment for their choices,
22 including alternative scenarios of other nations’ mitigation strategies, international mitigation
23 decisions, and implementation and compliance.

24 ***Scenarios for mitigation decisions should include a wide range of baseline emissions***
25 ***assumptions, and should not pre-judge the likely level of mitigation effort.*** Scenarios used
26 to inform mitigation decisions should consider the full range of potential mitigation choices
27 on the agenda, defined relative to baseline assumptions that, as much as possible, reflect only
28 efforts already enacted or committed, including a range of reasonable assumptions about
29 implementation and compliance. This assumption typically implies a wider range of
30 emissions futures than is considered in scenarios to support impacts and adaptation decisions.

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

39 ***Informing mitigation decisions requires capacity for scenario development at the national***
40 ***level.*** While core scenarios of global emissions and climate-change can provide some of the
41 required input into mitigation decisions, these decisions require additional information that

1 must be provided at the national or sub-national level where the decisions are being
2 considered, generated in consultation with relevant decision-makers or their surrogates.

3 ***Energy resource and technology managers are a third major type of climate-change***
4 ***scenario users with distinct needs.*** Energy resource and technology managers concerned
5 with private responses to mitigation policy primarily need scenarios that represent alternative
6 policy regimes. Emissions and climate change underlie these as influences on policy
7 decisions, but do not capture the most important uncertainties for these decision-makers.
8 While many actors may wish to generate these scenarios privately to keep their assumptions
9 and analyses confidential, there may also be value in multi-party collaborative scenario-
10 building exercises in which today's policy-makers and corporate planners jointly examine
11 what range of policy, economic, and energy regimes is plausible or likely over the 30 to 50-
12 year time horizons relevant for investment and technology-development decisions.

13 ***Scenarios must be periodically revised and updated.*** For all types of decisions and decision-
14 makers, developing scenarios, applying them to inform decisions, and refining scenario
15 methods, are iterative processes. Limitations to present scenarios or methods do not in
16 general justify delaying consideration of such decisions, any more than scientific
17 uncertainties do. Still, scenarios must be periodically updated, based on new knowledge,
18 experience, and priorities, as well as further developments in scenario-related methods. Such
19 updates are needed much more frequently than the decision time horizons.

20 ***5.2 Use of Scenarios in Climate-Change Assessments***

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

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

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

38 ***In assessments, scenarios can strongly influence issue framing.*** Also because of their
39 prominent dissemination, scenarios presented in major assessments can exercise substantial

1 influence over the framing of policy discussions, or provide simple, widely used metrics of
 2 the seriousness of the issue. They may consequently exercise broad influence over many
 3 decisions that depend upon such aggregate perceptions of seriousness. The prospect of such
 4 influence further heightens the responsibility for transparency in production of scenarios.

5 ***Scenarios contain unavoidable elements of judgment in both their production and use.***

6 Although they draw on relevant data, knowledge, and analysis, scenarios inevitably contain
 7 elements of judgment. In addition to putting serious responsibilities onto scenario
 8 developers, this implies that there is no authoritative way to resolve arguments over whether
 9 a scenario is plausible or not. When a wide enough range of potential futures is considered,
 10 some scenarios are likely to draw criticism, in part motivated by opposition to their
 11 foreseeable implications for action. Any scenario can be attacked as unreasonable,
 12 speculative or unlikely, and close enough scrutiny of any scenario can usually reveal
 13 inconsistencies, but these do not provide sufficient basis for excluding a scenario from
 14 consideration. Indeed, scenarios designed to represent extreme events, or to lie near one end
 15 of a distribution of potential outcomes, should by definition appear unlikely. The most
 16 productive response to such criticisms lies in transparency about the process, reasoning, and
 17 assumptions used to produce scenarios. Such transparency can shift arguments to underlying
 18 uncertainties, and help limit biases in the production of scenarios.

19 ***5.3 Characteristics of “core” emissions and climate scenarios***

20 ***Centrally provided scenarios of emissions and climate change can help inform mitigation***
 21 ***and adaptation decisions at national and sub-national scale, but these will usually require***
 22 ***additional information as well.*** Central scenarios can provide information about trends in
 23 world emissions, underlying socio-economic conditions at the scale of major world regions,
 24 and the large-scale pattern of global policy response. They can also provide access to
 25 climate-model scenario output, plus tools, data, and support for producing finer-scale
 26 scenario information needed for particular impact and adaptation applications. Mitigation
 27 and adaptation decisions and associated assessments at national or smaller spatial scale will
 28 have more detailed and finer-scale needs for both climate and socio-economic information
 29 than can be provided by centralized scenarios, so these must be extended and/or modified by
 30 national and sub-national scenario processes.

31 ***Scenarios of emissions and resultant climate change should be global in scope and***
 32 ***century-scale in time horizon.*** Core emissions and climate-change scenarios should specify
 33 major climate-relevant emissions and other perturbations, globally and for major world
 34 regions. They should extend over a time horizon of at least 100 years (including some that
 35 extend 200-300 years to support assessments of sea-level rise), with interim results at roughly
 36 decadal resolution.

37 ***Emissions scenarios of several distinct logical types will be needed to serve diverse***
 38 ***purposes.*** These will include some combination of alternative baselines, alternative levels of
 39 incremental stringency of mitigation effort, and specified future targets to support
 40 backcasting and feasibility analysis.

1 ***For some uses, emissions scenarios should be coupled to explicit scenarios of alternative***
2 ***socio-economic futures.*** For these scenarios, the range of potential socio-economic and
3 policy futures considered should be wider than has been considered to date, including
4 scenarios of policy failure and conflict, and a wide range of stringency and timing of
5 mitigation effort. For example, what if development stagnates in major world regions? What
6 if world emissions grow sharply for several decades with little control effort, followed by a
7 subsequent shift to stringent mitigation efforts? What if part of the world makes a lot of effort
8 and part makes very little? Considering such varied future histories is crucial for considering
9 long-term risks and opportunities from major mitigation choices.

10 ***Scenarios should reflect various explicit degrees of coordination, depending on their***
11 ***intended uses.*** Some uses will require groups of simple coordinated scenarios to provide
12 standardized inputs for downstream modeling and analysis – e.g., standard emissions
13 scenarios as inputs to climate models and standard climate scenarios as inputs to impact
14 assessments – for exploring present uncertainties and tracking developments of knowledge
15 over time. Other scenarios should be based on multiple models using common input
16 assumptions. Non-standardized scenarios produced at the initiative of researchers and
17 modelers should also be produced, which explore alternative assumptions or meet specific
18 user needs, provided these meet basic standards of quality control, transparency, and
19 documentation.

20 ***Some scenarios should seek to link qualitative and quantitative elements.*** Some scenarios
21 of socio-economic conditions, whether produced to support global emissions scenarios or
22 impacts assessments, should include both qualitative and quantitative elements and sustained
23 analytic efforts to link the two. Qualitative or narrative scenario elements can provide a
24 vehicle to explore major historical uncertainties with large implications for global emissions,
25 climate change, and vulnerability to climate impacts; provide a coherent rationale and logical
26 structure to connect assumed trajectories for multiple variables, including both quantitative
27 and qualitative ones; and provide guidance to other analysts or users who may wish to extend
28 the scenarios by elaborating additional detail. Achieving these benefits will require more
29 sustained effort to integrate model-based projections of quantitative variables with qualitative
30 and narrative scenario elements, to iterate between these, and to critically examine each
31 element in light of the other, than has been made thus far. These efforts should seek to
32 connect alternative qualitative and narrative scenarios not just to alternative parameter values
33 in quantitative models, but also to alternative forms of causal relations and model structures.
34 Generating multiple alternative model quantifications based on the same narrative and
35 associated causal logic is one promising route to enriching understanding of uncertainties in
36 key quantitative variables such as future economic output and emissions.

37 ***5.4 Scenario Process: Developer-User Interactions***

38 ***There is value in collaboration between scenario developers and users, particularly at the***
39 ***beginning and ending stages of a scenario exercise.*** The appropriate degree and means of
40 this collaboration vary substantially among scenario exercises. User engagement is most
41 important in the initial scoping and design of a scenario exercise, and in the evaluation and

1 application of the scenarios generated. The value of user engagement in details of scenario
2 development, quantification, elaboration, and checking, depends on the specific case.

3 ***The ease of achieving such collaboration and its value are likely to be greater when***
4 ***scenario users are clearly identified, few in number, and similar in their interests and***
5 ***perspectives.*** When potential scenario users are identified, relatively few, and relatively
6 homogenous, close and intensive collaboration between users and developers is likely to be
7 most productive. When potential users are numerous and diverse, intensive engagement may
8 be infeasible and more structured processes for consultation, representation, and information
9 exchange are needed. While progress has been made in new methods to allow larger
10 numbers to participate in scenario exercises, further development of such methods is needed.

11 ***5.5 Communication of Scenarios***

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

21 ***Transparency of underlying reasoning and assumptions is crucial.*** Scenario
22 communication should include transparent disclosure of underlying assumptions, models,
23 and reasoning used to produce the scenarios, to support the credibility of scenarios, to alert
24 potential users to conditions under which they might wish to use or modify them, and to
25 inform criticism and improvement of scenarios. This should include explicit identification of
26 the major uncertainties represented in each scenario and the sources of underlying
27 information, whether drawn from the scientific literature, formal expert-elicitation exercises,
28 or informal judgments of the scenario team. It is possible in virtually all cases to formulate
29 simple, accessible, honest descriptions of why a scenario was undertaken, why it was
30 necessary, what was done, how and why, and why it merits respect as a reasonable judgment.

31 ***5.6 Consistency and Integration in Scenarios***

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

36 ***In scenario exercises that use multiple models to explore potential uncertainties in future***
37 ***conditions, consistency between models should be pursued primarily through coordination***
38 ***of inputs, not outputs.*** Use of multiple models in parallel to produce alternative descriptions
39 of future conditions can improve understanding of uncertainties, if models are run under

1 consistent assumptions about exogenous inputs. Forcing models to generate consistent
 2 trajectories for endogenous outputs poses several risks, including suppressing variation from
 3 alternative causal structures that could provide valuable insights into uncertainties, and
 4 encouraging over-confidence from spurious precision. For quantities that are exogenous in
 5 some models and endogenous in others, the appropriate treatment varies case by case, but it
 6 is not generally desirable to force multiple models to convergent values of such variables
 7 without more detailed examination of the underlying uncertainties.

8 ***Imposing consistent outputs in multi-model exercises can be useful, however, when these***
 9 ***outputs represent common goals for policy evaluation.*** For example, consistent constraints
 10 on some environmentally relevant target such as emissions, atmospheric concentrations, or
 11 radiative forcings, can be used to examine inter-model uncertainties in the technological,
 12 economic, and resource conditions associated with meeting the specified targets.

13 ***Transparency in reporting scenario and model differences as well as underlying***
 14 ***assumptions and reasoning can help mitigate the effects of inconsistencies among***
 15 ***scenarios.*** Ideally, multiple scenarios in an exercise should differ only on those elements
 16 intentionally chosen to distinguish them, and be consistent in all other factors. This is not
 17 always possible, however, particularly when scenarios are produced using different models.
 18 Pursuing maximal transparency about the models, assumptions, and reasoning underlying
 19 each scenario – perhaps by issuing detailed diagnostic reports that include explicit discussion
 20 of points of weakness, uncertainty, and disagreements, and the means used to resolve them –
 21 can mitigate any resultant confusion.

22 **5.7 Treatment of Uncertainty in Scenarios**

23 ***Some scenario exercises should include more explicit characterization of likelihood***
 24 ***judgments than has been practiced so far.*** The advantages of being more explicit about the
 25 probability judgments that underlie scenario exercises are likely to outweigh the
 26 disadvantages. Such specification should be pursued further than has been done in major
 27 global-change scenario exercises to date, although not necessarily in all scenario exercises.
 28 The means available to express these judgments are of widely varying specificity, ranging
 29 from agreed terminology to explicitly quantified probability distributions. All such
 30 judgments should include explicit acknowledgement of their inevitable subjective elements,
 31 and appropriate caveats to help users avoid mistaking them as objectively true.

32 ***Explicit probability judgments are easiest to produce and least controversial in scenarios***
 33 ***generated using quantitative models of climate change or specific impact domains.***
 34 Scenarios generated using such models can be conditioned on specific assumed values for
 35 socio-economic inputs such as emissions, and can represent explicitly and quantitatively the
 36 effects of specified variation in initial conditions or unknown parameter values. These
 37 devices are also available, although in less widespread use, in economic models used to
 38 project emissions. These devices aid the construction of distributions of key quantitative
 39 characteristics such as measures of global or regional climate, or of prominent quantitative
 40 impact measures such as changes in river flows or sea level, although they neither capture all
 41 relevant uncertainty nor avoid the inevitably subjective nature of such probability judgments.

1 Explicit probability judgments are more difficult and controversial when they involve socio-
2 economic factors such as major technological innovations, large-scale changes in attitudes or
3 norms, or policy response, for which quantitative models are not available, and that do not
4 depend in well understood ways on identified quantitative parameters.

5 ***Attempting to include explicit probability judgments is likely to be most useful and***
6 ***successful when key variables are few, quantitative outcomes are needed, and potential***
7 ***users are numerous and diverse.*** The case for assigning explicit likelihood judgments is
8 strongest when scenarios' most salient components are quantitative projections of a few key
9 variables, such as emissions or average temperature change over the globe or some region,
10 because the technical barriers to assigning probabilities are least severe in this case. The case
11 is strongest when a primary purpose of the scenario exercise is to provide inputs to other
12 quantitative assessment activities, or to inform decisions that primarily depend on one or a
13 few key quantitative variables, because such uses are most likely to require probability
14 judgments. The case is strongest when the set of potential scenario users and uses is large
15 and heterogeneous, because this situation provides the least opportunity for informal
16 communication of implicit judgments of likelihood or priority through intense, sustained
17 collaboration between scenario developers and users.

18 ***Attempting to include explicit probability judgments is likely to be least useful and***
19 ***successful when scenarios specify multiple characteristics, including prominent narrative***
20 ***or qualitative components; when the purpose of a scenario exercise is sensitivity analysis***
21 ***or heuristic exploration; and when potential users are few, similar, and known.*** When
22 scenarios are primarily construed as rich, qualitative narratives that present major alternative
23 historical and socio-economic trajectories, the technical obstacles to explicit probability
24 assignment are greatest and the likely confidence in scenario developers' subjective
25 probability judgments lowest. When the main purpose of a scenario exercise is to stimulate
26 critical or creative thought, to probe the limits of a model or decision strategy through
27 sensitivity analysis, or to explore ways of meeting a specified target, explicit probability
28 assignment provides little or no benefit. When users are few, similar, and specifically
29 identified, they can be intensively involved in scenario production, allowing effective
30 informal communication of likelihood judgments without stating them explicitly. Under
31 these conditions, scenario exercises can also be structured to engage users in the potentially
32 instructive activity of assigning and discussing their own probability judgments, rather than
33 putting that responsibility exclusively on the researchers or analysts developing scenarios.

34 ***Centrally provided scenarios of global emissions and climate change should attempt to***
35 ***include explicit probability judgments.*** Because of the large, diverse set of users for these
36 scenarios, explicit likelihood judgments should be provided for ranges of key quantitative
37 outputs, including global emissions and global-average temperature change. Scenarios
38 should typically include several paths that span a wide range of judged uncertainty, e.g., 95
39 percent to 99 percent. The associated probability judgments may include some that are
40 unconditional and some that are conditioned on specific assumed prior conditions. Such
41 estimates should be provided by multiple groups using diverse methods. As for all such

1 probability judgments, their unavoidably subjective nature and the specific assumptions on
2 which they are conditioned should be stated explicitly and prominently.

3 ***Providing explicit probability judgments allows scenario users to choose whether to use***
4 ***them or not.*** Some users may choose to use these explicitly in their subsequent analysis or
5 decision support, while others may use them only to help decide which scenarios to use and
6 still others may disregard them entirely. Users may select a different group of scenarios or a
7 different subset of the uncertainty range for various reasons, including differences in risk
8 aversion, differences in the scope of their decision authority, or differences in their
9 assumptions about decisions by other actors, present or future. Presenting complete
10 descriptions of scenarios together with underlying assumptions and reasoning, including
11 probability judgments, preserves all these options for users.

12 ***Scenario exercises should give more attention to extreme cases.*** Some uses of scenarios
13 require consideration of low-probability, high-consequence extreme cases, such as loss of a
14 major continental ice sheet or major changes in meridional ocean circulation. Consequently,
15 such scenarios should be included in large, general-purpose scenario exercises producing
16 emissions or climate-change scenarios, together with more likely middle-case scenarios.
17 When extreme scenarios are included in an exercise, it is especially critical to be explicit and
18 transparent about the reasoning and assumptions underlying each scenario, and scenario
19 developers' judgments of relative likelihoods.

20 ***In addition to enhancing the utility of scenario outputs, probabilistic methods can***
21 ***contribute throughout the scenario development process.*** Developing scenarios requires
22 making many judgments about unknown characteristics and developing many arguments and
23 pathways to link these. Scenarios based on quantitative models typically require specifying
24 many exogenous inputs and parameters. Even narrative scenarios require specifying values
25 of multiple characteristics, both qualitative and quantitative. Explicit discussion of
26 uncertainties and associated probabilities can help structure and facilitate many aspects of the
27 scenario development process, including deciding appropriate ranges of variables to consider,
28 defining boundaries of what outcomes are considered plausible, elaborating associated causal
29 mechanisms and linkages, discussing and integrating knowledge and judgments from
30 multiple participants, and clarifying disagreements. Explicit conversation about probabilities
31 can support insights throughout these processes, in addition to their role supporting clear
32 communication of scenario judgments to users.

33 ***5.8 Expanding and Sustaining Capacity for Production and Use of Scenarios***

34
35 ***Present scenario capacity is inadequate.*** Although scenario-based reasoning is required for
36 many aspects of global change assessment and decision support, the present capacity to
37 produce, disseminate, apply, evaluate, and adapt scenarios is inadequate. There has not been
38 enough continuity to enable effective learning, because scenarios are typically produced *de*
39 *novo* for each major application. There has not been enough transparency about methods,
40 reasoning, and assumptions. Constructing integrated scenarios and exploring alternative
41 methods has been difficult, in part because scenario exercises have tended to be dominated

1 by use of quantitative models, separated along disciplinary lines. Inadequate resources have
2 been devoted to methods development, for scenarios and related decision-support tools.
3 Finally, there has been no systematic evaluation and critique of scenarios or their application.
4

5 ***To help fulfill these presently unmet needs, the CCSP should establish a program to:***
6

- 7 • ***Commission scenarios for use in assessments and decision-support activities.*** This
8 task includes facilitating agreement among relevant producers and users on standard
9 scenarios in those cases where multiple assessment activities require these for
10 comparability, and convening and supporting a diverse collection of more extensive
11 and detailed scenario-related exercises, by multiple groups using a wide range of
12 models and approaches.
13
- 14 • ***Disseminate scenarios with associated documentation, tools, and guidance***
15 ***materials.*** This task includes multiple forms of support and capacity-building for
16 diverse groups seeking to apply, modify, and extend existing scenario-based
17 information at various regional and sectoral scales, through providing data, models,
18 tools, resources, and associated documentation and technical support, in multiple
19 forms and through multiple media.
20
- 21 • ***Commission various groups to evaluate scenarios and their applications and to***
22 ***develop improved methods.*** This task includes defining and promulgating standards
23 for quality control – which, given the need for diverse approaches, would principally
24 concern matters of process such as transparency, documentation, evaluation, and
25 dissemination of results and supporting information. The task also includes broad
26 efforts to develop scenario-related skills, tools, and methods, e.g., by providing
27 resources for methods development and evaluation projects; conducting and
28 establishing procedures for evaluation of particular activities and programs; and
29 convening workshops, conferences, etc., to evaluate progress overall, or in particular
30 methodological areas.
31
- 32 • ***Archive results and documentation related to all these tasks, to provide historical***
33 ***perspective and institutional memory for future scenario-related activities.*** This
34 task includes preserving for retrospective scrutiny a wide range of materials: not just
35 the methods, contents, and results of scenario exercises, but the progressive
36 evaluations of particular activities and approaches, and of the entire program. In its
37 ongoing development and evaluation of methods, the program should not draw rigid
38 boundaries between scenario development and application and other related methods
39 of assessment and decision support for long-term global change issues.
40

41 ***Several conditions in the design and management of this new program would be required***
42 ***to ensure its effectiveness.***
43

- 1 • ***The program should build and maintain strong connections with outside relevant***
2 ***expertise, and analytic and modeling capability.*** While the program must develop
3 enough internal expertise to be a full participant in debates over scenarios and
4 assessment methods, it cannot and should not attempt to impose a unilateral vision of
5 preferred scenarios, methods, or approaches. Rather, it must build and maintain close
6 collegial connections with outside networks of researchers and analysts in multiple
7 fields of expertise, including emissions modelers, climate scientists and modelers,
8 impacts researchers, and resource managers. These relationships would be facilitated
9 by establishing governing mechanisms, such as a senior advisory board, drawn from
10 the broad communities of researchers, modelers, analysts who are developing and
11 using scenarios and related methods. While established as a US national program, it
12 must also support, collaborate, and coordinate with parallel activities in other nations
13 and internationally, and with relevant sub-national activities.
14
- 15 • ***The program should integrate and balance goals and criteria related to scientific***
16 ***and technical quality, and those related to utility and relevance to users.*** This
17 balance is needed for the program to support promising but speculative activities, to
18 encourage creativity and diversity of approach, to avoid being captured by any
19 particular discipline or modeling approach, and to be willing to make and explain
20 judgments about quality and promise that reflect both scientific and practical
21 considerations. To achieve this, the program needs broad discretion over the type of
22 projects supported, including sponsoring fairly sharply targeted activities, supporting
23 speculative activities, and investing to develop and assess capabilities that do not yet
24 exist.
- 25 • ***The program should be insulated from political control.*** For the scenarios and
26 analyses based on them to be perceived as credible by their diverse users, the capacity
27 needs enough insulation from political control, at both the national or international
28 level, to prevent scenarios from becoming proxies for conflict over near-term
29 policies, and to allow exploration of the implications of alternative futures that
30 represent plausible risks but that some political actors would find objectionable.
- 31 • ***The program should strive for maximum transparency in its own activities, in***
32 ***addition to demanding it from activities it supports.*** The capacity should strive for
33 maximal transparency regarding inputs, models, assumptions, and reasoning
34 employed in developing scenarios, as well as any significant disagreements that arose
35 and how they were resolved and any remaining weaknesses recognized by the
36 developers. The broader and more diverse the collection of intended uses and users,
37 the more crucial is transparency of the scenario-production process – because
38 different users may require scenarios produced using different underlying
39 assumptions, and they must be able to track the underlying logic to exercise this
40 choice. This would enhance credibility in the scenario-development process. While
41 calls for such transparency are widely made, experience suggests it is difficult to
42 achieve, particularly for such matters as disagreements or recognized weaknesses that

1 may risk professional embarrassment. Still, achieving more transparency and more
2 widely informed debate on such matters is essential for advancing scenario methods.

3 • ***The program will require the authority and resources necessary to articulate and***
4 ***promulgate standards for transparency, consistency (e.g., of units, formats, etc.),***
5 ***and quality control.*** This task involves facilitating discussions among the
6 community and formulating persuasive guidelines and supporting arguments. It also
7 requires use of incentives such as seals of approval, access to participation in
8 particular processes, access to particular dissemination outlets, access to resources,
9 etc. A weak “clearinghouse” that solicits, supports, or publicizes scenarios but cannot
10 exercise quality control, propose and stimulate new directions, or convene critical
11 reviews, of the whole enterprise and of particular exercises, is not an adequate model.

12 • ***The program will require adequate sustained resources.*** The program must build
13 and maintain a sophisticated analytic capability, and develop skills and institutional
14 memory regarding prior experiences, successes, and failures. This requirement
15 precludes the program being a series of *ad hoc* one-time activities or a part-time
16 burden imposed on people and organizations with other full-time responsibilities.

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