EXECUTIVE SUMMARY

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 to inform planning, analysis, and decision-making for environmental issues, including climate change.

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.

SCENARIOS FOR CLIMATE CHANGE: FIVE TYPES

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; these 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.)

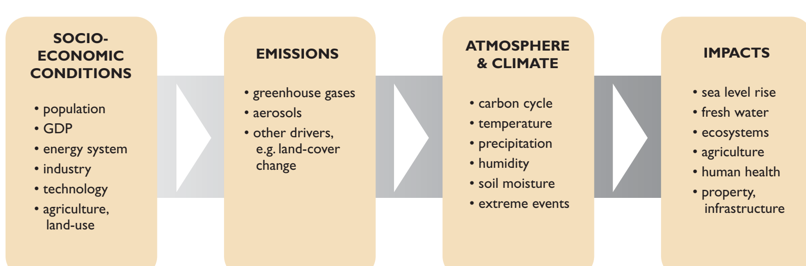

Figure ES-1. Scenarios of anthropogenic climate change: simple linear causal chain

Emissions Scenarios for Climate Simulations: Emissions scenarios present future paths of greenhouse-gas emissions or other climate perturbations. A major use of these is to provide needed inputs to climate models. Such scenarios may specify simple arbitrary perturbations of emissions or concentrations (e.g., doubling atmospheric CO_2), or time-paths reflecting specified assumptions for evolution of socio-economic drivers such as population, economic growth, and technological change.

Emissions Scenarios for Exploring Alternative Energy/Technology Futures: Another use of emissions scenarios involves specifying an environmental or emissions target, arbitrarily or based on normative or political goals, to examine what patterns of socio-economic change, energy resources, and technology development are consistent with the target and/or what interventions might be needed to meet it. Such scenarios have examined conditions for stabilizing atmospheric CO_2 concentration at various levels and the implications of stabilizing radiative forcing for multi-gas reduction strategies.

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

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

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

SCENARIOS FOR CLIMATE CHANGE: MAJOR EXAMPLES

The report reviews four major exercises producing or using scenarios for climate-change applications. The examples include national and international activities, produced by different sets of actors for different purposes.

The Intergovernmental Panel on Climate Change (IPCC) has produced three sets of scenarios of 21^{st}-century greenhouse-gas emissions, of which the most ambitious and important were produced for the *Special Report on Emissions Scenarios* (SRES) between 1997 and 1999. SRES produced four qualitative storylines on which six "marker" scenarios were based – one model quantification of each storyline plus two technological variants of one storyline that stressed fossil-intensive and low-carbon energy supply technologies – each produced by a different energy-economic model. Other models' replications of each other's marker scenarios plus a few additional explorations yielded 40 scenarios in total. These scenarios highlighted several insights, including the ability of alternative paths with similar emissions in 2100 to differ widely in their interim pathways and thus in atmospheric concentrations; the ability of alternative technological assumptions alone to generate as wide a range of emissions futures as substantially divergent socio-economic pathways; and the fact that similar emissions paths can come from widely different combinations of underlying socio-economic factors and so pose distinct mitigation problems. A widely publicized critique of the SRES scenarios alleged over-estimation of future emissions growth due to the metric used to compare incomes in rich and poor nations, but the overestimation was later found to be insignificant. More serious and illuminating challenges associated with these scenarios concerned how to balance and integrate qualitative and quantitative scenarios; how to use and how much to coordinate multiple models to generate the most useful insights; and whether, when, and how it is appropriate to assign explicit probability judgments to alternative scenarios or associated ranges of quantitative variables.

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

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

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

SCENARIOS FOR CLIMATE CHANGE: CHALLENGES AND CONTROVERSIES

Scenarios and Decisions

Scenarios can inform climate-change mitigation and adaptation decisions, but most uses so far have had relatively indirect connections to such decisions. Although there is no single global climate-change decision-maker, scenarios can inform the many decision-makers with diverse responsibilities that will affect and be affected by climate change. Three groups of decision-

makers with distinct information needs can be distinguished: mitigation policy-makers, who are mostly but not exclusively national officials; impacts and adaptation managers, including national officials and others who are responsible for particular climate-sensitive assets, resources, or interests; and energy resource and technology managers, who include owners, developers, and investors in energy resources and energy-related capital stock and new technologies.

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

Scenarios in Assessments and Policy Debates

In climate-change assessments, scenarios can provide required inputs to other parts of the analysis and help to organize multiple components of the assessment. When scenarios are used in a prominent assessment, they may subsequently be adopted in planning or decision-support processes outside the original assessment. Scenarios can also help frame public and policy debate, in part by providing an aggregate metric of the issue's severity. They consequently may gain prominence in contentious policy debates, and so become subject to political attempts to influence their content and political criticism based on their perceived implications for policy action. The unavoidable judgments underlying construction of scenarios provide opportunity for partisan efforts to make scenarios policy prescriptive, and for claims that only certain scenarios are plausible (e.g., high- or low-emissions scenarios, depending on the critic's motivation). These claims are unavoidable, since scenarios represent key uncertainties bearing on high-stakes policy decisions, but such attempts to restrict scenarios should be resisted, principally through prominent communication of the reasoning, assumptions, and treatment of particular uncertainties underlying scenarios.

Scenario Development Process: Expert-Stakeholder Interactions

Scenario developers must decide how and how much to involve scenario users and stakeholders in scenario development. In other fields – where users are clearly identified – relatively few and homogeneous, intensive collaboration between scenario developers and users or their representatives is desirable. Close user involvement is also advantageous in developing scenarios for climate change, but potential users of these scenarios are more numerous and diverse, may not be clearly identified, and may have contending material interests in the scenarios' content or use. This situation calls for delicate decisions about participation and representation to keep scenarios tuned to practical users' needs while keeping the development process small enough to be manageable.

Communication of Scenarios

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

Consistency and Integration in Scenarios

Scenario developers should strive for internal consistency. At one level, this means avoiding clear contradictions with well-established knowledge and not moving inadvertently outside bounds of historical experience – although such sharp departures from experience may be useful if pursued intentionally to examine low-probability risks or broaden decision-makers' perceptions. Perceptions of internal consistency or coherence in scenarios ultimately rest on subjective judgments, which pose well-known risks of bias if not carefully structured and controlled. Potential inconsistencies grow when scenario exercises use multiple models and attempt to harmonize them, particularly when some key quantities are externally specified for some models and calculated within others. Attempting to avoid such inconsistency by standardizing model outputs, however, can carry more serious risks by obscuring interpretation of results and precluding use of model variation to illuminate uncertainty. Attempts to connect qualitative and quantitative aspects of scenarios have been particularly challenging for pursuit of consistency. Different narrative scenarios often reflect different assumptions about how the world works, which correspond more closely to different model structures than to parameter variation. Better integrating the two approaches will require developing ways to connect narrative scenarios to model structures, rather than merely to target values for a few variables that models are then asked to reproduce.

Treatment of Uncertainty in Scenarios

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

CONCLUSIONS AND RECOMMENDATIONS

Use of Scenarios in Climate-Change Decisions

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

- Scenarios of global emissions and resultant climate change are required by many diverse climate-related decision-makers, but beyond these common requirements decision-makers' needs from climate-change scenarios are highly diverse.

- Impacts and adaptation managers include both national officials and others responsible for more specific domains of impact. They need climate-change scenarios, driven by specified global emissions scenarios, to represent potential climate-related stresses on their areas of responsibility, plus other environmental and socio-economic information at appropriate scales. Their combined needs – for centrally produced climate scenario information, associated tools and support, and a capability to develop and apply additional scenario information related to their responsibilities – suggest the need for a cross-scale organizational structure to provide scenario information.

- Mitigation policy-makers, who are mainly but not exclusively national officials, need scenarios of global and national emissions trends, resultant climate change, and aggregate impacts. In addition, they need scenario information about the potential policy environment for their choices, including alternative scenarios of other nations' mitigation strategies, international mitigation decisions, and implementation and compliance. In some cases, they can usefully employ target-driven scenarios for backcasting analysis. Mitigation decisions require scenario development capacity at the national level.

- Scenarios for mitigation decisions should include a wide range of baseline emissions assumptions and should not pre-judge the likely level of mitigation effort, while scenarios for impact and adaptation managers should be based on emissions assumptions that include the range of mitigation interventions they judge likely.

- Energy resource and technology managers, who are mainly private-sector actors, primarily need scenarios that represent alternative policy regimes over the 30- to 50-year time horizons relevant for investment and technology-development decisions. Scenarios of emissions and climate change may provide background, but do not capture the most important uncertainties for these decision-makers.

Use of Scenarios in Climate-Change Assessments

- Large-scale, official assessments are currently the main users of scenarios and will likely remain major users. Scenarios in assessments mostly support further analysis, modeling, and assessment. They can also help frame the climate issue for the public and policy-makers. Presentation of scenarios in assessments leads to additional unforeseen uses.

- Scenarios contain unavoidable elements of judgment in their production and use. This makes them vulnerable both to attempts at bias and to partisan attack. The most productive response lies in transparency about the process, reasoning, and assumptions used to produce scenarios, which can both help limit bias in scenario production and focus subsequent argument on underlying uncertainties.

What Should Centrally Provided Emissions and Climate Scenarios Look Like?

- Centrally provided scenarios of emissions and resultant climate change should be global in scope, with major climate-relevant emissions and other perturbations specified at least for major world regions. They should have a time horizon of a century or longer, with interim results at roughly decadal resolution.

- Centrally provided scenarios of global emissions and climate change can help inform mitigation and adaptation decisions at national and sub-national scales, but such decisions require additional information at these scales.

- Emissions scenarios of several types are needed to serve diverse uses, including alternative baselines, alternative levels of incremental stringency of mitigation effort, and specified future targets to support backcasting and feasibility analysis. Some emissions scenarios should be coupled to explicit scenarios of wide-ranging alternative socio-economic futures, but this is not necessary for all uses. Scenarios should reflect various explicit degrees of coordination, including simple fully standardized scenarios for evaluating and comparing downstream models, multi-model scenarios using common input assumptions, and non-standardized scenarios to explore alternative assumptions or meet specific user needs.

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

Scenario Process: Developer-User Interactions

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

Communication of Scenarios

- Effective communication of scenarios is essential, in forms useful to audiences of diverse interests and technical skills. In addition to scenario contents, communication should include associated documentation, tools, and support.
- Transparency of underlying reasoning, assumptions, and major uncertainties is crucial. Such transparency is necessary to support the credibility of scenarios, to alert potential users to conditions under which they might wish to use or modify them, and to inform criticism and improvement of scenarios.

Consistency and Integration in Scenarios

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

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 espe-

cially 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.
- Design and management conditions of this new program should include six elements.
  - The program should build and maintain strong connections with outside relevant expertise, and analytic and modeling capability.
  - The program should integrate and balance goals and criteria related to scientific and technical quality, and those related to utility and relevance to users.
  - The program should be insulated from political control.
  - The program should strive for maximum transparency in its own activities, in addition to demanding it from activities it supports.
  - The program will require the authority and resources necessary to articulate and promulgate standards for transparency, consistency, and quality control.
  - The program will require adequate sustained resources level of effort.