Review of Major Climate-Change Scenario Exercises

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

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

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

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

3.1. IPCC EMISSIONS SCENARIOS

Since its establishment in 1989, the IPCC has organized three exercises to develop scenarios of greenhouse-gas emissions, of increasing scale and complexity. For its first report, IPCC's Working Group 3 on "Response Strategies" included a sub-group on emissions scenarios. Four scenarios were produced but little used in this assessment because of time limits and because, with one exception, only doubled-CO_2 equilibrium climate-model runs were available at the time.[58] The next exercise produced six new scenarios, called IS92a through IS92f.[59] These were the first global emissions scenarios with a full suite of greenhouse gases and at least some explicit calculation underlying each. The IS92a scenario, one of the central scenarios in this group, was used in climate-model comparisons conducted for the 1996 IPCC assessment, along with the simpler transient scenario of 1 percent annual increase in equivalent-CO_2 concentration and further equilibrium runs.[60]

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

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

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

Prior scenarios were compiled in a web-based database,[65] and any researcher was invited to submit new ones. By mid-1998 the database contained more than 400 scenarios. Most of these projected only energy-related CO_2 emissions, but they were highly diverse in their coverage and resolution, the variables included, and their methodologies. The usefulness of these scenarios in constructing new ones was limited by several weaknesses, however. Many were incomplete, lacked documentation of inputs, or made inconsistent assumptions. Few included

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58 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 percent annual CO_2 concentration increase. See Mitchell et al. 1990, Bretherton et al. 1990, IPCC 1990.

59 Leggett et al. 1992.

60 The 1 percent scenario was similar to IS92a, but gave total radiative forcing about 20 percent greater by 2100. Washington and Meehl 1989; Stouffer et al. 1989; Bretherton et al. 1990:180-182.

61 Nakicenovic and Swart 2000.

62 Alcamo et al. 1995.

63 Parikh 1992, 1998.

64 Nakicenovic and Swart 2000: 324, Appendix I (terms of reference).

65 Morita and Lee 1998.

sulfur or land-use emissions, which were specifically requested of the new scenarios. Many were unclear on whether they assumed mitigation efforts, while the new scenarios were instructed to exclude them. Consequently, the development of new scenarios had to proceed largely independently of the collection of existing scenarios through the literature review and open process.

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

Combined, these gave four scenarios, which were sketched in preliminary terms at the workshop. In the A1 (economic, global) scenario, economic growth and inter-regional income convergence continue strongly worldwide – all developing countries grow like Japan and Korea from the 1950s to the 1980s – while world population peaks at 9 billion by 2050. Rapid innovation yields many advanced energy sources, while acid rain and other local and regional environmental problems are aggressively controlled. In contrast, the A2 (economic, regional) scenario has higher population growth, lower economic growth with more continuing regional disparities, slower innovation, and weaker international institutions. B1 (ecological, global) has low population growth, moderate economic growth with strong convergence, and strong reductions in per capita energy use, mostly through higher efficiency, while B2 has intermediate population growth, low economic growth with weaker convergence, and moderate improvements in energy efficiency and development of non-carbon energy sources.[68] The storylines were elaborated in short text descriptions with some preliminary numbers attached in fall 1997.[69]

Modeling teams were asked to produce initial quantifications of these scenarios in fall 1997, to match specified 2100 target values within 10 percent. In February 1998, the preliminary quantitative targets were re-confirmed and modelers asked to continue work on quantifications, now including a breakdown of economic output into four world regions.[70] In April, one model's quantification was chosen as a "marker scenario" for each of the four scenarios – a particular scenario that would provide the basis for interim reporting to climate modelers, some of whose results other participating models would be asked to replicate. The specifications and models for these marker scenarios are shown in Table 3.1.

The SRES interim marker scenarios were used to provide emissions scenarios to climate models participating in the IPCC third assessment.

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

66 See, e.g., WEC/IIASA 1995, WBCSD 1997.

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

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

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

70 Draft minutes, informal modelers meeting, Berkeley, Feb 7-8:4.

71 Minutes of the Laxenburg meeting, July 2-3, 1998, reporting results of June 29-July 1 IPCC Scoping Meeting, Bonn.

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 A1R a stabilization case (at about 550 ppm) (Laxenburg report, July 2-3, 1998:1).

Table 3.1. Target Values for 2100 in Initial Scenario Quantifications

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

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

The SRES scenarios have been the most comprehensive, ambitious, and carefully documented emissions scenarios produced to date.

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

With a further year of work, modeling teams produced a total of 40 scenarios that were retained in the report, of which 26 replicated one of the marker scenarios. Although a few of the 14 non-replicates reflected a model's inability to match the results of a marker scenario, most were produced because a modeling team intentionally sought to explore alternative assumptions. For example, the A1 scenario, which originally balanced fossil and non-fossil energy sources, was augmented by variants with different assumptions about fossil resources and non-fossil technology development, giving widely divergent emissions paths stressing coal, gas, and non-fossil energy technology. Modifications of the scenario set continued until late in the process. For example, it was decided in October 1998 to drop several B variants with explicit mitigation, including one stabilization scenario.[75] At the final IPCC approval meeting, it was decided at the request of the Saudi delegation to reduce the two fossil-intensive variants of A1 to one, a variant of the gas-intensive scenario which was renamed A1FI (for "fossil-intensive").[76]

3.1.1 Significance and use

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

Several significant insights were illuminated by the SRES scenarios.

- Scenarios with similar emissions in 2100 can follow markedly different paths in the interim, giving wide differences in cumulative emissions and concentrations.
- Technology and energy-resource assumptions can strongly perturb future emissions, even with constant socio-economic assumptions. For example, the three A1 variants show that changing these assumptions alone can generate as wide a range of emissions futures as substantial variation of demographic and economic futures.

[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 percent for GDP and 10 percent for final energy, but substantial discrepancies in base-year energy could not be harmonized due to time constraints (SRES modelers meeting report, Beijing, October 6-7, 1998:2).

[75] SRES modelers meeting report, Beijing, October 6-7, 1998:4. 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.

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

[77] Morita et al. 2001.

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

3.1.2 Criticisms and controversies

The SRES experience raised issues of great significance for subsequent attempts to develop more useful climate-change scenarios: the desirability of and appropriate methods for characterizing probabilities associated with scenarios; the quantitative representation of the relationship between North and South; methods for developing and using narrative scenarios and integrating them with quantitative model results; alternative modes for coordinating use of multiple models and their implications for the interpretation and use of scenarios; and the relationship between scenario exercises and their users, including the need for clarity about specific intended uses, appropriate methods for engaging users in scenario development, and how to improve utility of scenarios when not all potential user groups are specifically identified. These are discussed in Sections 4 and 5.

The first two of these issues were the subjects of forceful public criticisms. We discuss these, followed by several other issues that have received less attention but which in our view pose more central and instructive challenges for future scenario exercises.

Assigning explicit probabilities

The SRES team decided at the outset to make no probabilistic statements about the scenarios. Their report used great care in its language to avoid any suggestion that one scenario might be more central or more likely than any other.[78] This decision was consistent both with standard practice in developing narrative scenarios, and with the instruction in their terms of reference not to favor any model.[79] They were sharply criticized for this decision.[80] Critics argued that there were no technical obstacles to assigning probabilities to emissions ranges bounded by the marker scenarios; that scenario developers must have made probabilistic judgments in generating and evaluating the scenario quantifications and that not making these judgments explicit would withhold relevant information; and that if scenario developers decline to assign probabilities, others who are less informed will do so. Indeed, many probabilistic emissions calculations have been produced since the SRES, using various methods such as assigning uniform or other specified distributions over the emissions range of the marker scenarios, counting scenarios lying in specified intervals in the larger SRES set, unbundling and recombining alternative values of the drivers underlying SRES emissions figures, or sampling over parameter distributions within a single model. In response to these criticisms, SRES authors argued that attempting to assign probabilities to scenarios would require assigning joint distributions to the underlying driving factors, and that this would lead to an explosion of combinatoric possibilities over which any attempt to assign probabilities would be spurious and arbitrary.[81]

It may well be unhelpful to assign probabilities to rich, multi-dimensional narrative scenarios, yet still useful to assign interval probabilities when scenarios principally represent uncertainty in one or two quantitative variables

The situation of the SRES scenarios is in fact more nuanced than the arguments of either their authors or critics would suggest. It may well be unhelpful to assign probabilities to rich, multi-dimensional narrative scenarios, yet still useful to assign interval probabilities when scenarios principally represent uncertainty in one or two quantitative variables. And while the SRES scenarios began their lives like the former type of storyline scenario, they finished more like the latter. For many users, the scenarios ***are*** their projections of greenhouse-gas emission trends. When they are viewed in this way, a potential user may reasonably ask, how likely are emissions to be higher than this – a distinct and better-posed question than, what is the probability of an A1 world? The uncertainty issue has no clear resolution in this case, and poses hard design problem for scenarios and assessments more broadly. Although the SRES exercise has

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

79 Draft minutes of the Washington, DC, meeting, April 29-30, 1998:6.

80 Schneider 2001, 2002; Pittock et al. 2001; Allen et al. 2001; Reilly et al. 2001.

81 Grubler and Nakicenovic 2001.

raised this controversy most explicitly to date, the problem is a general one that any scenario exercise must confront. We discuss it further in section 4.6.

Exchange rates: PPP versus MER

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

…while MER overstates future income growth in poor countries, it also overstates future reductions in energy and emissions intensity.

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

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

[82] Castles and Henderson 2003a, 2003b; The Economist 2003a,b; Michaels 2003b.

[83] Nakicenovic et al. 2003, McKibben et al. 2004, Holtsmark and Alfsen 2005, Manne et al. 2005, Grűbler et al. 2004.

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

Underdevelopment of narrative scenarios

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

[84] Minutes of the Beijing meeting, October 6-7, 1998:10.

[85] Draft minutes of the Bilthoven meeting, September 17-19, 1997:7-8; draft minutes of the Berkeley meeting, February 7-8, 1997:6; draft minutes of the Washington, DC, meeting, April 29-30, 1998.

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

Harmonizing scenarios, interpreting the results

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

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

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

Clarity about uses, involving users:

The SRES scenarios were charged with serving uses beyond driving climate models but given little guidance on what specific additional uses or users to serve, or how the scenarios might best serve them, neither of which is obvious.[88] Providing climate-model inputs remained the most prominent and most clearly specified use, as well as the only use that had an early deadline. But climate modelers were not involved in the scenario development process, and there was substantial divergence between their needs and the outputs and capabilities of the SRES process. A September 1997 briefing identified the principal needs of climate modelers as early availability of scenarios and greater emissions detail.[89] They wanted separate emissions trajectories for major greenhouse gases, not just

[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 the Bilthoven meeting, September 17-19:7-8; draft minutes of the Berkeley meeting, February 7-8, 1997; UKCIP 1998 report summarizing SRES progress; Pitcher 1998 presentation slides.

[87] Minutes of the Bilthoven meeting, September 17-19, 1997:11.

[88] Alcamo et al. 1995.

[89] Draft minutes of the Bilthoven meeting, September 17-19, 1997:5.

CO_2-equivalent, including regional detail for some emissions such as sulfur – even suggesting that it would be desirable to have sulfur emissions disaggregated by stack height, to distinguish dispersed emissions from large point sources. Although SRES provided gridded sulfur data by post-processing model outputs, in most cases the emissions included and their spatial detail (not to mention stack height) were limited by the capabilities and structures of participating models.

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

3.2. THE US NATIONAL ASSESSMENT

The US National Assessment was the most comprehensive attempt to date to assess climate impacts on the United States over 25-year and 100-year horizons, and to consider both major sub-national regions and sectors.[93] Responding to a requirement in the 1990 Global Change Research Act, the National Assessment was organized by federal agencies participating in the US Global Change Research Program. Work began in 1997, with various components completed between 1999 and 2003. Regional impacts were initially considered in 20 regional workshops, followed by more extended analyses of impacts, leading to published assessments for 12 regions, conducted by university-based teams. Sectoral impacts were examined by national teams focusing on agriculture, water, human health, coastal areas and marine resources, and forests. A federal advisory committee, the National Assessment Synthesis Team (NAST), provided direction for the assessment and synthesized its results in two published reports.[94] Roughly two thousand experts and stakeholders participated.

The US National Assessment was the most comprehensive attempt to date to assess climate impacts on the United States over 25-year and 100-year horizons, and to consider both major sub-national regions and sectors.

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

3.2.1. Emission and climate scenarios

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

90 See, e.g., discussion with Mike Hulme on behalf of TGICA, draft minutes of the Washington, DC, meeting, April 29-30, 1998:9.

91 January 1998, meeting with Richard Moss, WG2 Technical Support Unit, described in draft meetings of the Berkeley meeting, February 7-8, 1997.

92 Pitcher 2005.

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

94 NAST 2000, 2001.

usable. The assessment encouraged the use of three types of climate scenarios: historical scenarios produced by extrapolating observed trends or re-imposing historical climate variability or extremes; an inverse approach using sensitivity analyses to explore the responses of climate-sensitive systems, with particular emphasis on thresholds defining key vulnerabilities; and climate model simulations of future climate conditions.[95]

Of these three approaches, the climate-model scenarios were the most precisely specified and the most widely used. The National Assessment did not have the resources or time to commission new climate model runs and so had to rely on those completed and published when it began its work. A set of criteria was developed by the NAST for the climate model scenarios to be used in the assessment. Climate-model scenarios used in the assessment should, to the greatest extent possible:[96]

1. Include comprehensive representations of the atmosphere, oceans, and land surface, and key feedbacks among them

2. Simulate the climate from 1900 to 2100, based on a well-documented emissions scenario that includes greenhouse gases and aerosols

3. Have the finest practicable spatial and temporal resolution, with grid cells of less than 5˚ latitude x longitude

4. Include the daily cycle of solar radiation, to allow projections of daily maximum and minimum temperatures

5. Be able to represent significant aspects of climate variability such as the El Niño-Southern Oscillation (ENSO) cycle

6. Be completed in time to be quality-checked and interpolated to the finer time and spatial scales needed for impact studies

7. Be based on well-documented models participating in the IPCC Third Assessment (for comparability between US and international efforts)

8. Be able to interface results with higher-resolution regional model studies

9. Provide a comprehensive array of results openly over the internet.

Of the three approaches, the climate-model scenarios were the most precisely specified and the most widely used.

To ensure timely dissemination, the National Assessment chose climate-model scenarios to be used in its analyses in mid-1998. At that time, only two groups had completed runs that met most of the key criteria: the UK Hadley Centre (Model Version 2) and the Canadian Centre for Climate Modeling and Analysis (Model Version 1).[97] All participating regional and sector teams were asked to use these scenarios. The climate sensitivity of these models was 2.5°C (UK Hadley) and 3.6°C (Canadian), lying in the middle of the 1.7 to 4.2°C range of sensitivities represented by models participating in the IPCC Third Assessment.[98]

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

For these two climate models, model runs using only one emissions scenario were available, and only one ensemble run was used for each.[99] The

[95] NAST 2001:25. It is arguable whether or not 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. However, we are following the usage of the NAST reports in calling these approaches three types of scenarios.

[96] NAST 2001:31-32; MacCracken et al. 2001; MacCracken et al. 2003:1714.

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

[98] Cubasch et al. 2001, Table 9.1:538-540; and Table 9A.1:577.

[99] 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 National Assessment was only able to use one.

emissions scenario was IS92a, which represented the middle of the range of IPCC's 1992 scenarios.[100] In addition to greenhouse gases, the scenario included atmospheric loadings of sulfate aerosols, which were assumed to increase sharply through 2050 and then level off for the rest of the 21st century.[101]

The applicability of these two scenarios was tested by checking the models' ability to replicate broad patterns of US climate change over the 20th century when driven by historical greenhouse-gas forcings. Model results were compared against the VEMAP (Vegetation-Ecosystem Mapping and Analysis Project) dataset, a corrected climatic dataset for the 20th century. This comparison showed reasonable accuracy in reproducing the spatial distribution of average temperatures and century-long temperature trends, but significantly weaker reproduction of observed patterns of precipitation, mainly because the spatial distribution of precipitation depends on topographic detail that is too fine-scale to be captured even by the 0.5-degree VEMAP grid.[102]

With the specified scenario of future emissions, the two climate-model scenarios projected global warming by 2100 of 4.2°C (Canadian) and 2.6°C (Hadley).[103] These projections were at the high end and in the middle, respectively, of the range of warming projected for this emissions scenario by models participating in the IPCC Third Assessment Report.[104] For the continental United States, the two models projected warming by 2100 of 5.0°C (Canadian) and 2.6°C (Hadley), at the high end and below the middle, respectively, of the range of projections in the IPCC Third Assessment.[105] In their projections of precipitation change over the United States, these scenarios both lay at the high end – the Hadley scenario projected the highest precipitation in 2100 and the Canadian the second-highest[106] – but the Canadian model's greater warming offset the effect of this precipitation increase on soil moisture, which was projected to decrease over most of the continental United States.[107]

Although only the Hadley and Canadian climate-model scenarios were used throughout the assessment, several others that met some or all of the assessment's needs became available during its work. Several region and sector teams were able to use these additional scenarios. In some cases, the additional scenarios allowed groups to strengthen their conclusions. For example, an analysis of future Great Lakes water levels under climate change using eleven climate models found that ten of these showed lower levels and only one higher.[108] In other cases, using multiple models allowed more detailed characterization of uncertainties in future regional changes. For example, the Pacific Northwest team presented distributions of regional temperature and precipitation change in the 2030s and 2090s using seven GCMs.[109]

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

[100] 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.

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

[102] VEMAP members 1995, Kittel et al. 1995.

[103] NAST 2001:36, Table 2.

[104] Cubasch et al. 2001, Figure 9.5a: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.

[105] 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. See NAST 2001:547, Figure 7.

[106] NAST 2001:545, Figure 8.

[107] NAST 2001:552, Figure 16 and 18.

[108] Lofgren et al. 2000; NAST 2001:175.

[109] NAST 2001:256.

assessment's publications. Two uses of historical climate data – describing observed impacts of climate variability and using observed historical extremes as benchmarks to compare projected future changes – were made by all groups. To support systematic use of historical scenarios, the VEMAP 20^{th}-century dataset was provided to all groups, but no further guidance was provided on how to generate climate scenarios from these historical data, e.g., on what periods to choose or how to use them to assess potential future impacts. Several groups used these historical data to describe the impacts of particular recognized patterns of climate variability, such as ENSO or the Pacific Decadal Oscillation (PDO).[110] Many groups examined past climate extremes, but only in qualitative ways; most did not follow the approach, taken in some previous impact studies, of using historical extreme periods as quantitative proxies for potential future climate.[111]

The third approach, vulnerability analysis, was the least used in the National Assessment. This "inverse" approach involves describing the properties of a climate-sensitive system, specifying some important change or disruption, and asking what climate changes would be required to bring about that disruption and how likely – based on historical data and model calculations – such climate changes appear to be. Given the complex dynamics of climate-sensitive systems and models of these systems, and the multiple dimensions of climate on which these can depend, this approach requires a substantial program of new research, analysis, and methodological development.[112] In part because of the intrinsic difficulty of this task – and in part due to management and resource problems – this approach was not pursued. The NAST proposed it, but more tractable approaches to analyzing climate impacts dominated the assessment's work. This remains an important area for further work in development of assessment and modeling methods.

110 E.g., Mote et al. 2003, Southeast Regional Assessment Team 2002.

111 Rosenberg et al. 1993.

112 For an example of such efforts, see the AIACC (Assessments of Impacts and Adaptations to Climate Change) project, information at http://www.aiaccproject.org.

3.2.2. Socio-economic scenarios

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

Socio-economic scenarios are also needed to assess climate-change impacts on human communities.

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

113 Parson et al. 2001:102-103.

nomic model.[114] Beyond 2030, national projections of these variables followed OECD growth rates in the SRES marker scenarios.[115]

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

More useful assessments of impacts and vulnerability will require more extensive use of socio-economic scenarios, improved integration of socio-economic with climatic and environmental scenarios, and substantial further investment in development and testing of new methods.

Implementation of socio-economic scenarios in the National Assessment was weak. Few assessment teams used the proposed approach. Many made no socio-economic projections at all, but rather projected only biophysical impacts based on GCM results. One assessment team found the socio-economic scenarios were inconsistent with superior local estimates of current population, and so decided not to use them.[116] The teams that did use the socio-economic scenarios used only aggregate projections of population and economic growth, or in some cases assumed continuation of present conditions in the assessment period. None used the proposed template for identifying and projecting additional important socio-economic characteristics.

[114] Terleckyj 1999a,b.

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

[116] Rosenzweig and Solecki 2001.

Several factors contributed to this limited use of socio-economic scenarios. In addition to various managerial and communication problems, many participants were reluctant to use socio-economic scenarios, especially the proposed decentralized approach. Some preferred to avoid any socio-economic projections, implicitly presuming either that socio-economic conditions did not matter for impacts, or that those that did matter would remain similar to present conditions. Others objected to specific contents of the scenarios or the methods used to generate them, or judged that their team lacked the expertise required to evaluate them. Still others objected that uncertainties in future socio-economic conditions made any attempt to construct scenarios for more than a few years in the future unacceptably speculative.[117] Consequently, while the assessment attempted to advance scenario methods, weak implementation of these methods limited its ability to identify key vulnerabilities. More useful assessments of impacts and vulnerability will require more extensive use of socio-economic scenarios, improved integration of socio-economic with climatic and environmental scenarios, and substantial further investment in development and testing of new methods.[118]

3.2.3. Criticisms and controversies

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

The first, widely circulated during 2000, was that the use of non-American climate models for climate scenarios was inappropriate and potentially injurious to national interests.[119] While this criticism indicates a dimension of political

[117] Morgan et al. 2005.

[118] Lorenzoni et al. 2000, Berkhout and Hertin 2000, Parson et al. 2003.

[119] Congressional Record, June 16, 2001, Statements of Senators Hagel (page S5292) and Craig (page S5294).

vulnerability of the assessment, it does not address the assessment's technical quality. Since climate models represent the physics of the global atmosphere, they contain no representation of political or economic factors. The Hadley and Canadian global climate models were extensively documented in peer-reviewed scientific literature – and, moreover, were the only models that met the most critical of the assessment's criteria. That they were developed by scientific groups outside the United States has no significance for their ability to provide scenarios to assess US impacts. Using US models would have avoided this criticism, but at the cost of either weakening the analysis by using scenarios that did not meet the assessment's needs, or delaying the work by one to two years. In deciding to proceed with non-US models, assessment organizers judged that these costs were too high.

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

The National Assessment's organizers and its critics agreed that using more models would have been preferable, but the assessment was limited by its schedule and its technical requirements. Given a limit of only two, there can be good reasons to choose one scenario in the middle of current projections and one near the top that provides a plausible upper-bound, but the significance of the results must then be communicated with great care. Some critics suggested that presentation of results based on the relatively high Canadian scenario should be more carefully qualified to highlight its position near the top of current projections.[120] Such qualifications must be crafted very subtly, however, lest they imply these results may safely be ignored, when most analyses suggest the full range of future climate-change uncertainty extends both below the Hadley scenario and – in a long, thin tail – above the Canadian.

A related criticism of the climate scenarios claimed that the emissions scenario driving them was implausibly high. The issues bearing on choice of emission scenarios are similar to those for choice of climate models. It would be preferable to have a wide and relevant range of emissions scenarios driving an impact assessment – at least for the post-2050 period. Using a wide range of emissions scenarios would also allow comparison of projected impacts under high and low emissions futures, and so give insights into what degree of impacts could be avoided by what degree of mitigation effort. Model runs with this emissions scenario were all that were available, however. Moreover, there is no clear basis to reject this particular scenario, since it was the scenario most widely used in climate-model runs at the time and lies near the middle of the range of both the 1992 and the 2001 IPCC scenarios. Finally, there is no support for the claim that this scenario was chosen with the aim of making 21st-century climate change appear as frightening as possible.[121] But, although using just two climate models with one emissions scenario was unavoidable in this assessment, it still represented a serious limitation. With more model simulations testing a range of emission scenarios already available, future assessments will be able to remedy this deficiency.

In contrast with the preceding criticisms that the scenarios used in the assessment understated uncertainty, another criticism focused on the disparities between the two scenarios' projections. Some critics argued that such disparities – e.g., the Canadian scenario projects the Southeastern states becoming much drier than the Hadley model does – show that our limited knowledge of regional climate change makes any attempt to assess future impacts and vulnerabilities irresponsible.[122] This criticism im-

[120] MIT Integrated Assessment project, comments on National Assessment, Aug 11, 2000:15.

[121] Michaels 2003a:171-192.

[122] 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.)

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

Future assessments will need to invest substantial resources in developing the state of underlying knowledge, models, and assessment methods for integrating socio-economic considerations into assessments of climate impacts.

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

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

3.3. THE UK CLIMATE IMPACTS PROGRAMME

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

The 1998 climate scenarios provided information only at the rather coarse scale of the Hadley Centre's HadCM2 climate model, with four grid-cells over the entire UK. Four scenarios, called "high," "medium-high," "medium-low," and "low," combined variation in emissions assumptions with variation in assumed climate sensitivity. The medium-high and medium-low scenarios both used the HadCM2 model, with a sensitivity of 2.5°C.[123] The medium-high scenario was driven by a 1 percent per year equivalent-CO_2 transient scenario, similar to IS92a. The medium-low scenario was driven by a 0.5 percent per year equivalent-CO_2 transient scenario, similar to the lowest IS92 scenario, IS92d. The high and low scenarios used the same two emissions scenarios driving a simpler climate model, whose sensitivity was set at 4.5°C for the high scenario and 1.5°C for the low. These scenarios were used in an initial impact assessment focusing predominantly on direct biophysical impacts.[124] The scenarios did not include any explicit statements of probabil-

123 UKCIP 1998:13-15.

124 UKCIP 2000.

ity, although their documentation suggested that the medium-high and medium-low scenarios "in one sense … may be seen as being equally likely,"[125] while the high and low scenarios captured part of the tails of the distribution. Nor did they include any potential extreme climate events such as those associated with large changes in the North Atlantic circulation.

The UKCIP's socio-economic scenarios drew on the Foresight Program, a broader exercise of the UK Department of Trade and Industry to develop scenarios for long-range planning in several policy areas, with additional detail in areas relevant to greenhouse-gas emissions and climate impacts.[126] As in several other scenario exercises, developers identified two fundamental uncertainties and combined two alternative outcomes of each to produce four scenarios. The two core uncertainties they chose were similar to those used in the SRES exercise: social and political values, which varied from an increased focus on individual consumption and personal freedom ("consumerism") to a widespread elevation of concern for the common good ("community"); and governance, which varied from authority and power concentrated at the national level ("autonomy"), to power increasingly flowing to global institutions, downward to local ones, and outward to non-governmental institutions and civil society ("interdependence"). The two dimensions of uncertainty, values and governance, were assumed to be independent of each other. Other major uncertainties such as demographic change, the rate and composition of economic growth, and the rate and direction of technological change, were treated largely as consequences of alternative realizations of the two core dimensions of values and governance.[127]

The four scenarios built around these two dimensions of variation were called "National Enterprise," "World Markets," "Local Stewardship," and "Global Sustainability." Each was initially developed as a qualitative narrative of future conditions in UK society intended to apply broadly to both the 2020s and 2050s. Each scenario specified several dozen socio-economic characteristics qualitatively, including multiple aspects of economic development, settlement and planning, values and policy, agriculture, water, biodiversity, coastal zone development, and the built environment.[128]

Each scenario was also realized in projections of multiple quantitative variables, at the national scale only. For the 2020s, these provided detail on population, GDP (including the governmental share and the sector split between industry, agriculture, and services); household numbers and average household size; land use and rates of change; total transport and modal split; agricultural production (including such details as chemical and financial inputs, subsidies, yields, and organic area); freshwater supply, demand, and quality; and several indicators of biodiversity and coastal vulnerability. For the 2050s a smaller set of quantitative variables was projected, describing population, GDP, land use, and transport. The plausibility of projections was checked, mainly by comparing projected future rates of change to historical experience. The scenarios were published with a detailed guidance document, which provided suggestions on how to use them together with climate scenarios for impact studies.[129]

The UKCIP's socio-economic scenarios drew on the Foresight Program, a broader exercise of the UK Department of Trade and Industry to develop scenarios for long-range planning in several policy areas, with additional detail in areas relevant to greenhouse-gas emissions.

As of 2005, the socio-economic scenarios had been used in six impact studies.[130] There has been some difficulty applying the national-level scenarios in specific, smaller-scale regions. The most ambitious use has been a preliminary integrated assessment of climate impacts and responses in two regions of England, the Northwest and East Anglia.[131] This study produced four integrated scenarios of regional climate impacts, by pairing each of the four socio-economic scenarios with one climate scenario based on a rough correspondence between the socio-economic scenario and the IPCC emissions scenario underlying the climate scenario[132] Based on these four scenarios, the

125 UKCIP 1998:iv.

126 UKCIP 2001.

127 UKCIP, 2001.

128 Berkhout et al. 2001.

129 Berkhout and Hertin 2001.

130 UKCIP 2005.

131 Holman et al. 2002.

132 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).

study elaborated preliminary regional scenarios corresponding to the four national socio-economic scenarios, and conducted an assessment of coastal-zone impacts and responses using these scenarios and a formal land-use model.

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

The UK program's experience highlights some of the same issues for future scenario exercises as the US National Assessment, in particular the importance of continuity of institutional and analytic capability and the desirability of developing and supporting scenarios using an organizational structure that combines centralized and decentralized elements.

Several analyses are continuing to use the 2002 climate scenarios in conjunction with the socio-economic scenarios. For example, a 2004 integrated analysis of flood risk and erosion control over a 30-100 year time horizon produced a threat assessment, a set of scenarios of flood risk, and a set of policy recommendations. An evaluation of this study's effects one year later found that it was being used by several public and private actors to inform decision-making.[133]

The UKCIP, in contrast to the US National Assessment, has built a sustained assessment capability. In addition, the central program has less authority over the separate assessments, instead acting more as motivator, resource, and light coordinator. Access to scenarios is to licensed users, of whom there are about 130 – roughly half in universities, the rest about equally split among private sector and all levels of government. Most active users have been national officials responsible for climate-sensitive resources, with less participation from the private sector and local governments.[134]

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

[133] UK Office of Science and Technology 2002.

[134] West and Gawith 2005.

3.4. THE MILLENNIUM ECOSYSTEM ASSESSMENT

The Millennium Ecosystem Assessment (MEA) was a large, United Nations (UN)-sponsored assessment of the current status, present trends, and longer-term challenges to the world's ecosystems, including climate change and other sources of stress. Conducted between 2001 and 2005, the MEA sought to assess changes in ecosystems in terms of the services they provide to people and the effects of ecosystem change on human well-being. It also sought to identify and assess methods to mitigate and respond to ecosystem change, for various private and public-sector decision-makers, including those responsible for the several international treaties that deal with ecosystems.[135] More than 1350 authors from 95 countries participated in the global assessment's four working groups, and hundreds more in about 30 associated sub-global assessments. The assessment's goals were broad, ranging from providing a benchmark for future assessments and guiding future research to identifying priorities for action.[136]

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

All components of the assessment used a common large-scale conceptual framework, which distinguished indirect drivers of ecosystem change, direct drivers, ecosystem indicators, ecosystem services, measures of human well-being, and response options. Direct drivers included direct human perturbations of the environment such as climate change, air pollution, land-use and land-cover change, resource consumption, and external inputs to ecosystems such as irrigation and synthetic fertilizer use. Indirect drivers included underlying socio-economic factors such as population, economic growth, technological change, policies, attitudes, and lifestyles.[137]

The scenarios working group sought to apply this conceptual framework to long-term trends in ecosystems, looking ahead to 2050 with more limited projections to 2100. They developed the structure of the scenarios in an iterative process, including consultations with potential scenario users and experts in a wide range of decision-making positions around the world.[138] Like several other major scenario exercises, they initially sought to identify two basic dimensions of uncertainty in long-term ecosystem stresses, which together would produce four scenarios.[139] For the first dimension, like SRES they chose globalization: continuation and acceleration of present global integration trends, versus reversal of these trends to increasing separation and isolation of nations and regions. For the second dimension, in contrast to the broad value-based uncertainties used in the SRES and UKCIP scenarios, they chose one more specifically related to ecosystems: whether responses to increasing ecosystem stresses are predominantly reactive – waiting until evidence of deterioration and loss of services is clear – or predominantly proactive, taking protective measures in advance of their clear need. The combination of two polar values of each of these uncertainties yielded four scenarios, summarized in Table 3.2.

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

The MEA sought to assess changes in ecosystems in terms of the services they provide to people and the effects of ecosystem change on human well-being.

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

[136] MEA 2006:xii.

[137] MEA 2006:153 (Table 6.1) and 304 (Table 9.2).

[138] MEA 2006:152.

[139] MEA 2006, Figure 5.2.

Table 3.2. Millennium Ecosystem Assessment Scenarios

ECOSYSTEM MANAGEMENT	WORLD DEVELOPMENT	
	Global	Regional
Reactive	Global Orchestration	Order from Strength
Proactive	TechnoGarden	Adapting Mosaic

problems.[140] In Order from Strength (regional, reactive) the reactive approach to ecosystem problems takes place in a fragmented world preoccupied with security and less attentive to public goods.[141] This scenario exhibits the highest population growth and lowest economic growth. Economic growth is particularly low in the developing countries, and it decreases over time. In Adapting Mosaic (regional, proactive), political and economic activity are concentrated at the regional ecosystem scale. Societies invest heavily in protection and management of ecosystems in locally organized and diverse efforts. Population growth is nearly as high as in Order from Strength, and economic growth is initially slow but increases after 2020. Finally, TechnoGarden (global, proactive) presents a world that is both focused on ecosystem management and globally connected, with strong development of environmentally friendly technology. Population growth is moderate, and economic growth is relatively high and increasing.[142]

Each scenario was initially constructed as a qualitative description. Population and GDP were specified quantitatively, while all other indirect drivers – including social, political, and cultural factors – were qualitative. Population scenarios were derived from the International Institute for Applied Systems Analysis' (IIASA's) 2001 probabilistic projections, capturing the middle 50-60 percent of the distribution, with world population in 2050 ranging from 8.1 billion (Global Orchestration) to 9.6 billion (Order from Strength).[143] No statements of probability or likelihood were made about the scenarios.

From the indirect drivers, a more specific and quantified set of direct drivers was developed, using formal models where possible. Species introduction and removal was the only unquantified direct driver.[144] Separate pre-existing models were used of the world energy-economy, greenhouse-gas emissions and climate change, air pollution, land-use change, freshwater, terrestrial ecosystems, biodiversity, and marine and freshwater fisheries. To the extent possible, these quantitative models were used to reason from indirect and direct drivers to ecosystem effects, changes in ecosystem services, and effects on human well-being.[145] In some cases this was achieved by soft-linking models, using outputs from one as inputs to another, but this was limited by different variable definitions, spatial and temporal resolution, and other model incompatibilities.[146] Not all scenario elements could be modeled quantitatively, so expert judgments were also extensively used. The qualitative scenario process proceeded in parallel with quantitative modeling – elaborating aspects of the scenarios that were not amenable to modeling, filling gaps, and stipulating feedbacks between ecosystem services and human well-being and behavior.[147]

140 MEA 2006, Ch 5.5.1

141 This scenario was originally named "Fortress World" (report of first meeting of MEA 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 2006:133)

142 MEA 2006:131.

143 MEA 2006:182.

144 MEA 2006:304, Table 9.2.

145 MEA 2006, Table S3.

146 MEA 2005, Table S2.

147 MEA 2006:155.

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

Many of the conclusions developed from the scenarios are common to all four scenarios, while in others Order from Strength is the exception. For example, one major conclusion is that rapid conversion of ecosystems for use in agriculture, cities, and infrastructure will continue, and that habitat loss will continue to contribute to biodiversity loss. However, if ecosystem services increase as projected, some ecosystem services – although not biodiversity – may be decoupled from ecosystem stresses. Food security is projected to remain out of reach for many people. Extreme, spatially diverse changes are projected for freshwater resources, with general deterioration in developing countries under both "reactive" scenarios. Increasing demands for fishery products are projected to increase risks of regional marine fishery collapses.[148] In sum, ecosystem services show mixes of improving and worsening trends in all scenarios except Order from Strength, in which nearly all ecosystem services are projected to be more impaired in 2050 than in 2000. The same three scenarios also suggest that significant changes in policies, institutions, and practices can mitigate some negative consequences.[149]

[148] MEA 2006, Table S3.

[149] MEA 2006:127.

In sum, the MEA scenarios project invested substantially more effort in developing rich qualitative and narrative scenarios than the SRES, but also fell short on integrating qualitative and quantitative components. In part because of the greater elaboration of the qualitative components, this limited coordination resulted in significant inconsistencies and requirements to resolve conflicts between the two components. These inconsistencies arose even with just one model used for several components of the assessment, so the challenges of harmonization among models – and the associated possibility to explore model-structure uncertainty – did not arise. A related problem was that for many factors it was difficult to generate the desired level of variation between scenarios.[150] This raises issues of potential methodological interest, such as how to distinguish robust results from inadvertent convergence of assumptions or model structures, which remain to be investigated. Finally, the great breadth of conditions represented in the scenarios, as well as possible concerns with logical circularity between their presumptions and results,[151] make interpreting the significance of the results difficult.

The experience of this scenario exercise provides a different perspective on some of the same key challenges for future scenarios highlighted by the other activities reviewed. The quite distinct difficulties faced here in attempting to combine quantitative and qualitative scenarios highlight the central importance and the difficulty of developing new methods to integrate these two approaches. In addition, this experience highlights the value of clarity about the intended uses of scenarios, including clarity about whether they are intended to address specific questions, guide decisions, or explore long-term conditions. The risk of scenarios becoming

[150] Report of the First Meeting of the MEA Global Modeling Group, 7 Jan 2003, at www.usf.uni-kassel.de/ma-gmgroup/dl/first_report.doc; Second Report of the MEA Global Modeling Group, 7 March 2003, available at www.usf.uni-kassel.de/ma-gmgroup/dl/sanjose_report.doc.

[151] This concern is particularly present regarding implications of the assumption that ecosystem management is either proactive or reactive (See, e.g., MEA 2006, Ch 8.4.2.1 and Ch 9).

less useful due to breadth and vagueness may be particularly acute for scenarios that attempt to capture multiple stresses on some system – even though such multi-stress assessment is repeatedly advocated for climate-change and other forms of environmental assessment.[152]

[152] NAST 2001.