3. Review of Major Climate-Change Scenario Exercises

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

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

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

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

3.1. IPCC Emissions Scenarios

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

The 1990 Scenarios

For its first Report IPCC's Working Group 3 on "Response Strategies" included a sub-group on emissions scenarios. After meeting three times in 1989, this group produced four emissions scenarios in December 1989. Two models were used, principally to provide accounting frameworks by which the assumptions contributing to alternative emission paths could be compared: the Atmospheric Stabilization Framework (ASF), developed at US EPA,[64] and the Integrated Model for Assessment of the Greenhouse Effect (IMAGE 1.0).[65] Four scenarios were produced: a baseline called "high emissions," in which equivalent CO_2 concentration reached 550 ppm by 2030; a "low-emissions" scenario in which 550 ppm was reached in 2060; a "control policies," scenario, in which moderate mitigation policies delayed 550 ppm until 2090; and an "accelerated policies" scenario, in which aggressive mitigation policies stabilized CO_2 below 550 ppm. Each scenario represented emissions of CO_2 plus highly simplified representations of five other gases for five world regions, under high and low-economic growth variants.[66] Although prepared for the assessments of climate change and its impacts conducted in parallel by IPCC Working Groups 1 and 2, the scenarios were little used in this assessment, because of time limits and because with one exception only doubled-CO_2 equilibrium climate-model runs were available at the time.[67]

The 1992 Scenarios

IPCC decided in March 1991 that updated scenarios were needed because of several events and policy changes since 1990 – e.g., the Montreal Protocol's decision to phase out several ozone-depleting chemicals that were also greenhouse gases, new population projections from the UN and World Bank, and political transformations in the Soviet Union and Eastern Europe. In contrast to the 1990 scenarios, the new mandate explicitly excluded scenarios that assumed mitigation policy.[68]

The exercise produced six new scenarios, called IS92a through IS92f. These were the first global emissions scenarios with a full suite of greenhouse gases and at least some explicit calculation underlying each. The middle scenarios, IS92a and IS92b, updated the "high emissions" or "A" scenario from 1990. Assuming a 2100 world population of 11.3 billion and 2.3% average annual world economic growth through 2100, these projected world CO_2 emissions of roughly 20 GtC and 19GtC in 2100.[69] IS92a was the most prominent and widely used of these scenarios. Of the other scenarios, two assumed lower population and economic growth, giving world emissions of 5 - 10 GtC in 2100, while the other two assumed higher growth and projected 27 - 35 GtC of world emissions in 2100.[70] The ASF model was used as an accounting framework to track assumptions and emissions for all six scenarios, which were presented with more detailed reporting of underlying assumptions than the 1990 scenarios.[71]

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

[65] Rotmans 1990

[66] 3% average GDP growth in OECD 5% in rest of world for high, 2% OECD 3% rest of world for low.

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

[68] Swart et al, 1991

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

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

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

In the climate-model comparisons conducted for the next IPCC assessment, published in 1996, the IS92a scenario was used in several model runs along with the simpler transient scenario of 1% annual increase in equivalent-CO_2 concentration and further equilibrium runs.[72] The new transient runs still represented all greenhouse gases as CO_2-equivalent, rather than explicitly representing each gas separately.

The Special Report on Emissions Scenarios (SRES)

The third and most ambitious IPCC scenario exercise was established partly in response to two widely circulated criticisms of the IS92 scenarios. The first of these criticized the 1992 scenarios for inconsistency with other published scenarios of energy and carbon intensity for major world regions; failing to reflect economic declines in Eastern Europe and the former Soviet Union and increasing restrictions on sulfur emissions; relying inappropriately on a single model; and being useful only as inputs to climate models, not for other purposes such as mitigation studies or supporting climate-change negotiations.[73] The second criticized the IS92a scenario for assuming further divergence in per capita emissions between industrialized and developing regions, and argued that this represented a strong bias in favor of already developed regions.[74]

In response to these criticisms, the May 1996 IPCC Plenary session asked Working Group 3 to develop a new set of emissions scenarios. The new scenarios were instructed to improve treatment of sulfur aerosols and emissions from land-use change, and to not rely on a single model or expert team, but instead draw on the existing literature and invite any group with relevant expertise to participate through an "open process."[75] They were also charged to serve more purposes than just providing inputs to climate models, such as supporting impact analyses, but to assume no new climate-policy interventions. Although not explicitly stated in the terms of reference, it was also clearly understood that the scenarios would address the criticism of the IS92 scenarios by focusing convergent development paths between North and South.

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

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

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

[74] Parikh 1992.

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

As part of the team's review of published scenarios and open process, a web-based database of scenarios was developed by Japan's National Institute for Environmental Studies (NIES).[76] Prior scenarios were compiled here, and any researcher was invited to submit new ones. By mid-1998 the database contained more than 400 scenarios from more than 170 sources. The great majority of these projected only energy-related CO_2 emissions: otherwise, the scenarios were highly diverse in their temporal and regional coverage and resolution, the variables included, and their methodologies. The usefulness of these scenarios in constructing new ones was limited by several weaknesses, however. Many were incomplete, lacked documentation of inputs, or made inconsistent assumptions. Few included sulfur and land-use emissions, which were specifically requested of the new scenarios. Many were unclear on whether they assumed mitigation efforts, while the new scenarios were instructed to exclude them. Consequently, the development of new scenarios had to proceed largely independent of the collection of existing scenarios through the literature review and open process.

Work on new scenarios began in early 1997, aiming to provide preliminary scenarios to climate modelers by early 1998 and final scenarios by late 1998.[77] Early on, it was decided to use narrative scenarios in addition to quantitative models, and include experts in this approach on the writing team. This decision responded to the charge to make the scenarios more integrated and serve more purposes than emissions projections, and recent successes using such scenarios for energy and environmental applications.[78] An April 1997 workshop in Paris began the process of developing the narrative scenarios. Here, participants sought to identify a few key uncertainties and develop coherent narratives around them. They chose two: whether world values would mainly stress economic prosperity or balance economic and ecological concerns (labeled "A" vs. "B" scenarios); and second, whether the organization of economies and institutions would keep shifting toward global integration, or reverse and shift toward regional fragmentation (labeled "1" vs. "2" scenarios).[79]

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.[80] The storylines were

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

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

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

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

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

elaborated in short text descriptions (one to two pages) with some preliminary numbers attached, between September and November, 1997.[81]

Modeling teams were asked to produce initial quantifications of these scenarios in fall 1997, to match specified 2100 target values within 10%. At this point, the set of modeling groups participating in the exercise was not finalized. Participation posed delicate management issues because while the process had to be open, it was clear from the outset that only a few groups, most of them already included on the writing team, had the capability to produce scenarios meeting the requirements of the mandate. In February 1998, the preliminary quantitative targets were re-confirmed and modelers asked to continue work on quantifications, now including a breakdown of economic output into four world regions.[82] In April, one model's quantification was chosen as a "marker scenario" for each of the four scenarios – a particular scenario that would provide the basis for interim reporting to climate modelers, some of whose results other participating models would be asked to replicate.

Table 3.1.1 Target Values for 2100 in Initial Scenario Quantifications

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

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

These interim marker scenarios were used to provide emissions scenarios to climate models participating in the IPCC third assessment. An IPCC meeting in June 1998 agreed to use SRES scenarios and asked for three cases, central emissions, stabilization, and high emissions.[83] The writing team initially discussed identifying scenarios they had produced, including markers and others, as providing each of these cases,[84] but later decided to provide only the marker scenarios and recommend that climate modelers use all four without identifying any as "central."

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

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

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

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

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

endpoint and for several interim years.[85] Achieving the requested replication posed significant challenges for modelers.[86]

With a further year of work, modeling teams produced a total of 40 scenarios that were retained in the report, of which 26 replicated one of the marker scenarios. Although a few of the 14 non-replicates reflected a model's inability to match the results of a marker scenario, most were produced because a modeling team intentionally sought to explore alternative assumptions. For example, the A1 scenario, which originally balanced fossil and non-fossil energy sources, was augmented by variants with different assumptions about fossil resources and non-fossil technology development, giving widely divergent emissions paths stressing coal, gas, and non-fossil energy technology. Modifications of the scenario set continued until late in the process. For example, it was decided at Beijing to drop several B variants with explicit mitigation, including one stabilization scenario.[87] 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").[88]

Significance and Use

The SRES scenarios have been the most comprehensive, most ambitious, most carefully documented exercise producing emissions scenarios to date. They represented a substantial advance from prior scenarios, and contributed to assessments and subsequent research on climate impacts and responses. The SRES scenarios formed the basis for climate-model comparisons in the IPCC Third Assessment (2001) and current work for the Fourth Assessment. Most subsequent climate-model work has used only a few of the marker scenarios – typically A2 and B2, sometimes with A1B added. SRES scenarios also provided baselines for analysis of mitigation scenarios in the Third assessment.[89]

Several significant insights were illuminated by the SRES scenarios.

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

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

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

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

[88] 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.

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

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

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

Criticisms and Controversies

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

Assigning Explicit Probabilities

The SRES team decided at the outset of their work to make no probabilistic statements about the scenarios. Their report uses great care in its language to avoid any suggestion that one scenario might be more central or more likely than any other.[90] 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.[91]

They were sharply criticized for this decision.[92] Critics argued that there were no technical obstacles to assigning probabilities to emissions ranges bounded by the marker scenarios; that scenario developers must have made probabilistic judgments in generating and evaluating the scenario quantifications and that not making these judgments explicit would withhold relevant information; and that if scenario developers decline to assign probabilities, others who are less informed will do so. Indeed, many probabilistic emissions calculations have been produced since the SRES, using various methods such as assigning uniform or other specified distributions over the emissions of the SRES marker scenarios, counting scenarios in the larger SRES set that lie in specified intervals in the larger SRES set or the literature (a particularly troublesome approach, in view of the tendency to over-sampling and re-publication of well-known prior scenarios), unbundling and recombining the underlying inputs to SRES emissions figures, or sampling over parameter distributions within a single model. In response to these criticisms, SRES authors argued that attempting to assign probabilities to scenarios would require assigning joint distributions to the underlying driving factors, and that this would lead to an explosion of combinatoric possibilities over which any attempt to assign probabilities would be spurious and arbitrary.[93]

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

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

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

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

93 Grubler and Nakicenovic, 2001.

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

Exchange Rates: PPP versus MER

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

In a series of letters to the IPCC chairman and several subsequent publications, two critics argued that the use of MER caused SRES scenarios to over-estimate future income growth in developing countries (because they over-estimated the initial income gap), and consequently to over-estimate future emissions growth. Their criticism was widely circulated and repeated by prominent climate-change skeptics.[94]

While the criticism is correct that using MER overstates future income growth, it does not follow that future projections of emissions growth are also over-stated. MER is universally recognized as a flawed measure of income, whose use in global-change scenarios is only justified by better availability of current and historical data, and the fact that international emissions trades in any future mitigation regime will likely be made at market exchange rates. But in switching from MER to PPP, changing the measure of income also changes the relationship between income and such physical quantities as energy and food consumption, which determine emissions. Consequently, while MER overstates future income growth in poor countries, it also overstates future reductions in energy and emissions intensity. These opposing errors are likely to be similar in size, in which case any error in emissions projections from using MER will be small.[95]

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

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

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

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

Under-Development of Narrative Scenarios

Although the SRES storylines were produced first and were featured prominently in publications, they remained underdeveloped and underused throughout the process. In part due to time pressure, in part due to the predominance of quantitative modelers in the process, little attention was given to further development of the storylines once initial quantifications were established and work on model runs began. Nor was significant effort devoted to integration and cross-checking between storylines and quantitative scenarios, although a major purpose of the narratives was to give coherent structure to quantifications.[96] 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.[97]

There was even substantial divergence among participants over the meaning of some of the scenarios – indicated by the persistent difficulty they had in agreeing on descriptive names.[98] These were eventually dropped, in the context of a broad retreat from attempting to flesh out the storylines late in the project. By spring 1998, it was agreed that only brief narratives would be posted on the web for use in the open process. By late 1998, it was agreed that storylines should be kept simple, that any evaluative language should be avoided in storylines, and that any conflict between quantifications and storylines should be addressed by revising the storyline to fit the quantification.[99] That so little integration of qualitative and quantitative components was achieved when this project appears to have engaged the task more seriously and persistently than any other climate-change scenario exercise suggests the magnitude of the analytical and methodological challenges involved in realizing the potential benefits of such integration.

Harmonizing Scenarios, Interpreting the Results

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

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[96] Beijing minutes, pg 10.

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

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

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

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

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

The problems associated with attempting to harmonize model outputs are related to the under-development of narrative scenarios and limited integration of qualitative and quantitative components. The initial quantitative targets were specified as part of sketching the narrative scenarios, but there was little subsequent re-examination of either the narratives or the associated numerical targets. Consequently, the storylines were associated with these relatively restrictive targets even though the storylines did not develop the richness or detail needed to cohere as narratives that would carry implications for additional characteristics beyond those explicitly specified. The preliminary targets were only slightly modified throughout the project, despite subsequent discovery of significant problems. For example, the UN 1998 population projections, with substantial reductions in projected fertility, were completed while the scenario development work was underway but not incorporated.[100]

Clarity about Uses, involving Users:

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

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[100] Bilthoven minutes, p. 11.

guidance on what specific additional uses or users to serve, or on how the scenarios might best serve them – neither of which is obvious.[101]

Providing emissions inputs for climate models remained the most prominent and most clearly specified use, as well as the single use that had an early deadline. But while climate modelers became by default the primary targeted users – and a substantial downscaling effort was appended to the SRES process to address their needs – they were not involved in the scenario development process and there were some differences of detail over the usability of the scenarios. A September 1997 briefing identified the principal needs of climate modelers as haste and greater emissions detail.[102] They wanted separate emissions trajectories for major greenhouse gases, not just CO_2-equivalent, including regional detail for some emissions such as sulfur – even suggesting that it would be desirable to have sulfur emissions disaggregated by stack height, to distinguish dispersed emissions from large point sources. Although SRES provided gridded sulfur data by post-processing model outputs, in most cases the emissions included and their spatial detail (not to mention stack height) were limited by the structure of participating models, so there was limited ability to respond to these requests.

For other potential uses, the SRES process received less detailed and specific requests and potential users or their representatives were still less involved in the process. Supporting assessment of mitigation strategies was largely deferred to the post-SRES scenarios prepared for the IPCC Third Assessment Report, although ambiguity about the degree of mitigation effort implied by some SRES scenarios complicated that subsequent task. For supporting impact and vulnerability assessment, the basic organization of the activity limited the detail and specificity of information it could provide, since many dimensions of impacts depend on diverse small-scale socio-economic and ecological factors that a global exercise centered on energy-economic models cannot provide.[103] For the population and economic projections that were provided in the course of generating emissions scenarios, the key issue for impacts and adaptation was the degree of spatial detail provided. For consistency among scenarios, and to avoid base-year discrepancies with national and regional datasets, SRES scenario results were reported only for four large world regions. Greater regional detail was available from individual models, but not with consistent regional boundaries. Providing the greater regional detail desired for impact assessments would generate discrepancies between the global-model results represented in scenarios and the more detailed data and projections available at national and regional levels.[104] Developing valid methods to down-scale socio-economic scenario information and integrate it with national and regional datasets remain key challenges for producing useful scenarios for impact assessment, on which further progress is needed.[105]

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

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[101] Alcamo et al, 1995.

[102] Bilthoven draft minutes, p. 5.

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

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

[105] Pitcher 2005.

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

3.2. The US National Assessment

The U.S. National Assessment (USNA) was the most comprehensive attempt to date to assess climate impacts on the United States over the 21st century and to consider both major sub-national regions and sectors.[106] Organized in response to a call for climate-impact assessments in the 1990 Global Change Research Act, the Assessment was organized by the federal agencies participating in the U.S. Global Change Research Program. Work began in 1997, with various components completed between 2000 and 2002. The assessment included separate teams examining US climate impacts and vulnerability on sub-national regions, sectors, and the nation as a whole, and included participation by roughly two thousand experts and stakeholders. The National Assessment was charged with assessing US impacts of climate variability and change over 25-year and 100-year time horizons. Regional impacts were initially considered in twenty regional workshops, followed by more extended analyses of impacts leading to published assessments for twelve regions, conducted by university-based teams. Sectoral impacts were examined by national teams focusing on agriculture, water, human health, coastal areas and marine resources, and forests. A federal advisory committee, the National Assessment Synthesis Team (NAST), provided intellectual direction for the assessment and synthesized its results in two published reports (NAST 2000, 2001).

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

Emission and Climate Scenarios

For climate scenarios, the Assessment relied predominantly on data and model results previously produced, and conducted additional checking, processing, documentation, and dissemination as needed to make these usable by its study teams. The Assessment encouraged the use of three types of scenarios: historical scenarios produced by extrapolating observed trends or re-imposing historical climate variability or extremes; an inverse approach using sensitivity analyses to explore the responses of climate-sensitive systems, with particular

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

emphasis on thresholds defining key vulnerabilities; and global climate model (GCM) simulations of potential future climate conditions to the year 2100.[107]

Of these three approaches, the GCM scenarios were the most precisely specified and the most widely used. The Assessment did not have the resources or time to commission new GCM runs, so relied on model runs completed and published when it began its work. A set of criteria was developed by the NAST for the climate model scenarios to be used in the Assessment. Climate-model scenarios used in the Assessment should, to the greatest extent possible:[108]

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

To ensure timely dissemination, the Assessment chose climate-model scenarios to be used in its analyses in mid-1998. At that time, only two groups had completed runs that met most of the key criteria: the UK Hadley Centre (Model Version 2) and the Canadian Centre for Climate Modeling and Analysis (Model Version 1).[109] These two were consequently chosen as the Assessment's primary climate-model scenarios, which all participating regional and sector analyses were asked to use. The climate sensitivity of these models was 2.5°C (UK Hadley) and 3.6°C (Canadian), lying in the middle of the 1.7 to 4.2°C range of sensitivities represented by models participating in the IPCC Third Assessment.[110]

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

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

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

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

These two models were limited in their ability to reproduce observed patterns of inter-annual and inter-decadal climate variability, so this was the criterion most weakly met. Other scenarios available at the time from other climate-modeling groups had more serious limitations that made them unusable as standard scenarios for the Assessment. These included unavailability of documented results; projections that stopped short of 2100; non-standard emissions scenarios that made results non-comparable with other models; and failure to treat the day-night cycle explicitly. But because an important part of the analysis conducted by the Assessment was based on quantitative ecosystem models that required not just projected changes in daily-average temperatures, but separate projections of daily highs and lows, this requirement was essential.

For each of these two climate models, only model runs using one emissions scenario were available, and only one ensemble run was used for each.[111] The emissions scenario was IS92a, which represented the middle of the range of IPCC's 1992 scenarios.[112] In addition to greenhouse gases, the scenario included projections of future trends in atmospheric loadings of sulfate aerosols (SO_4), which were assumed to increase sharply through 2050 and then level off for the rest of the 21st century.[113]

The applicability of these two scenarios was tested by checking the models' ability to replicate broad patterns of US climate change over the 20th century when driven by historical greenhouse-gas forcings. Model results were compared against the VEMAP (Vegetation-Ecosystem Mapping and Analysis Project) dataset, a corrected climatic dataset for the 20th century. The VEMAP dataset used statistical methods to interpolate observations to a uniform fine-scale (0.5-degree) grid, fill in missing values, and generate representative daily weather data when only monthly means were available. In addition, it sought to correct for the warm bias present in high-elevation temperature records because observing stations tend to be located in valleys, by adding readings from mountain snow stations. When 20th-century model results were processed using VEMAP algorithms to produce fine-scale data comparable to VEMAP historical observations, they showed reasonable accuracy in reproducing the spatial distribution of average temperatures and century-long temperature trends, but were significantly weaker in replicating observed patterns of precipitation, principally because the spatial distribution of precipitation depends on topographic detail too fine-scale to be captured even by the 0.5-degree VEMAP grid.[114]

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

[112] 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.

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

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

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).[115] This projected global warming put these two models at the high end and in the middle, respectively, of the range of warming projected for this emissions scenario by models participating in the IPCC Third Assessment Report.[116] 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.[117] In their projections of precipitation change over the US, these scenarios both lie at the high end – the Hadley scenario projects the highest precipitation in 2100 and the Canadian the second-highest[118] -- but the Canadian model's greater warming offsets the effect of this precipitation increase on soil moisture, which is projected to decrease over most of the continental United States.[119]

To provide the finer-scale projections required for impact assessment, model-generated projections of monthly climate data were distributed across space (finer points within each model grid-cell) and time (days within the month) following the same finer-scale patterns produced by VEMAP for the observed 20th-century data.[120]

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.[121] In other cases, using multiple models allowed more detailed characterization of uncertainties in future regional changes. For example, the Pacific Northwest team presented distributions of regional temperature and precipitation change in the 2030s and 2090s using four current models and three earlier-generation models.[122]

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115 NAST 2001 p. 36, Table 2.

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

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

118 NAST 2001 p. 545, Fig. 8.

119 NAST 2001 p. 552, Fig. 16 and 18.

120 NAST 2001, p. 39.

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

122 NAST 2001 p. 256, Fig. 9, from Mote et al 1999, p. 19.

Despite the Assessment's aim of exploring future climate using three distinct types of scenario, historical scenarios and sensitivity analyses were less extensively used than GCM scenarios and featured less prominently in the Assessment's publications. Two uses of historical climate data – describing historically observed impacts of climate variability, and using observed historical extremes as benchmarks to compare projected future changes – were made by all groups. To support systematic use of historical scenarios, the VEMAP 20th-century dataset described above was provided to all Assessment groups, but no further guidance was provided on how to generate climate scenarios from these historical data, e.g., on what particular historical 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).[123] Most Assessment groups did not select extreme periods from the historical record as quantitative proxies for potential future climate change, an approach that has been used to create scenarios for impact studies,[124] but many groups did examine past climate extremes in qualitative ways.

The third approach, vulnerability analysis, was the least used in the Assessment. This 'bottom-up' approach involves describing the properties of a climate-sensitive system, specifying some important change or disruption, and asking what climate changes would be required to bring about that disruption and how likely – based on historical data and model projections – such climate changes appear to be. Given the complex dynamics of climate-sensitive systems and models of these systems, and the multiple dimensions of climate on which these can depend, this approach requires a substantial program of new research, analysis, and methodological development[125]. In part because of the intrinsic difficulty of this task – and in part due to management and resource problems – this approach was not pursued in the Assessment. The NAST proposed it, but more tractable approaches to analyzing climate impacts dominated the assessment's work. This remains an important area for further work in development of assessment and modeling methods.

Socio-economic scenarios

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

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

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

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

characteristics of the community interacting with a dynamic climate will strongly influence the community's vulnerability to potential changes and its capacity to adapt.

In contrast to climate scenarios, little prior information or experience was available at the U.S. federal level on constructing scenarios of socio-economic conditions for impact assessment. Consequently, the assessment invested effort in developing methods and procedures for constructing them. A hybrid process was adopted, which was partly centralized and partly decentralized. The centralized component was required because a few socio-economic variables, such as population, economic growth, and employment, are likely to be important in all regions and sectors. For these variables, consistent assumptions are needed to allow comparison of impacts across sub-national regions and sectors, and to aggregate from separate regional or sector assessments up to overall national impacts.

A sub-group of the NAST developed three alternative scenarios of these variables at the national level, representing high, medium, and low growth assumptions. Through 2030, these scenarios followed the assumptions of the US Census Bureau high, middle, and low scenarios for fertility and mortality, while employing a wider range of assumed values for net immigration to account for possible illegal immigration.[126] National totals of population, GDP, and employment were then disaggregated among sub-national regions and sectors using a commercial regional economic model.[127] Beyond 2030, the same three variables were projected only at national level, using simple specified annual growth rates chosen to be roughly consistent with the OECD growth rates in the SRES marker scenarios.[128]

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

To support decentralized scenario development, the NAST proposed a consistent template for region and sector teams to follow in creating their own scenarios. Each team was asked to identify two socio-economic conditions they judged most important for the impact they were studying; to identify a range of these conditions that the team judged to represent roughly

[126] Parson et al 2001, p. 102-103.

[127] Terleckyj, 1999a, 1999b – cited in Foundation p. 102.

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

90 percent confidence; and to generate socio-economic scenarios by jointly varying these factors between their high and low values, in addition to middle or best-guess values if the team chose.

The implementation of this decentralized component of scenario development was weak. With a few exceptions, regional and sector teams did not use the proposed approach. Many teams made no socio-economic projections at all, but rather projected only biophysical impacts based on GCM projections. The Metropolitan East Coast assessment found the socio-economic scenarios were inconsistent with superior local estimates of current population, and so decided not to use them. The teams that did use the socio-economic scenarios used only the aggregate projections of population and economic growth, or in some cases assumed continuation of present conditions in the assessment period. None used the proposed template for identifying and projecting additional important socioeconomic characteristics.

The limited use of socio-economic scenarios was a key weakness of the National Assessment, which greatly limited its ability to identify key factors likely to shape impacts and vulnerability. More useful assessments of impacts and vulnerability will require more extensive use of socioeconomic scenarios and improved integration of socioeconomic with climatic and environmental scenarios.[129] There were several reasons for this limited use of socioeconomic scenarios in the assessment. Some of the obstacles were managerial, such as inadequate time and resources, and insufficiently clear and timely communication of the proposed approach through the large, cumbersome management structure of the assessment. The proposed approach was only developed by NAST in spring 1998, and presented to team leaders in July 1998, when many teams had their analytic work well underway. Consequently, the time and attention required to implement the approach – including communicating it, persuading and training teams to try it, and working collaboratively between teams and the NAST to test its feasibility and work through problems that arose – were simply not available.

In addition to these managerial obstacles, many Assessment participants were reluctant to use socio-economic scenarios, especially the proposed decentralized approach. Some preferred to avoid any socio-economic projections, implicitly presuming that whenever socio-economic conditions mattered for an impact, relevant conditions in the future would resemble those of the present. Others found the specific contents of the aggregate scenarios or the methods used to produce them suspect, or judged that without social scientists with relevant expertise on their teams they were unable to adequately evaluate the scenarios. Still others objected that the high levels of uncertainty in future socio-economic conditions made any attempt to project conditions more than a few years in the future unacceptably speculative.[130]

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

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

[130] Morgan et al 2005.

Criticisms and Controversies

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

The first criticism, widely circulated during 2000, was that the use of non-American climate models to develop climate scenarios was inappropriate and potentially injurious to national interests.[131] While this criticism indicates a dimension of political vulnerability of the assessment, it does not address its technical quality. Since climate models represent the physics of the global atmosphere, they contain no representation of political or economic factors. The Hadley and Canadian global climate models were extensively documented in peer-reviewed scientific literature – and, moreover, were the only models that met the most critical of the Assessment's criteria. That they were developed by scientific groups outside the United States has no significance for their ability to provide scenarios to assess US impacts.

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

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

The Assessment's organizers and its critics agree that using more models would have been preferable, but the Assessment was limited to these two by its schedule and its technical requirements. Given a limit of only two, there are good reasons that one might choose one scenario in the middle of current projections and one near the top that provides a plausible upper-bound, but such a choice requires care in communicating the significance of the results. Some suggested that presentation of results based on the relatively high Canadian scenario should be more carefully qualified to highlight its position near the top of current projections.[132] Such qualifications require substantial subtlety, however, lest they imply that such results may safely be ignored, when most analyses suggest the full range of future climate-change uncertainty extends both below the Hadley scenario and – in a long, thin tail – above the Canadian.

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

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

A related criticism of the climate scenarios focused on the emissions scenario driving them, claiming that it was implausibly high. The issues bearing on choice of emission scenarios are similar to those for choice of climate models. It would be preferable to have a wide and relevant range of emissions scenarios driving an impact assessment – at least for the post-2050 period, since variation in emissions makes little difference in climate projections before then. Using a wide range of emissions scenarios would also allow comparison of projected impacts under high and low emissions futures, and so give insights into what degree of impacts could be avoided by what degree of mitigation effort. But in this assessment, as with the choice of climate models, model runs with this emissions scenario were all that was available. There is no clear basis to reject this particular scenario, since IS92a was the scenario most widely used in climate-model runs at the time and it lies near the middle of the range of both the 1992 and the 2001 IPCC scenarios. And there is no support for the claim that this scenario was chosen with the aim of making 21st-century climate change appear as threatening as possible.[133] But while using just two climate models with one emissions scenario was unavoidable in this assessment, it still represented a serious limitation. With more model simulations testing a range of emission scenarios already available, future assessments will be able to remedy this deficiency.

In contrast with the preceding criticisms that the scenarios used in the Assessment understated uncertainty, another criticism focused on the disparities between the two scenarios' projections. Some critics argued that such disparities – e.g., the Canadian scenario projects the Southeastern states becoming much drier than the Hadley model does – show that limitations of present knowledge of regional climate change make any attempt to assess future impacts and vulnerabilities irresponsible.[134] This criticism implies that impact assessment should wait until precise, high-confidence regional climate projections are available. Since a major purpose of the assessment was to represent current uncertainty about climate change and its impacts, such discrepancies between model projections served a valuable purpose, as indications of the uncertainty of projections at the regional scale – particularly when the model disparities had a clear origin, such as differences in projected jet-stream location.

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

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

[134] 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.)

The experience of the National Assessment raises three issues of greatest significance for future climate-change scenario exercises. First, like several of the experiences reviewed here, it illustrates the difficulty and scale of effort involved in producing scenario-based assessments. Second, the large required start-up effort and time to build the capacity to conduct such an exercise illustrates the great value of sustaining analytic and institutional capacity over time, rather than relying on separate projects. Such continuity of capacity will be necessary to avoid wasteful repetition of start-up efforts, to support accumulation of learning and experience, and to develop and maintaining the required collaborative networks. Finally, the assessment's experience illustrates both the need for consistency in large-scale assessments, and the great specificity of information needs within particular impact and adaptation assessments. This combination of centralized and decentralized needs strongly suggests the merit of a cross-scale organizational structure for developing and applying scenarios, such as was attempted but not fully implemented in the National Assessment.

3.3. The UK Climate Impacts Program

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

The 1998 climate scenarios were based on simple transient emissions scenarios similar to the IPCC 1992 scenarios, and runs of the Hadley Center's HadCM2 climate model, the same model used in the US National Assessment.[135] The scenarios provided information only at the model's rather coarse scale, with four grid-cells over the entire UK. Downscaled data were not provided, although the scenarios' documentation noted that finer-scale patterns of variation in current climate data could be used to downscale the data as needed. The four scenarios, called "high", "medium-high", "medium-low", and "low," combined variation in emissions assumptions with variation in assumed climate sensitivity. The medium-high and medium-low scenarios both used the HadCM2 model, with a sensitivity of 2.5°C.[136] The medium-high scenario was forced by a 1% per year equivalent-CO_2 transient scenario, similar to IS92a. The medium-low scenario was forced by a 0.5% per year equivalent-CO_2 transient scenario, similar to the lowest IS92 scenario, IS92d. The high and low scenarios used the same two emissions scenarios, now driving a simpler climate model whose sensitivity was set at 4.5°C for the high scenario and 1.5°C for the low. These scenarios were used in an initial impact assessment focusing predominantly on direct biophysical impacts.[137] The scenarios did not include any explicit statements of probability, although their documentation suggested that the medium-high

135 UKCIP 1998.

136 UKCIP 1998, pg. 13-15.

137 UKCIP 2000.

and medium-low scenarios "in one sense … may be seen as being equally likely," while the high and low scenarios captured part of the tails of the distribution. 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 were published in 2001.[138] They drew on the Foresight Program, a broader exercise of the UK Department of Trade and Industry to develop scenarios for long-rang planning in several policy areas, but added further detail in areas relevant to greenhouse-gas emissions and climate impacts. As in several other scenario exercises, scenario developers identified two fundamental uncertainties and combined two alternative outcomes of each to produce four scenarios. The two core uncertainties they chose were similar to those used in the SRES exercise: social and political values, which varied from an increased focus on individual consumption and personal freedom ("consumerism") to a widespread elevation of concern for the common good ("community"); and governance, which varied from one pole in which authority and power remained concentrated at the national level ("autonomy"), to an opposite pole in which power was increasingly distributed away from national institutions, upward to global institutions, downward to local ones, and outward to non-governmental institutions and civil society ("interdependence"). The two dimensions of uncertainty, values and governance, were assumed independent of each other. Other major uncertainties such as demographic change, the rate and composition of economic growth, and the rate and direction of technological change, were treated largely as consequences of alternative realizations of the two core dimensions of values and governance.[139]

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.[140]

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

[138] UKCIP 2001.
[139] UKCIP, 2001.
[140] Berkhout et al, 2001.

document, which provided suggestions how to use them together with climate scenarios for impact studies.[141]

As of 2005, the socio-economic scenarios had been used in six impact studies.[142] 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.[143] 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[144] Based on these four scenarios, the study elaborated preliminary regional scenarios corresponding to the four national socio-economic scenarios, and conducted an assessment of coastal-zone impacts and responses using these scenarios and a formal land-use model.[145]

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

Several analyses are continuing to use the 2002 climate scenarios in conjunction with the socio-economic scenarios. For example, a 2004 integrated analysis of flood risk and erosion control over a 30-100 year time horizon produced a threat assessment, a set of scenarios of flood

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[141] Berkhout and Hertin 2001.
[142] UKCIP, 2005.
[143] Holman et al 2002.
[144] 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).
[145] Shackley et al 2005.

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.[146]

The UKCIP has followed a substantially different model from the US National Assessment, based on building a sustained assessment capability rather than a single project. In addition, the central program has less authority over the separate assessments, instead acting more as motivator, resource, and light coordinator. Access to scenarios is to licensed users, of whom there are about 130 – roughly half in universities, the rest about equally split among private sector and all levels of government. Most active users have been national officials responsible for climate-sensitive resources.[147] The program has found it harder to attract serious participation from private-sector and local governments, perhaps because they are less accustomed to long planning horizons.

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

3.4. The Millennium Ecosystem Assessment

The Millennium Ecosystem Assessment (MEA) was a large, UN-sponsored assessment of the current status, present trends, and longer-term challenges to the world's ecosystems, including climate change and other sources of stress. Conducted between 2001 and 2005, the MEA sought to assess changes in ecosystems in terms of the services they provide to people and the effects of ecosystem change on human well-being. It also sought to identify and assess methods to mitigate and respond to ecosystem change, for various private and public-sector decision-makers including those responsible for the several international treaties that deal with ecosystems.[148] More than 1350 authors from 95 countries participated in the global assessment's four working groups, and hundreds more in roughly 30 associated sub-global assessments. The assessment's goals were broad, ranging from providing a benchmark for future assessments and guiding future research to identifying priorities for action.[149]

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146 UK Office of Science and Technology 2002.

147 West and Gawith (2005).

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

149 MEA 2006, pg xii,

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

All components of the assessment used a common large-scale conceptual framework, which distinguished indirect drivers of ecosystem change, direct drivers, ecosystem indicators, ecosystem services, measures of human well-being, and response options. Direct drivers included direct human perturbations of the environment such as climate change, air pollution, land-use and land-cover change, resource consumption, and external inputs to ecosystems such as irrigation and synthetic fertilizer use, while indirect drivers were underlying socio-economic factors such as population, economic growth, technological change, policies, attitudes, and lifestyles.[150]

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.[151] Like several other major scenario exercises, they initially sought to identify two fundamental dimensions of uncertainty in long-term ecosystem stresses, which together would produce four scenarios.[152] For the first dimension, similar to the SRES process, they chose globalization: continuation and acceleration of present global integration trends, versus reversal of these trends to increasing separation and isolation of nations and regions. For the second dimension, in contrast to the broad value-based uncertainties used in the SRES and UKCIP scenarios, they chose one more specifically related to ecosystems: whether responses to increasing ecosystem stresses are predominantly reactive – waiting until evidence of deterioration and loss of services is clear – or predominantly pro-active, taking protective measures in advance of their completely clear need. The combination of two polar values of each of these uncertainties gave four scenarios, summarized in Table 3.4.1.

Table 3.4.1. Millennium Ecosystem Assessment Scenarios

Ecosystem Management	World Development	
	Global	Regional

[150] MEA 2006, p. 153 (Table 6.1), p. 304 (Table 9.2)

[151] MEA 2006, p. 152.

[152] MEA 2006, Fig 5.2.

Reactive	Global Orchestration	Order from Strength
Proactive	TechnoGarden	Adapting Mosaic

The Global Orchestration (global, reactive) scenario presented a globally integrated world with low population growth, high economic growth, and strong efforts to reduce poverty and invest in public goods such as education. In this scenario, society focuses on liberal economic values, follows an energy-intensive lifestyle with no explicit greenhouse-gas mitigation policy, and takes a reactive approach to ecosystem problems.[153] In Order from Strength (regional, reactive) there is also only a reactive approach to ecosystem problems, but this takes place in the context of a fragmented world preoccupied with security and paying less attention to public goods.[154] Population growth is the highest in this scenario, and economic growth is the lowest, particularly in developing countries, and decrease with time. In Adapting Mosaic (regional, proactive), political and economic activity are concentrated at regional ecosystem scale. Societies invest heavily in protection and management of ecosystems, but these efforts are locally organized and diverse. Population growth is nearly as high as in Order from Strength, and economic growth is initially slow but increases after 2020. Finally, TechnoGarden (global, proactive) presents a world that is both focused on ecosystem management and globally connected, with strong development of environmentally friendly technology. Population growth is moderate, and economic growth is relatively high and increasing.[155]

Each scenario was defined in terms of the assessment's overall structure – indirect drivers, direct drivers, etc. – and was initially constructed as a qualitative description, defined principally in terms of indirect drivers. Population and GDP were specified quantitatively, while all other indirect drivers – including social, political, and cultural factors – were qualitative. Population scenarios were derived from the IIASA 2001 probabilistic projections, capturing the middle 50-60% of the distribution, with world population in 2050 ranging and from 8.1 billion (Global Orchestration) to 9.6 billion (Order from Strength).[156] GDP growth was high in Global Orchestration, somewhat lower but recovering after 2020 in TechnoGarden, medium-low in Order from Strength, and initially low but recovering after 2020 in Adapting Mosaic.[157] No statements of probability or likelihood were made about the scenarios.

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

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[153] MEA 2006, Ch 5.5.1

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

[155] MEA 2006, Pg. 131.

[156] MEA 2006, pg. 182.

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

unquantified direct driver.[158] Separate pre-existing models were used of the world energy-economy, greenhouse gas emissions and climate change, air pollution, land-use change, freshwater, terrestrial ecosystems, biodiversity, and marine and freshwater fisheries. The IMAGE 2.2 model generated greenhouse-gas emissions projections similar to the SRES marker scenarios – Global Orchestration was compared to A1B (although somewhat higher), Order from Strength to A2, Adaptive Mosaic to B2, and TechnoGarden to B1.[159] 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.[160] 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.[161] Not all scenario elements could be modeled quantitatively, so expert judgments were also extensively used. Qualitative scenario process proceeded in parallel with quantitative modeling – elaborating aspects of the scenarios that were not amenable to modeling, filling gaps, and stipulating feedbacks between ecosystem services and human well-being and behavior.[162]

There were attempts to check for consistency between quantitative and qualitative scenario elements through periodic consultations between the two groups. This was particularly important for feedbacks that could not be modeled analytically. Some of these were interactions between direct drivers and ecosystems, but the most difficult occurred in scenarios that assumed strong socio-economic feedbacks and regulating mechanisms. Adapting mosaic, for example, assumed strong feedbacks from new ecosystem observations and knowledge to changes in human behavior that could not be incorporated into the models used. Representing these required allowing qualitative scenario logic to over-ride both the quantitative results and the structure of models. Unfortunately, time limits prevented this consistency checking from being done thoroughly, so remaining unexplored disparities between the qualitative and quantitative representations remained a significant weakness of the scenarios work.[163]

Many of the conclusions developed from the scenarios are common to all four scenarios, while others are common to all except Order from Strength. For example, it is concluded that rapid conversion of ecosystems for use in agriculture, cities and infrastructure will continue, and that habitat loss will continue to contribute to biodiversity loss.[164] Many forms of ecosystem services are projected to increase, however, suggesting the possibility of de-coupling some ecosystem services – although not biodiversity – from ecosystem stresses. Food security is projected to remain out of reach for many people, however. Extreme, spatially diverse changes are projected for freshwater resources, with general deterioration of freshwater services in developing countries under both "reactive" scenarios. Increasing demands for fishery products

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

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

[160] MEA 2006, Table S3.

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

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

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

[164] Summary chapter.

are projected to increase risks of regional marine fishery collapses.[165] 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.[166] The same three scenarios also suggest that significant changes in policies, institutions, and practices can mitigate some negative consequences of growing pressures on ecosystems, although the required changes are substantial.[167]

In sum, the MEA scenarios project investment substantially more effort in developing rich qualitative and narrative scenarios than the SRES, but also fell short on linking and integrating the qualitative and quantitative components. In part because of the greater elaboration of the qualitative components, this limited coordination resulted in significant inconsistencies and requirements to resolve conflicts between the two components. These inconsistencies arose even with just one model used for several components of the assessment, so the challenges of harmonization between models – and the associated possibility to explore model-structure uncertainty – did not arise. A related problem was that for many factors it was difficult to generate the desired level of variation between scenarios.[168] This raises issues of potential methodological interest, such as how to distinguish robust results from inadvertent convergence of scenario assumptions or failure of model structures to capture the important differences between scenarios, which largely remain to be investigated. Finally, the great breadth of conditions represented in the scenarios, as well as possible concerns with logical circularity between their presumptions and results,[169] makes interpreting the significance of the results difficult.

The experience of this scenario exercise provides a different perspective on some of the same key challenges for future scenarios highlighted by the other activities reviewed. The quite distinct difficulties faced here in attempting to combine quantitative and qualitative scenarios highlight the central importance and the difficulty of developing new methods to integrate these two approaches. In addition, this experience highlights the value of clarity about the intended uses of scenarios, including clarity about whether they are intended to address specific questions or guide decisions, or are focused more on long-term exploration. The risk scenarios becoming less useful due to breadth and vagueness may be particularly acute for scenarios that attempt to capture multiple stresses on some system – even though such multi-stress assessment is repeatedly advocated for climate-change and other forms of environmental assessment.[170]

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[165] Scenarios, Table S3.

[166] Id. at 127.

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

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

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

[170] NAST 2001.