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

There is a long recognized need for improved methods for structuring and supporting environmental decisions.[34] Efforts have been made to develop scenarios to support understanding and decision-making for global environmental issues since the 1970s, beginning with the global models of the mid-1970s and the attempts to use scenario-based thinking in early assessments of acid rain and stratospheric ozone in the late 1970s and early 1980s.[35] The motivations for using scenarios in global change are similar to those that apply to other decision domains: high-stakes decisions that must be made under deep uncertainty about the conditions that will determine their consequences, the values at stake, or the relevant set of choices and actors. As in other domains, well designed scenario exercises can provide a structure for assessing alternative choices, and can help focus broader investigation of the nature of the issue, the relevant choices and actors, the values that might be at stake, and the types of research or analysis that might help clarify preferred choices.

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

2.1. Climate-Change Decisions and Potential Contributions of Scenarios

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[34] See, e.g., NRC 1996, 2005.

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

Decisions related to climate change are conventionally sorted into two categories, mitigation and adaptation.[36] Mitigation consists of actions that reduce the human perturbations of the climate system, by reducing net anthropogenic greenhouse-gas emissions or other stresses such as land-use change. Adaptation consists of actions to reduce the harm or increase the benefit from climate change and its impacts. Despite uncertainty about the precise decision agenda, we can identify in general terms the type of information scenarios might provide that would be useful to each type of decision.

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

The relevant decisions will have many time-scales of effect and response: e.g., some decisions such as what varieties to plant, can be revised frequently (in this case annually) and have consequences extending over a similarly short time horizon. Others may have tails of consequences, and implied commitments ranging from several decades (e.g., what range of flood conditions to consider in designing and building a water-management system), or even centuries (e.g., location decisions for key infrastructure investments such as roads or other transport right-of-way, coastal facilities, and water and sewer systems, which can influence subsequent settlement patterns for far longer than the lifetime of the original investment). Decisions made today may have to consider processes and consequences that occur over multiple time-scales.[37]

To help inform adaptation decisions, scenarios might help to characterize the nature and severity of relevant potential impacts; identify key vulnerabilities, particularly those that might not otherwise have been recognized; identify research or monitoring priorities that might give advance warning about impacts, particularly acute vulnerabilities; help to expand the perceived set of potential responses;[38] and provide a framework for evaluating alternative adaptation measures: feasibility, effectiveness, cost, tradeoffs with other values. They may also help to clarify the structure of overlapping time-horizons of relevant decisions, helping to identify those near-term decisions that might have important but under-recognized connections to future impacts and vulnerability.

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

[37] Shell International 2001; Davis 2003.

[38] Schelling 1983.

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

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

We now shift from how scenarios could in principle inform global-change decisions to how they have principally been developed and used to date. To date, most uses of global-change scenarios have been embedded in larger exercises of assessment, modeling, or analysis that seek to characterize the climate-change issue. These uses have included formal integrated-assessment models,[39] comprehensive assessments conducted by multi-disciplinary expert bodies (e.g., IPCC), and more narrowly focused assessment exercises targeting specific aspects of the climate-change issue. In these uses, scenarios represent components of the climate-change issue that are required inputs to an assessment or model.

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

When scenarios are used to specify exogenous inputs to a model of some aspect of the climate-change issue, the causal logic of the analysis can be greatly simplified from that shown in Figure 2.1. Instead, the logic of the issue can be represented by a simple linear structure that extends from human activities to emissions to climate change to impacts. This highly simplified causal structure is illustrated in Figure 2.2. This representation is even more suitable for the uses of scenarios in other types of global-change assessments, which have been organized around much simpler causal structures than those that integrated-assessment models seek to represent.

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

Note that we are not claiming this simple logical structure adequately represents the true structure of the climate-change issue: only that it illustrates the ways that scenarios are used to provide exogenous inputs to global-change models and assessments.

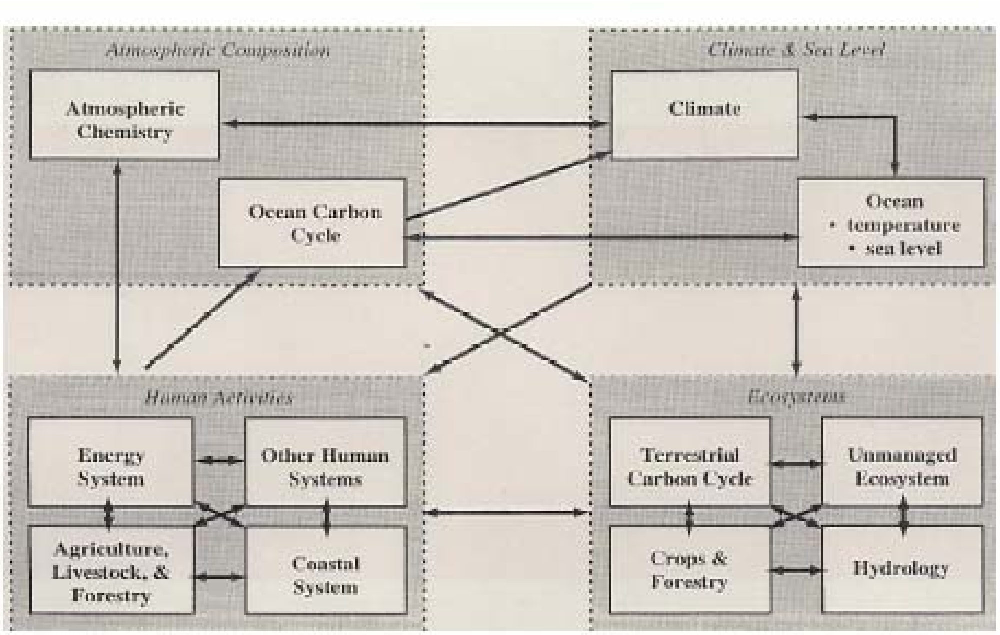

Figure 2.1: Wiring Diagram for Integrated Assessment models of climate change. (Source: Weyant et al, 1996, IPCC 1995 WG3)

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

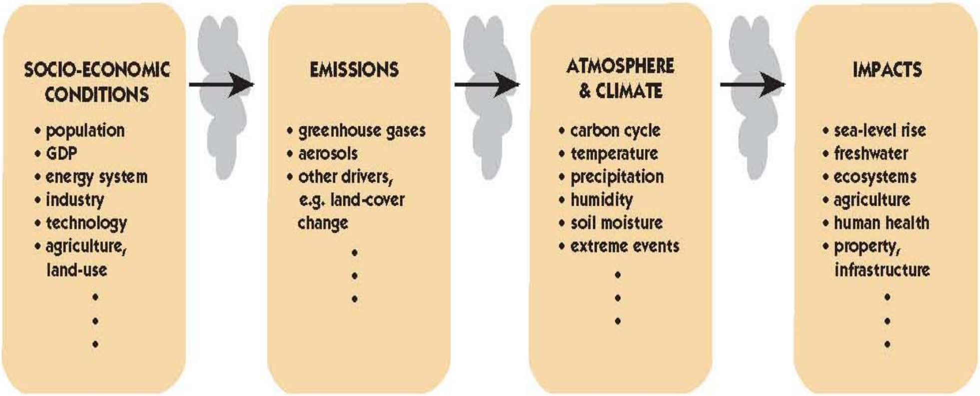

Figure 2.2: Anthropogenic climate change: Simplified linear causal chain

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

2.3. Emissions Scenarios for Future Climate Simulations

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

Fig 2.3: Emissions Scenarios for Climate Simulations

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

The earliest such model studies used a "step-change" increase in atmospheric concentration of CO_2 from its pre-industrial value, to either twice or four times that value.[40] The models' equilibrium responses to doubled CO_2 provided the climate sensitivity, a standard benchmark of model responsiveness, which has remained around the range of 1.5 to 4.5°C for more than twenty years. This range of modeled equilibrium responses to a standardized perturbation says almost nothing about how the climate will actually change under human perturbations, although it has often been mistakenly treated as such. The next generation of climate-model studies, beginning in the early 1990s, specified a time-path of atmospheric concentrations rather than a one-time perturbation. These studies for the first time allowed comparison of models' transient responses, examining not just how much the climate changes, but also how fast it gets there. They still used a simple, highly idealized standard scenario of greenhouse gases, most frequently a 1 percent per year increase in atmospheric concentration of

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

greenhouse gases, expressed as CO_2-equivalent. Only two such transient simulations had been conducted by the first IPCC assessment (1990),[41] but by the time of the second assessment (1996), most modeling groups had produced at least one.

Since the mid-1990s, climate-model projections have increasingly sought to produce realistic pictures of how the climate may actually change, requiring a new approach to emissions scenarios. Rather than arbitrary standardized perturbations, scenarios instead must present well founded judgments, or guesses, of actual future emissions trends and their consequences for atmospheric concentrations. The required emissions scenarios have been constructed either by extrapolating from recent emissions trends, or particularly for energy-related CO_2, representing emissions in terms of underlying driving factors such as population, economic growth, and technological change, and projecting these factors using some combination of modeling and trend projection. Driven by such scenarios, climate models for the first time can claim to be reasonable estimates of how the climate might actually change. In addition, comparisons using multiple models and emissions scenarios have allowed partitioning of uncertainty in future climate change into roughly equal shares attributed to uncertainty in climate science and models, and in emissions trends.[42] These comparisons have also allowed estimation of the climate-change benefits available from specified emissions reductions.

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

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

[42] Cubash et al 2001.

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

2.4. Emissions Scenarios for Exploring Alternative Energy and Technology Futures

Emission scenarios can also be used to examine the socio-economic implications of alternative emission paths. For example, a scenario specifying a particular trajectory of emissions over time can be used to explore what patterns of demographic and economic change, energy resource availability, and technology development are consistent with that trajectory. Alternatively, scenarios can be used to examine what policies, technological changes, or other changes would be required to shift emissions from some assumed baseline onto a specified lower path, and to estimate the size and distribution of the costs of such a shift. Figure 2.4 illustrates this type of scenarios. As in Figure 2.3 the content of the scenario is emissions, but the scenario is now used to examine the socio-economic conditions that lie upstream in the causal chain. The specific emissions scenarios used for this purpose might be specified arbitrarily, to support general exploration of socio-economic conditions associated with different emissions paths, or might be fixed to achieve some environmental target or goal that is judged desirable. This is the one type of global-change scenario that has been used backcasting mode, working back from future targets that might be set based on normative criteria, as discussed above in Section 1.2. While the most frequent use of this type of scenario has been to examine emissions trajectories that stabilize atmospheric CO_2 concentrations at specified levels, recent projects have instead adopted stabilization of radiative forcing as the target, in order to examine the role of non-CO2 greenhouse gases in stabilization regimes.[43]

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

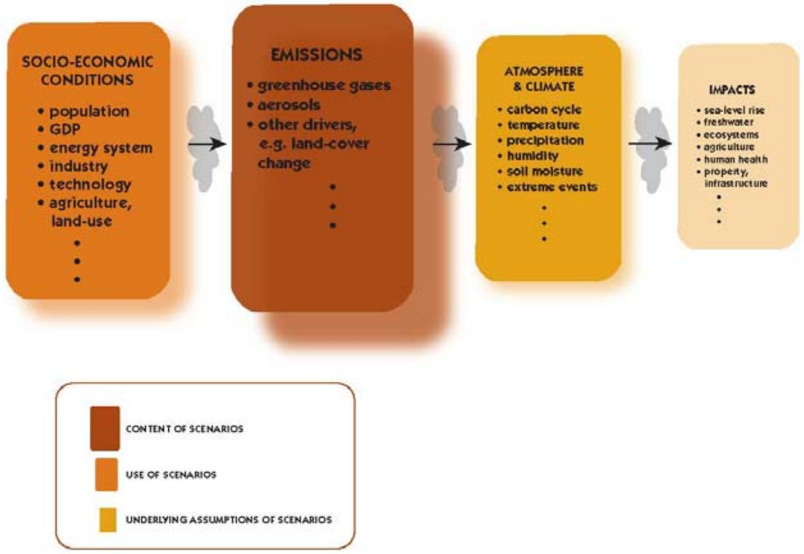

Fig 2.4: Emissions Scenarios for Energy/Technology Futures

An important early example was provided by the WRE scenarios, which presented emissions pathways that stabilized atmospheric CO_2 concentration at five different levels ranging from 450 to 1000 ppm.[44] Working heuristically with a simple model of the global carbon cycle and two energy-economic models, these scenarios illustrated the large cost savings attainable by approaching stable concentrations through emission paths that initially rise and then decline steeply, rather than by beginning a more gradual decline immediately. Although these were not strictly optimal (cost-minimizing) scenarios, they demonstrated that this qualitative shape of emissions trajectory would tend to reduce costs for four reasons. First, it allows more time to develop technological innovations that lower the cost of emissions reductions in the future. Second, it allows lower-emitting equipment to be phased in with normal capital turnover, avoiding premature abandonment of long-lived equipment. Third, it takes advantage of natural carbon-cycle dynamics, which gradually remove CO_2 emissions from the atmosphere and so allow more room for increases in earlier emissions than later emissions while still meeting the concentration target. And finally, by shifting mitigation expenditures further to the future, it reduces their present value through discounting.

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

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[44] Wigley, Richels, and Edmonds 1997.

implications of including non-CO_2 gases and carbon sequestration in mitigation targets and policies.[45]

In a current scenario exercise of this type, three modeling teams are each constructing a separate reference-case scenario, then examining the implications of stabilization scenarios for radiative forcing similar to CO_2 concentrations of 450 ppm, 550 ppm, 650 ppm, and 750 ppm. Without suppressing uncertainty by forcing conformity in models' base cases, they are examining the energy system, land-use, and economic implications of moving to stabilization. A major goal is to aid understanding of the role of multiple greenhouse gases, and alternative multi-gas control strategies, in pursuing stabilization. These scenarios may also serve as a point of departure for future analyses by the CCSP, the Climate Change Technology Program (CCTP), or others.[46]

2.5. Climate Change Scenarios

Climate scenarios describe potential future climate conditions. They can be used as inputs to assessments of climate-change impacts, vulnerabilities, and associated options for adaptation, and to inform decision-making related to either adaptation or mitigation. Depending on their specific use, climate scenarios may include multiple variables, such as temperature, precipitation, cloudiness, humidity, and winds. They may describe these at various spatial scales, ranging from the entire globe, through broad latitude bands, large continental and sub-continental regions, GCM grid-cells, or finer scales down to order 10 km. And they may project these at various time resolutions, from annual or seasonal averages to daily or even faster-scale weather.[47]

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

[46] CCSP Synthesis and Assessment Product 2.1a.

[47] IPCC – TGCIA 1999.

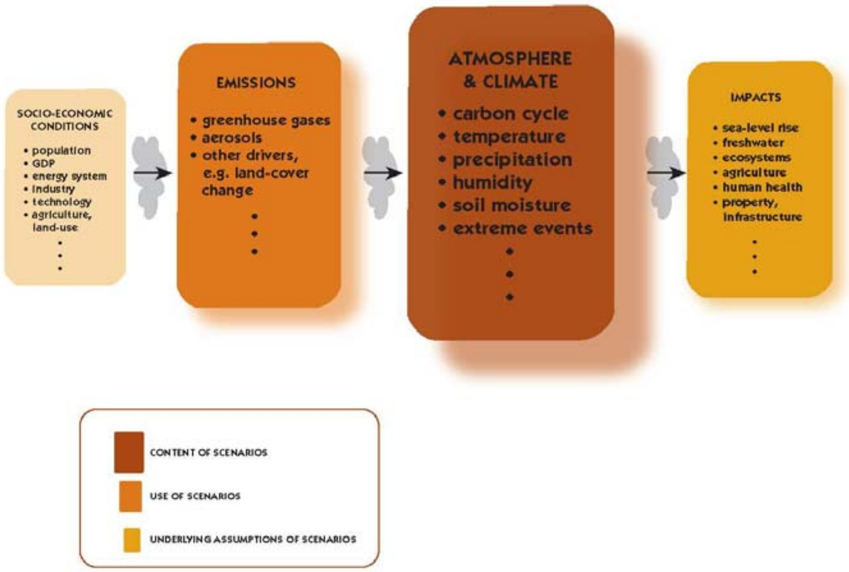

Fig 2.5: Climate-Change Scenarios

Three major types of climate scenarios are distinguished by how they are produced: incremental scenarios, analog scenarios, and climate-model scenarios.[48] Incremental climate scenarios change current conditions by plausible but arbitrary increments. For example, a region's temperature might be warmed by 2, 3, or 4°C from present conditions, or its precipitation increased or decreased by 5, 10, or 20 percent. Such adjustments can be made to annual or seasonal averages, to finer-period measurements of current conditions, or to the variability of temperature or precipitation over days, months, or years.[49] Like the simple emissions scenarios used for climate-model comparisons, incremental climate scenarios are simple to produce but make no claim to represent actual future conditions. They are used for initial exploratory studies of climate impacts and to test the sensitivity of impacts models.

Analog climate scenarios represent potential future climates by the observed climate regime at another place or another time. A spatial analog imposes the climate of one location on another, e.g., representing the potential climate of New York in the 2050s by that of Atlanta today or that of Illinois in the 2050s by that of Kansas today.[50] A temporal analog imposes some climate observed in the past, either in the historical record or in earlier paleoclimatic observations, e.g., using the hot, dry climate of the 1930s to study impacts of potential hot, dry climates in the future.[51] Like incremental scenarios, analog climate scenarios are more useful for exploratory studies of the climate sensitivity of particular resources or ecosystems than for projecting likely impacts. While they represent climate states that are known to be physically possible, since they actually happened or are happening, they are limited as representations of

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[48] Mearns et al 2001.

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

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

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

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

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

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

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

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

Mismatch between impact analysts' needs and climate-model output is especially common with respect to the spatial scale of data. Impact analyses frequently need data at substantially finer scale than the relative coarse grid of a climate model, which might have only 60 to 100 cells over the continental USA. One advantage of incremental and analog scenarios is that they can typically provide data at substantially finer scale. There are several techniques that seek the benefits of model-based scenarios – physical realism and explicit emissions-scenario drivers – yet provide climate-scenario data at finer scales. These techniques are called downscaling, for which the two major approaches are statistical downscaling and nested regional modeling.[52] Statistical downscaling involves estimating statistical relationships between large-scale variables of observed climate, such as regional-average temperature, and local variables such as site-specific temperature and precipitation.[53] These relationships between smaller and larger-scale climate variables are then assumed to remain unchanged under global climate change. A regional climate model provides an explicit physically modeled representation of climate for a specific region, with boundary and initial conditions provided by a global climate model. Regional climate models include representations of factors that influence local climates such as mountain ranges, complex coastlines, lakes, and complex patters of surface vegetation, and can provide projections at scales as small as 10 to 20 kilometers. Although downscaled results are anchored to local features with well understood climatic effects (e.g., precipitation falls on the windward side of mountains), downscaling also introduces additional uncertainties beyond those already present in global climate-model projections.[54]

2.6. Scenarios of Direct Biophysical Impacts: Sea Level Rise

Although climate-change scenarios can be used to study any form of impact, scenarios can also be constructed of particularly important forms of climate-change impact, such as sea level rise – one of the more costly and certain consequences of climate warming. Sea level rises as the climate warms, because of thermal expansion of seawater and the melting of alpine and continental glaciers, which adds more water to the oceans. Because of the large heat capacity of the ocean, sea level rise will continue for centuries even after stabilization of atmospheric greenhouse gases.[55]

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

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

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[52] Giorgi et al 2001.

[53] Wilby and Wigley 1997.

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

[55] IPCCa 2001.

accretion, tide range, wave height, local land use and coastal protection, salinity tolerance of coastal plant communities, etc. – in addition to local sea level rise.[56]

In addition to its gradual impacts, sea level rise is subject to large uncertainties associated with the potential loss of continental ice sheets in Greenland and West Antarctica. The consequences of these events for global sea level rise are well known because they can be calculated quite precisely from the volume of the ice sheets – roughly 7 meters rise from complete loss of the West Antarctic Ice Sheet and 5 meters from Greenland. But the probabilities of these events and their likely speed of occurrence are both highly uncertain. One recent study has suggested a probability of a few per cent that the West Antarctic Ice Sheet will contribute an additional one meter per century beyond that calculated from gradual warming.[57]

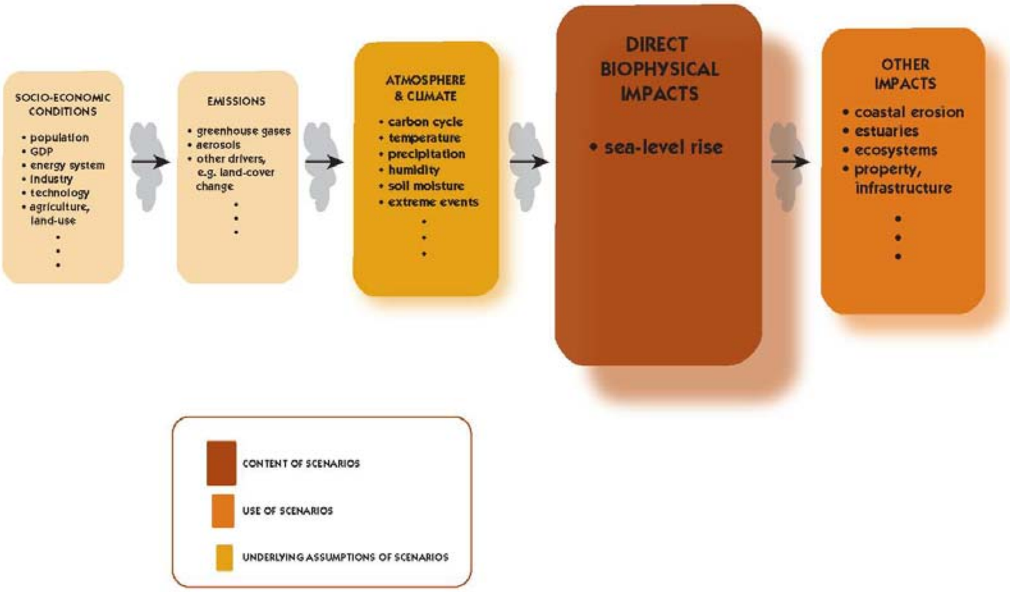

Figure 2.5: Scenarios of Direct Biophysical Impacts: Sea Level Rise

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

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

[57] Vaughan and Spouge 2002.

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

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

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

Ecosystems are affected by climate change, but also by many other changes in environmental conditions that are influenced by human activities, such as nitrogen and sulfur deposition, tropospheric ozone and smog, and changes in erosion, runoff, loadings of other pollutants, land-use, land-cover, and coastal-zone characteristics. Consequently, realistic projections of future impacts on ecosystems require specifying the most important forms of human-driven stresses jointly, not just climate.[58]

In addition, many important forms of climate-change impact have strong human components in their causation and valuation. Consequently, they depend not just on climate change, its direct biophysical impacts such as sea level rise, and perhaps other forms of environmental stress, but also on the nature of the society on which these climate and other environmental changes are imposed – e.g., how many people there are, where and how they live, how wealthy they are, how they gain their livelihoods, and what types of infrastructure, institutions, and policies they have in place.[59]

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

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[58] Millennium Ecosystem Assessment 2005.

[59] Parson et al 2001, 2003. Arnell et al 2004.

hydrological systems, because of the effect of reservoir management practices on evaporative losses.

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

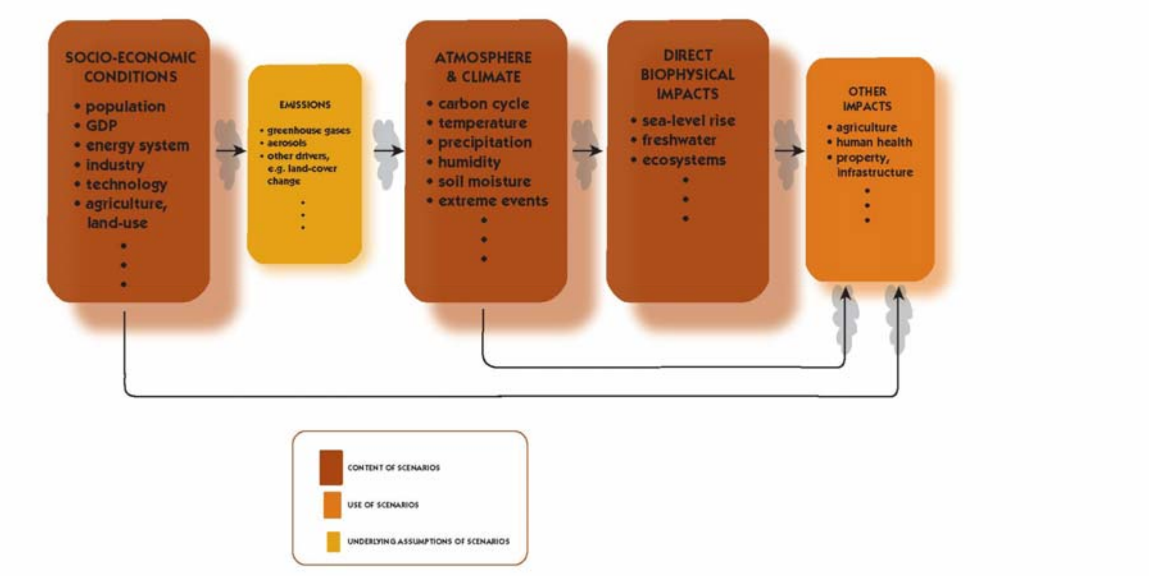

Figure 2.6: Multivariate Scenarios for Impact Assessment

Some socio-economic characteristics that are likely to be relevant for many impact assessments – e.g., the size and perhaps the age structure of population, the size and perhaps the sectoral mix of GDP – are normally generated in the course of producing emissions scenarios. Consequently, when current emissions scenarios exist for the region for which an impact assessment is being conducted, it makes sense to strive for consistency with them.[60] Even for these variables, however, there may be significant problems of incompatible spatial scale. Impact assessments are often conducted at smaller spatial scale than emissions projections, and so may need these socio-economic data at finer scale than is available. Downscaling future socio-economic projections has proven challenging thus far. There is no generally accepted method for doing so, and several research groups are now doing exploratory development of alternative methods.[61]

In contrast to the few clearly identified aggregate characteristics needed to construct emissions scenarios, the socio-economic factors that most strongly shape adaptive capacity and

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

[61] Toth and Wilbanks 2004. Pitcher 2005.

vulnerability for particular impacts may be detailed, subtle, and location specific. The identity of the most important characteristics may not even be clear before doing a comprehensive analysis of potential causal pathways shaping impacts. The most important characteristics may interact strongly with each other, or with other economic or social trends defined at national or international scale. And they may not be readily described or analyzed quantitatively. All these factors make the development of socio-economic scenarios for impact assessment a much more difficult endeavor than constructing emissions scenarios.

Because scenarios are schematic, it is not possible to create a set of scenarios that include all factors. Details are typically not included, and when they are, they are intended to be merely illustrative, with minimal confidence placed in their specifics. But in determining vulnerabilities to climate impacts, it may be particular details – which cannot be identified a priori – that are crucial.[62] Impact assessments have made various responses to this challenge. These all involve acknowledging the need for subjective expert judgment, regarding both what factors to include and what variation in them to consider. They also all recognize the unrealism of extrapolating recent trends or assuming current conditions will persist unchanged in the future,[63] and the risk of under-estimating uncertainty and so not projecting future possibilities broadly enough.

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

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

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[62] Berkhout et al 2002.

[63] Berkhout et al 2001; Parson et al 2001.