CHAPTER SIX

The SAS Approach: Combining Qualitative and Quantitative Knowledge in Environmental Scenarios

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Contents

Form follows function – Architect Louis Sullivan, 1896

1. Introduction

Although the maxim "form follows function" was coined with buildings in mind,[1] it can also be applied to scenarios which tend to take the qualitative form

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[1] Sullivan, Louis H., 1896. The tall office building artistically considered. Lippincott's Magazine, March 1896.

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when used for education or planning, and quantitative when the aim is research. But we will see in this chapter that many contemporary environmental studies require both qualitative and quantitative scenarios. Besides, recent experience shows that the advantages of both types of scenarios can be captured by combining them in a single scenario exercise. This chapter analyzes the pros and cons of qualitative and quantitative scenarios and how they fulfill the different requirements of scenario developers and users. It also describes major international scenario exercises in which combined scenarios were used. This international experience is then distilled into a general procedure for combining qualitative and quantitative scenarios called the SAS ("Story and Simulation") approach. Finally the successes and drawbacks of this approach are pointed out and some ideas are presented for producing more scientifically-sound scenarios.

2. Features of Qualitative and Quantitative Scenarios

Although there is no standard way to distinguish between "qualitative" and "quantitative" scenarios, qualitative scenarios are usually taken as those describing possible futures in the form of words or visual symbols rather than numerical estimates. They can take the shape of diagrams, phrases, or outlines, but more commonly they are made up of narrative texts often called "storylines." Qualitative scenarios have the advantage of being able to represent the views of several different stakeholders and experts at the same time. Well-written storylines can be an understandable and interesting way of communicating information about the future, at least as compared to dry tables of numbers or confusing graphs.

Qualitative scenarios have performed important functions in environmental science and policy. They have been useful for gathering views from experts or policy-makers on possible future societal developments and their environmental implications, as well as to help stakeholders, policymakers and others to "think big" about an environmental issue, i.e. to take into account the large time and space scales of a problem (see, e.g. Bood and Postma, 1997; Rothman et al., 2007). Qualitative scenarios have also been used to raise the awareness of policymakers, stakeholders, citizens and students about environmental problems and possible ways to solve them. "Strategy-driven" scenarios tend to be qualitative, as described in Chapter 1. A drawback of qualitative scenarios is that they do not, by definition, satisfy the need for numerical information. Another disadvantage is that qualitative scenarios are sometimes considered "unscientific" because their assumptions are not transparent and the procedure for developing them is usually not reproducible. We address these criticisms later in the chapter.

Quantitative scenarios, usually based on computer models, serve a practical function in environmental science and policy by providing numerical results where they are needed. It can be argued that the assumptions of quantitative scenarios are more transparent than their qualitative cousins since these assumptions are expressed in the form of model equations, inputs and coefficients that can be examined by any trained observer. Although equations are not easily understood by everyone, the assumptions are at least written down and perhaps are more accessible than the undocumented and unspoken assumptions behind qualitative scenarios. After all, most of the assumptions behind qualitative scenarios usually remain in the heads of the stakeholders and experts that specify these scenarios. Another advantage of quantitative scenarios generated from models is that these models are often already published in the scientific literature and have therefore received some degree of scientific scrutiny.

In the field of environmental science and policy, most scenarios have been quantitative because of the demand for numerical estimates of the future state of the environment. From the perspective of scientific research, quantitative scenarios are used as a research tool to investigate changes in the environment due to changing driving forces, e.g., to estimate the future ability of forests to take up CO_2 from the atmosphere under different intensities of future land use and forest management. Most "inquiry-driven" scenarios, as described in Chapter 1 are quantitative.

From the perspective of policy development, quantitative scenarios express the relationship between specific policies and their consequences on the environment. Examples here are the quantitative scenarios that relate trends in sulfur and nitrogen air pollution emissions to changes in acidification in Europe (e.g. Alcamo et al., 1990; Hordijk, 1991), greenhouse gas emissions to global climate change (e.g. IPCC, 2001), and the release of a variety of gaseous chemicals with the depletion of ozone in the upper atmosphere (e.g. WMO/UNEP, 1995 & 2003). These scenarios provide concrete input to environmental policymaking because they indicate the level of emission reductions required to protect the environment. They have also influenced the selection of emission targets incorporated in international treaties.

While quantitative scenarios provide needed numerical data, a subtle disadvantage is that the exactness of their numbers gives a false sense of knowing more about the future than we actually do. A scenario estimate of 22 gigatons of carbon dioxide emissions in 2100 could be interpreted to mean that we already know the magnitude of emissions several decades from now. Another disadvantage is that the computer models used to generate the scenarios contain many implicit assumptions about the future. Since models can only capture a part of the complex reality of environmental problems, it has been argued that they represent a narrow point of view about how the future will unfold, and in this way produce scenarios that are unnecessarily narrow in view. An additional drawback is that the basics of modeling are difficult for the non-specialist to understand. Hence, the basic assumptions behind the scenarios could be difficult to comprehend.

While it is useful to think about the advantages and disadvantages of qualitative and quantitative scenarios, sometimes the distinction between them is blurred. Qualitative scenarios can be derived by formalized, almost quantitative methods (e.g. Bunn and Salo, 1993; Godet, 2000), while quantitative scenarios can be developed by soliciting numerical estimates from experts or by using semi-quantitative techniques such as fuzzy set theory.[2] Storylines can also be interspersed with nu-

[2] See Zarnowitz (1984) for a discussion of approaches to solicit numerical estimates of future conditions from experts.

merical data and thereby look both qualitative and quantitative.[3] In these cases it is better to speak of hybrid scenarios rather than one type or another.

Since there are advantages and disadvantages to using either qualitative or quantitative scenarios, which type should be used for a particular scenario exercise? The challenge is to match the advantages of a particular scenario type with the function or purpose of the scenarios. In Chapter 2, Alcamo and Henrichs suggest three main purposes for environmental scenarios: education and public information, scientific research, and decision support and strategic planning. At first glance it would seem that the attributes of qualitative scenarios make them more appropriate for education and public information, while quantitative scenarios are more appropriate for scientific research, and both types could be used for decision support and strategic planning. The accent is on *more appropriate* because it is not possible (or necessary) to precisely match the type of scenario with its function. To complicate matters, contemporary environmental studies (especially the more comprehensive ones) have many different objectives, some of which can be better satisfied by qualitative scenarios and some by quantitative scenarios. Consider the scenario exercises that were part of major global environmental assessments of world water resources (Rijsberman, 2000), global greenhouse gas emissions (Nakicenovic et al., 2000), and world ecosystems (Carpenter et al., 2005). The goals of these exercises were both scientific (What is the future state of the environment? What are the scientific uncertainties in understanding the environmental system?) and policy-oriented (What are emerging problems? What are the consequences of a continuation of current policies? What can be done to protect the environment?).

Given this situation, how do we decide between qualitative or quantitative scenarios? The answer from recent international scenario exercises is that *we do not need to decide. Rather, a combination of qualitative and quantitative scenarios can be the best answer to achieving the goals of a scenario analysis*. Some prominent cases in which combined qualitative and quantitative scenarios were developed include the World Water Vision scenarios of the World Water Commission (Cosgrove and Rijsberman, 2000a), the SRES greenhouse gas emission scenarios of the Intergovernmental Panel on Climate Change (Nakicenovic et al., 2000), the global scenarios of ecosystem services from the Millennium Ecosystem Assessment (MA, 2003; Carpenter et al., 2005), and the global environmental scenarios of the Global Environmental Outlook reports published by the United Nations Environment Programme (UNEP, 2002, 2007).

We now briefly describe some of these exercises and discuss the general lessons they offer to the practice of scenario analyses.

[3] This was the case for the storylines from the IPCC SRES scenarios of greenhouse gas emissions (Nakicenovic et al., 2000) described later in this article.

3. The World Water Vision Scenarios – The World Water Situation in 2025

The First World Water Forum in Marrakech, Morocco in 1997 was a huge enterprise which brought together many private, governmental, academic and advocacy groups concerned with world water issues. One of the important outcomes of the Forum was the call for a "World Water Vision" to raise global awareness about global water problems and solutions. The main objective of the Vision, and the process to develop it, was to "convince the world of the urgency of the water crisis and the need to involve many more people in development of water policy" (Cosgrove and Rijsberman, 2000a). It was declared that the Vision should be expressed in the form of scenarios that describe the world freshwater situation in 2025.

The World Water Council set up two bodies to oversee the activities of the World Water Vision and these groups also had a major influence on the development of the World Water Scenarios. The first was a "Vision Management Unit" which managed the day-to-day activities of the World Water Vision Exercise. The second body was the World Commission on Water for the 21st Century consisting mostly of water experts and decision makers. These two bodies set up a Scenario Panel of 17 technical experts and stakeholders to provide the creative input to the scenario construction. (The author of this chapter was a member of the Panel.)

Among many questions, the Panel had to decide whether to develop either qualitative or quantitative scenarios. Some Panel members argued for qualitative scenarios since the World Water Vision scenarios were intended to reach a large public and therefore should be easy to communicate. Furthermore, it was thought that qualitative scenarios could better reflect a wide range of views and opinions about the future world water situation. Other panel members made a case for quantitative scenarios because an important part of the scenarios' audience was intended to be the scientific and engineering community and they would expect numerical estimates of the future world water situation. Moreover, the quantitative scenarios could serve as a consistency check for the many views expressed in the qualitative scenarios.

In the end, both qualitative and quantitative scenarios were developed. The qualitative scenarios (storylines) described the unfolding of events related to the future world water situation. They also identified the important factors directly affecting the future world water situation (e.g. the future extent of irrigated land or the level of water supply infrastructure), as well as those with an indirect affect (e.g. the rates of population and economic growth). (An excerpt from a storyline is given in Box 6.1). Meanwhile, the quantitative scenarios (model calculations) reinforced the storylines in two ways. First, model output was used to assess the validity and consistency of the storylines, for example, to check if the population and economic assumptions were consistent with statements about future levels of water use. Second, they provided numerical information on water use and availability to supplement the qualitative information contained in the storylines.

Box 6.1 Excerpt of the business-as-usual storyline of the World Water Vision scenarios. *Source:* Gallopin and Rijsberman (2000).

> *The business-as-usual scenario assumes that following some setbacks caused by the Asian and other regional financial crises, global economic growth resumes. Workers in industrial countries who are displaced from traditional sectors use their entrepreneurial skills to develop service businesses. A heightened appreciation for the need to rehabilitate and protect the environment increases demand for environmental services...*
> *The global population continues to increase, reaching 7.8 billion people by 2025. More than 80 percent of the world's population – 6.4 billion people – live in developing countries. Throughout the world, the population is older and more urban. About 84 percent of the population in industrial countries and 56 percent in developing countries live in urban areas...*
> *Per capita material and energy consumption increase as lifestyles throughout the world become more like those in the North... Income inequality between and within rich and poor countries increases tensions, but conflicts over social issues that do occur remain largely within national boundaries...*
> *In some areas with limited water and rapid population growth, the development of water infrastructure lags behind population growth, and the number of people without access to safe water increases. In most parts of the world, however, economic growth, combined with technological improvements, result in better living conditions, including increased access to safe drinking water...*
> *Estimates of increases in area of irrigated agriculture from 1995–2025 range from 5 to 10 percent globally. This slow-down in expansion rate for irrigation is due to both a lack of investment funds and vigorous protests... that make most large dam projects controversial... Water is used more efficiently, however, particularly in the water-stressed areas of the South. The change reflects the use of more efficient irrigation systems, such as drip irrigation...*
> *Increased technological efficiency and improved management prevent widespread dramatic water crises, but a number of regional crisis arise in some of the most arid regions...*

The scenarios were developed in an iterative fashion, starting with a "zero order draft" of a storyline crafted by the Scenario Panel, which was then converted using best judgment into quantitative driving forces that could be used as model inputs. Results from the modeling were used to update the storylines. The entire cycle of developing or revising storylines, specifying quantitative driving forces, and running the models was repeated twice.

When completed, the storylines and quantitative scenarios were posted on the World Water Vision website and discussed at several regional meetings worldwide. Comments were incorporated into the final storylines. Three scenarios were developed:

1. "Business-as-usual" (BAU) examines the consequences of continuing current trends in population, economy, technology and human behavior up to 2025.

2. "Technology, Economics, and Private Sector" (TEC) adopts a "world view that is optimistic about the free market system (and) the potential of new technologies" (Rijsberman, 2000).
3. The "Values and Lifestyles" (VAL) scenario assumes "that a strong commitment to avert a water crisis will emerge... with efforts focused on reaching a set of global and regional targets. The emphasis is on... the importance of human values" (Rijsberman, 2000).

More information about the development of the scenarios is given in Rijsberman (2000) and Alcamo (2001).

It can be argued that the scenarios fulfilled the goal of the World Water Vision exercise by helping to raise public awareness about water issues. They did so by being an effective and credible method to communicate the main messages of the World Water Vision in numerous publications and public presentations (Cosgrove and Rijsberman, 2000b). In the view of the author, the combined qualitative/quantitative approach was an important factor in the scenarios fulfilling their goals. The qualitative storylines were an effective device for communicating with the general public and non-experts, while the quantitative calculations provided the hard numbers preferred by many scientists and water experts.

4. The SRES Scenarios of the IPCC – Global Greenhouse Gas Emissions up to 2100

Around the same time as the World Water Vision exercise, another major international effort was going on to develop scenarios to better understand the implications of future climate change. To assess how climate change might affect river runoff, forest growth, and the frequency of heat waves, as examples, it is necessary to first compute the extent of future climate change with climate models. These models require many inputs, in particular the future trend of greenhouse gas emissions. Hence, emission scenarios play a central role in the study of climate change. Moreover, estimates of future emissions are also needed by economists and engineers as a basis for calculating the costs of mitigating climate change. Recognizing their importance, the Intergovernmental Panel on Climate Change (IPCC) developed a set of greenhouse gas emission scenarios in 1992 (Leggett et al., 1992). In January 1997 the IPCC appointed a "Writing Team" to develop new scenarios based on recommendations of a 1995 evaluation panel (Alcamo et al., 1995).[4] Since the Writing Team was supposed to produce a "Special Report on Emission Scenarios," the scenarios became known as the "SRES" scenarios.

There was no question that the scenarios would be primarily quantitative since they were required as input to climate and economic models. However, the eval-

[4] The Writing Team consisted of 28 Lead Authors (the author of this chapter among them) and an additional 26 Contributing Authors. Six modeling teams quantified the scenarios. The huge number of actors would have been an unwieldy number had they all actively participated in the scenario development and report writing. As it was, meetings of the Writing Team were typically attended by around 10 to 15 authors, and only small numbers of authors were active in all phases of the report writing.

uators of the earlier IPCC scenarios (Alcamo et al., 1995) made specific recommendations on how to develop these scenarios: (i) they should be developed by an "open" procedure that embraced a wide range of viewpoints of experts and interest groups, (ii) they should be checked for consistency with knowledge about the driving forces of emissions, (iii) the assumptions of the driving forces of emissions should be stated explicitly so that economists and other analysts could better assess future costs of emission reductions. These recommendations led to the strategy of developing both storylines and model-based scenarios.

Although the SRES scenarios have the same two basic elements as the World Water Vision scenarios, namely storylines and model calculations, their importance is reversed. In the World Water Vision scenarios, the storylines were the main vehicle for carrying the scenario message while model calculations played a supporting role. In the SRES scenarios, the model calculations were more important because the main objective of the scenarios was to produce numerical estimates of future emissions. Meanwhile, storylines provided a supporting role, mainly to explain the logic of selecting the driving forces of emissions. In the SRES scenarios each storyline expressed a different view of future world development, especially in the degree of globalization versus regionalization, in the relative emphasis on economic growth, and in the level of environmental protection. For example, the storyline of scenario family "A1" described a future of rapid technological progress and economic prosperity (see excerpt in Box 6.2). Based on this logic the scenario developers selected appropriate numerical estimates of driving forces of future emissions, such as trends in population, economic growth, and land use distribution. These and other driving forces were used as input to six different models for producing estimates of the emissions of all important greenhouse gases and related substances.

The resulting scenarios were clustered into four scenario "families" made up of groups of individual scenarios. This hierarchical organization of scenarios and sub-scenarios was one of the traits that distinguished the SRES from the World Water Vision scenarios. Using the description from the SRES report (Nakicenovic et al., 2000), the scenarios consisted of:

- The A1 storyline and scenario family describing a future world of very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies.
- The A2 storyline and scenario family describing a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities.
- The B1 storyline and scenario family describing a convergent world with the same low population growth as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies.
- The B2 storyline and scenario family describing a world in which the emphasis is on local solutions to economic, social, and environmental sustainability.

The SRES scenarios were successful in that they provided a consistent set of assumptions for computing global climate change and for assessing climate change

Box 6.2 Excerpt of the A1 storyline from the IPCC-SRES scenarios.
Source: Nakicenovic et al. (2000).

> *In the A1 scenario family, demographic and economic trends are closely related, as affluence is correlated with long life and small families (low mortality and low fertility). Global population grows to some nine billion by 2050 and declines to about seven billion by 2100. . .*
> *The global economy expands at an average annual rate of about 3% to 2100. . . While the high average level of income per capita contributes to a great improvement in the overall health and social conditions of the majority of people, this world is not necessarily devoid of problems. In particular, many communities could face some of the problems of social exclusion encountered in the wealthiest countries during the 20th century. . .*
> *Energy and mineral resources are abundant in this scenario because of rapid technical progress, which both reduces the resources needed to produce a given level of output and increases the economically recoverable reserves. Final energy intensity (energy use per unit GDP) decreases at an average annual rate of 1.3%.*
> *With the rapid increase in income, dietary patterns shift initially toward increased consumption of meat and dairy products, but may decrease subsequently with increasing emphasis on the health of an aging society. High incomes also translate into high car ownership, sprawling suburbs, and dense transport networks. . .*

and its impacts in different countries and regions in the world.[5] These studies in turn have influenced discussions about global and national climate policies.

In conclusion, the quantitative aspects of the SRES scenarios provided the numerical information needed for climate analysis and were able to pass through the very vigorous scientific and political review process of the IPCC. Meanwhile the qualitative storylines provided an effective format for understanding the assumptions of the scenarios.

5. The Scenarios of the Millennium Ecosystem Assessment – The State of World Ecosystems up to 2050

While the World Water Vision and IPCC-SRES scenario exercises were winding down, another major international exercise was just getting underway, this time with a focus on global ecological systems. The scenario development of the "Millennium Ecosystem Assessment (MA) was part of a huge effort to assess world ecosystems, officially launched by the Secretary-General of the UN, Kofi Annan in 2000. The MA aimed to support decision makers involved with three landmark conventions from the 1990s related to world ecosystems – the Desertification,

[5] The SRES scenarios have not only been used as basic input for running global climate models, but have also been used in studies of global water use and availability (e.g. Alcamo et al., 2007a) and regional climate impact in Europe (e.g. Arnell et al., 2003).

Wetlands and Biodiversity Conventions. These agreements set out general goals for the protection of ecosystems but left the details to the policy and scientific communities. The MA sought to "create a mechanism to increase the amount, quality, and credibility of policy-relevant, scientific research findings concerning ecosystems & human well-being used by decision-makers, particularly those involved in the ecosystem-related conventions." The MA focused, in particular, on evaluating the "ecosystem services" provided by nature to society such as food and water supply, lumber, and products of all kinds. Since it was thought that policymakers needed not only information about current ecosystem services but also about their future trends and state, the Assessment invested a large effort in developing scenarios. The scenarios were to address the main question:

> What are the consequences of plausible changes in development paths for ecosystems and their services over the next 50 years and what will be the consequences of those changes for human well-being? (Carpenter et al., 2005)

Most of the work of the MA was carried out in three working groups, with one of these being the Scenarios Working Group. The scenario development followed 14 steps organized into three phases (see Box 6.3). The first was the organizational phase during which the various scenario committees were set up and the main questions and focus of the scenarios identified. A "scenario guidance team" was established to lead and coordinate the scenario-building process made up of the chairpersons and secretariat of the Scenarios Working Group. A larger panel, composed mainly of scientific experts, was assembled to build the scenarios. The scenario guidance team conducted a series of interviews with potential users of the scenarios (decision makers and other stakeholders) to solicit their views about the goals and focus of the scenarios. This was especially important for the MA because the number of potential users was very large and diverse (ranging from secretariats of the ecosystem-related international conventions to local educational organizations). These interviews also ensured input from stakeholders and users early on in the study. Based on the results of the user interviews and discussions with the scenario panel, the objectives, focus, leading themes, and hypotheses of the scenarios were derived by the scenario guidance team and panel (and later confirmed by the MA Assessment Panel).

The second phase consisted of the basic work in developing the scenarios. As with the World Water Vision scenarios and IPCC-SRES scenarios, a combined qualitative-quantitative scenario approach was used. But the MA departed from these other scenario exercises by putting equal emphasis on both qualitative and quantitative scenarios. The author estimates that roughly the same amount of effort and expense was invested in developing (and distributing) both types of scenarios.

In the second phase, the storylines were written and the scenarios quantified using an iterative procedure. These two elements were designed to be mutually reinforcing. The scenario storylines took into account a broad range of ecosystem elements and feedback effects difficult to quantify. Based on initial storylines, model inputs were defined and a set of global models were run to provide quantitative information about future ecosystem services. One of the unique aspects of the

Box 6.3 **Procedure of the Millennium Ecosystem Assessment for developing scenarios.** *Source: Alcamo et al. (2005).*

Phase I: Organizational steps
Establish a scenario guidance team.
Establish a scenario panel.
Conduct interviews with scenario end users.
Determine the objectives and focus of the scenarios.
Devise the focal questions of the scenarios.

Phase II: Scenario storyline development and quantification
Construct a zero-order draft of scenario storylines.
Organize modeling analyses and begin quantification.
Revise zero-order storylines and construct first-order storylines.
Quantify scenario elements.
Revise storylines based on results of quantifications.
Revise model inputs for drivers and re-run the models.

Phase III: Synthesis, review, and dissemination
Distribute draft scenarios for general review.
Develop final version of the scenarios by incorporating user feedback.
Publish and disseminate the scenarios.

MA scenario exercise was the large and complex set of models that were used to quantify the scenarios. To enhance the level of consistency of model calculations, a common set of driving forces were used and the models were coupled (output from one model was used as input to another) where this was technically possible (Figure 6.1). Eight different global models were used covering one or more important aspects of world ecosystems including air pollution emissions, land cover, terrestrial vegetation, food production, inland water resources, and regional marine fisheries. The only comparable effort to quantify global scenarios was the scenario analysis of UNEP's Fourth Global Environmental Outlook (UNEP, 2007) (see below).

During the third phase, the results of the scenario analysis were synthesized, and scenarios and their outcomes were reviewed by the stakeholders of the MA, revised, and disseminated.

Another unique aspect of the MA scenario exercise was its "multi-scale" approach. The advantage of such an approach is that it provides better coverage of different societal and environmental processes because they operate on different spatial and temporal scales. Consider the example of crop production. On the global scale, it can be argued that crop production is determined by changing international food import and export relationships, which in turn are affected by increasing food consumption and changing dietary habits. Meanwhile, on the local scale, crop production is determined by the local suitability of soils and topography, local dietary requirements, competition from urban land, and other factors that might be invisible on the global scale. The MA developed multi-scale ecosystem scenarios in the form of regional scenarios for Southern Africa, Portugal and the Caribbean islands

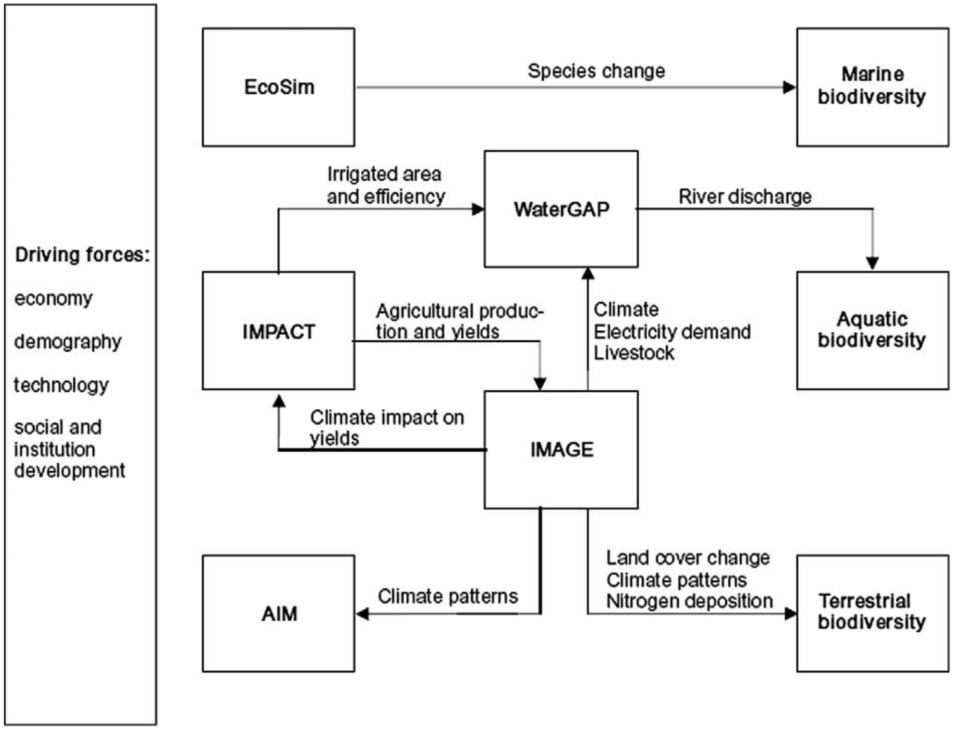

Figure 6.1 The set of global models with their soft linkages used to produce quantitative scenarios in the Millennium Ecosystem Assessment (Alcamo et al., 2005).

that were consistent the global scenarios of the MA (Lebel et al., 2005). One of the main problems in developing multi-scale scenarios is that they have to serve the needs of both global and local users.

The four scenarios developed by the MA were:

Global Orchestration which describes a globally-connected society focusing on global trade and economic liberalization and takes a reactive approach to ecosystem problems but also takes strong steps to reduce poverty and inequality and to invest in public goods such as infrastructure and education.

Order from Strength which describes a regionalized and fragmented world, concerned with security and protection, with an accent on primarily regional markets, paying little attention to public goods, and taking a reactive approach to ecosystem problems.

Adapting Mosaic which describes a world in which regional watershed-scale ecosystems are the focus of political and economic activity. Local institutions are strengthened and local ecosystem management strategies are common; societies develop a strongly proactive approach to the management of ecosystems.

TechnoGarden which is a globally-connected world relying strongly on environmentally sound technology, using highly managed, often engineered, ecosystems to deliver ecosystem services, and taking a proactive approach to the management of ecosystems in an effort to avoid problems.

If comprehensiveness is a mark of success, the MA scenarios are successful because they are among the most comprehensive and detailed global environmental scenarios produced to date. The scenarios provide a rich picture of alternative developments of key global ecosystems over the coming decades. Another benchmark of success is that the scenarios have been extensively documented in a very large volume (Carpenter et al., 2005), and in that sense they are accessible and transparent to potential users (at least those having the time to read the documentation). Since being published in 2005, the scenarios have been used for many different purposes, including as background information for the development of new aid programs at the UK Department of International Development, and as a departure point for two other international scenario exercises – the International Assessment of Agricultural Science and Technology for Development and the project on Global Environmental Change and the Food System (Reid, 2006).

6. The GEO-4 Scenarios – The Global Environment up to 2050

While previous global scenario exercises were large in scope, the aim of the GEO-4 scenarios had the even greater ambition of describing main developments of the entire global environment up to 2050. The GEO-4 scenario exercise was carried out by the United Nations Environment Programme (UNEP) as part of its fourth "Global Environmental Outlook" (hence "GEO-4") and it advanced the state-of-the-art of environmental scenarios by elaborating not only global futures but also a complementary set of world regional scenarios. As in the other scenario exercises described above, the GEO-4 scenarios consist of both storylines and model calculations. The storylines were originally developed as part of the GEO-3 report (UNEP, 2002), which in turn were based on earlier work of the Global Scenarios Group (e.g. Raskin et al., 1998). Eight scenario teams worked on the GEO-4 storylines – a global group plus seven teams representing the seven UNEP world-regions (Rothman et al., 2007). As a starting point for their storylines, the regional scenario groups used the text of the previously developed global storylines and then adjusted and adapted them to their own regions. The global storylines were then modified using input from the regional teams.

During the time that the regional and global storylines were being developed and revised, a large team of modelers produced quantitative scenarios on both the global and regional scale. The GEO-4 set of models was as comprehensive as that used by the Millennium Ecosystem Assessment. A linked set of seven global models and two regional models were used to compute agricultural production, freshwater use and resources, marine fisheries, terrestrial biodiversity, land use changes, and the magnitude and manifestations of climate change (Rothman et al., 2007). Another innovation of the GEO-4 study was the use of the International Futures model (Hughes and Hillebrand, 2006) to generate a consistent set of demographic, economic and other global drivers of the quantitative scenarios. Previous studies relied on several different, and not necessarily consistent, sources of data for future demographic, economic and other developments. The International Futures model provided a consistent method for specifying the most important driving forces of the quantitative scenarios.

Although UNEP originally planned to develop the storylines and quantitative scenarios in an iterative fashion, this turned out to be impossible because of lack of time. As pointed out earlier, the reconciliation and iterative development of qualitative and quantitative scenarios is a very time-demanding task. Another problem arose because there was insufficient time to consult thoroughly with policymakers and stakeholders about the regional storylines. Hence, the regional storylines received a lower level of acceptance than the global storylines.

The four GEO-4 scenarios consist of:

- *Markets First*: In this scenario, private industry and government cooperate on policies to maximize economic growth for improving human well-being and environmental quality. This future emphasizes technological and economic solutions to environmental problems.
- *Policy First*: This scenario describes a future in which strong public policies are carried out to improve human well-being and the environment. While these policies have the strong support of the private sector and general public, the emphasis is on top-down governance motivated in part by the desire to make rapid progress on key socio-economic and environmental targets.
- *Security First*: In this scenario, government and the private sector put their emphasis on maintaining or improving the well-being of the richer and more powerful segments of society. The accent is on national, regional and local self-reliance. Accordingly, the level of international cooperation is relatively low.
- *Sustainability First*: Under this future, government, civil society and the private sector work together to further human well-being and environmental quality. This scenario emphasizes the wide involvement of all segments of society in decision making, and equal weight is given to environmental and socio-economic policies.

While it is too early to judge the impact of the GEO-4 scenarios, some of the main messages of the scenarios gained considerable public attention when the GEO-4 report was published.

(For example, the fast tempo of global change over the coming decades and the possible slowing of the tempo after mid-century; the higher risk of exceeding thresholds in the earth system in the event the tempo does not slow; the high potential of policies to support both ecological sustainability and an increase in human well-being.)

7. THE SAS (*Story and Simulation*) APPROACH TO SCENARIO DEVELOPMENT

Although the World Water Vision, GEO-4 and other scenario exercises gave different weight to qualitative or quantitative scenarios, they shared many of the same characteristics:

- *The development of qualitative "storylines" by a group of stakeholders and experts*. These storylines provided an understandable and more transparent basis for understanding scenario assumptions, provided a more interesting method for communicating the substance of the scenarios than numerical data, and represented the complex views of the individual members of the stakeholders and experts.
- *The use of models to produce quantitative scenarios* which provided needed numerical data, and made possible a consistency check of the storylines.
- *The harmonization of the qualitative and quantitative scenarios* through an iterative process relying on interaction between scenario writers, experts, global modelers and stakeholders. The interactive process encouraged communication and discussion between these different actors.
- *The "openness" of the process* in that stakeholders were involved in the development of the scenarios, and all interested parties could comment on and contribute to the scenarios. This openness increased the legitimacy of the scenarios and hence their acceptability in policy circles.
- The use of a variety of means, including the Internet, *to solicit comments and contributions to the scenarios*, and to communicate scenario results. This increased the extent of use of the scenarios.

Although the developers of the scenario exercises described above did not consciously follow a common methodology, their main procedure can be distilled into the ten steps of the "Story and Simulation" approach (SAS) summarized in Box 6.4 and described in the following paragraphs.

Step 1. Scenario Team and Scenario Panel are established.

The first step is for the institution authorizing the scenarios to organize a Scenario Team, whose goal is to coordinate the scenario analysis. (Examples of authorizing institutions from the above scenario exercises were the United Nations Environment Programme and the World Water Commission.) An important initial task of the Team is to organize a Scenario Panel consisting of stakeholders in the scenario process and experts. The Scenario Panel provides the creative input and ensures that many different viewpoints are represented in the scenarios.[6]

The Panel should include individuals and/or organizations who have a special interest in the outcome of these scenarios – for example, representatives from different government institutions involved in environmental issues, members of

[6] The Panel should be large enough to represent a wide range of different interests, yet small enough to hold effective discussions and to take decisions. Experience suggests that a workable size of the Panel is between 15 and 25 members. By way of illustration, the World Water Vision exercise had a panel with 17 members, and the SRES-IPCC exercise had a panel with 28 members (although not all of these were active).

Box 6.4 **Overview of the SAS (Story and Simulation) approach to scenario analysis.**

1. A scenario team and a scenario panel are established.
2. The scenario team proposes goals and outline of scenarios.
3. The scenario panel revises goals and outline of scenarios, and constructs a first draft of storylines.
4. Based on draft storylines, the scenario team quantifies the driving forces of scenarios.
5. Based on assigned driving forces, modeling teams quantify the indicators of the scenarios.
6. The modeling teams report on the quantification of the scenarios and the scenario panel revises the storylines.
7. Steps 4, 5 and 6 are repeated until an acceptable draft of storylines and quantification is achieved.
8. The draft scenarios are distributed for general review.
9. The scenario team and scenario panel revise scenarios based on general review.
10. The final scenarios are published and distributed.

environmental organizations, representatives of industries especially affected by environmental regulations, and concerned citizens. The Scenario Panel could also include experts needed to construct the scenarios – e.g. individuals with either special environmental expertise, experience in building scenarios, or capable of modeling the scenarios. Experts are needed to inform stakeholders about which aspects of the environmental problem can be quantified and which not. Conversely, stakeholders must make it clear to the experts what needs to be quantified.

Step 2. Scenario Team proposes goals and outline of scenarios.

One of the first tasks of the Scenario Team is to propose the basic goals and outline of the scenarios. For example, what should the scenarios achieve? What subjects should they cover? What is their time horizon? It is advisable that they consult with a number of colleagues inside and outside their institution. In the Millennium Ecosystem Assessment, the scenario team conducted interviews with stakeholders to help identify the objectives of the scenario exercise.

The general aim of this step is to narrow the virtually unlimited scope of the scenario exercise and in this way increase the chances of its success and better utilize the time of the Scenario Panel. The goal is not, however, to limit the creative input of the Panel. Therefore, the Scenario Team should present the Panel with a proposed outline of the scenarios, not a *fait accompli* that the Panel must either endorse or reject.

Step 3. Scenario Panel revises goals and outline of scenarios, and constructs zero order draft of storylines.

After drafting the first outline of the scenarios, the Scenario Team convenes the first meeting of the Scenario Panel to discuss and revise the scenario goals and outline proposed by the Scenario Team. Agreement is needed on the main messages and themes of the scenarios, the number of scenarios, the indicators to be used in the scenarios, and the time horizon.

Another goal of the meeting is to construct a "zero order draft" of the storylines. These can be very preliminary sketches of the sequences of main events in the scenarios. (Calling it a "zero order draft" emphasizes its preliminary character and may encourage participants to be more experimental and creative.)

Step 4. Scenario Team quantifies the driving forces of scenarios.

After preparing the zero order draft of the storylines, the Scenario Team assigns numerical values to the driving forces of the scenarios based on the best information available. These driving forces will then be used to drive the models in the next step. These data are taken from previous studies, from models run specifically for this purpose, or are specified *ad hoc*. For example, assumptions about population growth in the IPCC-SRES scenarios and the MA scenarios were taken from previous studies of the United Nations and International Institute for Applied Systems Analysis. Sometimes an elaborate side study of driving forces is carried out and this provides background material for selecting the driving forces assumptions of the models. (This was the case for the MA scenarios; Nelson et al., 2005.)

Later we point out that this conversion from the qualitative knowledge in the storylines to numerical model inputs is one of the weakest links in the SAS procedure.

Step 5. Modeling Teams quantify the indicators of the scenarios.

The driving force assumptions from the previous step are then used by the modeling team or teams to compute the basic indicators of the scenarios. For the World Water scenarios, the main indicators were the use and availability of water in different river basins around the world. In the SRES scenarios, the main indicators were different types of greenhouse gas emissions in different world regions. The GEO-4 scenarios had these and many more indicators including crop production, land cover, and air pollution emissions.

Step 6. Storylines are revised.

At the next meeting of the Scenario Panel, the modeling teams present the quantification of the draft storylines. Quantitative information can be used in two ways at this point in the scenario analysis – first, to identify inconsistencies in the storylines. Second, to "enrich" the storylines by adding information that deepens or extends the storylines. As an example of the first case, model calculations in the World Water Vision exercise raised some questions about the sustainability of the original "sustainability" storylines and led to a revision in the name and storyline of this scenario. (Model runs indicated that water abstractions required for future irrigated crop land increased the risk of very high water stress in many river basins worldwide. Hence, the "sustainability" storyline was inconsistent with its name.) As an example of the second case, model results were used in Glowa Jordan River scenario exercise (Alcamo et al., 2007b) to "enrich" the storylines. (Model calculations showed that future water availability in the Jordan River Valley would be affected chiefly by declining precipitation and increasing temperature rather than changing land cover, and this knowledge was added to the storylines; Menzel, 2007.)

Based on the results of the quantification together with further discussion at the Scenario Panel meeting, the draft storylines are revised by the Scenario Panel.

Step 7. Iteration of Steps 4, 5 and 6 as necessary.

To this point in the scenario exercise, preliminary storylines have been drafted, refined and expanded, and model-based scenarios have been computed. Nevertheless the scenario exercise is not finished. Experience shows that Steps 4, 5 and 6 must be repeated before the Scenario Panel and Team are satisfied with the completeness and soundness of the scenarios. Usually two or three iterations of these steps are necessary.

Step 8. Draft scenarios distributed for general review.

The draft scenarios from Step 7 are distributed widely for the broadest possible review by experts and stakeholders. This can be accomplished by posting and publicizing the scenarios on the Internet, by distributing the scenarios in paper form, and/or giving presentations to solicit comments and input. A draft-version of the IPCC-SRES emission scenarios went through a very vigorous review process involving input from numerous governments worldwide. In the Millennium Ecosystem Assessment, briefings were held to obtain comments from specific audiences including the secretariats of the Biodiversity and other international Conventions. In the Glowa Jordan River scenario project, preliminary results of the scenarios were directly presented to decision makers involved in water resource planning in the Middle East.

Step 9. Scenarios are revised based on results of general review.

Taking into account the comments of stakeholders and experts, the Scenario Team and Scenario Panel revise the storylines and driving forces. The Modeling Teams then produce the final quantifications of the scenarios.

Step 10. Publication and distribution of final scenarios.

The final scenarios are published and distributed through the Internet, in the form of paper reports, at meetings, or by other means.

8. Advantages of SAS

How successful has the SAS approach been in achieving its scientific and policy objectives? As criteria for success we use the four points presented in Chapter 2: *relevance* to the concerns and needs of users of scenarios, *credibility* in the sense of producing plausible views of the future, *legitimacy* in that the messages of the scenarios are considered politically fair, and *creativity* in that the scenarios stimulate new, creative thinking. (Although these criteria apply to scenarios rather than scenario approaches, they provide a useful reference point for this discussion.)

The SAS approach produces results *relevant* to policy and science because of its iterative procedure which maximizes the chances that both stakeholders and experts obtain scenarios relevant to their objectives. This approach produces qualitative storylines that can represent the views of many different stakeholders and experts, and can be an interesting and understandable way to convey many messages about future developments.

The SAS approach produces *credible* results because it can incorporate state-of-the art computer models for generating numerical information about environmental changes and their driving forces and for checking the consistency of qualitative scenarios. Because of the combined storyline-modeling procedure, knowledge derived from models can be combined with the expert knowledge of a Scenario Panel.

The active involvement of decision makers, stakeholders, and experts in building scenarios also adds *legitimacy* to the scenarios produced with the SAS approach. The interaction of many viewpoints on the Scenario Panel can also be a source of *creativity* for the scenarios, especially if the scenario panel meetings are well moderated.

9. Drawbacks of SAS and a Way Forward...

Although it combines some of the advantages of qualitative and quantitative scenarios, the SAS method also has some serious shortcomings that limit its potential contributions to science and policy. First of all, it requires the use of models for quantifying storylines – but good models are not always available; and even when they are there is often a shortage of personnel to run them or interpret their output. Moreover, available models may not be suitable for linking with qualitative scenarios. Fontella (2000) has argued, for instance, that econometric-type models based on an analysis of past trends are too rigid to be coupled with creative, non-linear type of qualitative scenarios.

There are also some practical drawbacks to the SAS approach. It is a costly enterprise since it requires the organization of many meetings, and the participation of many scenario builders. In addition, it is time-consuming because it calls for multiple cycles of storyline writing, quantification and scenario review.

The above problems can be at least partly overcome with sufficient support and good management. However, two other problems are more fundamental and require an extension of the SAS methodology: the *reproducibility problem* and the *conversion problem*.

9.1 The reproducibility problem

A keystone of scientific credibility is the reproducibility of an experiment or analysis. For this reason it is significant that the storylines produced in the above scenario exercises do not meet this benchmark. Storylines are usually developed through a group process in which the assumptions and mental models of the storyline writers remain unstated. Therefore the storyline is difficult if not impossible to reproduce. This lack of reproducibility reinforces the impression that storylines are "unscientific" even though they may be based on a more sophisticated concept of an environmental system than portrayed by any mathematical model.

A straightforward solution is to make the assumptions behind the storylines transparent enough to allow future researchers to reconstruct the storylines. There is a set of visualizing techniques that can be used for this task These techniques are called "causal loop diagrams," "cognitive maps" and "digraphs" and they are similar in that they are all diagrams that depict the elements of a system and show the connections between these elements with lines or arrows. An example is shown in Figure 6.2. Such diagrams have been used for decades to portray complex human-environment systems (e.g. Forrester, 1961; Meadows et al., 1972). The point is that such diagrams can be used to document the mental models and other assumptions lying behind storylines. In principle, once such a clear visual map is available for a storyline, then its basic content should be re-constructible.

A disadvantage of causal loop and similar diagrams is that they quickly become very complex if they try to describe all the cause-effect relationships implied in a typical storyline, and subsequently they lose their explanatory ability. Hence, new developments are needed for constructing these diagrams that take into account the complexity of the systems behind storylines. Perhaps they can be organized in

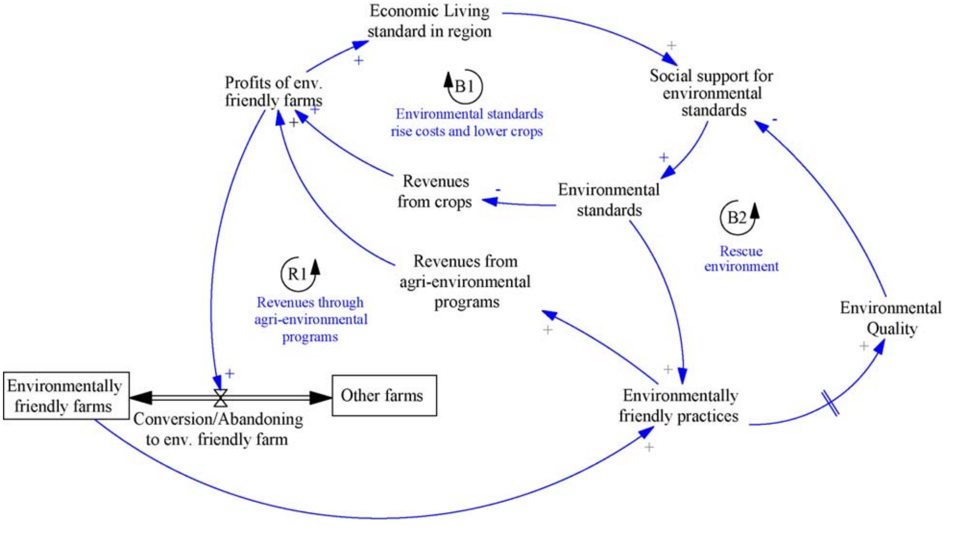

Figure 6.2 An example cognitive map describing the relationship between environmental standards and farming practices in an agricultural region. Constructed by stakeholders at a scenario workshop. This diagram can be taken as an expression of the stakeholders' mental models about the functioning of an agricultural system. Diagram courtesy J. Sendzimir, IIASA, 2007.

a hierarchical way, with the upper layer of the causal loop diagram depicting the simplest outline of the storyline followed by successive layers of causal loops that elucidate various aspects and details of the storyline. In any event, the practical problems of applying these diagrams must be addressed before they can become a routine part of the SAS approach.

9.2 The conversion problem

The SAS approach aims to produce consistent, or at least "harmonized," qualitative and quantitative scenarios. This requires, as we have seen above, the conversion of qualitative knowledge to quantitative knowledge, and back again. Two conversions are involved:

- First, the assumptions of the storylines must be converted to numerical model inputs so the models can be used to compute quantitative scenarios. For example, statements about driving forces in the storylines ("population growth is medium") must be converted to numerical form ("population growth = 2% per year") so that they can be input to models.
- Second, after the models are run, their numerical output ("change in water availability = –25%") must be converted back to linguistic statements ("water availability will moderately decrease") so that they can be used in a storyline if the Scenario Panel decides to do so.

In previous scenario exercises these conversions were based on expert judgment, or in clearer terms, the scenario team decided themselves (as logically as possible) how to translate the text in a storyline to quantitative model inputs. As noted previously, sometimes the translation is supported by an extensive review of the literature on driving forces, as in the case of the Millennium Ecosystem Assessment (Nelson et al., 2005). But usually the scenario team has to make the translation based on best available information. The problem is that "best judgment" tends to be neither reproducible nor transparent and as a result takes away from the scientific credibility of the scenario analysis.

Conversion 1. From storyline assumptions to model inputs.

The solution then is to make the conversion of knowledge as transparent and reproducible as possible by following a specific protocol. Such a protocol is being developed as part of the Glowa Jordan River scenario exercise (Box 6.5). It draws on techniques from the field of applied mathematics call "fuzzy set theory" to convert from qualitative to quantitative knowledge and back again. Fuzzy set theory has been applied to many questions of environmental science (e.g. Geyer-Schulz, 1995; Cornelissen et al., 2001).

The first step is for the Scenario Panel to make specific linguistic statements about the magnitudes or rate of change of all important driving forces in the storylines (e.g. "population growth is medium"). If the models used in the scenario exercise need assumptions about other driving forces, these should also be specified in the storylines. An example of statements about population growth in a scenario exercise are given in Table 6.1.

Box 6.5 **Protocol for converting qualitative to quantitative knowledge (and the reverse operation) in an environmental scenario analysis.**

1. The Scenario Panel makes explicit statements about magnitude or tempo of driving forces in the storylines, for instance, "population growth is medium," or "economic growth is large." The terminology, "small," "medium," "large," etc., must be agreed upon and consistently used in the storylines.
2. Members of the Scenario Panel articulate the ranges of numerical values that fit to the adjectives used to describe driving forces, for example, the numerical range of "medium" as in "medium population growth." Data from all Scenario Panel members are consolidated into separate "translation keys" for each adjective. These translation keys are used in the next step to convert linguistic statements ("medium population growth") to numerical values (2% per year). One type of translation key is a "membership function" which stems from fuzzy set theory (see text).
3. The Scenario Panel uses an appropriate translation key for objectively converting linguistic statements (e.g. "medium population growth") to numerical values (e.g. 2% per year).
4. The numerical values are input to models to compute quantitative scenarios.
5. Output from the quantitative scenarios are re-converted to linguistic statements for use in the storyline by employing translation keys similar to those in Step 2.

The second step is to derive a "translation key" for converting linguistic statements into numbers. There are various possibilities for accomplishing this, one of which is to use "membership functions." A membership function is a mathematical representation of the ambiguity that comes from translating exact linguistic statements such as "medium population growth" into numbers. Membership functions can be derived in different ways. In the Glowa Jordan River scenario project, 10 members of a Scenario Panel were asked to articulate their numerical definitions of different adjectives for driving forces, such as "small," "medium," and "large" population growth. For example, one member of the Panel said that a "medium population growth" was between 0.5 and 2.5% per year. The views of the 10 Panel members regarding "medium population growth" were consolidated into the single membership function shown in Figure 6.3. The *Y* axis of this and other membership functions runs from 0 to 1 and expresses the "degree of membership" or "degree of belief" in a particular value of the variable on the *X* axis. Figure 6.3 shows that the degree of belief of the Panel is zero (degree of membership = 0) when values of "medium" population growth are below 0.5% per year or above 3.0% per year. Put another way, when the Scenario Panel writes "medium population growth" its members mean that the population growth can range from 0.5 to 3.0% per year with various degrees of belief. Which number then in Figure 6.3

Table 6.1 Linguistic statements about population growth specified in the Glowa Jordan River storylines

Scenario period	State	Scenario			
		Poverty & Peace	Willingness & Ability	Modest Hopes	Suffering of the Weak & the Environment
2008–2010	ISR	Small increase	No change	Small increase	Small increase
	JO	Medium increase	High increase	High increase	Medium increase
	PA	High increase	High increase	Medium increase	High increase
2025–2030	ISR	Small increase	No change	Small increase	Small increase
	JO	Medium increase	Medium increase	Medium increase	Medium increase
	PA	High increase	Medium increase	Small increase	Medium increase
2050	ISR	Small increase	No change	Medium increase	Small increase
	JO	Medium increase	Medium increase	Medium increase	Medium increase
	PA	High increase	Medium increase	Medium increase	Medium increase

Source: Onigkeit et al. (2007).

reflects the least ambiguity? Fuzzy set theory says that under these circumstances the centroid of the triangle (1.9% per year) is a representation of the least ambiguous numerical value for "medium." Hence, this is the value should be used for model runs when "medium population growth" is mentioned in the storylines.

The point is that by working with stakeholders and experts it is possible to agree on the fuzzy boundaries of "medium" and from this knowledge the least ambiguous numerical value can be objectively selected. While this procedure does not eliminate the arbitrariness of selecting the boundaries of the definition of "medium," it does provide a consistent, transparent and objective way of deriving a single numerical value from the collective fuzzy numerical views of a Scenario Panel. Accordingly, this procedure is called "defuzzification."

The third step in the protocol is to repeat the defuzzification procedure for definitions of "small," "large," and other adjectives used to describe driving forces in the storylines.

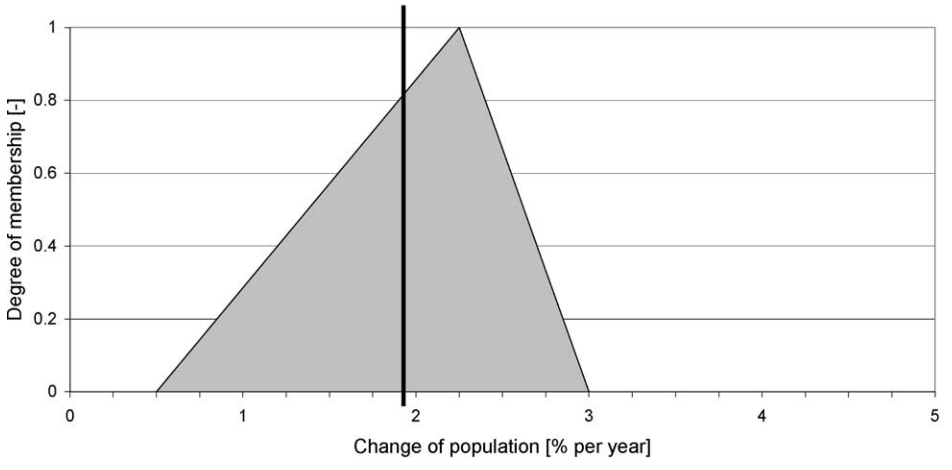

Figure 6.3 Example membership function for "medium" population growth derived from the views of stakeholders in a scenario exercise. The vertical line indicates the centroid of the triangle.
Source: Onigkeit et al. (2007).

Table 6.2 Numerical assumptions of population growth (% per year) corresponding to linguistic statements in Table 6.1

Scenario period	State	Scenario			
		Poverty & Peace	Willingness & Ability	Modest Hopes	Suffering of the Weak & the Environment
2008–2010	ISR	1	0	1	1
	JO	1.9	3.7	3.7	1.9
	PA	3.7	3.7	1.9	3.7
2025–2030	ISR	1	0	1	1
	JO	1.9	1.9	1.9	1.9
	PA	3.7	1.9	1	1.9
2050	ISR	1	0	1.9	1
	JO	1.9	1.9	1.9	1.9
	PA	3.7	1.9	1.9	1.9

Source: Onigkeit et al. (2007).

The fourth step in the protocol is to use the membership functions representing "small," "medium," and "large" population growth as translation keys to convert the linguistic statements in the storylines (e.g. in Table 6.1) to numbers (e.g. Table 6.2). The values in Table 6.2 can then be used as input to models.

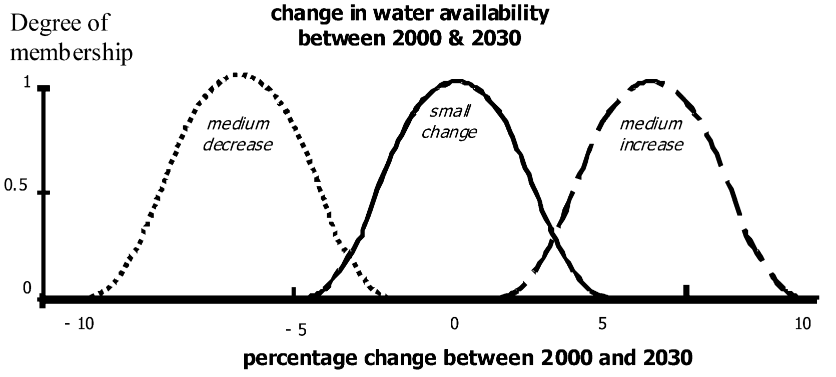

Figure 6.4 **Hypothetical membership function for converting numerical output from a model (the percentage change in water availability) to linguistic statements in a storyline. The advantage of using such a function is that it enables the conversion in a consistent and transparent way.**

Conversion 2. From model outputs to storyline inputs.

In the SAS approach, model results are used to check the consistency of storylines and to "enrich" the storylines with new knowledge. But this means that quantitative knowledge from models has to be converted back to linguistic statements in the storylines (the opposite of Conversion 1). Membership functions can also be used for this task. Figure 6.4 is a hypothetical membership function similar to Figure 6.3, but in this case it is used to convert from numerical model output to linguistic statements. In the parlance of fuzzy set theory this is called "fuzzification." As in Figure 6.3, Figure 6.4 should be based on the views of a Scenario Panel.

Figure 6.4 shows that a "medium increase" in water availability would range from 2.5 to 10%, with the highest level of membership/belief at 6 percent. This membership function would be used as follows. First, a model is used to compute the change in water availability in a region. If the model calculates a 4 percent increase, then Figure 6.4 would be used to translate this into the linguistic statement "small to medium increase." The use of membership functions in this simple way allows the Scenario Team to objectively convert model output to linguistic statements that can be used in the storylines.

But membership functions do not fully solve the conversion problem. First of all, storylines normally contain many different driving forces, and it is unlikely that an appropriate model will be available to quantify each of these driving forces. In this case, the Scenario Panel has to accept the fact that not all driving forces will be quantifiable. Second, the models to be used in the scenario exercise are likely to require many more input variables than are covered in the storylines. Hence the groups running the models will have to specify many input variables themselves, and the link between the storylines and model calculations will be incomplete.

Nevertheless, as noted above, membership functions provide a useful way to objectively make the conversion from qualitative to quantitative knowledge and back again, and should be considered in SAS scenario exercises.

10. Summing up

This chapter shows that both qualitative and quantitative scenarios provide valuable information for environmental scenario analysis. The *qualitative* storylines provide an understandable vehicle for communicating the messages of the scenarios, and can express the more complex dimensions and inter-connectedness of environmental problems. Meanwhile, the *quantitative* scenarios provide a consistency check to the different assumptions of the qualitative scenarios, and the numerical data often needed in environmental studies.

In order to capitalize on their advantages, qualitative and quantitative scenarios have been combined in recent international scenario exercises. In this chapter we have summed up the experience of these exercises in a procedure called the "SAS" (Story and Simulation) approach. While this procedure has been used successfully, it still has serious shortcomings that need to be addressed, in particular the procedure for converting between qualitative to quantitative information. By addressing these shortcomings the SAS approach can become a more useful methodology for developing environmental futures.

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