CHAPTER TWO

Towards Guidelines for Environmental Scenario Analysis*

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Contents

1. Introduction

Environmental assessments make use of a wide range of different approaches and methods for identifying concerns, analysing problems and testing possible response options. Over the past decade, scenarios that depict environmental change have played an increasingly large role in science and policy – and have become a commonly used tool in future-oriented and forward-looking studies. Simply put, scenarios present stories about the future built upon "if-then" propositions that provide a way to explore the implications of unfolding driving forces. However, although a plethora of environmental scenarios have been developed and analysed

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over the past three decades,[1] there is much less information available about the methodologies used to produce these scenarios, and even less critical examination of these methodologies. As a result (in the opinion of the authors) scenario-based environmental assessments too often follow ad-hoc procedures. The purpose of this document is thus to assemble and sum up some of the information available about, and reflect on, experiences made in the development and analysis of environmental scenarios – and for lack of a better term, we call this set of information and reflection "guidelines." Dictionary definitions highlight that the aim of a set of "guidelines" is to give an indication or outline of a policy of conduct. However, these guidelines should not be seen as prescriptive; instead they are meant to be read as a set of rather general recommendations or preliminary code of practise.

What do we wish to accomplish with these guidelines? First of all, we aim to inform new or potential practitioners (researchers, engineers, planners, strategists, policy advisers, community organisers) about the basic procedures of environmental scenario development and analysis. Next, we hope to improve the quality of practise of environmental scenario-based assessments by summing up and reflecting upon some of the key lessons learned by various practitioners. And not least, we also believe that such guidelines will further promote the use of environmental scenarios in both scientific research and policy studies.

What are included in the guidelines? Among other information, they consist of definitions of key terms, an overview of the basic steps in a scenario exercise, a description of the existing types of environmental scenarios, hints on how to assess the quality of environmental scenarios, and some recommendations about "best practice" for the development and analysis of environmental scenarios.

We caution the reader that this is an incomplete and first attempt at compiling guidelines, which is why we call it "*towards* guidelines." Still, we do hope that it kindles further discussions about what guidelines for developing and analysing environmental scenarios should include. In short, we believe that the development of guidelines should be an ongoing and "open" process, with this document representing only an opening salvo.

2. Concepts and Definitions: What is Environmental Scenario Analysis?

Environmental scenarios

We start with the basic question "What are scenarios?" Dictionary definitions stress that scenarios are "a sequence of events especially when imagined" or "an account or synopsis of a possible course of action or events." [2]

From an environmental perspective, the Intergovernmental Panel of Climate Change describes scenarios as "images of the future, or alternative futures that are

[1] For some examples, see reviews by Rothman (Chapter 3, this volume) and Alcamo et al. (Chapter 4, this volume).

[2] See, for example, Webster's Ninth Collegiate Dictionary, 1989.

neither projections nor forecasts,"[3] while the Millennium Ecosystem Assessment recently defined scenarios as "plausible and often simplified descriptions of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces and relationships."[4]

Although many more definitions exist and differ somewhat from the above, most scenario developers would agree that scenarios are made up of a set of explicit "if-then" propositions that explore the consequences of a range of driving force assumptions (i.e. each scenario should include a set of assumptions on how driving forces unfold as well as a representation of resulting pressures, states, impact and/or responses).

We propose the following working definition:

A scenario is a description of how the future may unfold based on 'if-then' propositions and typically consists of a representation of an initial situation and a description of the key driving forces and changes that lead to a particular future state.

Scenario exercises, i.e. the development and analysis of scenarios, provide an approach to thinking through plausible future developments and related uncertainties in a structured, yet creative manner. Scenarios can take many forms including an image, a graphic, a table, or text. In particular, scenarios have been seen as useful when trying to understand and reflect upon the considerable uncertainties about future developments in complex systems. Such uncertainty may arise from a system's dynamics, or may be related to assumptions on the future development of driving forces (see Figure 2.1).

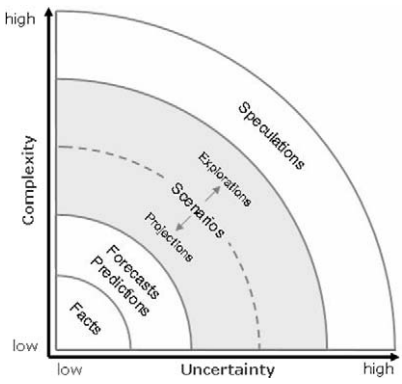

Figure 2.1 **Dealing with uncertainty and complexity in forward-looking environmental assessments – note that scenarios differ from facts, forecasts, predictions and speculations.**
Source: M.B. Zurek, T. Henrichs, 2007. Linking scenarios across geographical scales in international environmental assessments, Technological Forecasting and Social Change, doi:10.1016/j.techfore.2006.11.005.

[3] Nakicenovic, N., Alcamo, J., Davis, G., deVries, H.J.M., et al., 2000. Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES). Cambridge University Press.

[4] Carpenter, S., Pingali, P., Bennett, E., Zurek, M. (Eds.). Ecosystems and Human Well-Being. Volume 2 Scenarios. Island Press, Oxford, pp. 145–172.

Scenario development

A first step in environmental scenario exercise is usually to develop (or "build") a scenario or, preferably, a set of scenarios. Here we propose the following working definition:

Scenario development is the discursive procedure by which a scenario or a set of scenarios is conceived, formulated, and elaborated. A synonymous term is "scenario building."

Scenario analysis

Scenario analysis is a broader concept encompassing both scenario development and the analysis of scenarios. Here we propose the following working definition:

Scenario analysis is a procedure covering the development of scenarios, comparison of scenario results, and evaluation of their consequences. A key idea is to explore alternative future developments. The goal of environmental scenario analysis is to anticipate future developments of nature and society, and to evaluate strategies for responding to these developments.

We note here that the terms "*scenario exercise*" and "*scenario-based assessment*" are often used synonymously with "scenario analysis." In the remainder of this chapter, we therefore use the three terms interchangeably.

How does *environmental* scenario analysis differ from other types of scenario analysis? First of all, it is a type of scenario exercise specifically tailored to analysing environmental problems and issues. While it overlaps with other types of scenario-based approaches, it also has somewhat different objectives than a scenario exercise carried out, for example, to help with corporate planning or developing civic visions. In particular, environmental scenario analysis is anchored in the environmental sciences, and is consistent with the state of understanding of these sciences. It also mirrors the interdisciplinary nature of most environmental problems, including both natural and social sciences. In many cases it must be capable of taking into account the long time horizons of some environmental problems. It should also be noted that environmental scenarios have a very large scope, covering a wide range of topics and scales from scenarios of global sustainability to scenarios focusing on particular environmental issues in a specific province or county.

Since scenario-based environmental assessments are often used to underpin policy-relevant studies, the development and analysis of environmental scenarios should also reflect the values of contemporary environmental and sustainability policy in the sense that it should be practised in both a pluralistic and democratic manner. Later we come back to this point when we discuss some guidelines for involving stakeholders in environmental scenario exercises.

2.1 What are the key elements of environmental scenario analysis?

A representation of the initial situation

A key element of any environmental scenario is a representation of the initial situation the scenario starts off from, including an understanding how past trends have

shaped the current state. For quantitative scenarios (see Section 2.3), the initial situation is commonly attributed to a "base year" which is usually the most recent year in which adequate data are available to describe the starting point of the scenarios.

A description of drivers of change (driving forces)

Driving forces are the main factors or determinants that influence future developments of a system described in a scenario. As an example, the driving forces of greenhouse gas emission scenarios include the assumed change in population, economic growth, and rate at which energy use will become more efficient. It has proven useful to distinguish between "direct" driving forces (those that equivocally influence system) and "indirect" driving forces (those that alter the level or rate of change of one or more direct drivers). Main categories of driving forces in environmental scenarios include demographic, economic, social-cultural, political, and technological drivers.

A description of changes (time-steps)

A main element of an environmental scenario is the portrayal of step-wise changes in the future development of society and the environment – as well as a description of how driving forces are assumed to develop and interact, and how this affects the state of a system along different time-steps. Emission scenarios, for example, depict the change in emission levels of one or more polluting substances over time, while climate change scenarios cover the change of temperature and other climate variables over time and space. These changes can be depicted in a diagram, table, a set of phrases or a detailed storyline. The number of time steps in a scenario are usually kept to a minimum because of the large effort needed to describe each step.

A description of an image of the future (time horizon)

A description of an image of the future is usually a narrative description of the end-state of a scenario's step-wise changes which results from the assumptions made on how driving forces unfold and interact. The selection of an appropriate end-state year or "time horizon" for a scenario depends very much on the objectives of individual scenario exercises. As with the description of step-wise changes, images of the future can be developed using a diagram, table, a set of phrases or detailed stories. Illustrated and narrative descriptions of the future have often proven to be useful to illustrate and communicate the outcome of scenario assumptions to a wider audience.

A description of alternative pathways to the future (alternative images)

A single scenario is seldom developed as a stand-alone object, but instead is usually one of a consistent set of scenarios that together elaborate a range of alternative paths to the future.

2.2 What are the goals of environmental scenario analysis?

Environmental scenarios can be developed and analysed for a host of different purposes. These can be clustered into three categories: education and public information, science and research, and decision support and strategic planning (Table 2.1).

Table 2.1 Goals and purposes of environmental scenario analysis

Education/public information
Education and learning To educate and teach students or citizens about the dynamics of environmental problems and possible solutions. e.g. Some universities incorporate the study of environmental scenarios into their curricula.
Public information To raise awareness, inform, and consult among policymakers, stakeholders, or citizens about new or intensifying environmental problems and solutions. E.g. acid rain scenarios produced in the 1980s and climate change scenarios produced in the 1990s alerted many different groups about the future development of important environmental problems.
Science/research
Scientific assessment To assess future developments of environmental issues, and to combine qualitative and quantitative information about the future evolution of an environmental problem. Also, scenarios help to bridge science and policy by providing a common ground for expressing both political and scientific aspects of future environmental and sustainability issues.
Exploration To bring together information from different scientific disciplines (i.e. natural and social sciences) with the aim to highlight the complexity and inter-connectiveness of an environmental problem. At the same time, to investigate the connection between future problems, e.g. scenarios that examine the link between climate change and threats to biological diversity.
Speculation or curiosity To satisfy scientific curiosity about possible consequences of imaginable developments. To ask "What would happen if. . . ?." E.g. the fiction literature often builds very elaborate scenarios, many of which have explicit or implicit environmental storylines.
Decision support/strategic planning
Collective enquiry To gather views, opinions, expectations from experts or policy-makers on the possible future developments and their environmental implications. E.g. to provide input to a plan for managing water quality in a river basin.
Advocacy or moralising To induce changes in people's behaviour. E.g. scenarios showing increasing energy use and possible fuel shortages have been used to advocate energy-conservation measures.
(Long-term) planning To evaluate the legal and technical implications of an environmental policy or regulation. E.g. scenarios have been used to evaluate the consequences of new environmental regulations on the operation and profitability of companies.

(*continued on next page*)

Table 2.1 (*continued*)

Policy making To help policymakers and others to "think big" about an environmental issue, i.e. to take into account the large time and space scales of an environmental problem. Scenarios can be used as a device to illustrate the impacts of society on the natural environment, and to point out the need for environmental policies to avoid these impacts. At the same scenarios can illustrate how alternative policy pathways can achieve environmental targets, or help to identify the robustness of future policies under different future conditions.

Box 2.1 **Some alternatives to environmental scenario analysis.**

- Technical reports that evaluate (ex-ante) different future alternative policies.
- Computer simulations that extrapolate current trends (i.e. forecasting).
- Reports from expert panels.
- Public hearings and/or expert hearings.
- Delphi surveys.
- Cross impact analysis.
- Relevance trees and morphological analysis.
- Simulation and gaming exercises.
- Precursor analyses.
- Polls and surveys.

The user of environmental scenarios should be aware that other approaches can be used to accomplish the same or similar purposes (Box 2.1), and it is worthwhile considering the advantages and disadvantages of different approaches before embarking on a scenario exercise.

2.3 What are the different types of environmental scenarios?

Although there is no consensus about how to classify scenarios, some scenario analysts have nevertheless found it useful to distinguish between different types of scenarios, especially in the planning stage of a scenario exercise. Matching the different objectives of a scenario exercise with different types of scenarios can help the planners of a scenario analysis select the most appropriate type of scenario. For example, the Intergovernmental Panel on Climate Change in its various assessments wished to compare climate change scenarios with and without emission reductions and therefore found it useful to distinguish between "intervention" and "non-intervention" scenarios of greenhouse gas emissions ("reference" and "policy" scenarios in the parlance of this document).

But the distinction between different types of scenarios is often blurred, and as a result their classification seems to be constantly re-thought. Nevertheless, here we give an overview of some typical ways of classifying scenarios, and at the same time

advise the reader to use this information with care in their particular application of scenario exercises.

Exploratory scenarios versus anticipatory scenarios

Scenario developers sometimes distinguish between "exploratory" and "anticipatory" scenarios. This distinction emphasises the departure point of the scenarios, that is, whether they begin conceptually in the present or the future.

Exploratory scenarios start in the present (i.e. with an initial situation) and a set of assumptions on policies, measures and key driving to explore plausible future developments.

This comes close to the original meaning of the word "scenario" in the sense that this type of scenario builds on a sequence of emerging events. Exploratory scenarios are also called "descriptive scenarios." Exploratory scenarios are an option (i) when the goal of the scenario analysis is to explore the consequences of a specified future trend in driving forces (e.g. to estimate future emissions under demographic change), or (ii) when the goal of the scenario exercise is to investigate the consequences of implementing a policy (e.g. to estimate the implications of implementing the EU Water Framework Directive on water quality of Europe's rivers).

Anticipatory scenarios start with a prescribed vision of the future (either optimistic, pessimistic, or neutral) and then work backwards in time to visualise how this future could emerge.

Anticipatory scenarios are sometimes called "prescriptive scenarios" or "normative scenarios." Anticipatory scenarios are an option (i) when the goal is to investigate the steps leading to a specified end state, such as an environmental target (e.g. to estimate the emission reduction steps needed to stabilise CO_2 in the atmosphere), or (ii) when the aim is to inform policymakers and the public about how to achieve a "desirable" end state of the natural environment (e.g. to explain how the "sustainable development" of a community might be achieved).

As noted above, the difference between exploratory and anticipatory scenarios is often blurred in practise. In the case of the World Water Vision exercise, for example, the aim was to specify two alternative end-states to those depicted in a reference scenario of the world water situation, and to explain how these states would be reached. This is the classic "anticipatory" approach. But the only modelling tools available for the scenario analysis were those that calculated forward in time, or in other words, supported analysis of "exploratory" scenarios. In this case the modelling tools were repeatedly run until they generated the two alternative end-states specified by the scenario developers (i.e. a water crisis future and a sustainable water future). In effect, this was a combined exploratory/anticipatory approach.

Reference scenarios versus policy scenarios

When policy analysis plays a central role in developing scenarios, scenario developers sometimes distinguish between "reference" and "policy" scenarios.

Reference scenarios are scenarios that describe the future state of society and the environment in the absence of additional, new, and focused environmental policies.

Reference scenarios provide a reference point for estimating the benefits of policies, or conversely, the costs of not adopting policies. They are also sometimes called "baseline" or "benchmark" or "non-intervention" scenarios. Reference scenarios should be developed and analysed when the aim is to evaluate the consequences of current policies or "no new policy intervention," or similarly, to provide a baseline for new policy interventions (e.g. to investigate what would be the expected trends in NO_x emissions in Europe up to 2025 under current trends in traffic and energy use, and assuming that no new control policies were implemented).

Also, reference scenarios are an option when the aim is to take into account the uncertainty of driving forces (e.g. to investigate the expected trends in NO_x emissions in Europe up to 2025 under two alternative pathways: (i) if current trends in traffic and energy use continued, or (ii) if public transportation expanded faster than private vehicle use). Reference scenarios are also useful for taking into account the uncertainty of environmental conditions (e.g. to assess the expected levels of O_3 in different parts of Europe in the 2020s under average versus drought conditions).

Whereas reference scenarios portray a "default" view of the future, policy scenarios (in the context of environmental studies) depict the future effects of additional, new, and focused environmental policies.

Policy scenarios are scenarios that take into account new policies or measures additional to those already adopted or agreed upon.

Policy scenarios are sometimes also called "pollution control," "mitigation" or "intervention" scenarios. Policy scenarios should be developed and analysed (i) when the aim is to evaluate policies for achieving particular environmental targets (e.g. what kinds of policies will reduce the occurrence of ozone episodes in Europe?), (ii) when the aim is to evaluate the environmental and economic impacts of particular policies (e.g. by how much will ozone episodes be reduced if emissions of ozone-producing gases in power plants are reduced by 80 percent throughout Europe? What would be the costs of these reductions?), or (iii) when aiming to take into account the uncertainty of future environmental conditions (e.g. would climate change affect strategies to reduce ozone?).

Sometimes it is very useful to distinguish between reference and policy scenarios, particularly when the environmental issue is well-defined, focused, and of limited scope. An example is the assessment of the future consequences of treating or not treating wastewater in a river basin. In this case the contrast between reference and policy scenarios can provide useful information in evaluating the costs and effectiveness of environmental policies.

Conversely, it is often difficult to distinguish between these two types of scenarios. The basic problem is that environmental policies already permeate society and have many direct and indirect impacts on society and nature; this makes it tough to envisage a reference scenario free of the effects of environmental policies. Take the example of developing scenarios of local air pollution management in a particular region within the European Union. Air pollution here is likely to be affected

not only by local transport and city planning policies, but also by European-scale laws decided by European institutions. Should (alternative) future European-scale policies be part of a "reference" scenario or part of a "policy" scenario of local air pollution management? In this case one wonders whether there is any added value to distinguishing between "reference" and "policy."

Qualitative scenarios versus quantitative scenarios

One of the most common ways to classify scenarios is to distinguish between "qualitative" and "quantitative" varieties.

Qualitative scenarios describe possible futures in primarily *non-numerical form*, for example as outlines, phrases or complete text, or visually as diagrams or pictures. ("Primarily" is used advisedly because some qualitative scenarios do contain indicative numerical estimates of the subject of interest.)

The most common form is the narrative text, or "storyline." Qualitative scenarios are an option (i) when the objective is to stimulate policy ideas/brainstorming, (ii) when communication and education is an important objective, (iii) when many views about the future have to be included, and/or (iv) where modelling tools are not available for quantitative analysis.

Quantitative scenarios describe possible futures in numerical form such as graphs or tables of numbers. Most commonly produced using a model or models.

Quantitative scenarios are an option (i) for assessments explicitly requiring data and numbers, (ii) when a quantitative "theory" (model) is needed to back up scenario.

Often it is desirable to combine qualitative elements (i.e. narratives) and quantitative elements (i.e. numbers) in scenarios because this makes the best use of the benefits of both types of information (see Table 2.2). Methods of coupling these types of scenarios usually requires iteration between different stages of scenario development. Combined qualitative/quantitative scenarios are a particularly interesting option (i) when the problem is especially complex and has major policy and scientific implications, and (ii) when financial and technical resources are available.

3. Methods and Approaches

3.1 Methods for developing and analysing environmental scenarios

In this section we provide a very brief and incomplete overview of the methods for developing scenarios. For the sake of our overview we cluster scenario developing methods into two categories – "participatory approaches" and "analytical approaches." In the following paragraphs we explain the use of both approaches in developing qualitative and quantitative scenarios (Figure 2.2).

Table 2.2 Advantages and disadvantages of qualitative and quantitative scenarios

Qualitative scenarios

Advantages

- These scenarios can incorporate the views of several different stakeholders and experts at the same time.
- They can describe a complex system.
- 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.

Disadvantages

- Mental models are used to derive the scenarios, and the assumptions behind these mental models are usually not articulated.
- It is difficult to test underlying assumptions of these scenarios.
- By definition, these scenarios do not satisfy the possible need for numerical information.

Quantitative scenarios

Advantages

- These scenarios provide the numerical information needed for some environmental studies and assessments.
- Sometimes the assumptions behind the scenarios are transparent because the assumptions of the models used to compute these scenarios (their equations, coefficients and inputs) can be documented and examined.
- These scenarios are based on models that are often already published in the scientific literature and have therefore received some degree of scientific scrutiny.
- They can be used to check the consistency of qualitative scenarios.

Disadvantages

- The preciseness of their numbers is sometimes misinterpreted to mean that we know more than we actually do about the future.
- These scenarios are commonly based on results of computer models or other calculation schemes which bury many assumptions about the future.
- Often based on models that tend to represent only one point of view about how the world works, and in this way produce scenarios that are likewise narrow in point-of-view.
- The basics of modelling are difficult for the non-specialist to understand.
- Risk of limiting the focus of scenario-based assessments on dynamics that are well understood and for which models exist.

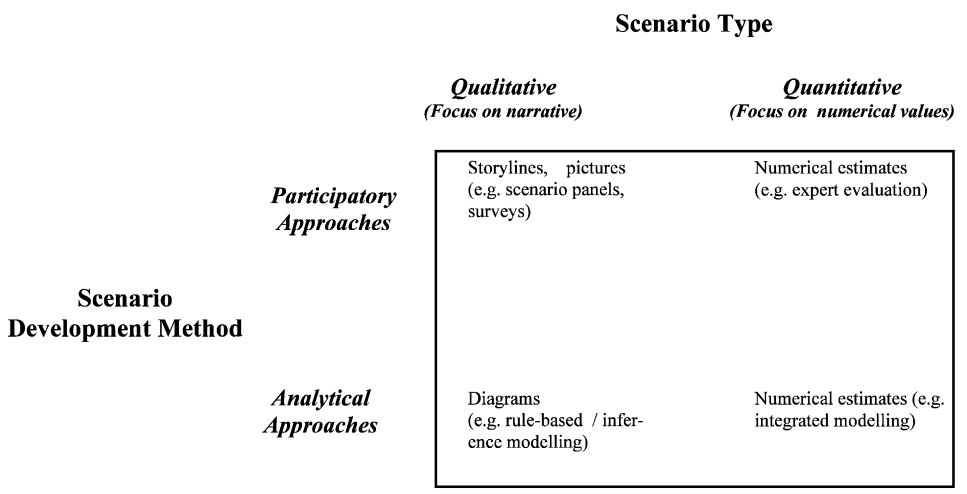

Figure 2.2 A scheme for classifying qualitative and quantitative scenarios and corresponding scenario development methods.

Participatory approaches for developing qualitative scenarios

There are several participatory approaches for developing qualitative scenarios. These include "Policy Exercises," "Shaping Actors–Shaping Factors," and a range of methods employed by the private sector for planning. The following are some of the typical steps in these methods:

(a) *Establish focal issue*: First the main goals and focal issue of a scenario exercise are established. Ideally, a focal issue should be phrased as a crisp and clear question. A focal issue of a scenario exercise can be as precise as a question requiring a yes/no decision, or as general as the exploration of an emerging issue. This step may include a round of interviews with different parties having interests in the scenario exercise.

(b) *Identify driving forces*: With respect to the focal question, scenario developers usually identify and discuss the main uncertainties, driving forces, and important factors that shape developments in the future state of the environment and society together with stakeholders and/or experts.

(c) *Label critical uncertainties*: It has proven useful to identify those uncertainties and driving forces that are most uncertain and most important for the future development of a respective focal issue.

(d) *Determine scenario logics*: Based on discussions of possible future developments of key driving forces, consistent scenario logics (or scenario skeletons) are outlined and sketched out. These scenario logics provide the backbone of the scenario building process.

(e) *Elaborate scenarios*: Building on scenario logics, the scenario developers then elaborate detailed step-wise changes and an image of the future. Once the step-wise changes of all relevant driving forces and their implications have been laid out, the outcomes are expressed in some non-numerical form such as written outlines, tables, pictures, or most commonly, storylines.

Participatory approaches for developing quantitative scenarios

Participatory approaches can also be used to develop quantitative scenarios. An example is asking experts to use their judgement to prescribe numbers for a scenario. Although transparent methods are often used for expert solicitation, the thought processes of the experts are neither entirely explicit nor apparent. Nor would we necessarily expect exactly the same answer if the enquiry is repeated with a different set of experts.

Analytical approaches for developing qualitative scenarios

There are a number of approaches developed in the field of systems research that serve as analytical approaches for developing qualitative scenarios (lower left corner of Figure 2.1). These include expert systems, decision support systems, digraphs, and inference models, to mention just a few examples. Although these approaches have seldom been used for scenario analysis they are, in principle, relevant for this purpose because they aim to express non-mathematical knowledge in an explicit, transparent and reproducible way.

The value of using such methods is that they provide a transparent system for organising a large volume of knowledge.

Analytical approaches for developing quantitative scenarios

Although participatory approaches are sometimes used to develop quantitative scenarios it is more common to use analytical approaches, in particular, computer models. The use of a computer model for scenario analysis is an example of an "analytical" method because, at least in theory, the model's equations and algorithms are explicit and transparent, and the model's calculations reproducible. The application of modelling typically involves the following steps:

(a) The scenario developers identify models that can be used to generate the needed scenario information.
(b) Driving forces of the scenarios (e.g. trends in population or the economy) are expressed as numerical inputs to the models.
(c) Additional model parameters are assigned values that are consistent with scenario assumptions.
(d) The specified model inputs are used to run the model.
(e) Numerical output of the model relevant to the scenarios is adapted and reported.

Combining approaches – developing combined qualitative/quantitative scenarios

In many cases it is desirable to combine qualitative and quantitative scenarios because this makes the best use of the benefits of both. The method of coupling usually requires iteration between different stages of scenario development. The so-called Story and Simulation (SAS) approach (Box 2.2) provides an example of such an iterative approach (see Chapter 6 for more information on this approach).

Box 2.2 Overview of the Story and Simulation approach.

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, modelling teams quantify the indicators of the scenarios.
6. The modelling 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.

3.2 How many scenarios should be developed and analysed?

The recommended number of scenarios to be developed will depend on many factors including the purpose and complexity of the scenarios as well as the resources available for developing them. Since these factors vary from project to project, no fixed number is recommended here. But developers of scenarios should take into consideration that the larger the number, the greater the variety of views and possibilities of the future that can be represented by the scenario set. On the other hand they should also keep in mind that the larger the number, the greater the difficulty to communicate the scenarios, and the larger the effort and resources needed for the scenario exercise.

Recent experience in building complex, global scenarios shows that it is feasible to develop 3 or 4 "main" scenarios – with possible additional variants of these main scenarios. These scenario exercises required several person-years of effort expended over a 2 to 3 year period.

3.3 How can the participation of stakeholders and experts be increased?[5]

There is an increasing trend towards increasing the number and types of participants in the development of scenarios. Whereas earlier scenario exercises were viewed upon as a *procedure* for developing a product, namely scenarios, now it is seen more and more as a *process* involving the potential users of the scenarios. It is thought

[5] For this discussion we draw on Pahl-Wostl (Chapter 5, this volume).

that the participation of the users of the scenarios will enhance the value of the scenarios, as we next explain.

Reasons for involving stakeholders

One of the most important reasons for involving stakeholders in scenario development is to enhance the legitimacy and impact of scenarios. This can be a crucial factor in the usefulness of scenarios to support public decision making.

At the same time, stakeholder participation can help scenario developers tap into the expertise and creativity of stakeholders or experts that would otherwise not directly contribute to the scenario exercise. Involving experts, scientists and stakeholders who have a deep understanding of aspects of the issue analysed, allows scenario developers to access inside knowledge or perhaps data that would otherwise not be available. Moreover, involving stakeholders can guide emergent (social) learning processes within public, research or policy communities.

Yet involving stakeholders in scenario analysis can also complicate the scenario development process. In particular, broad participation is complicated and time-consuming. Also, scenario developers should be mindful of the motivation of stakeholders' in participating in the scenario exercise; under some circumstances the scenarios could become biased towards the particular interests of the stakeholders.

Methods for involving stakeholders

There are different possible levels of involvement of stakeholders and experts in scenario analysis:

(a) *Stakeholders and experts are informed about the results of the scenario exercise*. The weakest form of 'participation' is to simply inform stakeholders and/or the general public of the scenario exercise and its findings. This type of participation usually occurs towards the end of the scenario exercise when final results are available. The outcome of a scenario exercise should be disseminated in a language accessible to lay-people (e.g. using brochures, the Internet, information events, etc.).

(b) *Stakeholders and experts are consulted during the scenario exercise*. A more interactive form of 'participation' is to consult with stakeholders during the scenario exercise, either after the scenarios have been completed or are near completion (e.g. to review or to comment) or during the scenario development process (e.g. to provide input). This type of participation usually also occurs towards the final stages of a scenario exercise. However, earlier consultation can help in defining the frame/context of the scenario exercise. Stakeholders should be given adequate opportunity to provide their opinion or input to the exercise (e.g. public hearings, Internet discussions, opinion polls, questionnaires, etc.). Scenario developers should be explicit from the outset about how the consultation will shape the scenarios.

(c) *Stakeholders and experts are actively involved in the scenario exercise*. In this level of involvement, stakeholders are actual participants in the scenario exercise. They provide not only input for the scenario development or comments on the final results, but co-produce the scenarios. If this type of participation is chosen, it should continue throughout the entire scenario exercise.

The level of stakeholder and expert involvement in scenario development depends, among other factors, on the goals of the scenarios. It is likely, for example, that a deeper level of involvement is necessary if the aim is strategic planning as compared to scientific research.

Before approaching stakeholders, scenario developers should be very aware of the players in the issue to be examined, their institutions, and the interests of their institutions. This is to avoid the situation that participants of the scenario exercise behave more like representatives of their organisation rather than as active team players. Also, one should be aware of the stakeholders' backgrounds and potential unwillingness to be open to new and unexpected outcomes. Only based on a thorough understanding of the 'rules of the game' can the appropriate stakeholders be identified. Criteria for selecting participants will vary from scenario exercise to scenario exercise but in general could include:

(a) What *function* will the stakeholders have? What role do they play in decision-making, planning, or other aspects of the issue being analysed?
(b) What *scale* are they interested in? What is their sphere of concern and influence with regard the issue analysed?
(c) Which *group* do they belong to? Are they part of a particular thematic or political network?

Once stakeholders are identified, their roles in the scenario exercise should be clearly defined, and preferably their role in the process mapped out. Furthermore, it is crucial to clearly define the ownership of the final scenarios in order to avoid confusion or misunderstandings that could undermine the scenario-building process.

There are several ways to encourage and support active participation of stakeholders in the development of scenarios:

(a) Interviews of focus groups – Scenario developers could interview a small group of participants and discuss the issue raised by a moderator in order to provide input to the scenario or sometimes complete scenario storylines.
(b) Stakeholder/scenario panel workshops – Group(s) of stakeholders develop a set of qualitative scenarios via several rounds of discussions. Possible approaches include organising a series of parallel small group discussions and plenary meetings, or organising a large number of small groups discussing specific topics, which are then brought together to develop and discuss the complete picture.
(c) Gaming workshops – Scenario developers work with stakeholders at a workshop in which simulation gaming techniques or training games are used as tools to discuss and develop scenarios. Sometimes participants assume roles and play through the 'if-then' aspects of a scenario.
(d) Policy exercises – A flexibly structured process that involves both scientist and policy makers (and possibly stakeholders). Usually this process comprises several rounds of preparations–workshop–evaluation in order to formulate and test policy scenarios.
(e) Story and Simulation approach – An iterative approach to develop combined qualitative and quantitative scenarios. See Box 2.2.

Independent of the method selected, experience has shown that employing professional facilitators will help considerably in keeping participation 'on-track,' and at the same time reduce unintended influencing of participants by scenario developers.

Despite the progress that has been made in involving stakeholders and experts, there remains a strong need to elaborate and clarify the theoretical basis as well as the available methods to enhance participation in environmental scenario analysis.

3.4 How can surprises be included in environmental scenario analysis?[6]

Scenarios aim to explore possible alternative future developments – yet these future developments are inherently very uncertain. Whereas some may be anticipated, other developments will undoubtedly come as a complete surprise. Here we refer to "surprises" as events, processes or developments that are radically different from what people expected or imagined. Looking at the past one can easily identify a host of very surprising developments, i.e. events or processes that were different from what people at that time expected or could hardly imagine. Examples include the fall of the Berlin Wall, the rapid dissemination of personal computers and subsequently the Internet, and the terrorist attacks of September 11th 2001.

Scenarios are good tools for anticipating and planning for surprises. Various surprising future developments can be assumed and their consequences played out as part of the scenario exercise. As part of the exercise the robustness of different policies and strategies to these surprises can be examined. For example, an input to a scenario exercise could be the assumption of a drought of unprecedented duration, and the scenario could explore the impacts of this event on regional water availability and water quality. This scenario could then be used to anticipate the strategies that would be most effective in coping with the impacts of this drought (e.g. additional above-ground or below-ground water storage, import of electricity to compensate for shut-down hydroelectric and thermal power plants, etc.). Investigating surprises as part of a scenario analysis can also help identify so-called 'weak signals' of impending problems, i.e. developments that could possibly have been imagined but came as a surprise to most people. In this way a scenario analysis can serve as a type of early warning system.

However, if surprises are not expected or considered plausible, should they be included in a scenario exercise? When does the discussion of potential surprises, non-linear trends and trend discontinuities make a scenario more meaningful?

Reasons for including surprises (or not)

The significance of including surprises in environmental scenarios very much depends on the purposes and users of these scenarios. If the aim of a scenario analysis is to speculate about or to explore future environmental developments, then including surprises could provide insight into new and interesting developments. In other cases, such as providing input to forecasting, a more likely surprise-free future may be more appropriate.

[6] For this discussion we draw on Toth (Chapter 8, this volume).

Despite the potential benefits and importance of including surprises in scenarios, they are usually omitted. One reason is that scenario developers do not want to undermine the credibility of their scenarios by including disputable assumptions on surprises. Since surprises, by definition, reflect radical departures from developments expected or even imagined by most people, incorporating surprises in scenarios could alienate the potential users of these scenarios.

Another reason for not including scenarios is that sometimes scenarios are specifically requested to be "surprise-free," since it is difficult enough to develop responses or policies for a surprise-free future. It may be less important to include surprises if the system is well understood and the problem has a comparatively narrow scope or time horizon.

A third reason for not including surprises is a methodological one: Often the (mathematical) models used to quantify scenarios are incapable of generating non-linear, 'surprising' behaviour. Under these circumstances surprises cannot be confirmed by model simulations, but could still be specified *ad hoc* in storylines. However without independent confirmation from models, the surprising event may be considered to be relatively implausible and may take away from the overall plausibility of the scenario if it is included.

Methods for including surprises in environmental scenario analysis

If it is decided to include surprises in a scenario analysis, then the appropriate types of surprises need to be selected. Surprises can be divided into two general categories

(a) *Surprises stemming from known, but unexpected events/relationships*. These include surprises that can be anticipated, i.e. events that may occur but are not deemed likely by contemporaries either in their manifestation or magnitude. Often these types of surprises may be detected if the available clues are re-examined or if their development are thought through in a scenario exercise. An example of this kind of surprise is the rapid changes in governments in Eastern Europe at the end of the 1980s and beginning of the 1990s. In retrospect, the economic and political situation in these countries made change likely, if unexpected at the time.

(b) *Surprises stemming from unknown events/relationships*. This includes 'out-of-the-blue' surprises, i.e. events/relationships that are truly surprising and remain to be so even in hindsight. These surprises usually defy detection even with the most elaborate methods. The events of September 11, 2001 fall into this category.

Both of these categories include so-called 'conjectural' surprises, i.e. events/relationships that no one thought of but seem perfectly conceivable in hindsight – detecting conjectural surprises or capturing them in a scenario requires expertise, imagination and luck.

A more specific way of categorising surprises for environmental scenario analysis is according to their place in the socio-economic and environmental system:

(a) Surprising environmental changes that occur independently from socio-economic changes (i.e. yet unknown natural fluctuations or random events). For example, volcanic eruptions or earthquakes.
(b) Surprising socio-economic changes that trigger environmental changes (i.e. innovations or policies with gradual effect). For example, market penetration of wind energy, or a fast proliferation of vegetarian diet in Western societies.
(c) Socio-economic changes that trigger surprising environmental changes (i.e. continuous socio-economic developments leading to discontinuities and/or sudden changes in the environment). For example, slow contamination of soil leading to rapid change in groundwater quality.
(d) Environmental changes that trigger surprising socio-economic changes. For example, the depletion of an environmental resource triggering technological innovations.

Once the types of surprises to be included in a scenario are selected, various approaches can be used to include these in the scenario:

(a) Model-based scanning – i.e. conduct sensitivity runs with available models (extending the range of variations of key model parameter beyond traditional intervals); this might reveal plausible constellations that result in strange model behaviour, and this in turn may point to potential for surprises in the system analysed.
(b) Cross-impact methods – i.e. systematically explore conditional probabilities of a large set of conceivable events.
(c) Environmental scanning – i.e. systematically look beyond the horizon of the current and planned operating environment with the intention to generate new perspectives.
(d) Participatory methods – i.e. to tap into the creativity of stakeholders participating in scenario development. Participatory methods that can be geared towards generating surprises for scenarios include Focus groups, Charett, Syncon, Public Delphi, Future Search conference, and Groupware.
(e) Brainstorming, intuition and visioning.

3.5 How can scenarios cover different scales?[7]

Reasons for addressing different scales and scale implications

An environmental scenario analysis usually deals with an issue on a particular spatial scale (global, national, regional, or local) and temporal scale (short-term, mid-term, or long-term). Yet, developments examined at one particular scale almost always are closely connected to other scales. At the same time, it is usually the case that insights regarding dynamics and relationships obtained at one scale cannot be easily transferred to another. Local developments often depend as much on global/regional trends as on local decisions. Conversely, global scenarios can be seen as the sum of individual developments at finer scales. The inter-connectiveness of processes and

[7] For this discussion we draw on Döll et al. (Chapter 7, this volume).

dynamics at different scales makes it imperative to be explicit about the scale implications within a scenario exercise. Often it may even be desirable to design a scenario exercise to be multi-scale in scope from the outset.

Which scale issues need to be addressed in a scenario analysis? To answer this question, scenario developers should consider the following factors:

(a) *Purpose and potential users of the scenarios* – For what purpose and for whom are the scenarios developed and analysed? What are the particular spatial and temporal scales of interest to the potential users of the scenarios?
(b) *Factors/processes* – At which scale are the key relationships in the scenarios operating? At which scale can the driving forces of the scenarios be influenced? At which scale do processes affect the scenario development?
(c) *Actors/institutions* – At which scale can institutions influence developments in the scenarios? At which scale do actors impact the developments analysed in the scenarios?
(d) *Quantification/data availability* – At which scale are tools (models) to quantify developments available? At which scale is data collectable or available?

Methods for ensuring scale consistency and transparency

Down-scaling. Down-scaling is required for translating global-level information about developments, processes, or impacts of change to local-scale scenarios. Different approaches can be taken:

(a) For quantitative downscaling methods, scenario developers can draw on the extensive experience of climate researchers in downscaling global modelling results to the regional level.
(b) One simple, but under-utilised approach to downscaling is to analyse the local impacts of global modelling results and develop a "local interpretation" of these results.
(c) Another simple approach is to develop local narrative scenarios based on a combination of global scenarios output and additional local knowledge.

Up-scaling. Up-scaling is required for translating and aggregating local/regional information about developments, processes, or impacts of change to global scenarios. Several approaches are available for up-scaling, including:

(a) Scenario developers can prepare specific summaries and syntheses of their local scenarios for audiences that are concerned with regional and global issues.
(b) Global scenarios can be created "from the bottom up" by developing storylines of global scenarios that explicitly incorporate existing local scenarios.
(c) Local, archetypical scenarios can be developed that are relevant to many parts of the world. This is close to the so-called "Syndrome approach" used to study global change processes.[8] Under this approach, typical "syndromes" of global change are defined (e.g. the "Sahel Syndrome" describing typical desertification causes and processes) that apply to many different parts of the world.

[8] Schellnhuber, H.J., Block, A., Cassel Gintz, M., Kropp, J., Lammel, G., Lass, W., Lienenkamp, R., Loose, C., Lüdeke, M.K.B., Moldenhauer, O., Petschel Held, G., Plöchl, M., Reusswig, F., 1997. Syndromes of global change. Gaia 6 (N1), pp. 19–34.

Methodological transparency. Since up-scaling and down-scaling procedures are likely to be major sources of uncertainty in the scenarios, scenario developers should aim to keep scaling methods as simple as possible. This makes it easier for scenario users to interpret or re-interpret scenarios at the scale they are most interested in. Also, a clear definition of procedures and their possible drawbacks used in the scaling process, adds considerably to the transparency of scale implications. It is good scenario building practise to make scale implications and restrictions as transparent as possible to scenario users. This can be accomplished by documenting scaling procedures in background and other documents. For example:

(a) noting in scenario storylines where scale implications may affect scenario outcomes;
(b) providing detailed descriptions of the methodologies used to transform information between different scales;
(c) reporting the scale of the original data/information used in the scenarios;
(d) graphically presenting overviews of major linkages between scales.

3.6 How can environmental scenarios be evaluated?

Reasons for evaluating the quality of environmental scenarios

While many environmental scenarios have been developed over the past years, very few have been evaluated as to their worth. But we should first ask, is it appropriate to evaluate scenarios? Some would argue, no, because virtually every scenario has information of relevance regardless of its perceived quality. Moreover, there are no accepted benchmarks for high quality scenarios, and evaluations are in any event too time-consuming. Others argue the answer is, yes, because scenarios judged to have low quality will have low credibility with their target audiences, whether it be policymakers, the scientific community or the general public. Moreover, evaluations of scenarios are needed as input for improving the quality of scenario-building methods.

Here we take the position that it is possible and desirable to evaluate scenarios and present criteria for this task.

Criteria for evaluating the quality of environmental scenarios

Borrowing from work on evaluation of integrated assessments[9] and land use scenarios[10] we propose four main quality criteria:

(a) Relevance. Are the scenarios relevant? Do they address the concerns and needs of their targeted users? Are they relevant to current scientific questions and/or policy decisions? Are scenario results thought-provoking, surprising? Do they challenge the beliefs and broaden the understanding of experts, policymakers, the general public?

[9] Criteria (a) through (c) come from NRC (US National Research Council), 2007. Analysis of Global Change Assessments: Lessons Learned. Committee on Analysis of Global Change Assessments. National Academies Press, 196 pp., and Jaeger, J., personal communication. "Relevance" is called "salience" in the cited document.

[10] See Alcamo et al., Chapter 4.

(b) Credibility. Are the scenarios plausible? Is the content of the scenarios (e.g. assumptions of causality) compatible with current understanding of the world, especially the understanding of potential scenario users? Are future developments described by the scenarios recognisable in the present? Are the assumptions of the scenarios transparent and well documented? Do the scenario developers have recognised credentials for this scenario work? Was the development procedure transparent? Was the development process scientifically rigorous? For example, were the models used to generate quantitative results credible?

(c) Legitimacy. Are the scenarios legitimate? Are the messages of the scenarios politically acceptable and perceived to be fair? Do the scenarios avoid promoting a particular set of beliefs or values? Are potential scenario users satisfied with the process used to develop and communicate the scenarios? In particular, were a wide enough range of stakeholders and/or experts involved in the scenario building process?

(d) Creativity. Do the scenarios provoke new, creative thinking? Do they challenge current views about the future? (If the challenge is justified.) Do they inform their audience about the implications of uncertainty?

While these criteria are applicable to all scenarios, one or the other might be more important depending on the purposes of the scenarios. If the main goal of building scenarios is to educate the general public or a particular target group, then it is particularly important that the scenarios be relevant – The scenarios should be stimulating and thought-provoking, and directly pertinent to this audience. They should communicate a big and clear message.

If the principal purpose of scenarios is scientific research, then it is clear that the scenarios must be relevant to current outstanding scientific questions. They must also be legitimate in that the scenario building process must involve researchers and/or data from relevant scientific disciplines. But while scenarios can be partly relevant and legitimate and still be useful to scientific research, they cannot be partly credible. – The procedure for building scenarios must unequivocally conform to good scientific practise, and the assumptions behind the scenario must be scientifically plausible. Hence it can be argued that the credibility of the scenarios in this case is more important than other criteria.

When the aim of scenarios is to provide input to decision making then the scenarios must be relevant to the questions posed by decision makers and stakeholders, as well as plausible and consistent with their knowledge. However, perhaps most importantly, they must have a high level of legitimacy. – They are likely to be quickly disregarded by decision makers and stakeholders if they are perceived to be unfair to a particular social group or otherwise lacking in legitimacy. Moreover, scenarios are often used by policy makers or their advisers to step back and consider the "big picture," for example, the long term consequences on the environment of policy actions they take or do not take. To provide this big picture, scenarios must be *creative*, in that they challenge the thinking of decision makers or other stakeholders. Hence, in using scenarios for policy advice and decision support, the criteria of legitimacy and creativity may be more important than the other criteria.

In some cases it can be argued that the criteria credibility and creativity collide with one another. Credibility argues for scenarios that are down-to-earth, and as noted above, recognisable in the present and compatible with the world views of the scenario users. By contrast, creativity calls for scenarios that take a chance and challenge the world views of the users; creative scenarios stimulate their users to think about imaginative solutions. Given this contradiction, it is wise for the initiators of the scenarios to establish at the outset which of these two criteria will be given more weight.

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