CHAPTER ONE

Introduction: the Case for Scenarios of the Environment

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If you cannot think about the future, you cannot have one – John Galsworthy

Look before, or you'll find yourself behind – Benjamin Franklin

1. Prologue: Environmental Scenarios and the Scientific Method

Intense curiosity has always been a motivating force for gaining knowledge. Take the case of the naturalists whose curiosity led them out to the woods, fields and mountains where they carefully observed the variety of plants and animals, the characteristics of lakes and streams, and the make-up of soils and rock crust. They recorded all they saw in lists, logbooks, and diaries. As Alexander Humboldt, one of the most accomplished naturalists of all, remarked "Insight into universal nature provides an intellectual delight and sense of freedom that no blows of fate and no evil can destroy." Eventually the curiosity of Humboldt and others began to take on a more systematic form in the disciplines of botany, ecology, geology,

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limnology, zoology, among other fields of inquiry. These "disciplines," as the name implies, followed a disciplined "scientific method" which was simple enough in its broad outline. As applied to environmental studies it involved observing nature and society, collecting and evaluating data, deriving a hypothesis about how an environmental system works, and testing the hypothesis against observed data. Indeed while intense curiosity was the driver of gaining new knowledge, the harnessing of this curiosity led to the modern approach to science.

After years of experience, the traditional scientific method has shown to be quite a successful approach for gaining environmental knowledge, at least when applied to the *current and past* state of the environment. But many of the research questions being posed today by science and society concern the *future* state of the environment: *How will earth's future climate be different from its current condition? Towards what state is an ecological system moving? Which driving forces will most influence the dynamics of an environmental system in the future? How could current environmental problems worsen or improve, or what new problems will emerge? What future policy steps could mitigate an environmental problem?* These are just a few examples of the many key questions of environmental science and policy that pertain to the *future*. In the annals of environmental research one of the clearest examples of fixing on the future was the issue of ozone depletion in the upper atmosphere. Scenario analysis of the atmosphere showed not only that the ozone layer would continue to deteriorate if emissions continued at their current level, but also that its deterioration would be reversed if emissions were decreased. Based on this and other knowledge, the international community agreed to reduce emissions of ozone-depleting gases (Benedick, 1998). In this case, international action to act on emissions was kindled by expectations about the *future* state of ozone in the stratosphere.

Another well-known example is the science and policy of climate change. A very large percentage of climate studies (perhaps the majority) centre around climate changes *beyond those we have already experienced*.[1] The fact is that a considerable scientific literature is devoted to discussing modelling results that relate, not to the current state of climate, but to its *future* state (IPCC, 2007a). An equally large literature is concerned with the impacts and mitigation of future climate change (IPCC, 2007b).

On the continental scale, policy action was taken to reduce transboundary air pollution after policymakers were confronted with estimates of possible future levels of acidic deposition (e.g. Hordijk, 1995). On the urban scale, many studies of air pollution management take into account both the current condition of the atmosphere as well as its future state under changed traffic and climate conditions.

In short, the concerns of modern environmental science and policy encompass not only the *current* state of the environment but also its *future* state. So how suitable is the traditional scientific method for studying a future that does not exist? Some scientists have tried to adhere to the method by conducting large scale field experiments that caricature possible future states of the environment. As an example, forestry scientists fumigate large outside stands of trees with high CO_2 air concen-

[1] Although the signs of climate change are already apparent in observed changes in temperature, precipitation, vegetation and other indicators, most studies about climate impacts, mitigation and adaptation concentrate on the future. See, for example, the climate change assessment of the Intergovernmental Panel on Climate Change – IPCC (2007a).

trations to try and simulate the effects of a future CO_2-enriched atmosphere (e.g. Luo et al., 2001), while other researchers put large roofs over tropical vegetation to simulate a future drier climate. Others have used "spatial analogies" to try and mimic the future – an example of this are the biologists who take plants from high elevations and re-plant them further down the slope to imitate possible conditions under a warmer climate. These experiments conform with the traditional scientific method because they provide scientists with data to collect, evaluate and use for testing hypotheses. On the other hand, they are often unwieldy, expensive, and cover only limited aspects of possible future states of the environment.

We now come to one of the most common approaches used for studying the future which is also the topic of this book – "environmental scenario analysis." As a methodology it can be summarised as the process of building scenarios, comparing them, and evaluating their expected consequences. Scenario analysis evolved from strategic studies conducted during World War II and became a popular method for studying the future in the 1960s.[2] The application of scenario analysis to environmental issues goes back to the beginning of the 1970s when it was used in the well-known global environmental study *Limits to Growth* to illustrate possible futures of society and the environment (Meadows et al., 1972, 2004). Since then environmental scenario analysis has been used to examine many different scales and types of problems ranging from global sustainability (e.g. Raskin et al., 1998) to very specific environmental issues such as changes in emissions, air quality, or land cover in a specific district or region (e.g. Mayerhofer et al., 2002).

As compared to large scale field experiments, scenario analysis has the potential to be more comprehensive, flexible, and perhaps less expensive. Scenarios can depict different future time steps and periods in the evolution of the environment. They can incorporate a virtually unlimited number of environmental compartments and their interactions, as well as the complex interactions between society and the environment. Indeed, the many examples presented in this book demonstrate that scenario analysis has become a common and useful tool in many future-oriented environmental studies and assessments. But we will also see that the current practise of environmental scenario analysis has serious deficiencies that need to be addressed.

2. Why Build Scenarios of the Environment?

What exactly do environmental scenarios have to offer to environmental science and policy?

- *They can provide an interdisciplinary framework for analysing complex environmental problems and envisioning solutions to these problems.* As an example, scenarios produced by the Millennium Ecosystem Assessment (Carpenter et al., 2005) were a vehicle for combining information from demography, economic sciences, geography, terrestrial ecology, as well as several other disciplines.

[2] See, e.g. (Kahn and Wiener, 1967).

- *They can provide a picture of future alternative states of the environment in the absence of additional environmental policies ("reference" or "baseline" scenarios).* In this way scenarios are a device to assess the impacts of society on the natural environment, and to point out the effectiveness of environmental policies in avoiding these impacts. For example, the "Business-as-usual" scenario of the World Water Vision exercise depicted future developments in water use and water stress under an assumption of no new major water policy initiatives (Cosgrove and Rijsberman, 2000).
- *They can illustrate how alternative policy pathways may, or may not, achieve an environmental target.* An example is the work of the Intergovernmental Panel on Climate Change which compiled and identified the global greenhouse gas emission scenarios that reached particular targets for future CO_2 levels in the atmosphere (Morita et al., 2001).
- *They can identify the robustness of a particular environmental policy under different future conditions.* This is important because "background" factors such as population growth, change in consumption habits or other trends might affect the success of an environmental policy. As an example, a plan to improve river quality by treating current wastewater discharges may in the end fail to achieve its goals if future population growth leads to higher wastewater loadings.
- *They can be helpful for organising and communicating large amounts of complex information about the future evolution of an environmental problem.* Examples of these are the scenarios of acid rain in Europe produced in the 1980s (Alcamo et al., 1990); global greenhouse gas emissions produced in the 1990s and later (Leggett et al., 1992; Nakicenovic et al., 2000); and world ecosystems produced over the last few years (Carpenter et al., 2005).
- *They can raise awareness about the emergence of new or intensifying environmental problems.* The above-mentioned acid rain scenarios helped raise the awareness of policymakers about the occurrence and impacts of intensifying acidification in Europe (Hordijk, 1995). Scenarios were also used to inform international climate policymakers about long term trends in climate change (Alcamo et al., 1996; Berk et al., 2002) and global environmental change (UNEP, 2007).
- *They can raise awareness about the current and future connection between different environmental problems.* The Millennium Ecosystem Assessment scenarios illustrate the possible future relationships between changing land use and climate on the one hand and future levels of terrestrial and aquatic biodiversity on the other (Carpenter et al., 2005; Alcamo et al., 2005).
- *They can help 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 which day-to-day policy action tends to exclude. An example of this is the European "Visions" scenario exercise during which stakeholders and policymakers evaluated various regional development scenarios up to 2020 and 2050 in the context of European and world-wide changes (Rotmans et al., 2000).
- *They can provide an opportunity for stakeholders to get involved in the development of public policies.* The World Water Vision exercise (Cosgrove and Rijsberman, 2000) and many other efforts have directly engaged stakeholders in the development of

environmental scenarios with the ultimate goal of influencing public policymaking.

3. The Two Threads of Environmental Scenario Analysis

Taken together, the point above suggest that scenarios *have the potential to link, and even integrate, environmental science and policy*. Why bother to link environmental science and policy? To be contrary, one could argue that they do not always have to be integrated. It is not necessary for ecologists studying lake ecosystems to interact with policymakers concerned about improving lake water quality (although it would be useful if the lake has a water quality problem). Nor does every policy adviser developing environmental regulations have to work closely with environmental scientists. On the other hand, science and policy are almost inseparable in many important environmental issues, such as stratospheric ozone depletion, regional acidification of the environment, and climate change. For these issues, stakeholders and policymakers rely on scientists for basic understanding of the problem, while the research agenda of scientists is largely driven by questions relevant to environmental policy.[3] In this situation scenarios can provide the needed link between the requirements of scientists and policymakers and other stakeholders.

But more often scenarios are developed to suit the needs of one or the other. For this reason environmental scenario analysis has developed two distinct threads – one largely catering to the needs of the scientific community, and one to the policy community. In the following paragraphs we try to sort out these threads and their implications for environmental science and policy.

4. Inquiry-driven Scenario Analysis[4]

One of the two major threads of environmental scenario analysis could be labelled "inquiry-driven" scenario analysis. Here scenario analysis is used by the scientific community as a research tool for estimating and assessing the future state of the environment. The product of this analysis is most often a set of quantitative scenarios, and researchers usually use computer models to produce these scenarios. Typically a researcher develops a model describing the cause-and-effect relationships in an environmental system, say the nutrient-phytoplankton-eutrophication relationships in a lake, or the relationship between air pollutant emissions and air concentrations over a city. Next, the model is tested and reported in peer-reviewed scientific journals. Finally, the researcher uses the model to generate scenarios by

[3] For example, in so-called "science-policy" dialogues, scientific analyses are carried out at the request of policy advisers or stakeholders, and policies are developed as a result of these scientific results. Examples were the use of the RAINS model in transboundary air pollution negotiations in Europe (Hordijk, 1995), and the use of the IMAGE and other models as part of the "Delft" and "Cool" processes concerning climate change (Berk et al., 2002; van Daalen et al., 1998; Alcamo et al., 1996).

[4] Note, that the two "threads" presented here are only caricatures of scenario types.

varying model inputs to mimic future changes in "driving forces" of the system. Once model inputs are changed, the model is run to calculate the response of the system to these changes. The step-by-step temporal changes computed by the model are called "scenarios."

To illustrate how these steps play out in a scenario analysis, consider one of the most prominent examples of this type of analysis, namely the development of climate scenarios using state-of-the-art global climate models (IPCC, 2007a). Climate modelling is carried out to better understand and anticipate future patterns of rainfall, temperature and other characteristics of the world's climate. Climate modellers change key assumptions about future driving forces of climate such as the temporal trend of emissions of greenhouse gases and the production of particles in the atmosphere and run the models to produce either a continuous picture of the evolution of climate over several decades ("transient" model run), or a snapshot of future climate corresponding to some future time period (a "time slice" model run).

Results about future climate are then compared to current climate conditions to derive information about changes in precipitation, temperature and other variables. The assumed changes in emissions, together with the picture of future climate produced by the model, make up the climate scenario.

A more local example comes from the water sciences and engineering in which models are frequently used to investigate the future environmental status of a river, lake or estuary. In this case a model user may wish to simulate the future impact on lake quality of increased wastewater discharges into the lake. To do so, he/she increases the magnitude of model input variables that represent nutrient loads to the lake (to mimic the increase in sewage discharges), and then runs the model to calculate the future level of algae and other water quality indicators. The assumed temporal changes in nutrient input, together with the resulting changes in algae and other indicators, make up the scenario.

Other examples of inquiry-driven scenarios are (i) scenarios of urban air pollution that depict changes in air quality of a particular city resulting from various assumptions about future vehicle usage and industrial air pollution emissions in the city, (ii) ecosystem scenarios that depict the future state of forests or other ecosystems responding to climate change and different management practises, and (iii) hydrologic scenarios that simulate the future level of runoff and other river characteristics based upon changes in land use and levels of water abstraction. A particular class of scenarios called "integrated scenarios" depict a combination of changes in society and the environment (e.g. Rothman et al., 2007; Alcamo et al., 1998).

Inquiry-driven scenario analysis has two main aims. The first is to increase scientific knowledge for its own sake. It can be argued, for example, that modelling and scenario analysis are pillars of global change science since many of its key research questions (Stern et al., 1992) have to do with the future state of society and the global environment. The second aim is to provide input to policy analysis. The classic example here are the climate scenarios produced by the climate modelling community as a response to requests for analyses from stakeholders and policymakers.[5]

[5] See footnote 3.

An important aspect of inquiry-driven scenarios is their scientific acceptance. Since both the models used to produce the scenarios and the scenarios themselves are commonly published in the peer-reviewed scientific literature, these scenarios are usually accepted by the scientific community as valid research results.

Although one of the main aims of these scenarios is to provide input to policy, the scenario builders have been criticised for not working closely enough with the policymakers and other stakeholders. Indeed, the scientific community tends to "deliver" model-produced scenarios to the policy community rather than interact with it. It can also be said that the models used to generate these scenarios reflect the views of the scientific group which developed them rather than society as a whole. Moreover, scientific groups usually do not give special attention to making their results comprehensible to non-scientific audiences.

To sum up, this thread of scenario analysis is anchored in the scientific community and usually concerns itself with scenarios as products of modelling. While the scenarios may be produced as input to the policy making process, researchers usually remain detached from this process.[6]

5. Strategy-driven Scenario Analysis

The second thread of environmental scenario analysis could be called "strategy-driven" scenario analysis. Here the goal is planning, i.e. evaluating and developing strategies to improve environmental quality and achieve "Sustainability" in the ecological, social and economic sense (e.g. Raskin et al., 1998). Techniques of strategy-driven scenario analysis stem mostly from the business community where it is used as a tool for corporate planning. This is the style of analysis carried out by the Shell Corporation's Scenarios Group (e.g. Wack, 1985), to mention one prominent group of practitioners.

While inquiry-driven scenario analysis usually does not involve a high level of interaction between researchers and stakeholders, "strategy-driven" scenario analysis entails intense engagement between scenario builders and the end users of the scenarios. Sometimes the scenario builders and end users *are the same*. Typically a moderator team works closely with a group of stakeholders and/or policy advisers at a multi-day meeting, and usually several of these meetings take place over a period of years. Using specific techniques of group moderation, brainstorming, and the like, the moderators guide the group step-by-step in the formulation of qualitative scenarios or "storylines." (For an example of this approach see the "Actors and Factors" method described in Bertrand et al., 1999.) In the environmental field, strategy-driven scenario analysis is used by experts from research, business, and NGOs to try and liven up the very dry scenarios produced by the scientific community with the aim to make them more palatable to stakeholders and the wider public. Another goal is to include a much wider set of viewpoints than usually represented in scenarios generated by the scientific community. As compared

[6] Although there are many exceptions to this rule. See, e.g. (Berk et al., 2002) or (van Daalen et al., 1998), and Chapters 5 and 6.

to inquiry-driven scenarios, strategy-driven scenarios tend to be more qualitative than quantitative. The key point is that strategy-driven scenarios are appealing to the policy community because they tend to be more understandable and inclusive of many points of view, at least as compared to inquiry-driven scenarios.

Yet strategy-driven scenarios also have deficiencies that need to be addressed (most of which also apply to inquiry-driven scenarios). Many scenario exercises have been criticised as not being inclusive enough, in that stakeholders and policymakers are often only on the margins of a scenario exercise, rather than having a central role in the scenario building process. Another criticism is that environmental scenarios tend to present an "unsurprising" view of the future although the past has shown that surprising events and developments can have a profound effect on priorities in environmental science and policy (e.g. the surprising discovery of the "ozone hole" in the stratosphere, or the collapse of communism in Eastern Europe which led to previously unexpected changes in Europe's environmental quality). Another problem is that most scenarios fail to address the different scales of importance to an environmental problem in a consistent way. For instance, global scenarios tend to ignore the linkage between global and regional changes in the environment, while local and regional scenarios often exclude the influence of global changes.

Moreover, and perhaps most importantly, scientists tend to dismiss strategy-driven scenarios as unscientific. This is because the assumptions and mental models behind this type of scenario are usually not transparent or reproducible. But it is worth noting that developers of this type of scenario are not necessarily aiming for scientific credibility. Referring to scenarios of this type, one distinguished practitioner has written, "Its origins are in the real world of management, it is therefore *more a craft than a science*" (van de Heijden, 1996). [italics added].

6. Do Scenarios Have a Future?

We have seen that inquiry-driven scenario analysis satisfies the requirements of the scientific community, and provides the scientific credibility needed by the policy community, but lacks the inclusiveness, range of views, and comprehensibility required by stakeholders and policymakers. Strategy-driven scenario analysis is stronger in fulfilling the needs of the policy community, but may lack the scientific credibility to engage the scientific community (among other deficiencies). Yet both types of scenario analysis fulfil equally important purposes (either to further scientific knowledge or to assist in strategic planning). How can we improve their quality and secure their future use?

One general and important task is to *bolster the scientific credibility of scenarios*. All types of scenarios can achieve a higher level of scientific acceptance if they address the two important keystones of the scientific method – transparency and reproducibility. A simple way to enhance both of these traits is to increase the rigour of definitions and methodology used in scenario analysis. (See Chapter 2.) Another approach, particularly relevant to model-generated inquiry-driven scenarios is to provide detailed documentation of the model and its input assumptions, as well as make the model accessible to a wider range of users. This strategy would also improve the scientific acceptance of strategy-driven scenarios but this would be a very big challenge because the models behind these scenarios are the usually unspoken *mental* models and assumptions of policymakers and stakeholders. These are much more difficult to bring to the surface (and likely to be more complex) than the models used by scientists to develop inquiry-driven scenarios. But difficult does not mean impossible. For example, some aspects of the mental models of stakeholders can be made more transparent and perhaps even reproducible with qualitative modelling techniques such as "mind-mapping" and "Bayesian networks" (see, e.g. Gamez et al., 2004; Debenham, 2001; and Chapter 6). These methods can help visualise the cognitive processes of individuals developing qualitative scenarios. Likewise, the assumptions behind qualitative scenarios can be made more explicit and reproducible by using fuzzy set theory (see, e.g. Cornelissen et al., 2001) to convert "soft" qualitative assertions such as "a large population increase will occur" into harder indicators such "population will increase by 2 percent per year." The advantage of "harder" indicators is that they are easier to compare with other scenario studies and can be more easily reproduced in other scenario analyses. In short, there is a vast literature in the fields of cybernetics, cognitive science, and knowledge engineering that can be mined for methodologies to improve the transparency and reproducibility of strategy-driven scenarios. This book presents many other ideas for improving environmental scenario analysis. For example:

- The credibility of scenarios could be increased by evaluating them and reporting the results of the evaluation to users of the scenarios, as well as by using a consistent procedure for this evaluation (Chapter 2).
- The legitimacy and creativity of scenarios could be enhanced by broadening stakeholder involvement in scenario exercises (Chapter 5).
- Scenarios could be made more consistent by using a structured approach which engages both scientists and stakeholders in the co-development of qualitative and quantitative scenarios (Chapter 6).
- The problem of dealing with different scales of an environmental problem could be addressed with various downscaling and upscaling techniques (Chapter 7).
- And finally, the problem that scenarios tend to present an "unsurprising" view of the future can be addressed by the cross-impact method, environmental scanning and a number of other techniques (Chapter 8).

To sum up, the two threads of environmental scenario analysis serve many valuable purposes in environmental science and policy. But it is also time to step back and examine the practise of scenario analysis and invest effort in addressing its weaknesses. We need to bolster its scientific credibility by adding rigour to its procedures. At the same time we need to make scenario analysis more relevant to environmental policymakers and non-scientists alike by involving them not only as end users, but also as co-developers in the scenario building process. These two tasks may sound contradictory, but they both have to be mastered if environmental scenarios are to have a future.

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