## CHAPTER SEVEN

# SCALE ISSUES IN ENVIRONMENTAL SCENARIO DEVELOPMENT[*]

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### Contents

## 1. INTRODUCTION

Scale relates to the spatial extent of a phenomenon, its duration and, for socio-economic or institutional phenomena, its specific societal embedding. Each scale is associated with a specific dimension (spatial, temporal, institutional, etc.). Temporal scales have only one, unidirectional dimension. Spatial scales can have up to three dimensions (length, area or volume). The institutional dimension refers to the extent of control, influence or access rights exerted by a particular level (individual, family, and society) and is per definition multi-dimensional (e.g. governance, organizational, economic or legal). For all types of scale, the principal issue is that results

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obtained at one scale level are not automatically valid at another level. Also, comparisons of scale-dependent variables must take place at roughly consistent levels.

Scale is closely linked to the concept of resolution or detail, which is the minimum extent, duration or boundary of a data element that can be distinguished at a given scale (e.g. the use of scale by cartographers). Typically there is a trade-off between scale and resolution driven by the volume of data, which would be generated if broad studies were carried out with fine resolution.

Most environmental, ecological and human processes exhibit characteristic scales, which are also called "grain." A characteristic scale can be defined as the typical extent or duration over which a process has impacts. If the impact of processes is assessed at scales significantly smaller than their characteristic scale, then there is a very large danger of misinterpreting a system's behavior. For example, trend analysis based on a short time series can easily overlook cyclic responses over longer periods. For that reason trend extrapolations could lead to particularly unreliable scenarios.

There is also a danger in describing a small-scale process at a much larger scale, since the resolution, which is available at the larger scale may smooth out important details and cause them to be missed. Even though computer and imaging technology now allows data to be captured and stored at fine resolution over large areas, the limiting factor remains the capacity of the human eye and brain to analyze, comprehend and synthesize such detail. Thus, it is not always useful to define the minimum unit of analysis to be the minimum technical resolution. One should thus explicitly define the appropriate scale and resolution for scenario development (and the related question of deciding where the boundaries should be placed).

One important general scale issue is the "scaling" issue, i.e. the question how variables and their values are translated from one scale to another. Some variables can be scaled in a very straightforward way. These variables are scale-independent, additive or linearly scaled. An example is population. The population of a village is the simple sum of the populations in every street in the village, and the population of a country is the sum of the villages (including cities). If villages are homogeneously distributed over the study region, then not every village needs to be measured to get the sum – it is simply the village density multiplied by the average persons per village in a sub-sample. Very many environmental, ecological and human or societal variables, however, do not scale in such a linear way. They follow non-linear scaling rules for a variety of reasons, including spatial or temporal interactions (feedbacks and synergies), high heterogeneity, or changes in the nature of the process regulating them as the scale changes. With such variables, data collected at different scales cannot be directly compared. They must first be brought to a consistent scale. For example, many environmental problems have their origin in a mismatch between the scale at which the ecological process occurs and the scale at which governance occurs. Scale-dependent variables cannot be aggregated by simple addition or averaging, or disaggregated by simple proportional rules. The terrestrial carbon balance is an example of a variable which has the same unit ($gC/m^2/yr$) at all scales but which changes its meaning according to the temporal and spatial scale. At the time scale of a few minutes and the scale of a leaf we call it photosynthesis (in the day) or respiration (at night). At a full day or greater time-scale, we call it net primary production (if considering plants only) or net ecosystem exchange (plants, animals plus microbes). In the long term, we must also consider the rare but large fluxes due to disturbance (fire, harvest) and we call it net biome production.

Scale issues are rarely comprehensively discussed in the literature on scenarios. In this paper we give an overview of the most important scale issues that are relevant for scenario development. In Section 2, we present selected scenario exercises and how they addressed spatial scale issues, and in Section 3, we discuss temporal scale issues. In Section 4, we shortly list issues related to the institutional dimension of societal scales. In Section 5, we identify methodological challenges caused by scale issues and propose some methods and approaches to tackle them during the scenario process.

In the following, we concentrate on qualitative–quantitative scenarios, which are considered by some to be the most powerful tool for communication between science and policy-making. This type of scenarios combines narration, in the form of storylines, with quantitative "interpretations" of the storylines that are mainly done by mathematical modeling. A version of this Story-and-Simulation approach, as it was named by Alcamo (2001), was applied both in the IPCC-SRES (Nakícenovíc et al., 2000), the World Water Vision exercise (World Water Council, 2000), and the Millenium Ecosystem Assessment (Carpenter et al., 2005; Alcamo et al., 2005). For the specific scale issues in climate change scenarios, please refer to Kundzewicz et al. (2007).

In scenario development, the term "large scale" means having a numerically greater extent or duration than something with a "small scale." This is to conform to the "natural language" usage of these terms, but is opposite to the sense used by cartographers, where a small-scale map (e.g. 1:10 million) covers a large area at low resolution, while a large-scale map (e.g. 1:10,000) covers a small area with high resolution. To avoid potential confusion, the terms "coarse scale" and "fine scale" are used here, and we propose that these terms be used in general when writing about scenarios.

## 2. SPATIAL SCALES

State-of-the art scenarios recognize the fact that interactions between different system components occur at specific spatial scales. For example, a farmer works within a cropping system that is adapted to local environmental conditions. She ploughs, plants and harvests her fields to support her family by either producing food for home consumption or selling the products to the local or international markets. Her activities only influence the local C-cycle, but the activities of all farmers will cumulatively alter the global C-cycle. Often these activities are synchronized through coarser-scale market incentives. If, for example, $CO_2$-sequestration leads to additional income, than this local farmer and many others will modify their activities to enhance income and well being of the farmer's families. Modeling these processes does not only involve a realistic description of the relevant processes, but also a proper integration of the different scales, resolutions and dimensions.

Initially, the multi-scale approach was mainly applied for generating qualitative scenarios (e.g. story telling) but in the meantime, multiple scales are also taken into

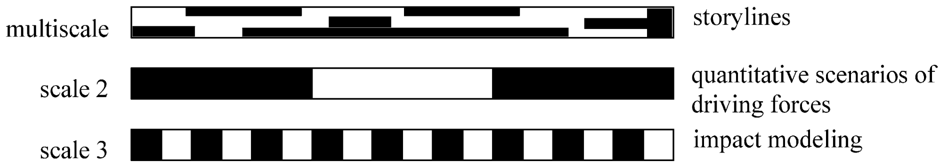

**Figure 7.1** A typical hierarchy of the spatial scales involved in scenario development (see text for explanation). The richness of the qualitative storylines with respect to processes and issues considered needs to be mapped on driving forces which are specified on scale 2, determined, e.g., by units of statistical reporting of the past. Finally, these driving forces need to be disaggregated onto the units of computational modeling.

account in quantitative modeling. Especially in ecological and land-use models, the multi-scale approach has flourished over the last years. Many of these models are spatially explicit with their resolution only limited by the available climate and soil databases, which is approximately 25–100 km$^2$. Land-use models now explicitly use locally or regionally derived demand for food products, corrected with import and export, to simulate the emerging land-use patterns on the high-resolution grid. Ecological models incorporate disturbances, such as fire, which are a function of the local vegetation (fuel load and ignition probability), and the landscape (spread and patterns).

In quantitative–qualitative scenario exercises, issues of spatial scale come up first in the qualitative part. Storylines might encompass issues taking place on many different scales ranging from global stories on main political or economic developments to examples of local variabilities and specific features. Another scale issue arises when the storylines are "quantified" or modeled – The richness or heterogeneity of the storylines is reduced when the storylines have to be mapped onto the limited number of driving forces covered by the models (Figure 7.1). Another scale issue arises when global or other large-scale driving forces have to be downscaled to the local or regional level as part of the quantitative–qualitative scenario exercise (Leemans, 2006).

In Section 2.1, we present some methods for downscaling global drivers that are relevant to scenario analysis. In Section 2.2, an example of regional-scale scenarios that are consistent with global-scale scenarios is provided, while multi-scale scenarios are described in Section 2.3. Finally, Section 2.4 discusses how the building of local-scale scenarios could lead to more relevant coarser-scale scenarios.

## 2.1 Quantitative downscaling of global scenarios

To derive quantitative and spatially-resolved global-scale scenarios, the storylines at scale 1 of Figure 7.1 (here the global scale) must first be downscaled to obtain quantitative values of the driving forces at scale 2 (here world regions or countries) and 3 (here 0.5° grid cells). This can be done with model-based or heuristic approaches (Sections 2.1.1 and 2.1.2). Section 2.1.3 discusses the reliability and relevance of the scenarios computed by the highly-resolved impact models that are based by the coarser-scale storylines and driving forces.

### 2.1.1 Model-based downscaling of the main driving forces in global environmental scenarios

The development of the IPCC-SRES greenhouse gas emission scenarios (Nakícenovíc et al., 2000) are an example of a model-based downscaling method. Here, four global storylines were quantitatively interpreted and then downscaled to four SRES world regions by applying six different global-scale models. There were no individual storylines for the four SRES regions. In order to make the emission scenarios more comparable, scenarios were developed with the six models which share population, gross domestic product (GDP) and final energy use assumptions at the level of the SRES regions within specified bounds (10–25%). Model results were aggregated to the four SRES regions.

One of the six models, the IMAGE 2 model (IMAGE Team, 2001) used the assumptions in the SRES storylines for GDP, energy use and other variables as input to a set of models for computing downscaled driving forces in 17 world regions. The demographic model Phoenix (Hilderink, 1999) was used to compute population, the economic model WorldScan (CPB, 1999) to estimate GDP, and the TIMER submodel to compute energy. Hence, the results of the IMAGE model for 17 world regions can be considered a direct model interpretation (downscaling) of the global SRES storylines. These IMAGE SRES scenarios were used as a starting point to further downscale towards the European state/provincial level in the ATEAM project providing land use and climate change scenarios for a comprehensive vulnerability assessment using other models (Schröter et al., 2005), and towards a one kilometer resolution in the Netherlands sustainability outlook study using geographic data, models and GIS (Milieu- en Natuurplanbureau, 2004).

### 2.1.2 Heuristic downscaling of driving forces as input to global impact models

In most cases, and in particular when suitable models are unavailable, downscaling requires a heuristic approach. As an example we consider the quantification of scenarios on population and GDP for the water scenarios in UNEP's Global Environmental Outlook 3 (GEO-3) (2002). A global model of water availability and water use, WaterGAP (Döll et al., 1999; Alcamo et al., 2003), was utilized for this quantification.

To compute water use with WaterGAP, the country-wise UN98 medium population projections are linearly scaled such that total population change of the world regions agrees with the respective IMAGE interpretation of the SRES scenarios. The per-capita GDP growth of each country within a world region is assumed to be the same as the per-capita GDP growth of the entire region itself. This assumption can pose problems if the absolute per-capita GDP of different countries within the region varies substantially. In the case of a scenario with economic convergence, it is better to assume that the per-capita GDP of various countries within a region converge after a certain point in time.

But downscaling usually does not end at the country level. To assess impacts of global change on society or nature it is usually necessary to downscale driving forces to a global grid, with a 0.5° or finer resolution, as input to state-of-the-art impact models. For example, to assess impacts of climate change on global water resources as part of GEO-3, the WaterGAP model required global population estimates with 0.5° spatial resolution. A series of assumptions were necessary to produce the required population data. For instance, it was assumed the population in urban grid cells grow faster than average if the fraction of urban population increases in the country as-a-whole.

In another scenario exercise the change in irrigated areas in the World Water Vision scenarios up to the year 2025 were downscaled to the grid cell level by assuming that the changes only occur in cells that were already equipped for irrigation around 1995. It might have been more realistic to assume that some part of the new irrigation would be realized in grid cells that have not been irrigated, but that would have required identification of suitable new cells as well as a decision on how what fraction of the new irrigated area is located in new cells. Both the spatial distribution of changes in population and irrigated areas within countries have a strong impact on water use in river basins, which are the preferred analysis units for freshwater issues.

### 2.1.3 Evaluation of impact model results

In general, impact models both quantify and downscale storylines. The reliability and relevance of the impact modeling results as well as the appropriate scale for the analysis of model output depend on

- the spatial resolution and quality of data for current conditions,
- the quality of the impact model, and
- the consistency and spatial resolution of the changes of the driving forces that are applied as model input.

As an example, the input to the WaterGAP model as it was used in the GEO-3 exercise were changes in population, income and other variables given at the *country level*, while the output of the model was water use on the *grid-scale* or *river basin-scale*. When interpreting the scenarios of water use, it is important to keep in mind that in reality the development of driving forces inside a particular river basin may be quite different from their development on the country-scale. Hence it is very important to keep scaling issues such as these very transparent to the end user of scenarios.

## 2.2 Derivation of scenarios which are consistent with coarser-scale scenarios

In the case of sub-global scenarios, it is generally recognized that coarser-scale developments have an impact on the spatial unit of interest (for which the storyline is written). The challenge is how to integrate these developments in the derivation of scenarios for the spatial unit of interest.

Wollenberg et al. (2000) present a method to identify, within the scenario exercise, the multi-scale relationships that affect local community forest management. They adapted an approach of Schoemaker (1991) for deriving business scenarios, which takes into account the impact of global and national economic trends on the future of the company business. As a first step, the most important trends, or driving forces, that affect local-scale futures are determined. Then, they are classified with respect to their scale, and finally, the relationships between driving forces are mapped (Figure 7.2). Here, the scales can be considered to be either spatial or institutional. This type of mapping is not only useful for the derivation of storylines at any scale below the global scale, but can also serve as a first step in the derivation of scenarios which are consistent with coarser-scale scenarios.

Examples of regional scenarios that are designed to be consistent with global scenarios are the scenarios for two federal states in the semi-arid Northeast of Brazil, Piauí and Ceará. Within the framework of the German–Brazilian WAVES program (http://www.usf.uni-kassel.de/waves), these qualitative–quantitative scenarios were developed to support sustainable land use and water management in the two states. As background for testing the impacts of certain management decisions, two reference scenarios were derived up to the year 2025. The scenarios were quantified by an integrated modeling approach, taking into account water availability, water use, crop productivity, agricultural economy and migration. Recognizing the dependence of regional development on the global-scale development, the two

| | |
|---|---|
| T1 | Global demand for forest products |
| T2 | UN convention support for community forest management |
| T3 | GATT trade requirements |
| T4 | World Bank loan conditions |
| T5 | Currency exchange rates |
| T6 | Support for mining |
| T7 | Policy to promote oil palm plantations |
| T8 | Regional tax base |
| T9 | Designation of nearby national parks |

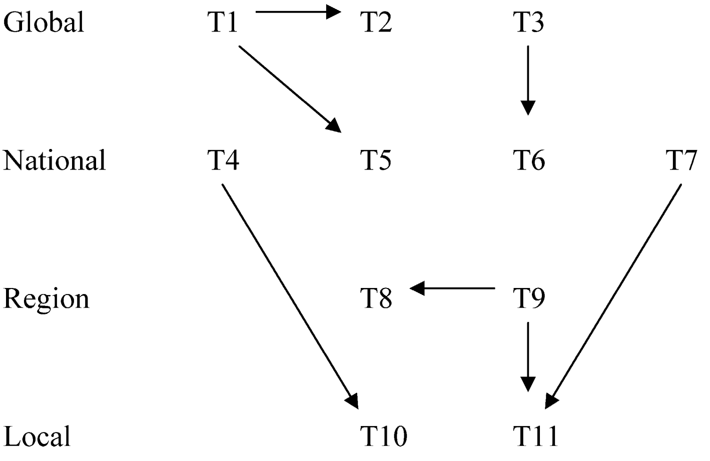

**Figure 7.2** Multi-scale relationships among drivers of scenarios of community forest management (adapted from Wollenberg et al., 2000).

reference scenarios for Piauí and Ceará were embedded into two of the global IPCC-SRES scenario families (Nakícenovíc et al., 2000). These global scenarios are a suitable framework for regional scenarios as they include storylines, have international support (as they were developed in the framework of the IPCC effort to support international negotiations on climate protection) and are used to derive scenarios of global climate change (which is one of the drivers of regional change in Northeastern Brazil). A detailed description of the scenarios is provided by Döll and Krol (2002). Here, we will give enough detail to understand the specific scaling issues that can arise when a fine-scale scenario is to be embedded in a coarse-scale scenario.

The two regional scenarios for Piauí and Ceará continue development trends that existed in the region at the end of the last century. Reference scenario A, "Coastal Boom and Cash Crops," carries on the trend of increased cash crop production for the Brazilian and external markets, the efforts to promote tourism mainly along the coast and the fast economic development in the growing metropolitan area of Fortaleza, the capital of Ceará. Reference scenario B, "Decentralization – Integrated Rural Development" takes up the strengthening of regional centers, e.g. by the establishment of universities, which had recently begun in the study area. These centers may provide a market for the farmers in the surrounding rural areas. In RS B, local initiative becomes more important as compared to RS B where government or big business driven activities prevail. A comparison of the storylines of these regional scenarios with the storylines of the four IPCC-SRES scenario families showed that the "Coastal Boom and Cash Crops" scenario (RS A) is consistent with the global scenario A1, and the "Decentralization – Integrated Rural Development" scenario (RS B) with B2 (Figure 7.3).

The main driving forces climate, population, gross domestic product and urbanization were quantified by considering the quantifications of the global scenarios. Climate change scenarios were derived by a statistical downscaling method, taking into account precipitation change in Northeastern Brazil as computed by global climate models. With respect to population, until 2025 there is very little difference between the A1 and B2 scenarios for the world region Latin America/Africa/Middle East. This encouraged us to also assume that the fertility and mortality rates can be assumed to be the same in both regional scenarios. The higher income growth in RS A might have the same effect on net migration as the regional strengthening in RS B, and therefore, also net migration and thus total

| | Oriented mainly towards economic growth | Oriented mainly towards the environment and social innovation |
|---|---|---|
| Globalized world | global A1/regional RS A | global B1/none |
| Regionalized world | global A2/none | global B2/regional RS B |

**Figure 7.3** Correspondence of WAVES regional scenarios for Piauí and Ceará in Northeast Brazil with the global IPCC-SRES scenario families (Döll and Krol, 2002).

population increase was assumed to be the same in both regional scenarios. The development of the total population in the study region was computed based on decreasing fertility and mortality rates. The scenarios for the fertility and mortality rates were derived by taking into account the historical development of population growth in the Latin America, Brazil and the study region, an early interpretation of the SRES A1 population scenario for Latin America using the IMAGE model (Bert de Vries, RIVM, The Netherlands, personal communication, July 1999), and a population projection for Brazil by a Brazilian institution.

With respect to economic growth, the regional scenarios qualitatively reflect the differences of the global scenarios A1 and B2. The absolute growth rates, however, were set to much lower values than those of the global scenarios, as it was felt that downscaling of the comparatively large growth rates of per-capita GDP for Latin America would result in implausible growth rates for the study region. In order to remain in the upper range of the historic per-capita GDP growth rates, we neglected the global scenario values and assumed that per-capita GDP of Brazil would increase by 2.2% $\text{yr}^{-1}$ (RS A) and 2.0% $\text{yr}^{-1}$ (RS B), respectively with the values for the study region being somewhat higher.

Each WAVES scenario does not only specify a storyline for the whole study region Piauí and Ceará but individual storylines for each of the eight scenario regions within the study region. The scenario regions were assumed to differ strongly with respect to their future development. Criteria for the configuration of the WAVES scenario regions were the similarity in agro-economic and natural conditions (precipitation, position within river basin, sedimentary vs. crystalline subsurface) as well as administrative boundaries. Based on the individual storylines, but consistent with the quantification of the driving forces for the whole study region, the main driving forces were quantified for each of the scenario regions by an interdisciplinary team. For most driving forces, downscaling from the scenario regions to the municipalities, which constitute the smallest spatial units of the impact models, was done by applying the same rate of change to all municipalities within a scenario region. Future public irrigation was located according to existing plans for specific irrigation projects.

## 2.3 Multi-scale scenarios

In the following, we present two scenario exercises in which scenarios at more than one scale were developed. They strongly differ in their methodological approaches.

### 2.3.1 The VISIONS multi-scale scenarios for Europe

The VISIONS project was funded by the European and pursued a multi-scale approach to scenario building (Rotmans et al., 2000, 2001). The objective of the project was to elaborate integrated visions of Europe for the year 2050 based on two distinct types of scenarios: one set of scenarios for Europe as a whole and sets of regional scenarios for three different regions (the Green Heart of The Netherlands, the Northwest of the United Kingdom and Venice in Italy), respectively. All scenarios were built within a common setting of factors (equity, employment, consumption behavior, and environmental degradation), actors (governments, non-governmental organizations, companies, scientists), and sectors (water, energy, transport, and infrastructure). By using consistent information between the different scenario-building processes methodological consistency was ensured, which at the very end enabled the building of integrated visions across scales.

Scenarios were built with a combination of participatory and analytical methods, i.e. stakeholder workshops, data analysis, computer modeling and qualitative methods were all applied at one time or another. There were three European scenarios and three to four scenarios for each sub-region. In the final integration step, the total of 144 possible combinations of scenarios were screened for inconsistencies, mutual reinforcement and evolving disparities to yield a final set of three visions for Europe covering the range of plausible futures. The storylines of the visions are diverse because they are regionally-specific. In the case of the "Living on the Edge" vision, for example, Venice serves as a detailed illustration of the effects of climate change on Europe.

From the methodological point of view, it is believed that the common framework of the Visions exercise, as well as the continuous dialogue within the project and the large number of scenarios it produced, enabled the building of a consistent set of integrated visions for Europe. This suggests that a multi-scale scenario exercise is best carried out within the umbrella of a single project.

### 2.3.2 The Global Environmental Outlook scenario exercise

Within its report Global Environmental Outlook Number 3 (GEO-3), the United Nations Environmental Program (2002) developed a set of four scenarios for the time span of 2002–2032. Though global in perspective, each of the four scenarios "Markets First," "Policy First," "Security First" and "Sustainability First" was developed by an iterative process involving a global scenario group, including modeling teams, and regional teams of experts. The task of the latter was not only to provide details about the storylines, but also to provide quantification of the driving forces on a regional scale. Taking into account regional expertise not only allowed for improved input compared to a purely "technical" downscaling of the drivers, but it also provided a basis for "regional ownership" of the final product. Nevertheless, some global scenarios, as in the case of the water scenarios, were not supported or checked by the regional teams or regional models.

The resulting global scenarios are, to a certain extent, multi-scale in nature. Within the "Markets First" scenario, for example, regional dimensions were added to the storyline with respect to political and economic integration, but also with respect to social issues and human health. The "Sustainability First" scenario provided regional examples of the transition to a world of changed values and attitudes. Furthermore, it is assumed that many of the initiatives for the transition come from local grass-roots movements and non-governmental organizations as well as increasing activities of organizations on the regional level.

In its latest Global Environmental Outlook report (GEO-4), UNEP went beyond global scenarios with regional aspects to a truly multi-scale set of scenarios (Rothman et al., 2007). Regional teams developed scenarios for 7 world regions that describe in detail how global scenarios play out in their region. A common set of driving forces, time scales and other parameters were used for both the global and 7 regional scenarios and a high level of consistency was achieved between them.

A similar attempt has been made for developing multi-scale scenarios under the Millennium Ecosystem Assessment (Carpenter et al., 2005; Alcamo et al., 2005; Lebel et al., 2005).

## 2.4 Local scenarios – global pictures?

Over the last years there has been a growing number of attempts to obtain a global view on the present state of global environmental change and its causes and consequences by means of individual local case studies (Kates and Haarman, 1992; Geist and Lambin, 2001; Petschel-Held and Lüdeke, 2001). The strength of these "place-based" approaches is that they take into account the local context which includes issues of local responses to environmental changes on short time-scales. They provide new views on problems of global environmental change which are not included in the macro-perspectives taken by global models. The question arises, how can these advantages be transferred to a global scenario analysis, i.e. how can local or regional scenarios be used to get a global picture of plausible futures? Up to now this has not been tried, but we speculate in the following paragraphs how this might be accomplished.

As a specific element, local scenarios often include traditional and indigenous knowledge. For example, within an assessment of ecosystem services of the Western Ghats of India, Gadgil and colleagues developed a set of scenarios based on three initial questions posed to local people (Gadgil, personal communication):

- What is the worst that can happen over the next years?
- What is the best that might happen?
- What do you actually expect to happen?

In a second step answers to these questions were formulated as so-called "basic scenarios" and compared with available scientific knowledge and with coarser-scale scenarios. These other scenarios covered, for example, economic issues such as prices for agricultural commodities or wage labor availability. This step lead to a set of "enriched scenarios" which in a final step were "consolidated" in local workshops to ensure acceptability by local users and consistency with local knowledge.

In general there is a much higher degree of freedom in aggregation and upscaling than for downscaling. This is due to the fact that downscaling covers the entire spatial domain of a subject area whereas upscaling only covers a representative subarea of the domain. Hence, it is extremely difficult to build global scenarios in a bottom–up manner. On the other hand, a family of scenarios covering scales from local to global are much richer in content and more powerful communication tools than just global or local scenarios alone. Moreover, scenarios on two scales can serve as checks of the consistency and plausibility of the other.

Local scenarios can add value to global scenarios in the following ways:

- Local scenarios generated under assumptions consistent with those used for a global scenario could provide insight into the geographic variability of the global scenario that is otherwise unavailable.

- Local scenarios can enrich a global scenario by providing more detailed information on how people react and cope with environmental changes now and in the future. This is particularly relevant to decision making.
- Local scenarios can provide ground truthing for models used to generate global-scale scenarios: To what extent does the model's quantification coincide with storylines developed at the finer scale? Do we have to adapt the quantification of the driving forces at the coarser scale or even the model itself to better reflect the finer scale scenarios?

## 3. TEMPORAL SCALES

In the last section we have demonstrated that multi-scale scenario development can improve the usability of scenarios and the ability to communicate these scenarios. Yet these scenarios also need to be multi-scale with regards to temporal scales. For example, events or effects that appear rather early in time within a local scenario, might be masked by other events occurring in other localities or on the regional or global scales. For example, the effects of a "regionalized world" as envisaged within the IPCC-SRES scenarios on total global emissions appear only after enough regions have switched to emission reductions.

Another major problem of time scales in scenario development is the potential delay between different actions assumed to happen in a particular storyline and their social and environmental implications. Reductions in the emission of greenhouse gases, for example, show a significant effect on climate with a delay of 30–50 years which are often the time horizons for the scenarios itself (e.g. 30 years for the GEO-3 exercise and 50 years envisaged for the Millennium Ecosystem Assessment scenarios exercise). Therefore it is difficult to include the direct effects of all plausible actions within a storyline. Within the GEO-3 scenarios, this effect was taken into account by considering consequences of the different scenarios at times beyond the actual horizon of 2032. The short to medium term effects might even be contrary to the long term changes. For instance, due to the indirect cooling effect of aerosols, the global mean temperature for the "Sustainability First" scenario is even higher within the first 20 years than in case of the "Markets First" or "Security First" scenarios. This is due to the much lower emissions of sulfur dioxide within the "Sustainability First" scenario. The effect is reversed only far beyond 2030 when the reduced emissions of carbon dioxide take hold and global warming becomes much less pronounced than in the "Markets First" or the "Security First" scenario.

Time scales also raise problems in the quantification phase of scenario development. This is due to the different time horizons for which models are assumed to give valid results. Whereas climate models are assumed to produce meaningful output over a time horizon of a hundred years or even more, economic models generally have much shorter time horizons. If quantitative models are not available for the topic and time horizon of interest, the Story-and-Simulation approach suggests that the information can be provided by qualitative scenarios. Thus, the existence of different time horizons within different scientific disciplines might introduce some "artificial" imbalance between qualitative and quantitative parts of the scenario.

One of the subtle issues with respect to temporal scales and scenario development concerns the question of how to deal with surprises, events or rapidly occurring changes which break a slow trend and have a massive impact on the overall scenery. This includes major shifts in the political realm, such as the collapse of the communist system of government in Eastern Europe in the late 1980s, or catastrophic events such as major earthquakes or rapid climate changes. It is unclear whether surprises should be included at all. By definition they are considered to be "low probability, high impact" events, which thus question the plausibility of a scenario. Yet their probability as well as their impact will vary from scenario to scenario, as, for example, the non-linear feedback loops which can induce these surprises are activated in different strengths across different scenarios. One option of dealing with surprises is to exclude them from the scenario development itself, but to discuss their possibility and impact in an extra analysis, e.g. a box or special section in the final report. The issue of including surprise in scenarios is addressed by Toth in Chapter 8 of this book.

## 4. INSTITUTIONAL SCALES

The aim of many if not most environmental scenario exercises is to bridge environmental science and policy. To make this bridge we must deal with issues of scale and institutions. These include:

- *Issues concerning scenario users*: Who are the users of the scenarios? Is the user community restricted to decision makers and stakeholders representing a single scale, or are they concerned with different scales (municipal, national, multilateral and/or international)? It is likely that each community of users requires specific information.
- *Issues concerning target organizations*: How can the range of scales of scenario analysis be matched with the range of decision-making and stakeholder organizations that are potential users of the scenarios? Here the appropriate aggregation level of scenario information is needed for successfully addressing the interests of the target organizations.
- *Issues concerning hierarchical decision making*: How can scenarios reflect the multi-scale character of the decision making process? In this sense, "good" scenarios for Europe should take into account the European as well as the national (and possibly even finer) governmental level. For example, a farmer who cultivates land in a specific locality produces for local (e.g. vegetables) and global markets (e.g. grains). At the local market she most likely can determine the price, whereas prices on the global market cannot be set by individual farmers. The different scales of decision making therefore provide different incentives and opportunities.

## 5. METHODOLOGICAL CHALLENGES AND WAYS TO TACKLE THEM

Sections 2 to 4 of this paper show that scale issues pose important methodological challenges in scenario development. These challenges depend on the specific approach taken to develop scenarios, that is, whether scenario developers focus on cross-scale linkages within the quantification phase of the scenario development or whether they develop multi-scale storylines in the qualitative phase. We have identified three major methodological challenges related to scale issues in scenario development and provide a few indications on how to deal with them.

### How can the implications and restrictions of different scales, in particular those related to the quantification of driving forces and model output, be made transparent to scenario users?

The discrepancy between the scales of storylines, the changes in driving forces and the computational units of models may lead to an incorrect interpretation of scenario results. For example, a single global scenario computed by a set of models may describe changes in income at the world regional level, changes in climate on a global grid of 2.5°, and impacts of climate change on a global grid of 0.5°. This mix of spatial scales could easily cause the user of the scenario to misinterpret the spatial scale of the scenarios. Transparency is needed here to make the scenario more useful – A clear description of the spatial scale of all aspects of the scenario is required.

There are a number of good practices which help to make scale implications and restrictions of scenarios more transparent:

- Documenting scaling procedures:
  - by showing a table with the scenario variables and their spatial and temporal scales,
  - by presenting a graph which shows the major scale linkages, or
  - by providing indicator maps with different spatial resolutions.
- Keeping scaling procedures as simple as possible.
- Analyzing one level below the target level and publish results to show restrictions of scale in maps and tables.
- Providing scaling methodology in technical background documents or journal articles (but not within the storylines).
- Preparing specific summaries for targeted audiences.

### How can we foster and organize coordinated multi-scale scenario development to achieve a harmonized set of scenarios as powerful tools of communication on all scales?

We distinguish three issues that are related to fostering and organizing a coordinated multi-scale scenario development: the timing of the scenario building process, the issue of scale specificity and scale interconnections, and the question of consistency across scales vs. relevance of individual levels. Good practices and approaches

**Table 7.1** How to organize multi-scale scenario development

| Issue | Good practice | How to achieve good practice |
|---|---|---|
| Timing of scenario exercise | Iterative process | • Provide and maintain strict phasing of scale-specific work and inter-scale interactions<br>• Provide communication<br>• Elaborate storylines well before quantification (may depend on addressee) |
| Scale-specificity and connections between scales | Definition of clear, relevant and appropriate policy issues, indicators and objectives/ motivation of scenario groups for each scale<br>Clear linkages | • Continuous documentation of scale-related decisions<br>• Report on scale-related issues up front<br>• Define only a few interlinkages between scales<br>• Consistent but not necessarily the same indicators at all scales |
| Scale consistency vs. saliency on individual scale | Flexible framework<br>Analyze one level deeper than will be published | • Provide common ground to all groups<br>• Assign a person in the coarse-scale scenario group to be the contact person for each fine-scale scenario group; or, organize one scenario group for all scales plus scale-specific support groups<br>• Use (different) models at all scales<br>• Common sectors, factors, actors |

to achieve these have been identified and are listed in Table 7.1. In addition, however, there are major methodological problems related to quantitative aggregation and disaggregation that remain to be solved (see Section 2 of this chapter).

### How can we take advantage of independent local-scale scenarios for deriving coarser-scale scenarios?

As noted above, local scenarios might include important aspects of the dynamics between human society and the natural environment which are difficult to include in large scale models. The comparison of scenarios on different scales can also serve as a mutual consistency check: does the regional/local specification of a global scenario reflect the regional/local scenario itself? If not, the scenarios on both scales might be revised, enriched or modified. Including local knowledge enriches scenarios since it adds variety instead of averages. However, incorporating local knowledge requires building a bridge between global and local knowledge and between scientific and non-scientific (e.g. indigenous) knowledge, and this requires new methods of integration. If global scenarios are available, more care should be taken in the "local interpretation" of modeling results and in formulating the local implications of the global scenarios. In addition, it should be possible to write local-scale narratives based on the regional output of the global scenarios plus additional local knowledge. If local scenarios are available, it should be possible to develop coarse-scale storylines and quantifications that consistently subsume the local scenarios. In addition, a categorization of local scenarios, e.g. according to the Syndrome approach (Petschel-Held et al., 1999), has the potential to enrich global scenarios.

A particularly thorny question regarding spatial scales is how to quantify phenomena in coarse-scale scenarios that emerge as the sum of many actions on the fine scale. For example, the global storyline of the Sustainability First scenario in GEO-3 assumes that human attitudes toward consumption are transformed on the global level as a result of many different local and regional initiatives. How can this emerging behavior be quantified? A strong advantage of the combined qualitative–quantitative approach of scenario development is that it provides a framework for assuming such emergent properties as part of a storyline and then testing these assumptions with models.

## 6. CONCLUSIONS

We recommend addressing scale issues in each scenario development process, especially as they concern the users of the scenarios and the objectives of scenario development. There are major methodological challenges related to scales that need to be dealt with. To improve the usefulness of scenarios, it is very important for scenario developers to make transparent the implications and restrictions of scale issues.

The consideration of multiple scales provides major opportunities for enriching scenarios. Expanding the single-scale perspective of many scenarios (e.g. global-scale scenarios or local scenarios) increases the quality of the scenarios as the interactions between processes occurring at the different scales can be considered. Decision-making with respect to issues of sustainable development takes place on all scales, ranging from actions to cope with local environmental change to global governance of environmental change through UN conventions. It is the interplay of these different decisions that largely shapes our future and for this reason this interplay should be incorporated and represented in scenarios.

Developing scenarios on multiple scales also increases their legitimacy because decision makers and stakeholders working at different scales feel that they have a stake in the scenarios. The potential usage of a scenario increases whenever it includes aspects relevant for stakeholders working in various domains of action.

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