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Scale issues in scenario development

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Abstract. Scale issues arise in all stages of the scenario development process, including the definition of the addressees of the scenarios, the formulation of the storylines, the quantification of the driving forces and the impact modeling. They encompass spatial, temporal and societal scales. A particular question is how processes and knowledge at different scales can be integrated. Examples of scenario development show the diverse methodological problems related to scale issues as well as the approaches that have been taken to deal with these issues. The main methodological challenges refer to 1) the transparency of scenarios with respect to scale implications and restrictions, 2) the organization of coordinated multiple-scale scenario development, 3) the inclusion of knowledge from independent local-scale scenarios in coarser-scale scenarios (including the quantification of emergent properties). We recommend to explicitly address scale issues in each scenario development process.

1 Introduction

Scale relates to the spatial extent of a phenomenon, its duration and, for socio-economic or institutional phenomena, its specific societal imbedding. Each scale is associated with a specific dimension (distance, size, time, institution, etc). Temporal scales have only one, unidirectional dimension. Spatial scales can have up to three dimensions (length, area or volume). The societal scale is per definition multi-dimensional (e.g. institutional, organizational, economic or legal). The institutional dimension, for example, refers to the extent of control, influence or access rights exerted by a particular level (individual, family, and society). For all types of scale, the principal issue is that results 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 forced 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 the process has its 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. Especially trend extrapolations could for that reason lead to 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 homogenize 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 for 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 country population, the sum of the villages. If villages are homogeneously distributed over the study region, then not every village needs to be measured to get the total – it is simply the village density in the total area of that region 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 this 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. Terrestrial carbon balance is an example of a variable, which has the same unit ($gC/m^2/yr$) at all scales but for which the meaning changes with 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.

Considering scale issues in scenario development in particular, the main question is how scale issues influence the communication, the information transfer between scientists and policy makers (or stake holders). Then, the following scale issues arise:

- *Addressee Issues:* Who is the addressee of the scenarios? Is the user community restricted to decision makers and stakeholders at a single scale or are decision makers and stakeholders from various scales going to use the scenarios?

- *Agency Issues:* How can the range of scales of the scientific analysis be matched with the range of agency of the decision makers and stakeholders addressed?
- *Hierarchy Issues:* How can scenarios reflect the multi-scale character of the decision making process? In this sense, for example, "good" scenarios for Europe should take into account the European as well as the national (and possibly even finer) level, as there is nothing like "the" European decision maker.
- *Quantification Issues:* the quantification part of the scenario exercise, the “usual” scale issues of impact assessment arise: up- and downscaling of input data, model (dis)aggregation or embedding, etc. We might have to consider, for example, how driving forces are downscaled which are based on a higher scale storyline, but have to be quantified at a finer model resolution. The particular relevance for scenario development of these issues is how scale-related scenario assumptions can be made transparent to the scenario readers, e.g. the policy makers.

The first three issues mainly relate to the institutional (societal) scales relevant for scenario development and whether and how institutional and spatial scales match together. The fourth issue relates to the different (mainly spatial but also temporal) domains in which the various drivers and impacts of global change as well as the responses to global change act.

Scale issues have been discussed very little in the literature on scenarios. In this paper we give an overview of the most important scale issues are 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 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 now considered 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. This story-and-simulation approach, as it was named by Alcamo (2001), was applied both in the IPCC-SRES and the World Water Vision exercises.

2 Spatial scales

State-of-the art scenarios recognize the fact that interactions between different system components occur at specific scale levels. For example, a farmer works within a cropping system that is adapted to local environmental conditions. He ploughs, seeds and harvests his fields order to support his family by selling his products to the local or international markets. His activities only influence the local C-cycle, but the activities of all farmers regionally will cumulatively alter the global C-cycle. Often these activities are synchronized through coarser-scale market incentives. If C-sequestration becomes an additional reward (i.e. income), than this local farmer and many other will modify their activities to enhance income and the well being of the farmer’s family. 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 strongly qualitatively (e.g. story telling) but in the meantime, multiple scales are also taken into account in the 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 that of the landscape (spread and patterns).

In quantitative-qualitative scenario exercises, issues of spatial scale come up first in qualitative part. In the quantification phase, they arise as the spatial scales covered by the storylines differ from those at which the quantification is done (Fig. 1). In general, only the largest spatial unit of interest (scale 1) is covered by the storylines. This unit is then disaggregated into the spatial sub-units for which the development of the driving forces will be quantified (scale 2). In the next step, values for the driving forces in each "scenario region" are set. As the spatial extent of the scenario regions is usually larger than the computational units of the impact models (grid cells, administrative units), the driving forces must be downscaled to the latter scale (scale 3) such that they can serve as model input. Finally, scale issues need to be taken into account when interpreting the model output. In addition to the scale issues related to modeling itself, the influence of the spatial scales of the model input, i.e. of the downscaling of the driving forces, must be considered.

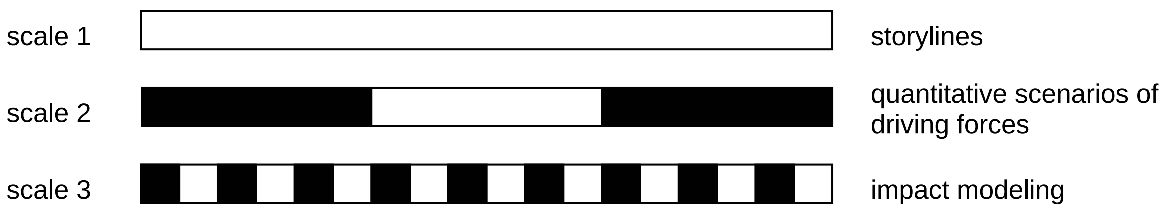

Fig. 1. A typical hierarchy of the spatial scales involved in scenario development. In section 2.2, a scenario exercise is presented in which storylines were developed at two scales, including the scale of the quantitative driving forces scenarios.

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" could be used.

In the following we present some methods for achieving the quantification (at scale 2 of Fig. 1) of the main drivers that is consistent with the coarse-scale (global) storylines (scale 1) and discuss the implications for the impact modeling results (scale 3)(Section 2.1). 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.

2.1 Quantitative downscaling of global scenarios

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

The development of the IPCC-SRES greenhouse gas emission scenario (Nakicenovic and Swart, 2000) represent an example of a model based downscaling method. Here, four global storylines were quantitatively interpreted and thus downscaled to four SRES world regions by applying six different global-scale models. In order to make the emission scenarios more comparable, "fully harmonized" scenarios where 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%). Each of the four global marker scenarios was computed by a different model and the spatially more disaggregated model results were aggregated to the four macro world regions, the SRES regions. There were no individual storylines for the four SRES regions.

The IMAGE 2 model, for example, which was used to obtain the marker scenario B1, does not perform any downscaling of the driving forces GDP and energy use, which were specified for the four SRES regions, to obtain scenarios for its 17 world regions. The GDP development in each of the 17 regions was obtained from the WorldScan model, which is very similar to IMAGE with respect to its regional breakdown, by changing the total factor productivity. For energy, the TIMER submodel of IMAGE was used to interpret the scenario storylines, and only the total final energy use was adjusted to the marker scenarios. Thus, the IMAGE scenario variables for 17 world regions are mainly a direct model interpretation (downscaling) of the global SRES storylines, which are in some cases scaled to the SRES region values (IMAGE Team, 2001).

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

In most cases, in particular when no model or theoretical rule is available, downscaling requires a heuristic approach. As an example we consider the quantification of scenarios on population and GDP for the “water part” of the scenarios in UNEP’s Global Environmental Outlook 3 for which the global model of water availability and water use WaterGAP (Döll et al., 1999; Alcamo et al., 2003) was utilized.

For the computation of water use in WaterGAP, the country-wise UN98 medium population projections are linearly scaled such that the total population change of the world regions agrees with the respective IMAGE interpretation of the SRES scenarios. The GDP growth of each country within a world region is assumed to be the same as the GDP growth of the entire region itself. The assumption that GDP growth of all countries within a region equals the regional average is particularly problematic if the absolute GDP-values differ strongly between the countries of the region. It might be better to assume, at least in the case of a converging world, that the growth rates of the region's countries converge until a certain point in time. This approach, however, would require an assessment of the country-specific growth rates, a country-specific macroeconomic modeling approach or, as will be discussed later, a refinement of the storylines on a regional scale.

In the next step, country-level or region-level driving forces need to be downscaled further, if highly resolved global impact models, e.g. with a resolution of 0.5°, are to be applied for impact modeling. As an example, population changes in global scenarios are only provided at the regional or country level, while present-day population is reliably available at a spatial resolution of 0.5 degree and below. In WaterGAP, the assumed changes of the country population, together with the changing split between urban and rural population is translated to grid cell population values such that cells with an urban population increase more than average if the urban population as a ratio of the total population of the country increases. Another approach to simulate the changing spatial distribution within a country is to base the scenarios on 2.5’ (≈ 4 km by 4 km at the equator) population maps for the years 1990 and 1995 (CIESIN, www.ciesin.org). Yet, the latter data lack a sufficient downscaling by themselves, as they are based on census departments and there is no convincing mechanism for downscaling onto the finer grid. Here we might expect significant improvements by using night light images as proxies for the downscaling procedures.

The country estimates of change in irrigated areas in the World Water Vision scenario up to the year 2025 were downscaled to the grid cell level by assuming that the changes only occur in cells that are 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 and the quality of the model and
- on the consistency and the spatial resolution of the changes of the driving forces that are applied as model input.

As an example, the driving force scenarios of the forces that drive water use are mainly given at the country level or even the world region level, while the output of a grid cell based water use model like WaterGAP is mostly averaged over river basins. When interpreting the resulting scenarios of water use in river basins, it is necessary to keep in mind, that the development of the driving forces inside the specific basin of interest might be rather different from the average development of the driving forces in the country in which the basin is located. Here we see a high necessity of keeping the restrictions and implications of the scaling issues more transparent for the final user.

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

In the case of less-than-global-scale 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 Shoemaker (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 the driving forces are mapped (Fig. 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.

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 bas
T9 Designation of nearby national parks
T10 Local customary law
T11 Destructive use of forests by outsiders

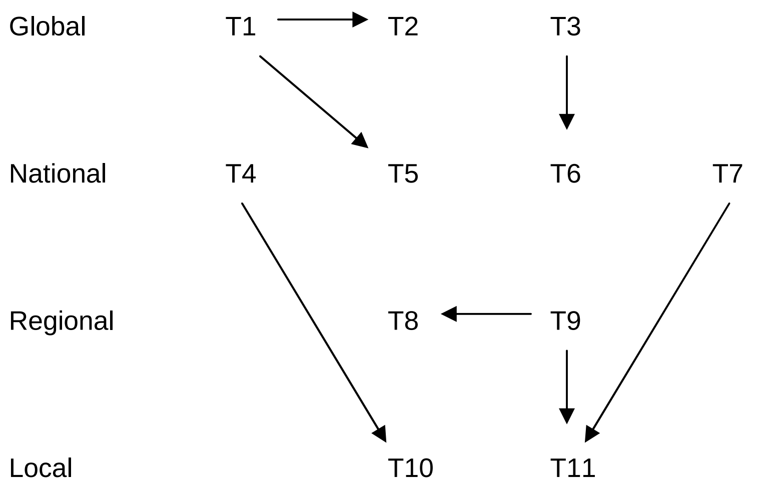

Fig. 2: Multi-scale relationship among drivers on community forest management (adapted from Wollenberg et al., 2000).

An example 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 reference scenarios for Piauí and Ceará were embedded into two of the global IPCC-SRES scenario families (Nakicenovic and Swart, 2000). These global scenarios are a suitable framework for regional scenarios as they include storylines, have international support and will be 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 (2003). Here, we will provide 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 exist in the region. Reference scenario A, “Coastal Boom and Cash Crops”, carries on the current trend of increased cash crop production for the Brazilian and external market, 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 has 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 (Fig. 3).

	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

Fig. 3. Correspondence of WAVES regional scenarios for Piauí and Ceará with the global IPCC-SRES scenario families (Döll and Krol, 2003).

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 RS A and RS B 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 the net migration and thus the total 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 the 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 the per-capita GDP of Brazil would increase by 2.2%/yr (RS A) and 2.0%/yr (RS B), 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 (Fig. 4), which 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) and 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. For private irrigation, the storylines for the eight scenario regions were interpreted by defining different extension rates for each scenario region, which were then downscaled to the municipalities by assuming that 50% of the additional areas is distributed homogeneously over all municipalities, and 50% in proportion to the 1996 irrigated area. Future public irrigation was located according to existing plans for specific irrigation projects.

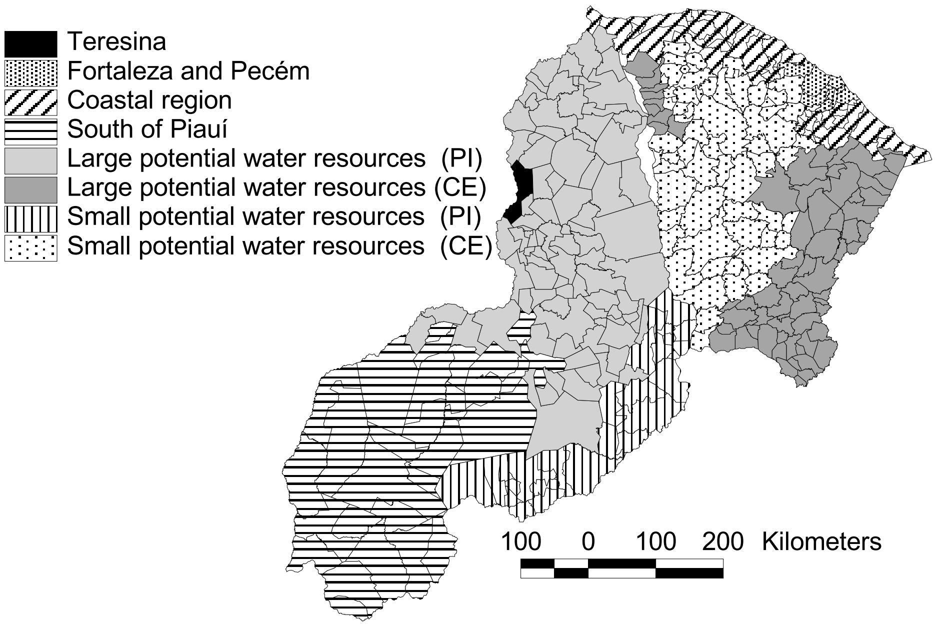

Fig. 4. The eight scenario regions of the study area Piauí and Ceará, two federal states in Northeastern Brazil. They are the spatial units for developing storylines and quantitative assumptions about the development of driving forces. Teresina and Fortaleza are the capitals of Piauí and Ceará, respectively. The smallest spatial units shown denote municipalities, for which system indicators were computed.

2.3 Multi-scale scenarios

2.3.1 The VISIONS multi-scale scenarios for Europe

The VISIONS project, which was funded by the European Commission within its 4^{th} framework program, has pursued another multi-scale approach to scenario building (Rotmans et al., 2000, 2001), developed in parallel and not subsequently. 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 consistent scenarios for Europe as a whole and sets of regional scenarios for three different regions (the Green Heart of The Netherlands, the North-West of the United Kingdom and Venice in Italy), respectively. All scenarios were build within a common conceptual 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 mutual information between the different scenario building processes methodological consistency was ensured which at the very end allowed to build integrated visions across scales.

All scenarios were build by iterating participatory and analytical methods, i.e. stakeholder workshops, data analysis, computer modeling and qualitative methods have all been applied. 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 was 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 highly illustrative as they contain regional examples and peculiarities. In case of the "Living on the Edge" vision, for example, the case of Venice serves as a detailed illustration of the effects of climate change on Europe: it was decided to build large protection constructions to preserve the cities cultural heritage.

From the methodological point of view, the VISIONS concept rested on the assumption that the common framework, the perpetuated discussion, and the vast number of possible combinations at the end will allow to build a consistent set of integrated visions for Europe. Thus the fact that the exercise was carried out within a single project can be seen as an important condition for the accomplishment of integrated visions. We therefore have to ask for methodological and organizational conditions for the success of such a parallel development of multi-scale scenarios.

2.3.2 The scenario exercise within UNEP's GEO-3

Within its latest Global Environmental Outlook (GEO-3) the United Nations Environmental Program (2002) developed a set of four scenarios for the time span of 2002-32. Though global in perspective each of the four scenarios "Markets First", "Policy First", "Security First" and "Sustainability First" was developed by an iterative process between a global scenario group, including modeling teams, and regional teams of experts. The task of the latter was not only to provide more details about the storylines, but also to provide quantification of the driving forces on a regional scale. Taking into account regional expertise not only allows for improved input compared to a purely "technical" downscaling of the drivers, but it may also provide better grounds for a regional ownership of the final product. Nevertheless, in some cases, e.g. the assessment of water stress within the different scenarios, the downscaling of driving forces was not sufficiently supported by the regional teams, and the quantification of important drivers like, in the case of water stress assessment, technological development or change of irrigated areas was carried out by the modeling teams themselves. It might also be criticized that only global models were used to illustrate the narrative scenarios without further check and refinement by regional models.

The resulting scenarios are, to a certain extent, multi-scale in nature. Within the "Markets First" scenario, for example, regional dimensions are 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 provides 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. A structurally similar attempt has been made for developing scenarios for the World Water Vision.

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 case studies (Kates and Haarman, 1992; Geist and Lambin, 2001; Petschel-Held and Lüdeke, 2001). It is the very strength of these "place-based" approaches to take into account the local context which includes issues of local responses to environmental changes taking place on very 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 this advantages can transferred to a global scenario analysis, i.e. how can local or regional scenarios be used to get a global picture of plausible future? There is, however, not yet any experience with this and we therefore restrain to a discussion of peculiarities of – existing or future – local scenario building exercises and how these at the very end might transpire into a global picture.

As a specific element, local scenario exercises often include local (traditional, indigenous) knowledge into the scenarios. For example, within an assessment of ecosystem services within the Western Ghats of India, Gadgil and colleagues have developed a set of scenarios based on three initial questions to the local people (Gadgil, pers. 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 the different answers of the people to these questions, the so-called "basic scenarios", are compared with scientific knowledge on interrelations, but also with coarser-scale scenarios which, for example, include economic issues like prices for agricultural commodities or wage labor availability. This step leads to a set of "enriched scenarios" which in a final step are "consolidated" in local workshops to ensure the acceptability by local users and the consistency with local knowledge.

In general there is a much higher degree in freedom in aggregation and upscaling than is for downscaling. This is due to the fact that downscaling covers the entire spatial domain of an exercise whereas, in most cases, for upscaling only a non-covering set of representatives is known which can in principle be part of an infinite number of coarser-scale ensembles. This degree of freedom makes the development of a plausible global future by means of local or regional stories without further assumptions not feasible. Nevertheless, the development of a family of scenario on scales from global to local does not only allow a richer set of plausible futures which are more powerful communication tools, but the scenarios within the set can serve as mutual consistency checks for plausibility.

Local scenario building exercise can have an impact on global scenarios within the following issues:

- Cross-checking a global scenario with (existing) fine-scale sets of plausible futures might add a significant degree of variability to the coarser-scale storylines and quantifications. As long as the different sub-global scale scenarios are mutually consistent as well as in accordance with some global constraints, the richness of sub-global scenarios can give hints on the range of geographical variability which might be difficult to disclose and visualize by a purely global – or any coarser scale – exercise.
- This enrichment of global scenarios, i.e. variability instead of averages, becomes even more salient in case of decision making: how do people react and cope with environmental changes now and in the future? A parallel development of local scenarios does even more allow a transfer of lessons learned. For the time being, global models are cannot capture these levels of human response to changes.

- Local scenarios can serve as a ground proof for the models used in the global-scale exercise. To what extend 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 and communication capabilities of scenarios. Yet, parallel scenarios on multiple scales face a problem related to the issue of time scales: due to the fact that small-scale processes are often much faster, including human responses, than global ones, scenarios on different scales might not necessarily be compatible with respect to their respective time horizons. Therefore care has to be taken when consistent scenarios on multiple scales are developed: whereas the global storylines and quantifications can tell plausible futures over the entire time horizon, the details of local and regional processes as represented in the local or regional scenarios might tell plausible futures over a much shorter time horizon only. Of course, this does not exclude that longer, yet less detailed, futures on the finer scales are constructed by the spatially explicit output of global models used in the global scenario development.

Another major problems of time scales in scenario development is the potential delay between different actions assumed to happen along 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 often is in order of magnitude of time horizons for the scenarios itself (e.g. 30 years for the GEO-3 exercise and 50 years envisaged for the Millennium Ecosystem Assessment). Therefore it is difficult to include the direct effects of all plausible actions within a storyline into the scenarios. 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 exhibit an effect contrary to the long term changes: due to the indirect cooling effect of aerosols, the global mean temperature for the "Sustainability First" scenario is even higher within the next 20 years than in case of the "Markets First" or "Security First" scenarios. This is due to the much lower emission of sulfur dioxide within the "Sustainability First" scenario. The effect is reversed only far beyond 2030 when the reduced emissions of carbon dioxide become effective 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 a climate model is in general assumed to be reliable over a time horizon of a hundred years or even more, economic models might have a much shorter time horizon. This is particularly true in case of models with a high sectoral disaggregation, e.g. computable general equilibrium models, whereas macro-economic growth models, e.g. Ramsey models, might give trustworthy results for GDP or other macro-economic variables on much longer time horizons. If quantitative models are not available for the topic and time horizon of interest, the combined story-and-simulation approach allows fill the topic qualitatively. 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 most 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, e.g. the break down of the communist block in the late 1980s, catastrophic events like major earthquakes or rapid climate changes. It is a subtle issue whether to include surprises 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, e.g., 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.

4 Methodological challenges and ways to tackle them

Sections 2 and 3 of this paper show that scale issues raise some essential methodological problems. These methodological challenges related to scale issues in scenario development differ depending on the concrete approach followed in the scenario process, i.e. whether we focus on the consideration of cross-scale linkages within the quantification phase of the scenario development or whether we already start with a multi-scale storyline 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 tackle them.

How can we make scale implications and restrictions transparent, in particular those related to the quantification of driving forces and the model output?

The discrepancy between the scales of the storylines, the changes in driving forces and the computational units of models may lead to insufficient transparency of the scenario results such than, for example, the spatial resolving capacity may be overestimated. This missing transparency might limit the usefulness of the scenario. A typical example for the scale discrepancies is the necessary downscaling of a global storyline to GDP (regions), population change (within a country), climate change (2.5 degree) and impact model output (e.g. 0.5 degree).

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

1. Document scaling procedures
    1.1. by showing a table with the scenario variables and their scale of quantification
    1.2. by presenting a graph which shows the major scale interlinkages, or
    1.3. by providing indicator maps with different spatial resolutions
2. Keep scaling procedures as simple as possible
3. Analyze one level below the target level and publish results to show restrictions of scale in maps and tables
4. Provide scaling methodology in technical background documents or journal articles but not within the storylines
5. Make 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.

saliency of individual levels. Good practices and approaches to achieve these have been identified and are listed in Table 1. In addition, however, there are major methodological problems related to quantitative aggregation and disaggregation that remain to be solved (compare section 2).

Table 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 • Provide communication • 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 Clear linkages	• Continuous documentation of scale-related decisions • Bring up scale-related issues up front • Define only a few interlinkages between scales • Different consistent but not necessarily the same indicators at all scales
Scale consistency vs. saliency on individual scale	Flexible framework as there are tradeoffs Analyze one level deeper than will be published	• Provide common ground to all groups • Fellow concept where in the coarse-scale scenario group there is a contact person for each fine-scale scenario group, or, one scenario group for all scales plus scale-specific support groups • Use (different) models at all scales • Common sectors, factors, actors

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

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 help to review each individual scenario: 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. To include local aspects and the knowledge about it enriches scenarios as it adds variety instead of averages. To achieve this inclusion it is necessary to bridge the gaps between global and local knowledge, but also between scientific and non-scientific, e.g. indigenous, knowledge. This requires new and innovative methods of integration.

If global scenarios are available (first), take more care in the "local interpretation" of model results and formulate local implications based on systems knowledge. Besides, it would be possible to tell local-scale narratives based on the regional output of the quantitative part of the global scenario and additional local knowledge not represented in the global model. If local scenarios are available (first), try to develop large-scale storylines and quantifications which consistently subsume the local scenarios. In addition, a typing of local scenarios, e.g. according to the Syndrome approach, has the potential to enrich global scenarios. Further research and new experiences are needed to learn how to take advantage of independent local scenarios when deriving macro-scale scenarios. In particular, the question remains how emergent properties, e.g. globally relevant value change in the Sustainability First scenario in the GEO-3 as a result of multiple local and regional initiatives, can be assessed and included in a quantitative way. Though it is a strong advantage of the combined qualitative-quantitative approach of scenario development that the inclusion of emergent properties is possible on the qualitative level, their (partial) quantification would allow to assess the conditions for emergence in a more systematic and profound manner.

5 Conclusions

The consideration of multiple scales provides some major opportunities for enriching and empowering 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 interaction between processes occurring a the different scales are considered. Decision-making with respect to issues of sustainable development takes place on all scales, from local coping strategies in changing environments to global governance issues like the UN-conventions. It is the interplay of these different decisions which shapes our future and should thus be taken into consideration in the development of scenarios. In addition, the legitimacy of scenarios is improved. Developing and telling stories on multiple scales might provide a much broader ownership of scenarios and can thus induce broader discussions on better actions to shape our future. The potential usage of a scenario increases, whenever a qualitative storyline or its quantitative specification includes aspects relevant for an additional stakeholder with another domain of action. Thus, we recommend to address scale issues in each scenario development process, beginning with the addressees of the scenarios and the objectives of scenario development.

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