New concepts for development of integrated multi-scale scenarios within the SCENES project

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Abstract

Within large integrative, multi-scale scenario studies two kinds of problems are often encountered. It is problematic to fully link narrative storylines and quantitative models, and cross-scale interactions could be improved. This study aims at testing and applying new concepts for scenario development that can help to bridge those gaps in the current methodologies. It is carried out in the framework of a larger EC-funded project, SCENES[1].

Introduction

In today's world where everything is increasingly connected with everything, there is an ever stronger need for integrated assessments that tackle current and future problems. Scenario development is widely considered as a valuable tool for integrated assessments that focus on this kind of complex, uncontrollable and uncertain problems (Peterson *et al.*, 2003; Biggs *et al.*, 2007). The Millennium Ecosystem Assessment describes scenarios as "plausible and often simplified descriptions of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces and relationships" (Millennium Ecosystem Assessment, 2005).

Scenarios can be either quantitative (numbers) or qualitative (words), and most assessments nowadays combine both. This combining is often done via approaches like the Storyline And Simulation (SAS) approach (Alcamo *et al.*, 2001).

The quantitative scenarios are mainly constructed by experts in the form of mathematical models. Qualitative scenarios consist mostly of storylines, and are more often produced in a participatory manner. Both types of scenarios have their strengths and weaknesses, which are described in more detail by (Rotmans, 1998). Models are consistent and offer a good system understanding; the need for hard data is however a drawback. Storylines (especially when created by participatory methods) tend to be less consistent and internally coherent. They give a broader perspective

[1] SCENES; Water Scenarios for Europe and Neighboring States; www.environment.fi/syke/scenes

including behavioral changes and other aspects that are difficult to model and quantify. The participatory development procedure is a good way to engage stakeholders.

Problem definition

One of the (practical) difficulties with the SAS-approach as proposed by Alcamo, is the link between narrative storylines and quantitative models. (Kok and Delden, in press). The concept of the SAS approach (see figure 1) clearly identifies the need for feedback between modellers and storyline developers, but in practice this iterative procedure is not executed to its full extent, often due to lack of time or budget. Additionally, the models are made by experts who try to use the information from the narratives. The difficulty is that the qualitative scenario products are often quite vague and subjective (Alcamo *et al.*, 2006). This is largely due to the fact that qualitative scenarios by definition do not give hard data because they try to capture the subjectivity of the unknown future. Stakeholders will for instance say that the population will grow faster in one scenario than in the other, but they are often unable to tell what the exact growth rate is. Experts thus have to interpret the storylines while quantifying, which is often a rather subjective exercise (Verburg *et al.*, 2006). At the same time, there are also variables in the narratives that are by nature hard to quantify, such as happiness, standard of living and state of the environment. This kind of variables is often not represented in the model, widening the gap between the narratives and the models even further.

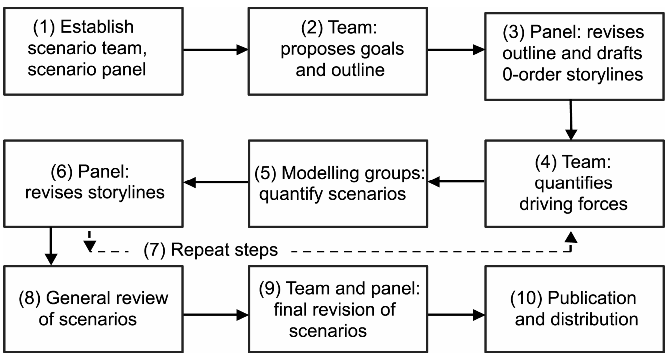

Fig. 1. Storyline And Simulation approach (based on Alcamo, 2001)

A second issue when developing scenarios is the scale issue. Most of the recent large-scale assessments are focused on multiple scales, as it is important to understand the relations between the scales (Biggs *et al.*, 2007; Zurek and Henrichs, 2007), and the driving forces, processes, perspectives and actors at these scales (Lebel *et al.*, 2005). Processes can have larger effects on some scales than on others (Millennium Ecosystem Assessment, 2003), which might be missed when studying just one scale. Additionally, cross-scale interactions are important in sociological economical and ecological systems (Willbanks and Kates, 1999). Multi-scale scenarios can better maintain relevance across the multiple scales (Biggs *et al.*, 2007) and be more relevant for all decision-making scales (Wollenberg *et al.*, 2000). However, formal approaches for linking the scenarios across the different scales are not yet very well developed or tested. Most multi-scale scenario exercises have been primarily top-down, with the emphasis being on downscaling of higher level processes. (Biggs *et al.*, 2007) According to (Biggs *et al.*, 2007) this is because of the difficulties that arise when incorporating diverse and inconsistent elements from smaller scales into the larger scale storylines.

Background – The SCENES project

This study is part of a larger project, called SCENES. SCENES is a 4 year EC 6th FP research project that started in late 2006. It aims on developing and analysing a set of comprehensive scenarios of Europe's freshwater futures up to 2050. It consists of a highly participatory part that will develop qualitative scenarios (storylines) and a quantitative part (WaterGap, indicators and drivers). The different parts will interact with each other via the SAS-approach (Alcamo *et al.*, 2001). The working hypothesis of SCENES is that one dimensional, single sector focussed policies and directives, relying on a limited set of characteristics of the water system, will not lead to a sustainable future of European waters. Hence an integrated approach is needed.

The SCENES scenarios will:

- provide a reference point for long-term strategic planning of European water resource development,
- alert policymakers and stakeholders about emerging problems,
- allow river basin managers to test regional and local water plans against uncertainties and surprises,
- be both qualitative and quantitative.

Two of the main goals of SCENES are to improve the connection between the multiple scales and to improve the SAS-methodology. In order to achieve those goals in the first year rapid progress had to be made, resulting in a initial set of fast-track scenarios. Additionally an improved scenario development methodology has been developed. The remainder of this paper reports on the initial efforts to achieve those two goals.

Research set-up

Within the framework of SCENES, the scenario development process will be carried out and analysed in the majority of the 8-10 case studies (Pilot Areas, see figure 2) that were identified. An elaborate training programme, including a joint training workshop at Wageningen University, will ensure that all case studies have a similar understanding of methods that we suggest to use.

During the first year of SCENES, European fast-track scenarios were created which will be used as input for the downscaling, participatory process. The overall objective of SCENES is to create scenarios on both the Pilot Area level as well as the pan-European level. The scenarios will also be compared with (WaterGAP) model output. In order to successfully iterate between the two scales and between the storylines and the quantitative model, rapid progress has to be made in the first year. This is why the so-called fast-track scenarios has been set up, based on the GEO-4 scenarios.

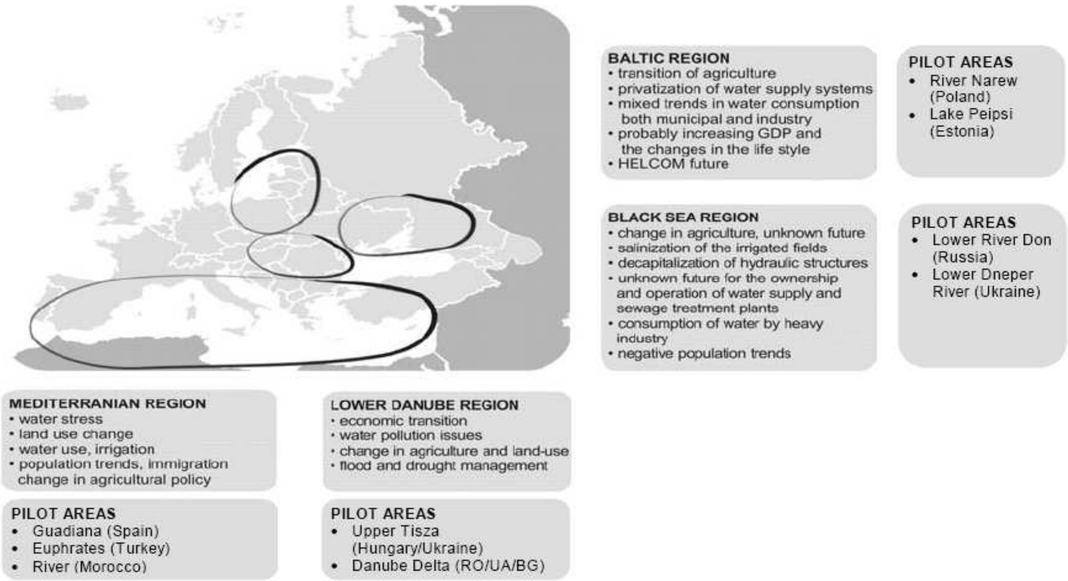

Fig. 2. Study area including the four regions and Pilot Areas (source: (SCENES, 2006))

The updated methodology

We propose a updated, partly new scenario development methodology that builds upon existing scenario development methods. More than in existing methods, we promote the use of qualitative and semi-quantitative approaches. It is assumed that involving stakeholders beyond the more traditional storyline development will increase their input in the quantification of their products. Included are well-known qualitative methods such as rich pictures, narratives, timelines and/or questionnaires (e.g.(Patel *et al.*, 2003; Evans *et al.*, 2006b)); but it includes also the semi-quantitative method Fuzzy Cognitive Maps (FCMs) (Kosko, 1986; Kosko, 1993; Özesmi and Özesmi, 2003) and other semi-quantitative methods. FCM is a conceptual modelling technique that focuses on feedbacks within a system.
First an overall description of the updated methodology is given, after which we will focus on FCM as it is the main new tool for scenario development. The other methods will not be discussed here.

Four steps

The new scenario development methodology consists of four steps in which the different qualitative and (semi-)quantitative methods are combined (van Vliet *et al.*, 2007):
step 1. Present and near future.
step 2. Looking at the future (long-term visions).
step 3. Critical review of developed visions.
step 4. Playing it back (short-term policy options).

These steps are chosen in order to gradually build and refine the storyline of the scenarios. A thorough understanding of the stakeholders' view of the present system is needed in order to understand why they think the future might evolve in a certain way. In this first step a Fuzzy Cognitive Map is made for the present system. In the second step visions are developed. These long-term visions show how the stakeholders' perception of the future might look like, given the external drivers from the fast-track scenarios. The visions will be enriched in step 3, where the stakeholders will critically review the developed visions. The stakeholders will be confronted with there own work and with new input from the pan-European level and models. This should lead to a more thorough story behind the visions. Fuzzy Cognitive Maps will be made of each vision in order to represent the future system under each vision separately. In Step 4 the focus is moved from the end visions to the time lag between the end visions and the present. The focus will be mainly on short and middle-term policy options that are needed to reach the desired visions. The developed Fuzzy Cognitive Maps form the framework for this exercise in order to stimulate system thinking. (van Vliet *et al.*, 2007)

Fuzzy Cognitive Maps

As said, FCMs as main new addition in the scenario development method, deserves extra attention. Axelrod (Axelrod, 1976) introduced cognitive maps for representing social scientific knowledge. He was the first to use cognitive maps to show relations among variables that where described by people instead of the researcher him selves. Cognitive maps show relations between variables in a graphical map. The variables are the nodes and the relations the arrows between them. Cognitive maps are a tool for formalizing understandings of conceptual and causal relations (Kosko, 1986).

Kosko (Kosko, 1986) extended the idea of cognitive maps by adding fuzzy logic, hence the name Fuzzy Cognitive Map (FCM). Besides the graphical representation of a FCM, it also has a mathematical representation in the form of a vector matrix calculation. A FCM consist of nodes (C), being the concepts or variables, with connections (e) between them that represent the causal relationships between the concepts. Each connection gets a weight eij (between 1 and 0) according to the strength of the causal relationship between the concepts Ci and Cj that it is connecting (Kosko, 1986). A relationship can be either positive (when one concept increases the other one also increases) or negative (when one increases, the other one decreases) (Kok, in prep.). This can be represented in a matrix. Each concept will also be given a weight consisting with the current weight in the system, which forms the state vector. The next state of the system can then be calculated via a vector matrix calculation. If iterated the system will (or not) reach a new balance. The weight of each concept in that end balance shows whether or not it will increase or decrease. All outcomes are however relative. You can only see if one concept will become bigger than the other, but how much bigger it gets is not defined. (Kok, in prep.) It does however give a good insight in how the system is working. Kok (in prep.) and also (Özesmi and Özesmi, 2003) gives a detailed overview of how FCMs can be constructed.

Fuzzy Cognitive Maps (FCMs) have been used in various research projects (e.g.(Cole and Persichitte, 2000; Özesmi and Özesmi, 2003; Giordano *et al.*, 2005)), but so far they have not been used in the scenario development processes. The key underlying assumption however is that FCMs can play a useful role in scenario development. FCMs can be used to structure the outcomes of the participatory processes by introducing system thinking. FCMs will force the participants to make the systems from which they reason explicit, and therefore more transparent. The continued attention on system understanding should also lead to more internally coherent storylines. This will facilitate an objective translation and will increase the reproducibility of the scenarios as developed by stakeholders. It will also improve the quantification of the storylines.

Within SCENES, FCMs will be created by stakeholders in a visual way with boxes and arrows. The FCMs will be created in a participatory setting, as part of the scenario development workshops. These boxes and arrows can then be represented in a mathematical way as a vector matrix analysis. This way it becomes easy to acquire insight in the behaviour of the system, as perceived by the stakeholders. This will lead to a better system understanding among the stakeholders and the researchers.

Multi-scale

Within SCENES, the Pilot Area scenarios will be up-scaled to the regional level and subsequently used to enrich the pan-European scenarios. The up-scaling process will be carried out either by a group of regional experts or a regional stakeholder panel (Baltic region) that will attempt to translate the Pilot Area results to regional scenarios. The three-level process of scenario development in SCENES (see figure 3) makes it to an excellent opportunity to study cross-scale differences and interactions. At least one iterative cycle from European level to Pilot Area and back will have to be made. It is therefore crucial that the scenario output from each Pilot Area is methodologically consistent, thus enabling comparison and combination. This is one of the reasons that FCM will be used. Several FCMs can be combined with each other to form one new FCM (Özesmi and Özesmi, 2003). We also strive to keep the methods that are used in the different Pilot Areas the same. The local scenarios will be created within the boundaries given by the fast-track scenarios.

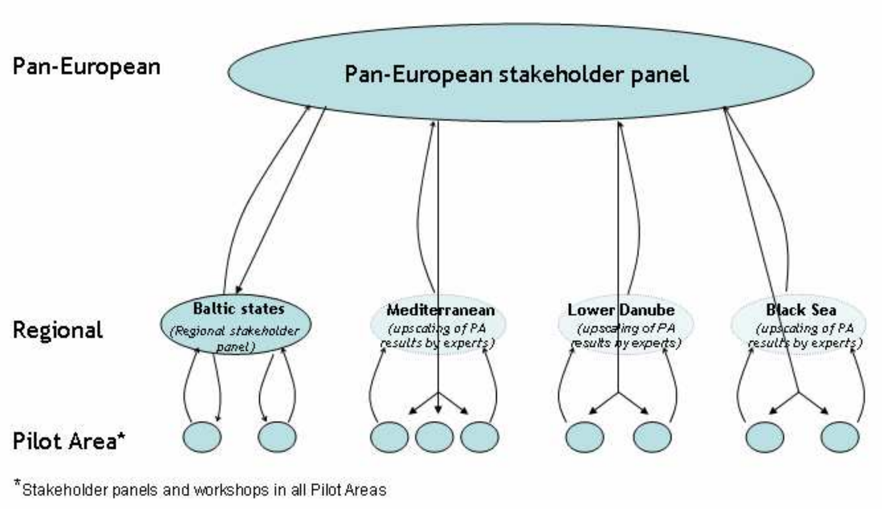

Fig. 3. The multiple scales in the scenario development process

Link storyline and simulation

Kok (Kok, in prep.) states that Fuzzy Cognitive Mapping can help in (a slightly revised form of) the SAS-approach. It can be used to structure the stakeholders' perceptions and the semi-quantitative output of this method can facilitate the quantification of the storylines.

By combining qualitative storylines and semi-quantitative FCMs, a product is created that is closer to the language used by modellers. The perceived systems can be compared with the system as understood by the modellers. This will help to bridge the gap between the stories and models, or at least make it smaller.

The FCMs can also indicate what the main drivers in the system are, and give indications on what elements form good indicators for system change. This information will be used by the work packages within SCENES that deal with drivers and impacts, by which it can also flow back to the modellers.

Figure 4 provides an overview of how semi-quantitative methods (such as FCM) can be used to increase the link between narratives and models. They can be used in the quantification phase, as an intermediate 'picture' between storylines and models, and they can be used in the feedback process from models to storylines.

As said, FCMs will be made of the present and the future. The future FCMs are derived from the storylines, which also serves as a check for their internal consistency (1).

The FCMs can be used in the quantification process (2), but also directly by the modelers (3) as they also give input on how the system is perceived. This system perception of the stakeholders can then be compared with the system perception of the model. The feedback from the models to the storylines (4) can also be either direct, by showing the stakeholders the model output, or through FCMs by showing the difference in system understanding between the stakeholders FCM and a (F)CM derived from the model.

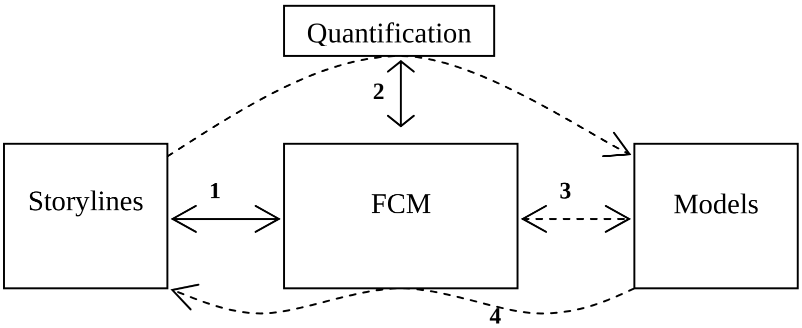

Fig. 4. FCM in the quantification process

Last but not least, the FCMs also form a product in its own right that can provide systematic, model information based on qualitative variables, without the need for hard data. This potentially richer system description can possibly serve as a stepping-stone between the narratives and the models, incorporating the best of both sides.

At the same time, however, the combination of different methods serves to gain a better understanding of the potential downsides of FCMs. In FCMs, time is ill defined and incomparable factors are compared. Factors are included that do not usually operate at the same temporal scale; the iteration steps are only iteration steps, not time steps. Another problem is that in FCM all different kind of factors, such as social, environmental and institutional, are compared, even if this is not logically possible. Finally, relationships in a FCM are only semi-quantified. It is therefore difficult to interpret the output in absolute terms. (Kok, in prep.) It is assumed that the ease of applying an FCM in a participatory setting will outweigh these potential disadvantages. Some of the key characteristics of storylines, FCMs, and mathematical models are given in Table 1.

Table 1 Some characteristics of storylines, FCMs and models

Storylines	***Fuzzy Cognitive Maps***	***Models***
- *qualitative*	- *semi-quantitative*	- *quantitative*
- *very broad*	- *system understanding*	- *system understanding*
- *not always internally coherent*	- *no hard data needed*	- *limited set of variables*
- *many of variables*	- *shows effects of changes in feedbacks*	- *need of hard data*
- *social effects included*	- *can handle all type of variables*	- *hard to include social effects*
- *vague*	- *social effects included*	- *fixed set of assumptions*
- *flexible*	- *flexible*	- *less flexible*

First results

The qualitative methods have been tried and tested many times before in various projects (e.g.(Wollenberg *et al.*, 2000; Patel *et al.*, 2003; Millennium Ecosystem Assessment, 2005; Evans *et al.*, 2006a; Kok *et al.*, 2006a; Kok *et al.*, 2006b)). They have often leaded to interesting and useful outcomes that also have impact on the targeted levels. The semi-quantitative methods are less well tested in scenario development. The use of FCM in participatory processes has mainly been tested as being derived from interviews. We have tested our approach of developing FCMs in groups once during a two day training in Bari, Italy (CERAM). The second test will take place shortly after the deadline of this paper during a four day scenario development training in Wageningen, the Netherlands (WU).

A week after the Italy workshop a questionnaires was send to the participants. They where asked a number of questions on the used methods and other aspects of the course. Answers could be given on a scale of 1 to 5, with 5 being positive and 1 negative.

The participants of the Italy workshop found FCMs very usable in the first stage of scenario development (describing the present), giving this a score of 4.4 on a scale of 1 to 5. The whole idea of using FCMs was quite clear to everybody after a one hour presentation (4.3). The participants also felt that they contributed more to the final product of the FCM exercise than of a visioning, collage making exercise (3.7 versus 3.1). The lower score for the collage making might also have been caused by the fact that the collages where made on a computer, giving the actual user of the computer more decision power as when it would have been conducted in the ‘normal’ way of cutting pictures from magazines.

The outcomes of the questionnaire give a strong indication that with the adopted methodology, FCMs were quite easy to teach and execute with the group of stakeholders present.

Conclusion

The SCENES project aims at developing integrated, multi-scale water scenarios for Europe, for all major river basins. It will make scenarios embedded in the Water Framework Directive, and will complement and stimulate ongoing activities. Within this overarching project we hope to improve the current state-of-the-art of participatory scenario development, by employing qualitative, semi-quantitative, and quantitative methods over a range of scales.

We hope that our new methodology will prove to be effective. The first test with FCM development in a participatory workshop setting was positive. The effectiveness for the up scaling and in the tuning between the storylines and models has yet to be tested.

Fuzzy Cognitive Maps seem to be a useful, easy to teach, and easy to use tool that can play an important role in bridging the gap between scenario storylines and models.

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