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How to make environmental models better in supporting social learning? A critical review of promising tools

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Abstract: Social learning, defined as a convergence in the perspectives of stakeholders on a complex (environmental) problem and its possible solutions, is considered an important mechanism in developing integrated solutions requiring broad societal support and concerted action. Quantitative environmental models can support social learning of stakeholders by providing a platform for communication and integration and by allowing exploration of the consequences of different choices. However, in many integrated assessment projects that combine quantitative modelling with stakeholder participation, the models fail to play a significant supporting role in social learning. Two major reasons for this failure are: (1) stakeholder perspectives are inadequately integrated into the model, and (2) insufficient iterations are made between model outcomes and stakeholder choices. In recent years, a number of software tools have become available that may help to remedy these shortcomings. For instance, with tools that link conceptual models with quantitative models the integration of stakeholder perspectives could be made more efficient. Other tools may make the feedback between model outcomes and stakeholder choices more efficient, for example, interactive visualisation or scanning tools. However, our analysis of the state-of-the-art reveals that most of these tools have not reached the stage of a fully functional version and so far none have been evaluated in real cases with real stakeholders. The major bottleneck in the interaction between stakeholders and quantitative models appears to be model complexity, and the tools discussed in this paper do not adequately address this problem. We conclude therefore, that if the aim is to better support social learning of stakeholders, the models used in integrated assessment must be simplified and the participatory processes intensified. For integrated assessment modellers this means that much more emphasis should be placed on the investigation of options to reduce model complexity.

***Keywords**:* participatory integrated assessment; social learning; participatory modelling; stakeholders

1 INTRODUCTION

Social learning, defined as a convergence in the perspectives of stakeholders on a complex (environmental) problem and its possible solutions, is considered an important mechanism in developing integrated solutions requiring broad societal support and concerted action [Röling 2002]. In participatory, model-based integrated assessment [PIA, Hisschemöller et al. 2001], social learning has therefore started to attract growing attention. The quantitative models used in these assessments can support social learning of stakeholders in two major ways [De Kraker et al. 2011]. First of all, the model provides the feedback link between choices and consequences that can turn the PIA process into an experiential, double-loop learning cycle when reflection on model outcomes is fed back to the problem definition stage. Second, the model provides a platform and structure for the stakeholders to communicate, negotiate and integrate their perspectives. However, in many PIA projects that combine modelling with stakeholder participation, the models fail to play a significant supporting role in social learning [De Kraker et al. 2011]. Two major reasons for this failure are: (1) stakeholder perspectives are inadequately integrated into the model, and (2) insufficient iterations are made between model outcomes and stakeholder choices. In recent years, a number of tools have become available that may help to remedy these shortcomings. For instance, with tools that link conceptual models with simulation models the integration of stakeholder perspectives could be made more efficient. Other tools may make the interaction between model outcomes and stakeholder choices more efficient, for example, interactive visualisation or scanning tools. In this paper we review the state-of-the-art of these tools. We discuss their potential and their major limitations and check whether a fully functional version of the tool is available and whether it has been tested in real cases with real stakeholders. The tools are divided into two groups, depending on the major shortcoming primarily addressed with the tool. The field covered is integrated assessment of natural resources management strategies and policies, in particular water management and land use. In the final section of the paper we present our conclusions as well as an outlook on the way forward.

2 TOOLS TO ENHANCE THE ROLE OF MODELS IN SUPPORTING SOCIAL LEARNING

The focus of this paper is on participatory integrated assessment of complex issues (PIA), typically combining a broad, integrated, quantitative model-based assessment with a long-term outlook on the issue and its possible solutions. As such PIA represents a specific type of participatory modelling [Bots & van Daalen 2008], and differs from other approaches in participatory modelling that have a more narrow focus and/or more short-term orientation. In two of these approaches, mediated modelling [Van den Belt 2004] and companion modelling [Bousquet & Trébuil 2005], computer models appear to be much more effective in supporting social learning than in model-based PIA. This is not surprising, as consensus-building and collective learning are explicit goals in these approaches. In both approaches, stakeholders are involved in model development from the start, through graphical interfaces or role-playing games. Stakeholders can bring in their views either by building the model together or through modellers working with highly flexible models. Frequent iterations, collective reflection on model outcomes and feedback to the definition of the problem and the range of possible solutions are important elements in both approaches. The advantage of this highly participatory approach is that the computer models used to assess options, will be generally accepted by the stakeholders as salient (relevant to their concerns), legitimate (reflecting their values and interests) and credible (in accordance with their causal beliefs) [Cash et al. 2003]. A drawback is that the approach is very time-consuming and resource intensive. Even with companion modelling, focussing on local communities and well-defined problems, it takes several years to complete the whole process and scaling up is therefore problematic [Lynam et al. 2002, Barnaud et al. 2007].

A more intensive participatory modelling approach similar to mediated or companion modelling may thus increase the effectiveness of quantitative models in supporting social learning, but to be feasible it must be made more efficient, given the complexity of issues and models in PIA and the usual limitations in time and resources. A number of recent developments suggest that there is scope for more efficiency in two major aspects. One aspect is the time-consuming integration of stakeholder perspectives into the complex quantitative models used in PIA. In section 2.1 we discuss tools addressing this issue by facilitating the translation from stakeholder perspectives to quantitative models or by making these models more flexible. Another aspect is the limited time that is usually available for interaction between the stakeholders and the model, often severely restricting the number of iterations and loops in the learning cycle. Tools addressing this issue are discussed in section 2.2. These include novel tools to visualize or to scan interactively model outcomes, and tools to determine the complete solution space and trade-offs between multiple objectives.

2.1 Tools facilitating integration of stakeholder perspectives

In the problem definition phase of an integrated assessment, qualitative, conceptual models, such as relational diagrams are often used to make stakeholder perspectives on the system and the problem at hand explicit. If stakeholders would make use of more structured, causal models to represent their perspectives, these might be better understood by modellers and more easily translated into quantitative, mathematical models, either from scratch or by adapting existing models. Two tools that have been suggested to have the potential to improve in this way the translation of stakeholder perspectives to quantitative models are Qualitative Probabilistic Networks [QPN, Van Kouwen et al. 2008, 2009] and Fuzzy Cognitive Mapping [FCM, Van Vliet et al. 2010]. Both tools are forms of computer-based cognitive mapping, a technique to represent a problem or system as a network of major elements and the causal relationships between them. QPN is qualitative and only distinguishes between positive, negative or neutral causal relationships. Van Kouwen et al. [2008, 2009] demonstrated that QPNs can be jointly developed by a group to represent a complex problem and also that complex quantitative models can be translated into a QPN. However, the tool has not been developed beyond this point: translation of QPNs into quantitative models has not been attempted (Van Kouwen, pers. comm.). FCM is a semi-quantitative form of cognitive mapping: the relative strength of each causal relationship is expressed with a number between 0 and 1, and the variables are given an initial weight. The development of the variables (increase, decrease, stable) can be assessed by stepwise calculating the net effects of the relationships in the network. Van Vliet et al. [2010] demonstrated that FCMs could be used by stakeholders to represent their perspective on the system and the problem, and that this formal tool did not significantly limit their freedom of expressing their views and ideas. FCMs could also be used by modellers to represent an existing quantitative complex model of the same system allowing a comparison between the stakeholders' and the modellers' perspectives [Van Vliet 2011]. Attempts to integrate stakeholder perspectives into the quantitative model on the basis of this comparison have not been made however. Van Vliet [2011] concludes that there are a number of obstacles to directly linking FCMs and quantitative models and that the potential of FCMs in this respect is rather as a tool for communicating a complex quantitative model to stakeholders.

Another avenue to facilitate integration of stakeholder perspectives into quantitative models is to make these models more flexible. Over the past decade, the tendency for quantitative models for natural resources management has been to become larger and more complex in an attempt to support comprehensive, integrated assessments. An alternative to creating a single, large integrated model, is to link models for different sectors or levels of scale in an integrating framework. Examples are the 'model chains' developed in several projects on integrated assessment of land use policies in the European Union: EURURALIS [Westhoek et al. 2006], SENSOR [Helming et al. 2008] and SEAMLESS [Van Ittersum et al. 2008]. In particular in SEAMLESS much attention has been paid to develop a modular software architecture that enables flexible coupling of models and tools [Ewert et al. 2009]. Flexibility in spatial and temporal scale of the system to be analysed is achieved by including models that cover the range from farmer's field to the entire European Union. Flexibility in the selection of policy performance indicators is provided through a large library of available indicators. In theory, there is also flexibility in model selection, but in practice it will require specialist expertise, new datasets and considerable work to include another (existing) model in the framework. The same applies to flexibility in the type of policy to be assessed: substantial reprogramming would be required to go beyond the currently available set of policies [Uthes et al. 2010]. As the component models are complex by themselves, structural changes in the system description, apart from temporal and spatial scale, cannot be easily accommodated. Whether the current flexibility of the

SEAMLESS Integrated Framework is sufficient to integrate the perspectives of stakeholders in real cases has not been tested yet.

Anticipating diversity in perspectives with a ‘pluralistic’ approach [Van Asselt & Rotmans 2002] is another way to achieve more flexibility in quantitative modelling to accommodate stakeholder perspectives. In the pluralistic approach, an integrated assessment is conducted with scenarios and models based on a limited number of stereotypical perspectives derived from Cultural Theory. A different perspective results in different choices for the values of input data, boundary conditions and model parameters, within the margins of uncertainty about these factors. The approach has been applied to river management [Middelkoop et al. 2004], but not in a participatory setting. An interesting experiment to apply the approach in a participatory way is the interactive water management game developed by Valkering et al. [2009]. Depending on the dominant perspective among the players, representing stakeholders, the ‘rules of the game’ can be adapted. These rules include interpretations of model uncertainty, i.e., typical parameter settings of the underlying water system model. The game includes ‘learning phases’ during which the players are stimulated to reflect on the consequences of different perspectives on the sustainability of water management. However, the game has not been developed in this direction beyond the prototype stage and has not been tested with real stakeholders. A major obstacle in participatory application of the pluralistic approach is that the stereotypical perspectives from Cultural Theory are not found in their pure and consistent form among real stakeholders [Valkering et al. 2011], who therefore may argue that their perspectives are not adequately represented in the assessment.

2.2 Tools facilitating feedback between model outcomes and stakeholder choices

The faster and better stakeholders can grasp model outcomes with regard to the performance of options, the more different options they can discuss and evaluate with subsequent runs of the model. Visualisation of numerical model outcomes is key in this respect and over the past decade much effort has been put into the development of graphical user interfaces that enable faster and better interpretation of outcomes. An aspect that is difficult to bring across to stakeholders are the modelled consequences of policy options for landscape quality. In the SEAMLESS project a novel tool was developed (Seamless Landscape Explorer) that generates a three-dimensional (3-D) image of the future landscape resulting from computed land use changes [Griffon et al. 2011]. The 3-D landscape images can be explored from various angles and serve as input for stakeholder discussions on perceived landscape quality. Griffon et al. [2011] applied the tool to visualise four land use change scenarios in a French Mediterranean region. A stakeholder panel assessing various methods of visualizing the scenarios preferred plain maps as a basis for discussion over 3-D views of the landscape. The researchers suppose that the stakeholders are suspicious of being manipulated in case of high-quality 3-D animations as these are nowadays commonly used for commercial business presentations.

Another approach to enable faster and better insight into model outcomes are ‘scenario scanners’. These are interactive graphical interfaces that enable users (e.g., stakeholders) to rapidly explore the outcomes of a range of options as calculated by complex integrated models or model chains. Examples of this approach are the Sustainability Impact Assessment Tool (SIAT) developed in the SENSOR project [Verweij et al. 2010] and the EU-ClueScanner based on the EURURALIS project [Koomen et al. 2010]. The high speed of model-user interaction is achieved by performing (part of) the model calculations for a range of options prior to confrontation with the users. The model calculations may then be stored in a database which can be interactively explored [Verweij et al. 2006]. Alternatively, the scanner makes use of a metamodel, constructed on the basis of the model calculations, which mimics the behaviour of the complex model [Sieber et al. 2008]. A third alternative is, in case of a model chain, to use only a relatively simple integration model that uses pre-calculated inputs from the more complex models in the chain [Koomen et al. 2010]. The metamodel approach has the advantage that interpolation is possible, so that more options can be chosen with less pre-calculations. The drawback in all three cases is that the range of options that can be explored is fixed. If stakeholders are interested in exploring options outside this range, the underlying models need to be adapted and new calculations need to be performed requiring specialized expertise and considerable resources in case of complex models. The approach is therefore only likely to be successful when the range of options of interest to the stakeholders is restricted and known.

A somewhat related, innovative approach to give stakeholders rapid insight into the performance of options is presented by Groot et al. [2007] and Groot & Rossing [2010]. The authors used multi-objective optimization methods based on heuristic search techniques (evolutionary algorithms) to explore the complete solution space for a range of economical, environmental and ecological objectives in multi-functional land-use. Whereas a policy scenario evaluation approach only provides information on the performance of a few options, this approach provides an overview of the performance of all possible options (given the system description), including the optimal solution for a given objective for each level of satisfaction of other objectives. In other words, the approach yields a complete insight into the trade-off relationships between all objectives included in the assessment. Through a visual display the solution space and trade-offs associated with different options can be explored and compared. The tool can support stakeholder discussions, learning and negotiation by showing the wide diversity of options stakeholders might choose from and the performance of these options according to objectives representing their perspectives [Groot & Rossing 2010]. Although the tool has been developed in consultation with stakeholders, it has not yet been tested with the stakeholders in a real case, neither has the approach been applied to more complex integrated assessment models.

3 CONCLUSIONS AND OUTLOOK

In the previous section we discussed the state-of-the-art of recently presented tools with the potential to make quantitative models better in supporting social learning. Most of the tools have not reached the stage of a fully functional version, and so far none have been evaluated in real cases with real stakeholders. The major bottleneck in the interaction between stakeholders and quantitative models appears to be model complexity. The more complex the model, the more difficult it is to achieve adequate integration of stakeholder perspectives and sufficient iterations between model outcomes and stakeholder choices. We specifically searched for tools with the potential to manage this trade-off, but our conclusion is that thus far no tools are available that have proven to realize this potential. Therefore, if models are to support social learning of stakeholders in participatory integrated assessment better, model-based PIA must become more similar to participatory modelling approaches that are successful in this respect, such as mediated modelling and companion modelling. This means that the models used in PIA must be simplified and the participatory processes intensified. Similar recommendations have been given by Edwards et al. [2010] and Dreyer & Renn [2011].

Simpler models may allow the application of promising approaches such as the highly efficient method developed by Groot & Rossing [2010] to explore the entire solution space and provide a comprehensive insight into the trade-offs between multiple objectives. Simpler models would also make it easier to communicate models to stakeholders and to involve stakeholders in model construction or the formulation of options. It may even open up the possibilities of using approaches resembling the MapTable approach in participatory spatial planning [Vonk & Ligtenberg 2010, Ligtenberg et al. 2011]. The MapTable is a combination of a large table-top digital display, a digital map library, a GIS database, and process models.

Up to ten stakeholders can gather around a MapTable, add information to the displayed area maps and make digital sketches of possible solutions to the spatial problem discussed. These solutions can be stored and their performance evaluated immediately with coupled process models [e.g., Bulens & Ligtenberg 2006]. For non-spatial problems or discussion of the underlying models use could be made of interactive whiteboard technology. Renger et al. [2008] explored the use of this technology to support participatory modelling and concluded that it has great potential to support the development of shared understanding and consensus among stakeholders. Since then, with the introduction of tablet computers, the possibilities to directly manipulate content on digital displays are rapidly increasing, making this a promising direction to pursue.

Simplification of integrated assessment models is a challenging task for modellers. Over the past two decades, modellers have developed evermore complex models and model chains in response to the demand from decision makers for tools that could address problems involving multiple domains, multiple scales and multiple actors. There are two ways to simplify these complex models again: by developing statistical metamodels or explanatory summary models [Ewert et al. 2011]. The metamodelling approach is relatively common and feasible in most cases, but as it is based on statistical relationships between output variables of the complex model, it cannot account for dynamic feedbacks nor can it produce outcomes outside the range covered by the original, complex model. This means that metamodels are inflexible and, though fast, not very suitable to support social learning. Explanatory summary models are derived by structural simplification of complex models, maintaining only the relationships that have a large and cross-scale influence on model behaviour. According to Ewert et al. [2011], explanatory summary models are rare because this form of model simplification requires a good understanding of the system and its behaviour, which for complex systems is obviously difficult to obtain. However, model simplification is needed to better support social learning in PIA and we thus recommend, in line with Ewert et al. [2011], that in integrated assessment modelling much more emphasis should be placed on the investigation of options to reduce model complexity.

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