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The role of computer modelling in participatory integrated assessments

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Abstract

In a number of recent research projects, computer models have been included in participatory procedures to assess global environmental change. The intention was to support knowledge production and to help the involved non-scientists to develop a deeper understanding of the interactions between natural and social systems. This paper analyses the experiences made in three projects with the use of computer models from a participatory and a risk management perspective. Our cross-cutting analysis of the objectives, the employed project designs and moderation schemes and the observed learning processes in participatory processes with model use shows that models play a mixed role in informing participants and stimulating discussions. However, no deeper reflection on values and belief systems could be achieved. In terms of the risk management phases, computer models serve best the purposes of problem definition and option assessment within participatory integrated assessment (PIA) processes.

Keywords: Participatory integrated assessment; Computer models; Sustainability science

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1. Introduction

The multi-dimensional problems that are related to global change phenomena cover complex and often nonlinear dynamic interactions between natural and social systems and occur on a multitude of temporal and spatial scales. Addressing these problems in a more comprehensive way than conventional scientific approaches requires inherent interdisciplinarity. In the last two decades, much effort has been spent on integrated assessment (IA) projects which combined different academic disciplines in order to obtain additional knowledge that provides input for political decision-making (Rotmans and Dowlatabadi, 1997; Toth and Hizsnyik, 1998; Rotmans, 1998; Sluijs and Kloprogge, 2001; Van Asselt and Rijkens-Klomp, 2002).

Experience gained from these projects revealed the apparent need for transdisciplinary approaches that additionally include societal groups and non-scientific experts into the knowledge generation process. Their knowledge and commitment is seen as pivotal for the development of practically relevant solutions to the problems at hand. Therefore, the fundamental inter-relations of social and natural processes need to be made transparent also to non-scientists. Transdisciplinarity, however, requires some recognition of the broad range of differing interests, views, knowledge structures, norms, and values which have developed in modern human societies (Becker and Jahn, 1999). To that end, the use of participatory procedures has been proposed to integrate diverging views and to incorporate knowledge from outside the traditional system of knowledge production and to increase the legitimacy of scientific research and results against societal claims (WBGU, 1996, Kates et al., 2001).

A number of recent research projects in the participatory integrated assessment (PIA) of climate change used computer models during the participatory procedure, mostly as an additional form of scientific input. Since models are at the core of climate science and widely used even in expert assessments like the Intergovernmental Panel on Climate Change (IPCC), it appears reasonable to employ them in other assessments as well. In the PIA projects, models were used as a tool during the assessments to understand the problem at hand and to explore and test scenarios developed by the participants and thus helped to evaluate policy options and envisaged solutions. In many cases, the models could be used in real-time and at the site of the assessment.

The use of computer models in PIA processes raises a number of problems both from a participatory as well as from a risk management perspective. From the participatory point of view, every introduction of authoritative forms of scientific knowledge such as computer models or expert talks to deliberative processes bears the danger of discouraging less accepted and more tacit forms of knowledge. Compared to human experts, computer models are often perceived as more comprehensive and reliable and thus more authoritative. Critics even argue that the use of computer models leads to a streamlining of cognitive frames and to uniform knowledge. Although such standardization is sometimes intended to ensure that everyone is talking about the same issue, in participative processes it counteracts the original attempt of including a variety of knowledge and cognitive frames to knowledge production. We therefore explore whether and how model use helped to achieve the objectives of participatory processes such as the generation of new insights and the development of innovative solutions. Specifically, we ask to which extent computer models facilitated mutual exchange and learning in participatory procedures and under which conditions and process designs these objectives can be achieved by the use of computer models.

The other problem focus addresses the use of models as a means in the risk assessment process that lies at the core of each integrated assessment. Although the design of existing IA models and their general appropriateness for participatory purposes has already been studied (Sluijs, 2001, 2002, Dahinden et al., 2000), the actual role of and the experiences with models in the various stages of a participatory risk assessment process raises additional questions: In which stages of the assessment process have computer models proven to be more fruitful than in others? Which effects did the inclusion of laypersons have on the use of models during the assessment? How did the assessment process benefit or loose through the use of models in a participatory context?

Both sets of problems will be studied by comparing experiences from three recent, model-supported PIA projects: ULYSSES, COOL and VISIONS. Section 2 addresses the problem from the participatory perspective whereas Section 3 focuses on the risk management aspects of computer models in PIA projects. The final section draws conclusions and describes perspectives for further research.

2. The participatory perspective on the use of computer models in PIA processes

2.1. Rationales and criteria

In the recent past, the challenges arising from global environmental change as well as more normative claims to change the entire relation between science and society led to approaches such as Mode-2 science, post-normal science and sustainability science. All of them highlight the involvement of lay citizens and provide rationales for participatory procedures for various reasons. In *Mode-2-science*, the integration of non-scientific knowledge is key to generate knowledge that is likely to be accepted by large parts of society and to increase the democratic legitimacy of knowledge production (Gibbons, 1994; Shinn, 2002; Nowotny et al., 2001). For the proponents of the *post-normal science* approach (Ravetz, 1999; Funtowicz and Ravetz, 1993, 1994a,b), the user perspective expressed in a dialogue is the ultimate criterion for the evaluation of research results, and also the criteria of quality applied have to be agreed upon in a participatory manner. In the *sustainability science* approach, participation and integration of various knowledge forms are essential to "understand the fundamental character of interactions between nature and society" (Kates et al., 2001, p. 641).

In sum, public participation in the generation of scientific knowledge fulfils four essential functions as expressed in these approaches (Forrester, 1999; Jaeger, 2002; Sluijs, 2002): (1) In fulfilling a *normative function*, participatory approaches are intended to increase the legitimacy of the process of knowledge generation through the involvement of various actor and interest groups. Whether this acceptance also applies to other societal groups that have not participated in the process remains questionable. (2) The *substantive rationale* implies that participation allows to integrate more sources of knowledge and more capacities for problem solving (O'Connor, 1999). In the sustainability science framework, most emphasis is given to the inclusion of local and traditional sources of knowledge that are valuable for finding practical solutions and, e.g. to analyse climatic change on the regional and local levels. (3) The *instrumental rationale* provides that people's commitment to the outcomes of the participation process is higher than in the traditional ivory-tower model of scientific research. Conflicts will be reduced and implementation of the research findings tend to be easier because of increased acceptance on the side of the stakeholders. In addition, participation is seen as a means of education and empowerment of local institutions, groups and individuals when their voice is noticed in the constitution of knowledge within sustainability science. Finally, (4) most participatory approaches target at *mutual learning* processes where participants acquire new knowledge from others and create new knowledge. More advanced forms of learning would go beyond cognitive changes but would imply changes in the values and mental models individuals have.

However, all these approaches make very limited reference to practical ways and supporting means for participatory approaches, giving ample room for researchers to explore and apply new methods in the context of participatory integrated assessment (PIA) processes. Among these, the integration of computer models emerged as an innovative approach to combine traditional scientific with participatory methods (Dahinden et al., 2000; Hisschemöller et al., 2001; Sluijs, 2002; Wilkens, 2003). In many sustainability-related science areas, computer modelling approaches already play a key role since they allow for the simulation and examination of complex and dynamic systems. Particularly in the integrated assessment of climate change, computer models are the dominant means of scientific knowledge production. Models are often and appropriately used to (Tuinstra et al., 1999; The Social Learning Group, 2001; Hisschemöller et al., 2001):

- provide a common understanding of environmental and social problems and their impacts
- analyse the causes of the problems
- explore and examine policy and management options
- support the structuring and formulation of goals and objectives.

In the following, we will analyse whether these strengths of model use go in line or conflict with the purposes of participatory approaches according to the functions (1)–(4) above. We will do this for a number of research projects that included participatory procedures and computer models in the generation of new knowledge in the integrated assessments (IA) of climate change. Our analysis describes the participatory method used in these projects and then looks at how computer models were used within this specific method and which experiences were made. We will not discuss at length the specifications of the utilised computer models.[2]

Our analysis is structured along the following three categories that reflect the above-mentioned functions (1)–(4) of participatory processes:

(1) *Project objectives*: Like any method used in participatory processes, the use of computer models in integrated assessment processes should be related and adjusted to the ultimate objective of the IA process. For example, the analysis of a problem and

[2] An analysis of which computer models serve which IA purposes best has been done elsewhere (Rotmans, 1998; Sluijs, 2001, 2002).

the projection of future developments is a largely different task and can best be reached using different techniques than when the objective is to build consensus around which goals are to be followed and which visions are most desirable (Van Asselt and Rijkens-Klomp, 2002). Therefore, when analysing the role of computer models in an integrated assessment process one has to consider the specific contexts and project objectives in which they are used. In addition, the question has to be raised to which extent the participatory procedure that included computer models produced relevant outcomes and how far it promoted commitment and empowerment of those who were part of the process and those that were not. Did the process lead to consensus or rather to a mapping out of different positions and interests? Was the use of computer models helpful in the production of new knowledge or concrete products that are relevant for other societal groups and actors, e.g. the political decision making process or did it merely lead to a juxtaposition of different opinions? Did the use of computer models lead to any practical steps taken in the follow-up?

(2) *Process design and moderation scheme*: Two issues are crucial for the substantive quality and legitimacy of a participatory process and its relevance for the users: the choice and sequence of the methods used on the one hand, and the selection of participants on the other (Siebenhüner, 2004). While proper and balanced recruitment of participants is extremely important when the goal of the participatory process is decision-making, the requirements are less strict for more deliberative and informative processes, although these should also aim at a balanced selection. Likewise, the selection of a method depends on the goal of the participative process. Computer models can be employed in most processes, but their role and the amount of time dedicated to their use will certainly depend on the overall objectives.

Particular attention will be given to the role of moderation during the participatory process. Moderators are commonly engaged to facilitate and structure the discussions, and thus can exert a strong influence on the direction of the process, the contents being discussed and thereby also on the transfer of knowledge among the participants. In addition to this ‘process moderator’, it turned out in practice that interaction of laypersons with IA models requires an additional expert (‘model moderator’) who is acquainted with the model(s) in use. Like the process moderator, the model moderator can exert strong influence on the interaction process by the way models are introduced and handled, and the selection of questions that are actually posed to the models. Thereby, the potentials of the participatory processes might be lost when the use of computer models results in an exclusion of certain perceptions and practical options.[3] Resulting questions for the analysis of computer-model usein participatory integrated assessment projects are: How was the process designed and where were computer models used? Which role did the moderator(s) play?

[3] In some instances, this exclusionary function of models is most welcome. For instance, in the negotiations of the sulphur protocol under the Convention on Long-Range Transboundary Air Pollution (LRTAP), the use of one particular model allowed decision makers to grasp the problem and to negotiate about the reality as portrayed in the model which otherwise would have been too complex, i.e. the RAINS model (Tuinstra, 2003, personal communication).

(3) *Mutual learning*: Participatory integrated assessment processes often view mutual learning as a key objective. Two forms of mutual learning can be distinguished that correspond to the concept of single- and double-loop learning as developed by Argyris and Schön (1996).
The first form describes changes in the knowledge of one particular group of participants that are restricted to new information and insights, e.g. non-scientific participants learn about the state of a problem. In this case, computer models have to provide information on the state and the interactions of complex systems like economic or ecological systems. The mutual learning version of this single-loop learning would entail cognitive enhancement of both non-scientific and scientific participants of the participatory procedure. In the case of IA models, modellers might gain new insights in possible model uses, the questions people would like to have answered by the models, or the preferences and perceptions of lay people. This might result in adjusted computer models which might again be fed into scientific discourses or be used in subsequent decision-making.
The second form covers a more advanced form of learning like changes in basic understanding, belief systems and values. This double-loop learning or "second-order learning" (Kerkhof, 2004) is often more likely to lead to changes in the participants' actual behaviour than the single loop mode since values are seen as crucial motivators for any form of activity. For example, on the side of the involved modellers this might include a reversed view on the role of models as such which are currently seen by many model builders as quasi-reality or as a well-reflected representation of reality rather than as images or metaphors by which a certain type of discourse and language is transported (Ravetz, 2003). In our study of related experiences, we will ask whether mutual learning related to the use of computer models has been observed and if so which forms.

2.2. Analysing the use of computer models in PIA projects from a participatory perspective

Which experiences have been made with regard to the developed criteria in recent PIA projects that used computer models or computer based tools? In passim, we will analyse three projects and their results on the basis of published project documentation, oral interviews and email communication.[4] These projects are: (i) Urban LifestYles, SuStainability and integrated Environmental aSsessment (ULYSSES), (ii) Integrated VISIONS for a sustainable Europe (VISIONS), and (iii) Climate OptiOns in the Long term (COOL). All of these had a focus on Europe or European national societies, although COOL featured a 'Global Dialogue' with participants from overseas, and the ULYSSES documentation on model use (Dahinden et al., 2000) also refers to a partner project in Pittsburgh (USA). All projects used different computer models that can either be used interactively or non-interactively. In the non-interactive mode, the flow of information is unidirectional from computer model results into the participatory process with no

[4] All project teams have been contacted by email in Summer 2004 with a list of related questions that were not answered by the written documentation. We received responses from all three projects in the form of two email responses and one telephone interview.

interaction in a question-and-answer mode being possible. By contrast, in the interactive model use, non-scientists pose questions, which are to be answered with the help of models (Rotmans, 1998). A detailed list of the different computer models used in the projects is included in Table 1.

2.2.1. ULYSSES

2.2.1.1. Project objectives. The ULYSSES project aimed at public participation in integrated assessment efforts in seven European metropolitan areas (Kasemir et al., 1999, 2000a,b, 2003; Sluijs, 2002). It has been the objective of the project to explore citizens' views on climate change in local communities and to investigate how personal lifestyles could be linked to the issue of climate change. Computer models were used to establish this link.

The method largely aimed at informing and consulting the participants, at the anticipation of the future, at co-production of knowledge and on their learning. For the first function, many participants found computer models helpful to get reliable data on the global situation of the climate systems. The poor regional disaggregation of the models available disappointed most participants since they were more interested in regional impacts of climate change. When compared to other forms of scientific input such as video shows or a debate with a climate expert, computer models were preferred only by a few groups that shared a significant trust in scientific information in general. Where scepticism against scientific knowledge prevailed, computer models were of little use in the processes (Dahinden et al., 2003).

Table 1
Computer models used in recent PIA projects

Project	Interactive use	Non-interactive use
ULYSSES	•IMAGE (Rotmans et al., 1990; Alcamo, 1994; Wenzel, 1996) •TARGETS (Rotmans et al., 1994; Rotmans and de Vries, 1997) •ICAM (Dowlatabadi and Granger Morgan, 1993; Morgan and Dowlatabadi, 1996) •PoleStar (Raskin et al., 1996) •IMPACTS (Pahl-Wostl et al., 2000; Schlumpf et al., 1997) •OPTIONS (Pahl-Wostl et al., 2000; Pahl-Wostl and Burse, 2001) •Personal CO_2 Calculator (PCC) (Schlumpf et al., 1999) •CO_2 personal account model (De Marchi et al., 1998)	
VISIONS	•Baby-LOV (White et al., 2004) •Atlas NW (Lindley, 2001)	•PHOENIX (Hilderink, 2000) •WorldScan (CPB, 1999)
COOL	•FAIR (Den Elzen et al., 2001)	•TIMER (De Vries et al., 2000) •WorldScan

To several participants, the uncertainty of the model results caused negative reactions and led to scepticism about the use of models to predict the future. In particular, those models that treated uncertainty typologically—such as TARGETS—were received even more critically than those with a probabilistic approach to uncertainty. Nevertheless, the insight into the uncertainty of climate science was new to nearly all lay citizens and empowered some of them to play a more active role in the qualitative part of the process where pictures and collages were used as means of expression (Dahinden et al., 2003).

Similarly, the use of computer models for the analysis of policy options on a regional level did not satisfy most participants. Only where computer models allowed for an interactive use of the model to develop possible scenarios and to thoroughly explore alternative policy options participants found the computer models helpful. The perceived insufficiencies of the models with regard to regional scales and the results of behavioural changes as opposed to policy decisions, however, stimulated lively debates on moral issues such as global equity and individual responsibilities.

In sum, ULYSSES had mixed results with regard to the use of computer models in participatory contexts. Even though computer models were generally seen as an interesting information source, most participants viewed the results of the computer models available as insufficient for building a consensus on them. Moreover, the initial goal of creating a feedback into integrated assessment modelling approaches proved difficult to fulfil within the framework of this project. However, the discussions were stimulated by the models and thereby fostered the project's objective of consciousness-building, even though this resulted from the uncertainties and the lacking regional disaggregation of the models, i.e. the insufficiencies of the models.

2.2.1.2. Process design and moderation scheme. ULYSSES had a particular focus on the use of computer-based tools in the PIA process. Therefore, a large variety of IA tools was available (Dahinden et al., 2000; Sluijs, 1999). Generally, each focus group used more than one model, covering at least one global-scale model (IMAGE, Targets, ICAM) and either a regional-scale model (PoleStar) or a CO_2 lifestyle calculator (PCC). Regional information platforms (IMPACTS, OPTIONS) which are not models in the narrow sense but contain some smaller submodels have also been employed. These tools could be used 'interactively' in the sense that participants could request their own scenarios to be computed by the models. For the more complex models used in the project, it was necessary that a specially trained 'model moderator/facilitator' operated the model, while the less complex models such as the PCC, IMPACTS, and OPTIONS and were run by the participants themselves. While most models could be run during the meetings, calculations by the IMAGE (and in part PoleStar) model had to be performed between two focus group meetings due to computer limitations. In contrast to most other regional groups, the focus groups in the Manchester region (and two in Pittsburgh, USA) decided not to use computer models at all (Dahinden et al., 2000; Sluijs, 1999). This was based on strong reservations on the side of participants in a pre-test process regarding the capabilities of models to represent the richness of lifestyles (Wynne, 2003, personal communication).

Each focus group met five times, where the first meeting explored expectations of the participants about future energy use and climate change. In the three following meetings, the participants discussed climate change and regional options, where different computer models generally were available as a background to and as an interactive information tool during the discussions. These discussions were summarised in the fifth session in a written assessment report on recommendations for action by the participants, which were presented to the project team. Group processes were guided by a moderator with regard to the framework conditions, the topic, the means, and some of the process steps. In addition, model moderators joined the group to facilitate the use of the more complex computer models. This person turned out to be pivotal for the success of the process since he or she had to translate the model results into normal language. Therefore, the openness and the ability of this person to respond to questions and to use the model adequately were crucial for the process (Dahinden, 2004, personal communication).

2.2.1.3. Mutual learning. Even though the project teams did not systematically analyse learning processes on an interview or questionnaire basis, all group sessions were documented through video recordings that were transcribed and evaluated afterwards (Dürrenberger et al., 1997). The results showed that learning from the scientists and the models employed was the predominant mode of learning on the side of the citizens. The ULYSSES project team found that "ordinary people from across Europe usually framed climate impacts in ethical rather than economic terms" (Kasemir et al., 2000b, p. 40). Computer models obviously helped to stimulate these ethical debates rather than to introduce sound scientific data that might underscore economic arguments. However, on the basis of the available data, it is difficult to judge to which extent changes in the underlying values of the participants took place. Given the short time frame of the focus group workshops, significant changes in individual values seem unlikely but participants' vague values with regard to climate change and their lifestyles became more concrete and nuanced through the process and the use of computer models (Dahinden, 2004, personal communication). This observation gives an indication of double-loop learning processes whereas most other learning in the project remained in the single-loop mode. Moreover, most learning was observed on the side of the lay citizens than on the side of the modellers involved. The more the focus of the discussion turned to local issues, the more lay citizens switched from a passive learning mode to a mutual mode where they took over a much more active role in sharing their own knowledge (Dahinden et al., 2003, p. 115). Thereby, the insufficiencies of the existing computer models served at least the mutual learning among the involved citizens.

In conclusion, project members found that most of the computer models used were of limited value for the participatory process. They recommend to employ new and better-suited models that are easy to use and to understand (Dahinden et al., 2003). Moreover, computer models should not dominate the group processes in order to facilitate the mutual exchange and the direct communication which might promote mutual learning on a double-loop level a little better.

2.2.2. VISIONS

2.2.2.1. Project objectives. Building on the experiences of the ULYSSES project, the VISIONS project has also been designed as an integrated assessment project on a European scale (Rotmans et al., 2000, 2001). The main objective of VISIONS was to create a set of alternative scenarios for future sustainable development paths, pertaining to Europe as a whole as well as to three selected regions. The time horizon of each scenario ranged between 2020 and 2050. These scenarios were developed and analysed using participatory methods for consensus building in combination with software tools. The VISIONS project aimed to provide a point of reference for future international debates and negotiations. It was also intended to produce practical decision-support tools for decision makers and stakeholders.

Computer models were used to visualise and analyse the developed scenarios. For the European scenarios, a global computer simulation model (WorldScan/Phoenix) was used mainly to visualise and analyse certain aspects of the scenarios developed by the participants. Further modelling tools have been utilised in two regional scenario development groups: The Northwestern UK group used Atlas NW, i.e. an adapted version of the QUEST software developed at the University of British Columbia (Hrynyshyn, 2002). In the 'Green Heart' of the Netherlands, Baby-LOV was used as a simplified version of the LOV-Environment Explorer developed for the national level. All models provided additional plausibility and consistency checks against which the scenarios were tested.

The main outcomes of the VISIONS project are the scenarios for the three specific regions and the whole of Europe. They have been published in written form and as a CD-ROM which allows to reproduce the model results by visualising the different scenarios developed in the process. With regard to the integration of qualitative and quantitative methodologies, the project team remained unsatisfied with the results that were restricted to visualisation and illustration. No further stimulation of the social processes were observed. The subproject that used Atlas-NW as a regional planning tool found it to be of some help for the process but its actual contribution to the final outcomes remained limited (Rothman, 2004, personal communication).

2.2.2.2. Process design and moderation scheme. The scenario development approach taken in the VISIONS project was adopted from a standard scenario technique developed by Royal Dutch Shell and focused on story lines which built on expert knowledge from the different disciplines and societal actor groups represented in the process. The group totalled 25 participants and included representatives from policy making, business, and NGOs as well as experts in the fields of economics, environment and social-cultural studies. In addition, so-called "free thinkers" such as artists, or journalists were invited to bring in their creative ideas or their non-partisan views. In general, the approach largely focused on experts less so on lay people.

A first phase employed a so-called 'free-format' encouraging participants to think and act creatively about possible futures and the necessary development paths that lead to these future situations. The resulting ideas were clustered and sorted to storylines, i.e. narratives describing a sequence of events that are logically linked. The support through the computer simulation models allowed to visualise, to illustrate and to analyse the resulting scenarios. For the European scenarios, a model run based on the extrapolation of current global trends was used as a background for the scenario development. Subsequent model runs based on the scenarios developed in the workshops were then compared to the initial baseline in following discussions. Further modelling tools have been utilised in two regional scenario developments for the purposes of visualisation and for the assessment of spatial trends.

2.2.2.3. Mutual learning. The specific method selected for the scenario development built on mutual learning among the different social actors involved. Mutual learning was particularly sought after in the exchange between experts and free thinkers to open up new ways of thinking about future events and to couple them with existing scientific or technical expertise (Rotmans et al., 2001). Even though it was not the intention of the project to facilitate a mutual learning process between stakeholders and model builders, the Atlas NW model was tailored to the use in the project and modellers were interested in how participants used it. It turned out, however, that stakeholders put an emphasis on soft issues such as cultural, social, institutional and political issues that do hardly allow for a thorough quantitative analysis by computer models. The learning mode related to computer models, therefore, remained in a single-loop form since most participants learned about the implications of the scenarios and causal connections between certain issue areas, but a thorough reflection process that includes changes in values and more fundamental belief systems was not reported by the project teams. Unfortunately, there have been no efforts to further explore changes in the beliefs and patterns of thinking which might indicate forms of double-loop learning on the side of the participants (Rothman, 2004, personal communication).

2.2.3. COOL

2.2.3.1. Project objectives. The Dutch COOL Project (Climate OptiOns for the Long term) concentrated on the identification of possible future strategies in response to climate change with a particular focus on the long-term perspective of about 50 years (Berk et al., 1999; Hisschemöller, 2001; Hisschemöller and Mol, 2002; Kerkhof et al., 2003). It included a 'National', an 'European' and a 'Global Dialogue' involving stakeholders from different social groups and economic sectors. Computer models were only used in the 'Global Dialogue' where the FAIR model developed by RIVM was employed interactively. Furthermore, modelling results from the WorldScan and TIMER models were also used as discussion inputs in the 'Global Dialogue' and the energy sector group of the 'European Dialogue' (Hisschemöller and Mol, 2002, Berk et al., 2002). The other groups made no use of models or model results as the COOL project focused on eliciting knowledge directly from the participants. Therefore, this analysis focuses on the 'Global Dialogue'.

The evaluation of the use of models in the 'Global Dialogue' concluded that the interactive models were useful and helped policy makers to analyse policy options and their implications. The report states: "participants were generally very positive about their use and indicated that they provided new insights" (Hisschemöller and Mol, 2002, p. 81). However, most participants were scientists or experts with a scientific background and were in one way or another acquainted with computer models. In contrast to the other dialogues, the 'Global Dialogue' resembled more a conventional scientific assessment exercise than a participatory process with non-scientific experts. Here, computer models were of great help and the included uncertainties did not cause major concerns with the participants. Contrasting to the deficient regional models, for the global scale, a number of advanced computer models were available and were able to produce somehow robust results. The results of the dialogue were fed into the final project report but did not instigate any further policy action.

2.2.3.2. Process design and moderation scheme. The 'Global Dialogue' involved stakeholders and policy makers from different parts of the world. About a third of the 33 participants came from developing countries and countries in transition. Over a series of four workshops, participation varied largely and turned group processes difficult since the group composition changed from one workshop to the other (Hisschemöller and Mol, 2002). The first was dedicated to problem definition and the identification of research needs whereas the second workshop focused on the definition of long-term goals for climate change and the assessment of their consequences of long-term goals. The FAIR model was used in this session and in the third one where emission reduction pathways were to be analysed. In the fourth workshop, a backcasting method was employed to identify short-term implications of long-term goals. The interactive backcasting method used also in the other COOL dialogues allowed to study the specific technological options in subgroups of four to six individuals with the support of one facilitator and one scientific expert. Furthermore, the different technological options that were in the focus of the different backcasting exercises had to be analysed in their relation to each other (Kerkhof et al., 2003).

2.2.3.3. Mutual learning. Given the heterogeneous composition of the groups, some mutual learning between the stakeholder groups was required in the participatory procedures in order to come up with commonly agreed results. However, this learning did not directly relate to the use of computer models. Thus, the question remains whether and how far-reaching model-related learning processes were and whether they included model builders or moderators. On the basis of the available data, all related learning processes remained in the single-loop mode. According to statements by the participating policy makers that have been reported by the project team, they learned from the models about consequences of policy choices and about possible technological options—as long as the models were simple and easy to be adjusted to the information needs of the decision makers. Project members concluded: "these models will very much enhance the communication of scientific insights to policy makers" (Hisschemöller and Mol, 2002, p. 83). By contrast, no account was given of any learning process by the model builders involved. Therefore, no mutual learning between the participating policy makers, stakeholders and the modellers was observed in the 'Global Dialogue'.

2.3. Findings

What can be concluded from these experiences for the criteria developed in Section 2.1 under the participatory perspective? In passim, we will aggregate the findings from the cases as detailed above.

In terms of the *project objectives*, we asked to which extent the participatory procedure including computer models produced relevant outcomes and was helpful in generating new knowledge. All outcomes of the projects are well documented but have not deliberately been fed into follow-up processes to disseminate the project results or to create further momentum among civil society groups. Books, CD-ROMs and online material have been generated but the assessment results were in most parts not fed into a political decision making process or similar processes. The use of computer models helped to produce these outcomes and supported their scientific credibility in the case of the COOL 'Global Dialogue' and—to a lesser extent—in the VISIONS project. In ULYSSES, computer models helped to trigger discussions on moral implications of the general topic and on the use of modelling exercises per se. Therefore, they helped parts of the participatory process but the traditional assessment of policy options was not found to be dependent on the use of computer models in this process. Similarly, the use of computer models did not have a direct impact on the participants' commitment and empowerment. In ULYSSES, computer models supported the participatory process rather indirectly through the displayed insufficiencies that gave participants the encouragement to voice their own knowledge, e.g. on regional impacts of climate change.

None of the projects reported significant disputes among participants about the knowledge provided by the computer models. Model results have been either accepted as scientifically sound input into the discussions or served as a trigger for debates about the implied uncertainties.

It can be summarised that the use of computer models helped the participatory process to some extent but they did not fulfil all the expectations that were put into them. All projects showed that computer models can serve the purpose of consensus building through a streamlining of knowledge to which further discussions can refer to. The transfer of modelling-related knowledge to other societal groups, however, proved difficult in all projects and remains a challenge for future participatory integrated assessment projects that intend to use computer models.

Process designs and moderation schemes varied slightly in all the examples presented in this paper. All projects integrated models in some form of group discussion with direct interaction of the participants. Thereby, they relied on the potentials of face-to-face communication which proved successful to come to a fruitful exchange of knowledge and to facilitate mutual learning—at least on a cognitive level. This strength of these procedures at the same time embodies its main weakness since face-to-face interaction is limited to small to medium-sized groups and to a certain location where all participants have to be present. Large-scale problems with a large number of individuals from various backgrounds and with numerous languages can hardly be dealt with in these procedures.

Model moderators introducing and running the computer models were paramount for the integration of the models in the social process. Generally, human 'model moderators' were an important interface to make use of the full potential of the more advanced models at hand—even though they channelled and controlled the knowledge flow from the models into the social process and vice versa. Unfortunately, their role was examined in detail only in the ULYSSES project, where three qualities have been found to be essential for successful model moderation: being fully prepared, being able to stimulate discussions and being neutral. The latter quality refers to the mode in which models are being introduced; this should be done in a "careful, respectful and unbiased" manner, without being overly enthusiastic or too negative about the model (Dahinden et al., 2000, p. 263).

Interestingly, all participatory processes consisted of multi-step procedures with certain similarities in the three to five phases. In general, the first step gave participants the opportunity to express their views and ideas. Whereas in the ULYSSES and VISIONS project, participants were given little formal constraints in expressing their thoughts, the COOL project required them to structure their initial views. The following phases in the ULYSSES project allowed for the inclusion of expert knowledge. The stakeholder-oriented projects as VISIONS and COOL did not require the additional inclusion of expert knowledge in this phase but urged their participants to structure, cluster and assess their knowledge. In this phase of assessment, computer models proved most helpful. The final phases in most project consisted of a synthesis of the developed knowledge and of the formulation of policy recommendations. None of the projects made use of computer models in this final phase.

Whether and which forms of *mutual learning* related to the use of computer models have occurred in the three projects is a difficult question to answer given the scarcity of systematic evaluation and documentation. By and large, computer-based tools have generally been received positively by the participants, even though their acceptance was dependent on the age and the participants' general familiarity with computers (Dahinden et al., 2000). In all three projects, learning effects of several participant groups have been observed. The lay participants in the ULYSSES project acquired new knowledge about climatic change and its consequences through the use of computer models. In all three projects, the possibility to visualise scenarios and the stimulation of discussions have been acknowledged as virtues of computer models. In particular, the possibility to 'play' with interactive models to address the consequences of changes in policy and/or behaviour was welcomed in the ULYSSES and the COOL project. Based on this, participants reported to have received new insights. In particular, the lifestyle indicators in ULYSSES helped to link the abstract topic of climate change to the living-world reality of users (Schlumpf et al., 1999). In addition, the perception and understanding of different user perspectives was facilitated by interactive models. By contrast, uncertainty and its treatment by the models generally was found difficult to comprehend by lay participants, and therefore they expressed problems and concerns to judge the quality of the models and their knowledge outputs. The degree of uncertainty exhibited by the models in ULYSSES was a "shock" to the participants (Dahinden et al., 2000, p. 259), and the 'black box' character of most models, in particular the more complex ones, added to this impression. In the COOL context, participants also asked for results from other models than those actually used to get a wider foundation for comparison. Connected to this is the question of the spatial resolution and time horizons addressed by the models. Users were generally interested in local or small-scale regional changes, which is usually below the grid size of global and even many regional models. Nevertheless, global information was considered to be necessary for discussions. Likewise, the 100-years-time horizon used in the global models in ULYSSES did not affect participants directly and thus appeared irrelevant for discussions.

These insights and knowledge gained from the use of models in the projects merely qualify as single-loop learning according to the initial definition given above. No further reflection of underlying values and belief systems in a double-loop mode has been initiated by the use of models. In this respect, computer models seem to be too quantitative to be able to stir individual beliefs or to irritate certain values. Particularly, the inherent uncertainties in the models can be used by participants as a cognitive exit and an argument against the results of the models.

With regard to the mutual exchange of knowledge and mutual learning processes between non-scientific participants and model builders, the experiences from the three cases show very poor results. Most model builders involved in the processes did not draw many conclusions from this form of application. In the ULYSSES project, some of them claimed that their models are not made for the use in a participatory context with lay citizens in order to explain lacking interest from lay participants. They did not reveal any intention to draw conclusions for their own modelling exercises (Dahinden, 2004, personal communication). In addition, the objective to feed back the results from the participatory process into integrated assessment models was not met in either of the projects.

3. The risk management perspective on the use of computer models in PIA processes

3.1. Rationales and criteria

Apart from the function of computer-based PIAs as participatory processes involving different social groups, they are also intended to provide a reliable assessment of the underlying risks for the policy process. Whereas the participatory function focuses on the inclusion of different forms and sources of knowledge, it is the risk assessment function that addresses the balanced and detailed analysis of the risks under deliberation. Therefore, the question will be addressed in this section, whether computer models can serve this function within participatory processes in general and with regard to the three projects under examination here in particular.

The risk management process of long-term societal problems like climate change is most adequately evaluated by focusing on the actions taken rather than looking at the actors involved (The Social Learning Group, 2001, p. 11). This strategy avoids the difficulties arising from actor constellations that change over time and vary between subjects addressed. The actions taken in risk management can be aggregated to the following steps (The Social Learning Group, 2001, Sluijs and Kloprogge, 2001):

(1) *Problem framing* addresses the setting of problem boundaries and problem definition;
(2) *Risk assessment* addresses the understanding of the nature of the risk in question, its causes, consequences, likelihood and timing;
(3) *Option assessment* addresses the assessment of possible measures to respond to the risk in question. This includes assessing the feasibility, costs, or benefits of these options;
(4) *Goal and strategy formulation* addresses the selection of management goals (i.e. objectives or conditions to be brought about), the design of packages of options to achieve these goals, and the selection of modes to implement these options. Strategies organise the means (options) to achieve the ends (goals);

(5) *Monitoring* includes the documentation of actual changes in the environment affected by the risk in question;
(6) *Implementation* addresses the actions taken to manage the risk in question. This includes normative, legal, educational and other kinds of actions; and
(7) *Evaluation* is a self-conscious effort to reflect and evaluate one's own and others performance in managing the risk in question.

IA processes usually fall into the conceptual phase of risk management and thus usually deal with the steps 1 to 4. The actual implementation and execution of measures to be taken (steps 5 to 7) is generally left to specialists and authorities. Thus, IA model use during risk assessment will in general also be of greatest value within steps 1 to 4, where they might help to address questions like the following in the climate change context:

- *Problem framing*: What kind of climate change is considered? Which dimensions of climate change are included in the assessment?
- *Risk assessment*: What consequences might climate change have? Where and when might what impacts occur? Who will be affected, and to what degree? How certain is the information we have?
- *Option assessment*: What are the basic cause–effect relationships? Where can measures be applied most easily? How effective is a proposed measure in terms of actual reduction of greenhouse gas emissions? How costly will that measure be for the national or world economy?
- *Goal and strategy formulation*: Is the proposed goal feasible from a natural scientific point of view? Does that goal lead to unwanted side effects? Does the proposed strategy lead to the achieved goal? Is that strategy feasible from an socio-economic point of view? What are the assumptions required to implement that strategy?

3.2. Analysing the use of computer models in PIA projects from a risk management perspective

The PIA projects considered here have addressed these four issues with various intensity. Model usage differed according to the context and scope of the projects. These conditions and their impact on the model usage will be the focus of our examination in the subsequent passages.

3.2.1. ULYSSES

3.2.1.1. Problem framing. The assessment in ULYSSES made intensive use of models, which were introduced at an early stage of the process. Since most participants were laypersons with neither strong experience in climate science nor in computer modelling, models strongly contributed to the framing of the discussions. Nevertheless, participants started to reflect on the models and model usage during the process and attempted to look beyond the surface of model results, which indicates that the models themselves became part of the puzzle rather than providing the puzzle frame.

3.2.1.2. Risk assessment. Models were widely used in addressing the consequences and potential risks of climate change. Regional models have been preferred in this respect by the participants, as risk assessment often starts from a local perspective.

3.2.1.3. Option assessment. Again, options were assessed mostly for the regional level and the personal realm of the participants, as this was the focus of the project design. Thus, models were mostly used to address lifestyle options and regional scenarios and to find out, what changes on this levels could bring about what kind of improvements.

3.2.1.4. Goal and strategy formulation. ULYSSES did not intend to formulate a precise policy strategy to counter climate change. Rather, the goal was to produce so-called citizens' reports during the final session, which summarise the previous discussions. Depending on the discussion outcomes, the citizens' reports focused on goals and strategies and provided more or less consistent pictures. Models were not used in writing the citizens' reports, but have been used during the previous discussions and to address and assess certain options.

3.2.2. VISIONS

3.2.2.1. Problem framing. Participant were mostly stakeholders who are well acquainted with climate change, so the problem-framing role of models was small.

3.2.2.2. Risk assessment. Risks and opportunities have in part been addressed with the help of computerised tools. This involved both environmental and socio-economic aspects.

3.2.2.3. Option assessment. Scenarios have been strongly tested and evaluated using models and computerised tools, so that these were strongly involved in options assessment.

3.2.2.4. Goal and strategy formulation. The aim of VISIONS was to develop several scenarios for a sustainable European future. These scenarios were mainly developed using participatory methods. Models were helpful in testing the feasibility of goals and the effectiveness of the strategies to reach them.

3.2.3. COOL

3.2.3.1. Problem framing. Participants were recruited from stakeholder groups and political cadres which have already worked on the climate change issue. Therefore, participants' framing of the climate change issue is likely to have been taken place outside the COOL context. The model use in COOL was not primarily intended to assist in framing the climate change problem.

3.2.3.2. Risk assessment. Models were used in the COOL 'Global Dialogue' as input to expert discussions and helped to address costs of climate protection policies but were not designed to display particular environmental risks. The economic risks could be assessed in an aggregated manner.

3.2.3.3. Option assessment. Only the 'Global Dialogue' made intensive use of model results in addressing and assessing options. In the 'European Dialogues', only the energy group used model results as input but not to assess options.

3.2.3.4. Goal and strategy formulation. The COOL project was to find strategies to reduce European GHG emissions by 50–80% in 2050 (corresponding to 15–20% reduction globally). Thus, the goal was predefined, while the strategies had to be developed by the participants. Strategies were tested by model use only in the 'Global Dialogue'.

3.3. Findings

In effect, the intensity of model use in the different phases of the risk assessment process varied over the three PIA projects as summarised in Table 2. In short, the pattern of model usage in ULYSSES appears to be distinct from that of COOL and VISIONS, which are relatively similar. While in ULYSSES models were mainly used during the assessment phase, the other projects utilised them mostly during the strategy formulation phase. The main reason for this difference is that strategy formulation was of minor importance in ULYSSES. In particular, there was no need to formulate explicit scenarios that needed to be tested for their feasibility, whereas this was the main project focus and the major issue for model use in COOL and VISIONS.

This difference also highlights the background of the involved participants. The laypersons in ULYSSES demanded much basic information about climate change and generally attempted to assess that issue in a comprehensive way for the first time. Thus, problem framing and assessment was the main task in the project. To the contrary, COOL and VISIONS mostly involved stakeholder representatives which generally had at least some experience with climate change and its assessment. Drawing on these experiences, these projects could easily turn to formulate and examine strategies that both projects aimed at.

Table 2 also shows some commonalities. All projects used models intensively for option assessment; since the associated construction and analysis of scenarios is the main task of IAMs this appears reasonable. Goal formulation on the other hand is done with few model support since this includes the formulation and valuation of objectives.

Hence, the intensity of model use does not depend as much on the stage in the risk assessment process than on the overall project goals. Like many other tools, computer

Table 2
Intensity of model use during the risk assessment process in recent participatory climate change assessments

	ULYSSES	COOL ('Global'/'European Dialogue')	VISIONS
Problem framing	+	–	–
Risk assessment	++	o	o
Option assessment	++	+/o	++
Goal formulation	–	– –	–
Strategy formulation	–	+/–	++

+(+)=(very) intensive use; o=moderate use, –=weak use; – –=no model use at all. Different classifications for the COOL 'Global' and 'European Dialogues' are separated by a slash.

models are to some extent flexible and can be made useful in a variety of circumstances as long as they are embedded properly in the project set-up. This holds in particular as in all considered projects computer models have not been the only source of information, but have been applied in a mix of expert information, computerised tools and deliberation among participants.

In general, model use is of different value in the stages of participatory risk assessment processes. The prime use of computer models in risk assessment processes relates to the option and the risk assessment. To a lesser extent and given proper embedding, models can also be useful as an input to formulate policy goals or to frame the problem under discussion.

4. Conclusions

Computer models in participatory integrated assessment projects aimed to fulfil different objectives that originate in a participatory and a risk management perspective. The former focuses on why, how and with what results different societal groups are involved in these processes, whereas the latter deals with the classical functions of integrated assessment projects to assess imminent threats, problems, possible responses to natural and human systems. At this crossroads, computer models have proved their applicability and value for certain phases of the risk assessment process. But they have also demonstrated a limited feasibility in participatory processes to facilitate mutual exchange, to raise awareness and to some extent to improve the outcomes of participatory integrated assessment processes with regard to the inclusion of a sound scientific basis into the deliberations.

Given their general potential in raising awareness and initiate and stimulate discussions, computer models can play an important role, particularly in the initial phase of the PIA process. For that purpose, easily accessible software tools like lifestyle indicators, which stimulate creativity appear to be better suited than full-blown IA models. In subsequent process stages, computer models can play a particularly fruitful role in the assessment of options and of future scenarios. They allow workshop participants to test and explore scenarios that have been developed during the discussions. They also may provide new insights and allow for the accounting of different perspectives. Here, sophisticated and detail-rich IA models are better suited than simpler software tools.

Therefore, the focus of the participatory process matters a lot in choosing the 'right' model: When deliberation and the exploration of different attitudes is the main focus, then simple models should be preferred. When the focus is more on user information and/or the development of actual policy recommendations, then a detail-rich model seems appropriate. Likewise, the scales considered in the PIA will influence the model choice. When the considered scale is global, a global model will be useful (like in the 'Global Dialogue' of COOL). Such a model will be of minor help when local consequences are discussed (e.g. in ULYSSES). It remains to be further explored how advanced regional IA models that have improved in recent years can be helpful in PIA.

Several other topics remain important when using computer models in PIA. First, uncertainty is a delicate issue. The level of uncertainty, which is embodied in all IA models of climate change can hardly be substantially reduced as it is connected to the huge amount of assumptions the models are built on. However, the recognition that scientific 'knowledge' is so insecure has frequently been reported to "shock" lay participants and might lead to their disempowerment: why should one care about climate change if even science cannot tell what its actual consequences will be? On the other hand, this lack of certainty can also serve as an encouragement for policy makers or local communities to improve the management of, or the responses to such inherent uncertainties. In the face of these uncertainties, individuals and collective actors can hardly withhold action until science could precisely deliver optimal solutions. Future research might assess the effects of more precise and standardised measures of uncertainties as proposed by Sluijs (1997) and Moss and Schneider (2000) on the perception of laypersons and their ability to cope with uncertainties. In doing so, it should particularly focus on when and how uncertainties could be turned productively rather than dis-empowering.

Second, the use of computer models in PIA is most fruitful when the models have a regional focus and are as simple as possible by focusing on a few key processes. Due attention should be paid to the simplicity of the user interface. Visualisation should reduce information to its essentials and contain colours and maps rather than tables and graphs. Given the current state of the art in IA modelling, these recommendations epitomise a significant challenge for the modelling community. Choosing or developing a model for participatory processes thus requires careful consideration and selection.

Third, all project reports agree that enough time should be provided for participants to accommodate to and work with the models. Although this is not a specific model characteristic, it is an important feature for the design of participatory processes where interactive models are to be employed. Generally, user inputs into the models need to be facilitated by appropriate editors or qualitative values which are converted to numbers internally. Model moderators proved to be most helpful in facilitating the exchange between participants and computer models since they were able to convert quantitative data provided by the models into oral language that can instigate group discussions.

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