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A way out of the credibility crisis of models used in integrated environmental assessment

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Abstract

Integrated Assessment Models (IAMs) have been widely used in environmental policy making because they simulate natural and socio-economic systems by integrating knowledge derived from a wide range of disciplines. The current IAMs have been found to be limited due to their inability to display both the value-laden nature of the assumptions that underlie the model and the uncertainties in their outputs. A Post-Normal Science approach is required for dealing with these issues, involving participation of 'extended peer communities' providing their 'extended facts'. © 2002 Elsevier Science Ltd. All rights reserved.

1. Introduction

In early 1999 a senior statistician (De Kwaadsteniet) of the Netherlands National Institute for Public Health and the Environment (RIVM) accused the institute of 'lies and deceit' in their State of the Environment Reports and other studies. He criticized RIVM for basing their studies almost completely upon the 'virtual reality' of poorly validated computer models and seldom on real measurements. According to De Kwaadsteniet, RIVM presents these results as point values with unjustified significant digits and without clarifying the uncertainties. His criticism was published in a Dutch quality newspaper (Trouw). It triggered a vehement public debate on the credibility, reliability and quality of environmental statistics produced by model-studies by semi-governmental research institutes such as RIVM. The case received front page and prime time coverage in the mass media and provoked questions and debate in the Netherlands parliament. RIVM responded by immediately suspending the employee

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and serving a writ on him against public speaking, which he ignored, consequently increasing the controversial nature of the debate.

The context of this case is that RIVM has, over the past decade, become the authoritative provider of environmental statistics and forecasts, which have provided the basis for the Netherlands environmental policy. RIVM has recently obtained legal status as the office for environmental policy assessment of the Netherlands and its reports have been very influential in policy debates on environmental issues.

The scope of the media-debate that followed can be sketched by providing an anthology of headlines from the quality newspapers: "Environmental institute lies and deceits"; "Society has a right on fair information, RIVM does not provide it"; "Then truth is less important..."; "The bankruptcy of the numbers"; "Dispute on environmental numbers, RIVM disapproves criticism of employee"; "Publish RIVM report together with criticism"; "Measuring would not benefit the RIVM research"; "Agitation in parliament after criticism on environmental numbers"; "RIVM angry about accusations by employee"; "Kafka and the environmental numbers"; "Stand for independence and dissent"; "Calculation model is always better than a crystal ball"; "Research poorly organized"; "Parliament wants to hear Minister about RIVM, Minister takes a too laconic position", "RIVM operates in a mine-field"; "Suspended employee summons RIVM for judge"; "Not everything can be scientifically sound"; "Not method but model determines outcome"; "Models give meaning to measurements"; "Thank the whistleblower"; "Credibility crisis surrounding environmental numbers"; "Wouldn't competition be better for RIVM?"; "Independent validation of environmental numbers necessity"; "Commentary/homage to the whistleblower"; "Work at RIVM not further examined"; "De Kwaadsteniet disappointed in parliament"; "RIVM wants to get rid of researcher De Kwaadsteniet"; "Judge considers suspension of De Kwaadsteniet unjustified"; "RIVM punishes critical employee after all"; "Trade union: More protection for whistleblowers"; "Aid for critical officials"; "Quality of RIVM-data will be controlled"; "Commentary: the whistleblower as sitting target"; "RIVM cheats us with over-exact prognoses"; "RIVM changes clothes".

One of the immediate consequences of the debate has been a decision to carry out a comprehensive external review of the scientific quality of the methodology used by RIVM to produce the environmental numbers published annually in the State of the Environment Report (Milieubalans). I have been involved as a reviewer of the methodology for the monitoring of CO_2 emissions. We found that the quality of the methodology itself is sufficient in view of its function, but the documentation, management and communication of uncertainties needs substantial improvement [1].

To me, the most interesting and relatively novel element in this recent public debate in the Netherlands is its focus on the dominant position of computer models in science for policy in relation to the questions of credibility and quality.

In their report 'Understanding Risk, Informing Decisions in a Democratic Society', the American National Research Council observed that: "Mistrust is often at the root of the conflicts that emerge over risk analysis" and "A combination of psychological tendencies to notice, believe, and give more weight to trust-destroying than to trust-building information, and social factors, such as the tendency of mass media to favour bad news and of some special interest groups to encourage distrust to influence policy debates, makes trust very fragile" [2]. This mechanism is exactly what happened around the trust in the RIVM in the Netherlands. The case was for instance immediately utilized by environmental NGOs to dismiss a recent RIVM study on the possibility of growth of air traffic at Amsterdam Airport, within given environmental standards. Others immediately used the case to put the issue of money-flows to research institutes and the monopoly position of the RIVM on the policy agenda.

As has been argued by many authors in the Post-Normal Science school, the way out of this type of credibility crisis must be found in extended quality control through broad public participation combined with systematic management of uncertainties. Broad public participation in the quality control of environmental assessment and environmental management processes may increase the acceptability of the process and its outcomes. One can distinguish three types of rationales for a participatory approach to Integrated Environmental Assessment: an instrumental rationale, a normative rationale and a substantive rationale [3]. The instrumental rationale reads that participation may decrease conflict and increase acceptance of or trust in the science that feeds into the environmental management process. The normative rationale reads that the processes of environmental assessment an environmental management should be legitimate. The substantive rationale is that relevant wisdom is not limited to scientific specialists and public officials. Participation by diverse groups and individuals will provide essential information and insights about environmental risks. For instance by identifying aspects of hazard needing analysis, by raising important questions of fact that scientists have not addressed, or by offering knowledge about specific conditions that can contribute towards more realistic assumptions for risk analysis. Participation is also essential for the examination, consideration and evaluation of social, ethical and political values that cannot be addressed solely by analytic techniques but also require broadly participatory deliberation.

In this essay, I will further explore the issue of public participation and extended peer review in Integrated Assessment Modelling of anthropogenic climate change, in the historic context of the developments in the Integrated Assessment (IA) field over the past few decades. It is my contention that Post-Normal Science can help to deal with the issue of the assessment of anthropogenic climate change. Decisions are urgent and political pressure on the research community is high. The subject is complex and surrounded by high and partly irreducible uncertainties. The use of computer models is unavoidable. The risk management process has to deal with multiple value orientations of the many national and international stakeholders. The decision stakes are huge. Post-Normal Science is a problem coping strategy, which does not aim at establishing the ultimate truth or the final resolution of the scientific puzzle. As long as both scientific uncertainties and decision stakes are high, such an aim is in principle unachievable and undesirable. The questions put on science by the policy process are urgent so we cannot wait until science has the ultimate answers. Instead, post-normal science aims at common commitments to approaches for dealing with complex policy issues.

The radical consequence of accepting the philosophical position of Post-Normal Science is the recognition that in such cases scientific and technical discourse is no longer restricted to expert communities but needs to be inclusive of non-specialist participants (stakeholders and citizens) [4]. This requires the involvement of an extended peer community and participation of stakeholders and citizens not only in the phase where solutions are debated, but also in the assessment process that precedes it. Although this insight was proposed as early as the seventies [5], it is still not common practice. The critical importance of stakeholder participation in a credible and legitimate assessment process requires further examination in studies of environmental management.

Integrated Assessment is emerging as an approach that is suitable for accommodating the uncertainties, complexities and value diversities of issues such as climate change [6]. IA is a reflective and iterative process that links knowledge and action, both directions, while taking into account the social context in which scientific and political activities operate [7]. The IA process overlaps with the policy development process. Until the mid-nineties, the label IA was often used to refer to the technical part of the process only, with Integrated Assessment Models (IAMs) as the dominant tools. Nowadays it is widely recognized that IAM is not a complete IA methodology, it is a set of tools used in a broader participatory assessment process. This essay discusses the changing role of IAMs within that process and in particular the responses of the IAM-community to the participatory challenge.

IAMs are computer tools, which combine expert knowledge from a multitude of scientific disciplines to support the IA process. However, the existing Integrated Assessment Models (IAMs) of climate change have been designed without sufficiently taking into account the epistemological and social characteristics of the issue of anthropogenic climate change [8]. Particularly, the IAMs fall short in the management of uncertainties and value diversity. IAMs are largely based upon uncertain, incomplete and provisional knowledge. Consequently, the building of an IAM inevitably involves subjective choices and value-laden assumptions. These often remain implicit as they are hidden in computer code, in scientific documentation of the model, or in the minds of the modellers. Often, the modellers themselves are not fully aware of the value-laden character of the assumptions made. In many cases, disciplinary sub-models are included without checking all implications of the assumptions upon which these models are based, and for those situations in which the modellers have some awareness, many value-laden assumptions in IAMs remain largely invisible for the IA users, this reducing the transparency of the process. In a participatory setting this is undesirable, because stakeholders involved in the climate policy debate need not necessarily share the values and subjective choices of the scientists. Consequently the usefulness of the current generation of IAMs to support participatory IA processes is limited.

This paper considers the conditions Integrated Assessment Models need to meet in order to be of better use in support of participatory Integrated Assessment processes. Section 2 explains what IAMs are, how IAMs emerged and how IAMs have been used in the process by which the risks of anthropogenic climate change have been managed over the past decade. We restrict our analysis to Europe. The paper proceeds by discussing the limitations of IAMs with regard to their use within participatory IA and the subsequent conditions that IAMs need to meet to be of use in a participatory assessment process. Section 4 discusses some experiences with participatory IAM-use in IA-focus groups obtained within a European research project (ULYSSES). The paper ends with conclusions in Section 5.

2. The emergence of IAMs as a science–policy interface

The increasingly complexity of environmental problems has required the integration of knowledge derived from a wide range of disciplines. In practice, expert panels and advisory bodies (combining mono-disciplinary assessments) have been too slow and too inflexible to fulfil, for example, the need from the policy process to evaluate and compare the potential impacts of a wide range of policy scenarios. Facilitated by developments in computer technology, integrated modelling emerged in the mid-eighties as a new approach for relating science to policy in complex environmental issues. Integrated Assessment Models (IAMs) are computer models in which knowledge from many different disciplines is combined to assess the problem at hand in an integrated fashion. IAMs are being used for several purposes, such as scenario analysis, (ex-ante) evaluation of the environmental, economic and social consequences of different policy strategies, translation of environmental quality standards into acceptable emission trajectories (safe landing corridors or tolerable windows), and optimization of key-policy variables such as rate of greenhouse gas emission reduction or level of carbon taxes.

Both the natural system and the socioeconomic system are simulated within IAMs. A perfect policy evaluation IAM would model the complete so-called causal chain, including all the feedbacks within this chain. The causal chain starts with socioeconomic drivers leading to economic activity and other practices, leading to emissions and other effects on the environment leading to environmental changes, leading to physical impacts on societies and ecosystems, leading to socioeconomic impacts, eventually returning to cause changes in the socioeconomic drivers.

The first generation of these integrated models focused on acid rain. The RAINS model (Regional Acidification INformation and Simulation) is the most obvious example [9]. RAINS was developed in the eighties at the International Institute for Applied Systems Analysis (IIASA) and the RAINS model played a major role in the international acid deposition negotiations in the framework of the United Nations Convention on Long-Range Transboundary Air Pollution and became an annex to the United Nations SO_2-protocol [10].

In the second half of the eighties, the Netherlands National Institute of Public Health and Environmental Protection (RIVM) developed the IMAGE model (Integrated Model to Assess the Greenhouse Effect), which was a pioneer in the field [11]. IMAGE has been used for scenario calculations in the influential Netherlands policy document ‘Concern for Tomorrow’ [12] and for the development of emission scenarios for the assessments by the Intergovernmental Panel on Climate Change (IPCC), the latter in combination with the Atmospheric Stabilization Framework of the US Environmental Protection Agency [13]. The substantially revised version of the model, IMAGE 2 [14], has been used by all three working groups of IPCC, mainly for developing reference and policy emission scenarios [15]. Results produced by IMAGE 2 were presented to the negotiators at the successive meetings of the United Nations Conference of Parties to the Climate Convention (COP) in Berlin (March, 1995) and Geneva (July, 1996) [16]. For the Kyoto process, the RIVM developed the so-called ‘interactive scenario scanner’, a computer tool for the science–policy dialogue, using results of IMAGE [17]. Overall, over the past decade IAMs have played an increasingly important role in the legitimization and scientific underpinning of policy making regarding global environmental risks.

In the literature on IA, the term Integrated Assessment Model (IAM) is used as a ‘container concept’ to refer to a broad range of computer tools which have been developed as tools to support IA. At least six different definitions of IAMs are in use [18]. In the past decade more than fifty different IAMs have been developed and the number is still increasing. These models differ in a number of aspects, such as purpose of use (scenario analysis, policy evaluation, policy optimization, etc.), transparency, uncertainty treatment, quality control, comprehensiveness, spatial and temporal scale of analysis, spatial aggregation level (globally averaged or geographically localized), aggregation level of the modelled processes, functionality and interactivity [19].

The collection of computer tools, which have been presented as being IAMs, is very diverse. However, most of these tools integrate knowledge which stems from a multitude of scientific disciplines in order to address interconnected aspects of one or more (global) environmental problems in an integrated fashion for the purpose of informing and supporting the policy debate.

3. Limitations of IAMs in relation to participatory IA

Climate IAMs have several limitations, which limit their usefulness for participatory assessment processes. In the following we will discuss these limitations, from which we will deduce conditions that IAMs need to meet to be of better use in support of participatory processes.

A major problem with climate IAMs is that our present-day knowledge and understanding of the modelled system of cause–effect chains and the feedbacks in between is incomplete and is characterized by large uncertainties, knowledge gaps, unresolved scientific puzzles and limits to predictability. In each stage of the causal chain there are both potentially reducible and probably irreducible uncertainties affecting the estimates of future states of key variables and the future behaviour of system constituents. The potentially reducible parts stem from incomplete information, incomplete understanding, low quality of input data and parameter estimates, weakly underpinned or artificial model assumptions, and disagreement between experts. The probably irreducible parts stem from ignorance, epistemological limits of science, indeterministic system elements, practical unpredictability of chaotic system components, limits to our ability to know and understand, limits to our ability to handle complexity, the ‘unmodellability’ of surprise, non-smooth phenomena, and from intransitive system components due to multiple equilibria [20].

Given the huge uncertainties and unresolved scientific puzzles surrounding the climate issue, it is not surprising that there is a controversy about the usefulness of IAMs for assessing climate change. The positions in the debate vary from “We are not ready to do integrated modelling, we must wait until all science used in the model has the status of well-established knowledge” to “We have a responsibility to use our best scientific understanding to develop reasonable policies. Integrated modelling is the best way of combining our knowledge in such a way that we can evaluate the consequences of different policy scenarios, do cost–benefit framing or optimize cost effectiveness to reach a target”. Given this controversy, the use of IAMs can only be justified if all actors that deal with IAMs and IAM results are fully aware of the limitations and caveats of IAM-assessments. This requires full-fledged uncertainty management. However, in the practice of uncertainty management in IAMs, we have identified major gaps in the systematic analysis of unreliability of the knowledge about input data, model parameters, and model assumptions, and also in the analysis of uncertainty about model structure [21]. Tools for assessing these types of uncertainty and how these might affect the outcomes of assessments, are either not available or have not been disseminated among the IAM community. An example of the latter is the NUSAP (Numeral Unit Spread Assessment Pedigree) methodology designed by Funtowicz and Ravetz [22]. Van der Sluijs et al. have developed and demonstrated a procedure to apply NUSAP to IAMs [23].

Studies addressing the phenomenon of scientific expertise have shown that expert interpretations are underdetermined by any given scientific knowledge because of the repertoire of interpretative possibilities existing at each link in the argumentative chain [24]. The more uncertainties and ignorance, the larger is the repertoire of interpretative possibilities of a given knowledge base. Often this leads to scientific controversies, expert disagreement and conflicting certainties. One needs to make climate risk assessment as transparent as possible in order to facilitate a shared understanding of the background of conflicting interpretations provided by various experts and various models.

Several authors have shown that current IAMs contain many value-laden assumptions [25]. One of the most obvious value-laden assumptions used in macro-economic oriented IAMs is the differential monetary value of human life. This so called ‘value of a statistical life’ (VOSL) is a measure of how much a society is willing to invest in order to prevent the loss of a ‘statistical person’. For poor societies this ‘value’ is much less than the rich. The attachment of monetary values to the costs and benefits of human intervention in the system by means of the concept ‘willingness to pay’ (WTP) is also highly value laden. Although VOSL and WTP might be analytically convenient since this objective method permits risks to be put into a common metric (i.e. the dollar), it values the losses of poor countries from climatic damages that include loss of life much below (in absolute dollar terms) that of rich countries in an integrated assessment. In these examples, the value-laden character of the assumptions is obvious. However, IAMs have many other value-laden assumptions, which are not so easy to recognize as such. During the development of a model, many subjective decisions are being made to include, exclude or simplify processes or characteristics. Many of these choices are inevitably to a certain extent arbitrary and hence are likely to possess a subjective component. Such choices trade on specific assumptions and premises, which need not necessarily be shared by the stakeholders involved. Because typical problems addressed in IA are characterized by values that are disputed, models with hidden or value-laden assumptions are not well-equipped for use in participatory IA.

To be of use to a participatory IA process, IAMs need to facilitate the comparison of many different user-definable scenarios, assumptions and policy options in a reasonable time frame. This sounds obvious, but most IAMs don't meet this criterion. Ideally, an IAM should be able to be used interactively by a stakeholder on her or his own desktop PC. In this respect, geographically differentiated models with high process detail such as the IMAGE 2 model have the problem that they require a lot of calculation time and that they need more powerful computers than an average PC. Usually IAMs also require much experience, skills, tacit knowledge and insight in the model in order to be able to perform a model run that makes sense. This is not usually made clear to non-experts, who are led to believe that one need only feed in the assumptions and then watch a future scenario emerge.

The risks involved in letting stakeholders use IAMS without control by the experts were shown in a classic case involving John Sununu, chief of staff to President George Bush from 1989 to 1991. He had a strong technology background (PhD in engineering at MIT). Sununu had a reduced-form version of the NCAR climate model installed on his office computer. He used (according to several members of the IAM community: misused) the model to support the stance that preventive measures were not necessary. He is widely reported to have convinced President Bush that the threat of global warming was overblown, and that arbitrary limits on carbon dioxide emissions would have a cost vastly exceeding their benefit [26]. According to Parson, "*the resultant outrage among modellers and analysts was in part puzzling, since this story seems to realise the vision of senior policy-makers becoming fully conversant with assessment models. Several legitimate bases for the outrage are plausible, though. He was a busy man, using a simplified (but still very complex) model but not able to spend much time on it, and so was no doubt at risk of serious misunderstandings. A model on his machine in the White House is not open to scrutiny and technical argument. Nor might it be easily updateable to reflect advances in understanding*" [27].

This embarrassing episode raises the question of the extent to which experts should control the participation by citizens in modelling. It also raises questions about the democracy of the process of establishing the policy meaning of scientific knowledge and expert interpretation. A monopoly of scientists in this process is undesirable, because as Funtowicz and Ravetz have argued: "in the light of such uncertainties, they [the experts] too are amateurs" [28]. The genuine issues of legitimacy of expertise have not been systematically addressed. Instead, scientists have maintained control, and depoliticized parts of a debate, by a technique described by the sociologist Thomas Gieryn [29] as *boundary work*. In her study on the role of scientific advisers in American regulatory politics, Sheila Jasanoff has further explored how scientists use a variety of boundary-defining strategies to establish who is in and who is out of relevant peer groups and networks of prestige or authority [30]. She argues that boundary work by scientists grows out of a premise that seems diametrically opposed to the concept of negotiation and yet is equally essential to the closure of controversy. By drawing boundaries between science and policy, scientists post 'keep out' signs to prevent non-scientists from challenging or reinterpreting claims labelled as 'science'. The creation of such boundaries seems crucial to the political acceptability of expert advice. She also found that the experts themselves seem at times painfully aware that what they are doing is not "science' in an ordinary sense, but a hybrid activity that combines elements of scientific evidence and reasoning with large doses of social and political judgement. It is not clear whether such boundaries could or should survive when the post-normal character of these issues is recognized.

It is not necessary for stakeholders to become expert in the operation of an IAM. Their principle use in a participatory context is their problem structuring quality: the value-laden assumptions in a model have to be transparent to the user, and also capable of being varied by the user. The models should accommodate a broad range of value-positions and they should stimulate the involvement of a multitude of conflicting views and perspectives in the participatory problem structuring process. Their usefulness as a source of information should not be one of providing the facts ('speaking truth to power'), but rather their heuristic function: the IAM should foster the creative generation and exploration of rival problem definitions, accommodating the entire spectrum of perspectives and values of the stakeholders involved.

With this understanding of the Post-Normal function of IAM's, we see that the extension of the peer community is not merely an ethical or political act. Extension of the peer community creates the opportunity to utilize local knowledge or 'extended facts', which can positively enrich the assessment process. As we mentioned before, the lack of inclusion of knowledge on local conditions has often led to solutions, which were for that reason predestinated to meet serious barriers to their implementation. Local knowledge can be knowledge of local conditions, which may determine which data are strong and relevant, and it can also help to diffuse the policy problems. Local knowledge can also take the form of anecdotes, informal surveys, official information published by unofficial means, etc. It may be argued that stakeholders lack theoretical knowledge and are biased by self-interest, but, as we have seen, it can equally well be argued that the experts lack practical knowledge and have their own unselfconscious forms of bias [31].

In conclusion, to make IAMs of better use for participatory IA, several conditions need to be met. The ones inferred from the limitations discussed here are:

- IAMs should be as transparent as possible;
- uncertainties should be made explicit;
- value-laden assumptions should be made explicit and variable;
- IAMs should be interactive;
- IAM use by stakeholders should be mediated by experts;
- IAM should encourage and facilitate problem structuring;
- IAMs should foster the creative generation and exploration of rival problem definitions;
- IAMs should allow the inclusion of local knowledge in the assessment.

4. Experiences from ULYSSES focus groups

Recently, European experiments with the use of IAMs in participatory IA have been carried out in the framework of the ULYSSYES (**U**rban **L**ifest**Y**les, **S**u**S**-tainability and Integrated **E**nvironmental A**S**sessment) project. The special approach of ULYSSES has been to design procedures allowing interfaces between expert models of environmental change on the one hand, and lay participants in focus group discussions on the other hand. These 'IA-Focus Group' procedures have been designed, and tested in seven urban regions throughout Europe for the topic of climate change in relation to urban lifestyles. The regions were Barcelona, Venice, Athens, Zurich, Frankfurt (Rhine/Main), Manchester and Stockholm.

In a focus group small groups of citizens share a moderated discussion on climate risks and options for climate policy. The ULYSSES project applied the following experimental set-up for the focus group experiments [32]:

- each focus group meets for five individual sessions or for two consecutive days;
- in the first session environmental problems and climate change are discussed in a general way and in some groups the participants are encouraged to produce collages to illustrate their concerns;
- in the second session global issues are addressed using an IA model to stimulate the discussion. The model use was moderated by an expert;
- the third and fourth sessions focus on regional and local issues, using a regional IA tool to stimulate discussion;
- in the fifth session the participants produce a 'citizens report' on the basis of the discussions in all sessions.

The focus-group process was facilitated by a group moderator (guiding the discussions) and a model moderator (introducing and demonstrating the IA tools). A number of IA tools have been used in the ULYSSES project. The experiences reported here are based on the use of three tools: IMAGE 2.0 [33], TARGETS [34] and PoleStar [35]. IMAGE 2 is a geographically localised global model, developed and used in the Netherlands. It has a strong focus on land-use change and feedbacks via vegetation changes. It includes three modules: Energy-Industry, Terrestrial Environment and Atmosphere-Ocean, and has global coverage and the spatial resolution varies across modules. The model permits experimentation with a wide variety of scenarios. The TARGETS model (Tool to Assess Regional and Global Environmental and Health Targets for Sustainability) was constructed by RIVM to allow the value-laden choices to be more explicit and transparent. Integrating a variety of sub-models, TARGETS employs multiple model routes depending on a typology of 'perspectives', whose categories derive from a slightly simplified version of the Cultural Theory of Douglas and Wildavsky [36], employing 'myths of nature' as developed by Schwarz and Thompson [37]. PoleStar was developed by Stockholm Environmental Institute for the examination of economic, resource and environmental information of a region. We will briefly describe how these models were used in the focus group experiments.

As regards IMAGE 2.0, the complexity of the model makes it impossible to run it and get results for new scenarios during the course of a focus group. Supported by the IMAGE Group at RIVM, within the ULYSSES project the Potsdam Institute for Climate Impacts Research (PIK) generated a series of scenarios produced by the IMAGE 2.0 model. These scenarios can be used within focus group sessions to present 'what if' kinds of questions at the global scale. These scenarios are not suitable for addressing either cost analyses associated with various atmospheric stabilisation and emission reduction targets or the analysis of local possibilities for action.

For the ULYSSES project the developers of the TARGETS model provided a special interface and a work package to inform model moderators how to introduce and use the model. The special interface presents the main causal links of the climate problem. Participants can change the major assumptions pertaining to economic, environmental and societal processes and explore different trends such as those for population growth or energy efficiency. PoleStar was used in ULYSSES focus groups to stimulate discussion about policy and lifestyle options for reducing greenhouse gas emissions at the regional level.

The findings of ULYSSES suggest that focus group contexts can indeed facilitate sophisticated debates among citizens about complex environmental issues. This is in contrast to the perceptions by some decision-makers that citizens lack the competence for such debates. In particular, ULYSSES has shown that lay people are able to engage with computer tools in IA-Focus Groups, given certain conditions.

The IAMs were successful in conveying to participants the temporal and spatial scale of climate change, the complexity of the system and the uncertainties in our understanding of it. However, it also turned out that despite considerable efforts, most models were not sufficiently user-friendly and transparent for participatory use in a IA focus group [38]. From the ULYSSES experience, van der Sluijs has identified a list of characteristics of the computer tools that are deemed important by citizens in relation to the usefulness of IAMs for a moderated discussion on climate risks and options for climate policy [39]. These characteristics are: Strong interest in the regional level; Possibility to evaluate user-defined policy options; Realistic and credible inputs and results; Easy to follow, detailed, and flexible user manual; Understandable model presentation; Interactive and attractive user interface; Explicitness and understandability of the uncertainties; Need for adequate model moderation.

Van der Sluijs has shown that these findings are mutually consistent with the conditions inferred in Section 3 of this essay, and that each required characteristic can be framed in terms of one or more of the conditions we formulated and *vice versa*. However, the list of characteristics is not sufficient to cover all implications of the conditions [40]. For instance, none of the listed characteristics corresponds with the need for making value-laden assumptions variable, and neither problem-structuring nor inclusion of local knowledge is satisfied by a focus on the regional level and the inclusion of user definable policy options.

Although the ULYSSES project has made a major step forward in developing a methodology for a participatory IA process including IAMs and citizens in the deliberation process, the procedure can be criticized for imbalance in the required mutual learning process between scientists and stakeholders. It is useful that the participants learn from the state of the art computer models and increase their understanding of the uncertainty and complexity of the climate problem. But what do the models and the modellers learn from the participants? The observed lack of transparency of the models may well have contributed to a lack of debate on and scrutiny of the IAM methodology and its underlying value-laden assumptions.

5. Discussion and conclusions

In this paper we have explored the issue of public participation and extended peer review in Integrated Environmental Assessment. We have focused on the question what conditions Integrated Assessment Models (IAMs) need to meet in order to be of better use in support of participatory IA processes regarding post-normal environmental management problems such as anthropogenic climate change. We have analyzed the limitations of IAMs with regard to their use within participatory IA. From these limitations we inferred the seven criteria listed above which IAMs should meet to improve their potential usefulness and credibility in the participatory context.

Overall, we found that the current generation of IAMs is not well suited for participatory IA, mainly because the IAMs have been developed within a paradigm with respect to the role of science in environmental management which is incompatible with the unstructured and *Post-Normal* nature of complex problems such as climate change.

A new generation of IAMs is needed, which accommodates value diversity but avoids the premature closure of the problem structuring in pre-defined static categories. To facilitate participatory IA processes, there is a need for more open, dynamic (interactive) forms to accommodate value diversity and to cope with plurality. Such an approach should take actual stakeholders as a starting point rather than static theoretical categories of perspectives and value orientations. In our view such a step forward is essential to regain long-term credibility for model use in Integrated Environmental Assessment processes.

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