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Current thinking on using scientific findings in environmental policy making

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1. Introduction

This paper provides an overview of current thinking about the use of scientific findings in policy making about environmental issues. As Funtowicz and Ravetz [14] have pointed out, issues of global environmental change differ from "traditional scientific problems", because they are global in scale and have long-term impacts, data are generally inadequate and the phenomena are complex and not well understood. Decisions have to be made on the basis of uncertain inputs and under somewhat urgent conditions. As a result, in the case of environmental issues science plays a different role than it has done in policy making on other issues. Funtowicz and Ravetz pointed out that the limitations of traditional problem-solving strategies in dealing with global environmental risks arise because decisions depend on evaluations of future states of the natural environment, resources and human society, all of which are unknown and unknowable. They concluded that a new methodology is required for science to provide support for decisions on global environmental issues. This will require "extended peer communities", because quality assurance requires participants outside the usual peer communities of experts. It also requires "extended facts", such as evidence that is initially anecdotal or information not usually available to the public.

Thus we see that in the environment area, we appear to be confronted with a special case, as far as the use of scientific information in policy making is concerned. Section 2 of this paper looks at some examples of the way in which the interactions of the science and policy worlds have been characterized. It shows that the simple and often used model that first the science is done and then the policy is formulated and implemented is not valid. Section 3 reviews some general conclusions about the design and use of integrated environmental assessment within the context of the use of scientific findings in policy making. A number of scholars have provided checklists of issues or practices to bear in mind in the design of assessments and others have looked at the advantages of the two main assessment practices – formal models and expert panels. Section 4 describes reported experience in using either integrated assessment models or integrated assessments in policy making for the issues of acidification and climatic change. Section 5 looks at criteria that could be used to evaluate current practice in linking science to policy for environmental issues. Finally, section 6 draws some conclusions about the interactions of the science and policy and the implications for future work of the European Forum on Integrated Environmental Assessment (EFIEA).

2. Characterizations of the interactions between science and policy

There is a broad literature that discusses the linkages between science and policy, much of which is relevant to the discussion of the use of scientific findings in environmental policies. This section concentrates on two aspects particularly relevant in the context of the European Forum on Integrated Environmental Assessment: how the science and policy worlds possibly influence each other and the time dimension of the interactions between science and policy. It is important from the outset, however, to remind ourselves that what science is, and how it is used, is not straightforward. This was illustrated, for example, in an essay by Jasanoff [23], who pointed out that

- Scientific enquiry does not always lead to the same explanation for the same observed phenomenon.
- When people reach scientific conclusions about the reasons for a particular natural phenomenon, their explanations are not always the same.
- What compels people to act upon a perceived problem is not necessarily knowledge that is endorsed by science.
- Just as too little science can sometimes aid decision making, so too much science sometimes overwhelms the capacity to act.
- Finally, there are instances where states or interest groups agree that a problem exists, but cannot agree about how the problem should be conceptualised for purposes of scientific investigation.

Shackley and Wynne [35] pointed out that the interaction of science and policy worlds has been characterized in three main ways: in terms of a two-way flow of information between the two; in terms of a distinctive "trans-scientific" set of problems; and in terms of "regulatory science", pictured

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as a sort of hybrid of science and policy. In the first model it is assumed that science and policy making are activities that can be understood to occur in largely distinct realms. The institutions, people, methods and practices are different in the two realms and the information flow between them occurs when scientific or technical information is required for solving particular policy problems. The second model was introduced by Weinberg [37], who proposed that there were some policy issues which cannot be resolved by scientists, because of the complexity or indeterminacy of the systems being addressed and/or the present impossibility or impracticability of testing knowledge claims through usual scientific processes. Weinberg called these issues examples of "trans-science", a hybrid realm of policy-relevant scientific questions, whose resolution required non-scientific methods. The third model, an elaboration of the "trans-science" model, referred to a domain of "regulatory science", in which the content and context of research was subject to political pressures to provide answers, often in a short period of time, to a specific policy- or legally-driven question. "Regulatory science" was, therefore, seen to involve evaluation and assessment rather than "new research", that is, it draws upon core scientific research in terms of scientific papers, personnel and, especially, expert advice.

Shackley and Wynne [35] pointed out that an interesting feature of the concept of regulatory science is the light it casts on the ways in which "closure" or consensus on the answers to particular science-based policy questions is reached. They suggested that closure is sometimes achieved by pragmatic regulatory policy decisions, though such decisions are frequently presented subsequently as having been purely scientific in character. The combination of various closure mechanisms constitutes the "mutual construction" model of science and policy, a further elaboration of the trans-science and regulatory models. Within the process of mutual construction the domain of science "helps to reinforce the belief that particular knowledge, ideas or "needs" in the policy field are realistic and valid, driven by policy-relevance and/or by the criteria defining "best science", and vice versa for the effects of policy on science" (Shackley and Wynne [35, p. 221]).

Shackley and Wynne [35] argued that the climate change issue is a powerful mutual construction. In particular, the scientific commitment to using general circulation models and the expressed policy "needs" are seen to be mutually reinforcing. Shackley and Wynne [35] concluded that it is important to understand these science/policy dynamics and the potential consequences, since they actually imply that it is necessary to think further about how existing social, political, institutional and "lay" knowledge and know-how might be developed and used in reducing greenhouse gas emissions and adapting to climate change.

In commenting on the paper by Shackley and Wynne, van Asselt and Rotmans [4] emphasized that, in their view, modelers do not seem to realize, or at least do not admit in public, that choices regarding research questions and research approaches are heavily influenced by subjective factors, of which influence by the policy realm is only one. The modeling approach adopted by van Asselt and Rotmans (see, for example, Rotmans and de Vries [31]) allows for a wide variety of perspectives to be given full consideration and explicitness in a model.

In the view of van Asselt and Rotmans [4] integrated assessment is an iterative, continuing process, whereby, on the one hand, comprehensive insights from the scientific community are communicated to the decision-making community, and on the other hand, decision-makers' experiences and learning effects contribute to the input for scientific investigations – mutual construction of science is, according to van Asselt and Rotmans, one of the pillars of integrated assessment.

Other discussions of the linkages between the science and policy realms address the time dimension or order in which things happen. A simple but often used conceptual model of the linkage between science and policy is that first the science is done and then the policy is formulated and implemented. This kind of "linear" or "sequential" model of the interactions is exemplified by the model of Jones [24], which takes "problem identification", based on scientific capacity or the available knowledge about an issue, as the determinant of the structuring of the rest of the process.

The idea that scientific consensus is an essential prior step before policy development and implementation has been challenged, for example, by Collingridge and Reeve [11], who argued that science is used either to legitimatize policies taken for non-scientific reasons or if either the consensus contradicts the policy or there is scientific dissent, then it is ignored. Thus, according to Collingridge and Reeve, new knowledge is of little use to policy and science can keep supporting more than one stance in the policy debate.

In contrast to the conclusion of Collingridge and Reeve, van Eijndhoven and Groenewegen [13] argued that the connections between given scientific findings and policy options are more like chains of linked arguments and beliefs. Van Eijndhoven and Groenewegen therefore emphasized the constructive, active character of scientific knowledge in policy development, as opposed to the "linear" view of knowledge simply being transferred from the science to the policy arena.

In order to improve understanding of the long-term and complex process of policy change in air pollution control and other policy areas, Sabatier [32] developed the "advocacy coalitions framework". In doing so, Sabatier rejected the "linear" model of the policy process, because it is *inter alia* unable to explain the continuing role of state and local governments in policy innovation. Further, Sabatier concluded that technical information is used throughout the policy process. The advocacy coalition framework is based on the premise that understanding the process of policy change requires a time perspective of a decade or more and that it is necessary to focus on policy subsystems, which consist of actors from a variety of public and private organizations who share a set of normative and causal beliefs. On the basis of new knowledge, each advocacy coalition can, according to Sabatier, revise its beliefs or modify its strategy. Sabatier emphasizes, however, that changes in relevant socio-economic conditions and system-wide governing coalitions can alter the composition and resources of coalitions and thus influence public policy. The framework suggests that changes in the core aspects of a policy are usually the results of perturbations in non-cognitive factors, like macroeconomic conditions.

Kingdon [25,26] considered public policy making to consist of a set of processes, including at least: the setting of the agenda; the specification of alternatives from which a choice is to be made; an authoritative choice among those alternatives; and the implementation of the decision. In his study, Kingdon concentrated on the first two processes and asked why some subjects become prominent on the policy agenda and others do not, and why some alternatives for choice are seriously considered, while others are neglected. The agenda was considered to be the list of subjects or problems to which government officials, or those not in government but close to the officials, are paying some serious attention at any given time. Kingdon concluded that in order to understand agenda setting and choice of alternative, it is necessary to conceive of three process streams flowing through the system – streams of problems, policies and politics. These streams are, according to Kingdon, largely independent of one another and each develops according to its own dynamics and rules. However, at some points in time the streams are observed to join and the greatest policy changes grow out of these junctures. Kingdon found that these separate streams of problems, policies and politics come together when "windows of opportunity" are open, either as a result of the appearance of compelling problems or of events in the political stream.

Thus Kingdon's "model" of the policy process holds that there is no smooth development in stages, steps or phases. According to Kingdon, "participants do not first identify problems and then seek solutions for them; indeed, advocacy of solutions often precedes the highlighting of problems to which they become attached".

These examples are, of course, by no means comprehensive but are illustrations of some "models" of the use of science in the policy process. In particular, they illustrate alternatives to the simple "linear" or "sequential" model. Through an examination of long-term developments in the management of global environmental risks, Jäger et al. [22] have identified broad patterns in the linkages between science and policy that can be described as a three-stage process. During the first phase, in which scientific capacity is building up through monitoring and assessment activities, there are few, if any, interactions between the science and policy worlds. In this first phase, the issues are located in the scientific domain, where they might reach the attention of one or another actor in the policy domain but where they are not on the broader policy agenda. In the second phase, a unidirectional flow of information from the science domain to the policy domain is observed, with the knowledge becoming the basis for goal statements on how to deal with the issue. In the third phase, when the issue is firmly on the policy agenda, there are linkages between science and policy in both directions, i.e., science influences policy and vice versa. To some extent this model is similar to Kingdon's model of parallel streams of problem generation, solution generation and the occurrence of windows of opportunity but with one important exception: the streams are no longer independent after the window of opportunity has occurred.

In the context of the EFIEA, it is probably most important to note from this brief survey of some of the relevant recent literature that for global environmental issues, it cannot be assumed that there is always a linear or sequential linkage between science and policy. Similarly, it would be misleading to think that science and policy making take place in two largely distinct realms. Certainly, experience shows that once an issue is firmly on the policy agenda, these realms are strongly linked. Integrated environmental assessment can be seen as a mechanism for providing linkages between the two realms. The literature also shows the importance of looking at the linkages over a long period of time. In the early phases of issue development, at least for the issues of acid rain, climatic change and stratospheric ozone depletion, the science and policy realms are not strongly linked, whereas after the issue is firmly on the policy agenda the linkages resemble the "regulatory science" or "mutual construction" model. Within the European Forum, as other issues are studied, it will be important to understand where they are in terms of the evolution of the issue, both in terms of providing further empirical evidence for the models available in the literature, as well as showing what the probable linkages between science and policy look like.

3. The design and use of integrated environmental assessment

This section looks at recent studies on the design and use of integrated environmental assessment, in terms of the usefulness of IEA in informing policy decisions. The words "Integrated Assessment (IA)", "Integrated Assessment Models (IAMs)" and "Integrated Environmental Assessment (IEA)" have been used in recent years to describe parts of the process of linking science and policy, in particular for global environmental issues. Parson [30] provided a definition of assessment, which could be useful in minimising confusion about terminology. According to Parson,

> "Assessment consists of gathering, synthesizing, interpreting, and communicating knowledge from various expert domains and disciplines, to help responsible policy actors think about problems or evaluate possible actions."

As Parson [28] pointed out, to be integrated means that the information is assembled from a broader set of domains than would usually be provided by good research from a single discipline. In this respect, there is some redundancy between "integrated" and "assessment", since most assessment will require some integration. Assessment does not mean doing new research, but it does mean making knowledge relevant and helpful for decision makers.

Parson [30] argued that policy making for global change issues requires several kinds of knowledge and that two conventional methods – formal models and multidisciplinary expert panels – have mainly been used to address these knowledge requirements but have distinct strengths and weaknesses. Parson identified seven distinct kinds of knowledge needs[1] that can characterize global change issues and suggested that these needs have major implications for what assessment must do to be useful. He then proceeded to discuss the strengths and weaknesses of the two conventional methods that have dominated assessment practice. The main weaknesses in formal integrated modeling result from weakness in representing important elements of behaviour of the system or issue being studied. According to Parson, current IA models are weak in the way they represent climate impacts and adaptation, policies and responses, and the basic drivers of long-term emissions trends, especially demographic and technological change. As Parson noted, some of these weaknesses represent computational limits and analytic tractability, while others reflect limited understanding.

The second main method in assessment practice, the multidisciplinary expert panel, has been used for global environmental issues for more than 25 years. Panels usually review, discuss and summarize various fields of knowledge, sometimes also drawing on formal models. Parson suggested that as procedural devices that seek to draw on broad-ranging expert authority to serve policy making, panels lie between the domains of science and politics, and hence are liable to attack on grounds drawn from either domain. Consensus on the panel is normally a necessary (though not sufficient) condition for withstanding such attacks. There are several devices used to reach consensus, such as diluting statements to a level of vagueness that raises no objections or restricting statements to areas where uncertainty is manageable and consensus is strong. Such devices basically lead to "dis-integrated assessment".

Parson concluded that there are several classes of knowledge needs, important for global environmental issues, that conventional assessment methods – models and panels – are not well equipped to provide. Current work on assessment models to improve representation of uncertainties, technological change and impacts will not alleviate the weaknesses identified by Parson, neither will current discussions on the composition and work of assessment panels. Parson suggested that alternative methods for assessment and synthesis exist and could help to address some of the knowledge needs in which conventional methods are weak. In particular, scenario planning exercises, policy exercises, political-military exercises, simulation-gaming and adaptive environmental assessment and management are mentioned. It is suggested that these assessment methods are likely to be useful for policy issues that are high in obscurity and complexity, such as those of global environmental change.

In an article addressing the problem of integrating science and policy in global change research, Brunner [8] suggested that global change might indeed be the largest policy problem to be tackled in terms of the number of significant variables and interactions involved and the scope of their spatial and temporal dimensions. Brunner questioned strongly, however, whether comprehensive, predictive models are required to reduce scientific uncertainty as a prerequisite for rational, comprehensive and cost-effective policy responses. In particular, he suggested that reliance on predictive models makes little sense if human behavior is taken into account. He concluded that a predictive model is neither sufficient nor necessary for improvements in the rationality of policy decisions and that the contribution of science should be to provide insights not predictions. For the U.S. Global Change Research Program, instead of comprehensive predictive models Brunner proposed action on "multiple modest alternatives", a national program based on decentralized policy teams that would generate and test a wide variety of limited policy formulations and action alternatives on a regional or even local scale over a short (2–3 year) cycle.

Edwards [12] took the proposal of Brunner [8] as the basis for a discussion of the role of comprehensive models, both Integrated Assessment Models (IAMs) and Earth System Models (ESMs), in politics and policy making. Edwards argued that the emergence of an "epistemic community" (see, for example, Haas [16,17]) including scientists, policy makers and other actors with compelling interests in global change issues came about as a result of comprehensive model building. Thus, Edwards argued that comprehensive model building serves an important political purpose, even if it does not and perhaps cannot serve the immediate needs of policy makers. That is, the models are contributing to a fundamental shift in the structure of scientific work towards trans-disciplinary collaboration and communication and have become one of the organizing principles of a community that believes that global natural systems may be significantly affected by human activities. The importance of the models in communicating community assumptions, beliefs and shared data is stressed by Edwards.

Furthermore, Edwards used the example of the "limits to growth" debate of the 1970s to provide another example of the way that models can acquire political significance, namely as purely heuristic guides to complex phenomena. As Edwards pointed out, *the limits to growth* probably had no direct policy impacts but through the models, the meetings, popular books and discussions between the authors

[1] These knowledge needs come under the headings of: framing, agendas, scenarios, instrumental relations, ordinary uncertainty, strategic uncertainty and valuation.

and politicians, two important heuristics were communicated to the broad public and the policy elite: (a) that exponential growth (especially in population) cannot continue unchecked, and (b) that the world should be viewed as a set of interlocking systems which cannot be successfully understood or managed piecemeal. Whether ESMs or IAMs can contribute to effective global change policy is, according to Edwards, less clear. He concluded, however, that the coupling of models to policy is, and should be, weak and heuristic rather than strong and deterministic and it is mediated by the formation of epistemic communities.

The role of IAMs in the global climate change policy debate was discussed in detail by Schneider [33], who suggested ways that IAMs can help with the policy making process and commented on the dangers that analytic methods with limited capabilities bring to the public debate given that not all potential users of IAMs will be aware of hidden values or assumptions that are inherent in all such tools. Schneider suggested that for both the explanatory and policy purposes of IAMs, it is necessary to test the credibility of their structural assumptions, input data, parameter values and outputs and he gave several examples of how this can be done. Furthermore, he suggested that it is important to explore the predictability limits of the models, since a great deal can be learned and useful projections of the sensitivity of a system to specific disturbances made even when individual realization (i.e., a single time series of state variables) may have no reliable predictability. Schneider agreed with Parson [29] that the policy utility of IAMs would increase with increased involvement of diverse policy actors in the development and use of assessments and assessment tools. However, Schneider pointed out that it is not easy to bring about this increased involvement and it requires that the modelers work hard at outreach to the decision-making community. Schneider listed several policy-relevant topics to illustrate where IAMs need more attention. Problematic but essential processes that need to be included in IAMs are, according to Schneider, induced technological change and adaptation. Furthermore, Schneider suggested that structural modifications to IAMs are required to incorporate transients, surprises and (subjective) probability analyses. Finally, he provided a checklist of issues or practices to bear in mind when building or applying IAMs for integrated assessment of the climate issue:

1. Specify clearly at the outset and in the conclusions of presentations or publications the limited context of each particular IAM exercise.
2. Cite alternative approaches and contrast them to your approach, stressing how each treats uncertainty and deals with the many value-laden components of the analysis.
3. Provide as many menu options as practical, especially for those choices which deal with culturally-dependent components or “imaginable surprises”.
4. Perform as many “validation” tests as possible, and when not practical, discuss, based on qualitative reasoning, the credibility of structural assumptions, input data, and model parameters, and their relevance to policy issues being considered.
5. Stress the likelihood that this generation of IAM results will change as “rolling assessments” provide an evolving picture of climatic effects, impacts and the efficacy of policy instruments and societal values.
6. Note components of the IAM which are particularly sensitive (or insensitive) to aspects of the problem that are controversial and thus likely to change with evolving research.

In conclusion, Schneider emphasized the need for efforts to include decision makers and citizens at all levels in the design, testing and use of IAMs for real policy questions.

Morgan and Dowlatabadi [27] summarized insights from five years of integrated assessment activity in which they played the leading role. They concluded that the decision makers in the case of climatic change are a diffuse and often divergent group spread all over the globe, who also make a series of climate-relevant decisions that are primarily driven by local, non-climate-related decisions. Thus the tools required to deal with the climate problem will often, according to Morgan and Dowlatabadi, be quite different from those associated with the conventional single-actor, single-decision models. On the basis of their experience, Morgan and Dowlatabadi presented basic principles, which, they believe, should guide all integrated assessments:

1. The characterization and analysis of uncertainty should be a central focus of all assessments.
2. The approach should be iterative. The focus of attention should be permitted to shift over time depending on what has been learned and which parts of the problem are found to be critical to answer the questions being asked.
3. Parts of the problem about which we have little knowledge must not be ignored. Order-of-magnitude analysis, bounding analysis, and carefully elicited expert judgment should be used when formal models are not possible.
4. Treatment of values should be explicit, and when possible parametric, so that many different actors can all make use of results from the same assessment.
5. To provide proper perspective, climate impacts should be placed in the context of other natural and human background stochastic variation and secular trends. Where possible, relevant historical data should be used.
6. A successful assessment is likely to consist of a set of coordinated analyses that span the problem ... not a single model. Different parts of this set will probably need to adopt different analytical strategies.
7. There should be multiple assessments:
    - Different actors and problems will require different formulations; and

- No one project will get everything right. Nor are results from any one project likely to be persuasive on their own.

Morgan and Dowlatabadi concluded that integrated assessment faces methodological and philosophical challenges. The incorporation of uncertainty and of values is extremely challenging but also crucially important if the assessments are to be useful for decision making.

Parson [28] concluded that current assessment projects show three particularly important weaknesses. First, they are weak in the projection of future emissions over decade to century time-scales, especially through exogenous determination of population growth and technological change. The second weak area, according to Parson, is the description and valuation of impacts of climate change. The third weakness is the representation of policy. Parson pointed out that if an assessment is intended to be of direct assistance to some responsible actor, it is helpful if it contains a representation of decisions they might take and consequences they might care about. The coarse spatial and sectoral resolution of most assessments make this difficult. Broadly, Parson concluded that integrated assessment can make four important contributions to understanding and making decisions about climate change. First it can in principle help to answer the broadest bounding question: how important is climate change. Second, it can help assess potential responses to climate change, either with a cost–benefit framing or a cost–effectiveness framing. Third, integrated assessment can provide a framework in which to structure present knowledge, which has several benefits, including keeping the whole problem in view, resisting "premature closure" on a few responses, and structuring uncertainty and sensitivity. Finally, Parson concluded that integrated assessment can serve the longer term goal of capacity building in the research community and in the policy-making community. Parson pointed out some important considerations for the relationship between assessment and decision making bodies:

> When integrated assessment is used to inform or assess policy decisions, the assessment must integrate broadly enough across disciplinary lines to serve the policy need, while still being deeply enough informed by the relevant range of disciplinary expert knowledge and opinion to draw on the legitimacy of science. Because assessments are introduced into contentious, pluralistic, partisan policy debates, all will be presumed biased unless they meet high standards of legitimate process. For example, policy makers will regard an assessment less suspiciously if they can consult experts from their constituency (however defined) who participated in it. The managerial dimensions of integration, such as authority, sponsorship, participation, and transparency, can thus be as essential for success and legitimacy as the conceptual or disciplinary dimensions.

This section has looked at the role of integrated assessment and integrated assessment models in the area of environmental decision making and has examined some of the suggestions that have been made for improving either the models or assessment practice. Integrated assessment is seen as a multi-step process that provides a bridge between the science and policy realms. Till now there have been two main methods for IA – formal models and multidisciplinary expert panels (which sometimes use models). Both of these conventional methods have their own strengths and weaknesses and it is argued that alternative methods could address some of the knowledge needs that are poorly addressed with conventional methods. The exploration of alternative methods within the EFIEA would certainly be of use to both the science and policy communities. While it is recognized that integrated assessment models have played an important role, for example, in increasing transdisciplinary collaboration, communicating assumptions and beliefs and shared data, several studies have indicated what kind of improvements are necessary. In particular, there have been calls for more attention to the issues of uncertainty and values. Furthermore, emphasis has been put on the importance of treating IAMs as heuristic tools that provide insights rather than predictions. Finally, it has been suggested that increased involvement of policy actors in the development and use of assessment and assessment tools is necessary. Achieving the latter is a major challenge for participants in the EFIEA.

4. Using scientific findings in environmental policy making

4.1. Using models

Alcamo et al. [2] discussed the use of two models in the development of environmental policy. First, they discussed the use of the integrated model RAINS (Regional Acidification INformation Simulation model), which was developed at IIASA (Alcamo et al. [3]). The model was developed with some guidelines, which reflected earlier experience with models developed by the Club of Rome and at IIASA in the 1970s or early 1980s:

- The model should be co-designed by analysts, experts, and potential users.
- The model should be of modular construction.
- The sub-models should be simple yet be based on more detailed data or models.
- To facilitate use, the model should have interactive inputs with flexible choices and clear graphic output.
- The model should be dynamic in nature.
- The model should have an appropriate temporal and spatial scale.

The RAINS model was used to inform the negotiations of the Second Sulphur Protocol of the UN/ECE Convention on Long-Range Transboundary Air Pollution (LRTAP) (Hordijk [18]). The model is presently being used to support negotiations on the Second NO_x Protocol of the LRTAP convention and the development of an EU acidification strategy.

Alcamo et al. [2] suggested that one lesson learned by the RAINS team was that the interaction between the model developers and the policy makers was a key ingredient in having the results of the RAINS model as a guide to the negotiations. The modeling team met with negotiators or their advisors and responded to specific requests for further analyses.

The second example that Alcamo et al. [2] cited is the use of the IMAGE 2 model to inform policy makers involved with the climate change issue. The IMAGE 2 model (Alcamo [1]) is a global model, designed to a large extent with the RAINS experience in mind, to look at the climate change issue. When the Berlin Mandate was signed in March 1995, the IMAGE team at the Dutch National Institute of Public Health and the Environment (RIVM) together with Delft Technical University organized a series of workshops with climate policy advisors to discuss how the IMAGE 2 model could assist in the negotiations. In each of the 3 meetings about 10 countries were represented. One of the main outcomes of the first meeting was that policy advisors asked for the analysis of "feasible" policy options, for example, stabilizing the atmospheric CO_2 concentration at above 450 ppm and controlling only OECD emissions. At the second meeting, the IMAGE team presented scenarios showing that the control of emissions only in industrialized countries would not "do too much to slow down the build-up of greenhouse gases in the atmosphere" (Alcamo et al. [2]).

The discussions at the second meeting also led to the concept of "safe landing", emissions reductions that were neither "too fast" nor "too slow" in coming decades. This was built upon in the third meeting. The modeling team considered climate goals such as global temperature change and average sea level rise, but also added an indicator for the maximum allowable rate of emission reductions to take into account the economic and technical feasibility of different emission pathways. The "safe emissions corridor" developed by the IMAGE 2 team was presented at a workshop at the start of the Ad Hoc Group on the Berlin Mandate.

Alcamo at el. [2] were unable to draw conclusions on the use of the IMAGE 2 model in the Delft process, because the process was still underway and because it was unclear whether the concepts would indeed be useful to the climate negotiations. Nevertheless, Alcamo et al. [2] drew some provisional conclusions about the factors that determine success in connecting models to environmental policy making based on experience with RAINS and IMAGE 2:

- Both models had enough detail and description to demonstrate and visualize interesting policy alternatives. [...]
- Both models took the scientific risk of providing maps of important environmental impacts. This laid them open to the valid criticism that geographic calculations are usually much more uncertain than regional or global averages, but at the same time it provided a powerful vehicle for policy makers and their advisors to visualize that it was *their* country that would be affected by acid deposition or climate change.
- Both models explicitly coupled policy actions with their immediate effects on reducing emissions and finally with their consequences on protecting the environment. Hence, a connection was made between the actions (such as emissions control) and environmental protection (which was driving policy action). Another way to put this is that both models took an "integrated" approach towards linking environmental science with policy.
- Both models could be used for *scenario analysis*, which was an effective form for communicating a large amount of technical information. Moreover, both models could produce these scenarios fairly quickly in response to the questions of policy advisors.

Other lessons learned include the fact that the models must be scientifically accepted before they can be policy relevant. Improvements needed in integrated modeling are, according to Alcamo et al. [2], that calculations must be testable, more transparent, easier to reproduce, better documented, and more accessible.

Shackley et al. [34] took a critical look at the conclusions drawn by Alcamo et al. [2] about the role of integrated assessment modeling in environmental policy making. In doing so, they cited the paper of Morgan and Dowlatabadi [27] on the validity, achievements and policy applications of integrated assessment models. Morgan and Dowlatabadi [27] pointed to the difficulties in including "knock-on" social, political and institutional effects following greenhouse gas emissions reductions. It is even questioned whether the social and institutional processes associated with learning by doing, technological change and innovation, problem and opportunity perceptions, changing values and so on can even be represented in numerical form at all. As a result, Morgan and Dowlatabadi argue that "... we should work to avoid exaggerated expectations about how much modest improvements in scientific understanding over the next decade or two can improve the situation".

Shackley et al. [34] concluded that the "safe emissions corridors" of the IMAGE 2 model depended on the use of four simple indicators and that their use effectively bypassed the problem of assessing climate change impacts and the socio-economic and political processes surrounding greenhouse gas abatement. Shackley et al. argued that the IMAGE 2 methodology ignores the main social and political issues inherent in the climate debate and cannot deal with issues such as equity between industrialized and less industrialized countries. Shackley et al. also questioned assumptions in the IMAGE 2 model, especially extrapolation of existing trends. They concluded that "the presentation of IMAGE 2 [...] as a "validated" tool for policy analysis is problematic, and the lack of a more thorough discussion of uncertainty and model limitations an important omission". Indeed, Shackley et al. went further and claimed that integrated assessment models, as a whole, face considerable credibility problems within the scientific and policy communities and should therefore only be used as heuristics and not to legitimize targets. Furthermore, they suggested that IA research could benefit from the many ideas and insights in the social sciences and humanities. This is clearly an area for further debate within the EFIEA – in particular the role and limitations of large computer models and the available insights from social sciences and humanities should be addressed further.

4.2. Using integrated assessment

The largest integrated assessments in the environment area in recent years are the assessments of the Intergovernmental Panel on Climate Change (IPCC). The IPCC was established in 1988 and reported in 1990 and 1995 [19–21]. Lessons from the IPCC as an Integrated Assessment Process were discussed at an international symposium in Toulouse in October 1996 (Sors et al. [36]).

The role of the assessments of the IPCC in decision making on global climate change has been discussed by a number of participants and analysts. Bolin [6] discussed the role of the 1990 assessments, which were published two years before the Framework Convention on Climate Change (FCCC) was signed in 1992. Bolin concluded that the status of the IPCC assessment played an important role in the rapid progress in agreeing to the FCCC. Furthermore, Bolin concluded that it is necessary to maintain continuity in the assessment process in order to have political impact. Thus, according to Bolin, the first assessment was the beginning of a process of collaboration between scientists and politicians, in which the scientists must protect their scientific integrity but also respect the role of the politicians. Bolin saw the role of scientists as follows: "Scientists need to inform politicians in a simple manner that can be readily understood, but the message must always be scientifically exact. In reality, little of what we know as scientists is politically interesting or even understandable." Bolin also pointed out that the assessment process should recognize both uncertainty and scientific controversy.[2] While recognizing the possibility that the IPCC could be influenced by value judgements, Bolin felt that in general the integrity of the scientific assessment had been upheld. The ultimate goal of the IPCC assessments must be, according to Bolin, to consider the global and long-term aspects of the issue and to present alternative possibilities and their consequences.

Three years later, Bolin [7] wrote a short analysis of the results of the Kyoto Conference of Parties to the FCCC in the light of the work of the IPCC. He pointed out that in fact the scientific issues were not much discussed in Kyoto (December 1997). Because the delegates in Kyoto did not appreciate the inertia of the climate system, Bolin concluded that another international effort will be required before 2010 to consider whether further measures are warranted. The protocol signed in Kyoto refers to work by the IPCC, to resolve questions about natural sources and sinks of greenhouse gases, before the next conference of parties but Bolin pointed out that it is not clear how satisfactory methods to achieve what is envisaged in the protocol can be devised. Bolin concluded that "the Kyoto conference did not achieve much with regard to limiting the buildup of greenhouse gases in the atmosphere". During the process of negotiating the Framework Convention and the Kyoto Protocol, the results of the IPCC have been in the minds of negotiators but it is clear that other factors constrain what can be achieved in terms of emissions reductions in the short to medium term.

5. How can we evaluate current practice in linking science to policy in the environment area?

On the basis of an examination of a large number of scientific inquiries that had policy implications that were generally thought to have been noteworthy or important, Clark and Majone [9] concluded that four "meta-criteria" of appraisal capture much of what practitioners and users have in mind when they cite a particular assessment as noteworthy or important. The meta-criteria are technical adequacy, value, legitimacy and effectiveness.

Criteria for assessing *technical adequacy* are used regularly in the scientific realm. The primary concern in assessing technical adequacy is to ascertain whether the analysis avoided well-known technical pitfalls, used state-of-the-art methods, data, models and expertise, dealt with technical uncertainty and disagreement appropriately and used appropriate measures of quality control, such as peer review.

Value is meant to capture the extent to which the study was relevant to the policy problem or debate. This includes questions of issue framing, study scope and timeliness, as well as the comprehensibility of the study to its potential users and the character of "executive summaries" or other similar ways of communicating the results.

Legitimacy is used to address the more political aspects of the assessment process. In particular, it is important to ask whether and to what extent relevant stakeholders and dissenting views were taken into account, whether science and value judgements were clearly distinguished and whether political judgements repressed or altered scientific findings.

Finally, *effectiveness* looks at the impact of the assessment on the outside world. In particular, it is possible to record the extent to which an assessment changed, stabilized or advanced the debate about an issue.

Clark and Majone [9] claimed that scientific studies or assessments that scored high on many of these criteria were

[2] The subsequent round of IPCC assessments that culminated in the 1995 report led to considerable discussion of whether IPCC had dealt effectively with questions of uncertainty and scientific controversy. As pointed out in section 3, this is an area where improvements are still needed in the assessment process.

more likely to be thought of as "important" than those that scored low. They did not suggest that all important assessments scored high on all of these criteria or that scoring low on one or more would automatically mean that the assessment was unimportant in the policy domain. An important point highlighted by Clark and Majone is that the evaluation of scientific assessment in terms of its interactions with the policy realm *requires* a comprehensive perspective, because any partial perspectives cannot deal with the integrative and synthetic considerations essential for useful inquiry on practical problems. For integrated environmental assessment this means that multiple criteria are essential. Furthermore, the criteria have to be appropriate to assessments, which occupy the space between pure science and the policy realm. The four meta-criteria proposed by Clark and Majone – technical adequacy, value, legitimacy and effectiveness – appear to be valuable for the appraisal of assessment efforts in the environment area and have been used in this way by Jäger et al. [22].

The meta-criteria were used by Clark et al. [10], when looking at the role of "Atmospheric Ozone 1985: Assessment of our understanding of the processes controlling its present distribution and change", published in 1986 by the U.S. National Aeronautics and Space Administration (NASA) in collaboration with the World Meteorological Organization (WMO) and other organizations. Work on this assessment began in 1984 and, according to its authors, it sought

> "to provide governments around the world with the best scientific information currently available on whether human activities represent a substantial threat to the ozone layer" (WMO [38, p. 4]).

To conduct the assessment,

> "Leading scientists were selected as chairpersons, and each charged with the responsibility to produce a specific chapter in the assessment report. . . . The participants were chosen for their expertise and represented a cross-section of the international scientific community." (WMO [38, p. 5])

On the political side, the 1985 Ozone Assessment was cited as effective. For example, Benedick, the chief U.S. negotiator of the Montreal protocol, referred to the report as a "landmark international report" (Benedick [5]) and stated that it dramatically changed the mood of international discussions leading up to the initiation of the Montreal negotiations. Clark et al. [10] quoted considerable other evidence of the acknowledged importance of the 1985 Ozone Assessment and went on to examine what it was about this particular assessment that made it so effective.

With regard to "technical adequacy", Clark et al. pointed to the involvement of senior ozone experts, the rigorous, independent and public review process and the fact that the report was still being cited as a definitive reference five and more years later. With regard to "legitimacy", Clark et al. pointed out that the central challenge was to establish an internationally accepted basis of science from which political negotiations could move forward. Legitimacy was secured by having sponsorship from a wide range of national and international agencies. As a result most of the countries involved in the Montreal negotiations accepted the assessment as "reasonably fair and definitive" (Clark et al. [10]).

Clark et al. argued that the only dimension of "value" on which the assessment did well was timeliness – it was published at a critical point of time in the formulation of policy. On other dimensions of "value", Clark et al. raised some interesting points. Conventional wisdom in the 1990s on what is needed for an effective bridge between science and policy claims that interdisciplinarity is important. The 1985 Ozone Assessment contained no discussion of impacts or of policy options. As Clark et al. described it, "the vast majority of its 15 chapters and 4 substantive appendices are impenetrable to anyone without university training in the atmospheric sciences". The assessment had no executive or policy makers summary, only a "science summary" of conclusions and research recommendations. Why was the assessment so successful in the policy domain, given these facts? Clark et al. examined the question of whether the value of the assessment would have been enhanced if it had addressed impacts and policy options or included a policy makers summary. They concluded, firstly, that the assessment did address centrally the most politically important question, i.e., whether human activities were a threat to the ozone layer. The assessment showed that much of the conflict was not a result of different interpretations of the basic chemistry and physics but from the use of arbitrarily different emissions scenarios for ozone depleting gases. Clark et al. concluded that the assessment's value would *not* have been enhanced by including impacts, since earlier attempts to address both ozone layer depletion and impacts had been severely criticized for the relatively inconclusive or controversial character of the impacts science. The scientific consensus in the 1985 assessment was not diluted by controversy about impacts. Similarly, Clark et al. argued that the value of the 1985 assessment was enhanced by *not* including policy options, because controversy on policy options could weaken the value of the assessment. Lastly, Clark et al. argued that, while somewhat problematical, the absence of an executive or policy makers summary did not detract from the value of the 1985 assessment. Few policy makers could read and understand the scientific summary of the assessment but they relied on verbal summaries by scientists and briefings. Actually, in this way the assessment gave a scientific justification for a wide range of policy options. The assessment established unequivocally that the possibility of ozone depletion must be taken seriously and Clark et al. concluded that it is possible to postulate that the perceived "value" of the assessment to participants in the debate may well have increased in proportion to the interpretive latitude induced by the absence of a self-explanatory executive summary.

In summary, on the basis of an extensive examination of a large number of scientific enquiries with policy implications, four "meta-criteria" have been proposed for the appraisal of whether an assessment is noteworthy or important: technical adequacy, value, legitimacy and effectiveness. Using these criteria to appraise an important assessment for the issue of stratospheric ozone depletion raises questions about the inclusion of impacts and policy options and of a policy-makers summary. At a minimum, those funding, doing and using assessments should be aware of these questions. The EFIEA could profitably explore them further.

6. Conclusions

This review of current thinking on the use of scientific findings in environmental policy making starts from the observation that as a result of the special characteristics of environmental issues, science plays a different role than it traditionally has played in decision making on other issues. It is also clear that the interactions between the science and policy realms cannot be viewed as entirely linear or sequential. While these realms remain largely distinct during the early phases of issue development, they influence each other once the issue is firmly on the policy agenda.

Assessment is seen as an important "bridge" between the science and policy realms. The two traditional assessment methods – formal models and multidisciplinary expert panels – have strengths and weaknesses. Alternative methods exist and could be useful for environmental policy issues. IAMs have been criticized in particular for containing hidden values or assumptions. The need for efforts to include decision makers and citizens in the design, testing and use of IAMs for environmental policy questions has been raised in a number of studies. In addition, several recent studies have produced checklists of issues, practices or basic principles to guide the design and use of IAMs or IA.

On the basis of actual experience of using models and integrated assessment in environmental policy making, it has been possible to draw conclusions about successes and failures, although some of these conclusions have been challenged, in particular with regard to the use of models. The largest integrated assessment in recent years, the IPCC, has not yet completely fulfilled its objective of convincing the relevant bodies about the global and long-term aspects of the climate change issue. Experience with a major assessment on stratospheric ozone depletion shows that interdisciplinarity, executive summaries, impact assessment and inclusion of policy measures in an assessment are not necessarily characteristics of an effective assessment in terms of its influence on policy making. This raises questions about how broad and inclusive an assessment has to be in order to be most effective. A set of meta-criteria has been proposed that can be used to evaluate whether an assessment was important in terms of having influenced policy. This is certainly an area that could be explored further in the EFIEA, also drawing on experience in other ongoing efforts, such as the Global Environmental Assessment project (GEA [15]).

A number of authors have pointed out that because it seeks *to inform policy*, integrated assessment is subject to evaluation by additional criteria that are not relevant when integrated assessment is regarded only as an interdisciplinary research activity. Parson [29] suggested that at least two additional kinds of criteria may apply: principled standards of fair process, participation and legitimacy and strategic criteria "that hold assessment responsible for its foreseeable use (and misuse) by partisan actors in a pluralistic political setting".

The question of participation has also been raised in a number of other recent studies. There is a call for inclusion of policy makers in the design and use of assessments and assessment tools. There have also been calls for the inclusion of stakeholders, including the lay public, in the assessment process. For example, by involving the lay public in structured discussions of environmental issues, the assessment community can find out more about the concerns of these people and the kinds of policy measures that they would support.[3] The inclusion of the policy making community and the lay public in the environmental assessment process are major challenges for the assessment community.

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