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The roles of computer models in the environmental policy life cycle

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Abstract

In this article, we identify four typical roles played by computer models in environmental policy-making, and explore the relationship of these roles to different stages of policy development over time. The four different roles are: models as eye-openers, models as arguments in dissent, models as vehicles in creating consensus and models for management. A general environmental policy life cycle is used to assess the different roles models play in the policy process. The relationship between the roles of models and the different stages of the policy life cycle is explored with a selection of published accounts of computer models and their use in environmental policy-making.
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1. Introduction

An impressive number of computer models aimed at supporting environmental policy-making have been constructed over the past decade. Some analysts even speak of a *renaissance* of environmental modeling during the 1990s, with the original heyday of environmental systems analysis of the early 1970s in mind (Edwards, 1996; Shackley, 1997). In many countries, this rebirth of environmental modeling during the 1990s more or less coincided with an epoch of renewed political attention for environmental issues. Policy attention and the production of policy-supporting computer models thus seem to be related, as may well be expected. The interlinkages involved in this relationship, however, deserve closer inspection. How are the life cycles of policy-making and model development interrelated, and what different roles have computer models played in environmental policy-making over the past few decades? In this article, we set out to explore these questions, using a selection of published accounts of computer models and their use in environmental policy-making over the past three decades.

Our starting point will be the present variety of models aimed at supporting environmental policy-making. This variety has generated lively debate in recent years about the appropriateness of certain models, and the question which type of model provides 'the best tool for the job' (e.g. Shackley et al., 1998). The present article can be considered as a contribution to these discussions; but unlike typical earlier contributions we do not aim to discuss the appropriateness of models in an absolute sense, isolated from the development of the policy process. Important earlier publications have, for instance, discussed topics like the absence of a representation of uncertainties in computer models, and the need to make cultural values visible and explicit (e.g. Rotmans and de Vries, 1997). While important issues as such, our aim in the present article is to look in another direction: instead of discussing properties of models as such, we will discuss different roles played by computer models in the policy process. Our aim will thus be a typology of model roles, rather than one of model properties and model types. After presenting such a typology of roles, we will consider the question of whether models need to be of certain types or need to have certain properties to be optimally suited for the different roles we propose to distinguish. A main focus of our analysis will be the adaptability of models. As the roles of computer models change over time in the policy process, is it possible, and desirable, to adapt a given model to these changing roles? Or would it be more effective to build new models for new policy needs?

To conclude this introduction, we will touch briefly upon the following three topics below. First, we discuss the relationship between policy-supporting computer models and *environmental* policy. Do computer models have a particularly important role to play in environmental policy, more so than in other policy domains? Second, we give a short impression of the variety and types of models that we are talking about. Third, we introduce earlier approaches in ex-

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isting literature regarding the use of computer models in environmental policy.

1.1. Computer models and environmental policy

Computerized mathematical models have been used in various domains of policy-making since the middle of the 20th century. Econometric models, for instance, acquired a central role in economic policy formulation in countries like The Netherlands and Norway (van den Bogaard, 1998). More in general, there was widespread optimism in the early post-war decades that the mathematical modeling of complex social and natural systems would significantly improve our human capacity for forecasting, planning and centralized control. Disciplines ranging from econometrics to meteorology all started to contribute dedicated models to the greater goal of enhancing human development and progress by rational means.[1] As Kwa has noted in a comparative analysis, optimism about large-scale models aiming at comprehensive control, for instance, of national economies or global weather, evaporated in many scientific disciplines and the related areas of policy-making around 1973. The reasons that can be given for this sudden decline are varied and intriguing (Kwa, 1993). One aspect that needs mentioning here is the relationship between political trust in comprehensive models and the political will to centrally plan and control vital parts of the social and natural world. Such a political will to centrally control and regulate, which was widespread and strong during the first post-war decades, was replaced in many western countries by a conversion to market-oriented thinking around 1980. At roughly the same moment, we can identify the start of a cultural reappraisal of the forces of chaos and unpredictability, and even celebration of the impossibility of centralized vision and control: a condition commonly referred to as post-modernity.

In spite of this apparent general decline in comprehensive policy-aimed modeling since the mid-1970s, the use of and trust in computer models has remained relatively widespread in the domain of environmental policy-making. This seems to be mainly due to the strong conceptual relationship between our modern perception of environmental problems and computer modeling as such. Some of the most poignant environmental issues of recent years have relied on computer modeling to calculate and visualize what the problem is about and how bad things are going to be. This can, for instance, be said of the issues of acidification and climate change, both prominent issues that can be said to characterize modern environmental discourse (Hajer, 1995). More in general, the very concept of ecosystem stability, which informs our present sense of ecological awareness, is closely linked to the *systems analysis* that policy-supporting environmental computer models typically support. In this dominant conceptual framework, environmental problems are not defined in terms of a present situation *x* where *y* people suffer from effect *z*; instead, problems are defined in terms of the turn events will take in the future if we do not change the dynamics of the *system*. Indeed, as Shackley (1997) identifies, the ‘strong claim’ often expressed with regard to environmental computer models is that they alone, of current research tools, are able to provide the degree of holism and complexity necessary to understand the open and complex systems that typically underlie our environmental problems. The promise that such models are able to deal with complexity is a strong claim indeed, as most environmental problems are bewilderingly complex in their social and physical interrelationships, not in the least in the number of different stakeholders involved.

1.2. Models in perspective

Various different types of models can be found in the broad area of computer modeling with the aim to support environmental policy-making. Models can vary in many dimensions such as: static versus dynamic models, degree of empirical orientation, optimization versus simulation, deterministic versus stochastic models, multi-criteria models or models using economic value as the only criterion, interactive models versus long run-times of experiments, and so on.

The differences between the models also affect how models can be used. Small transparent interactive models can be very useful for exchanging knowledge between model-builders and interest groups; however, a complex stochastic optimization model can only be used indirectly, for example by presenting the results in research reports. Some models are suitable for demonstrating qualitative dynamics and insights, whereas others extrapolate historical trends. Many models are built by one or a few expert scientists, whereas other models are the result of intense interactions between many scientists from various disciplines and with stakeholders.

We briefly mention a number of examples. The World3 model is a typical example of a relatively simple dynamic model (Meadows et al., 1972). For this model, the system dynamics approach was used, which describes systems as a combination of interacting feedback loops. Such models are suitable for studying dynamic long-term behavior of systems, but less so for predicting near future events. The integrated model for climate policy assessment described by Prinn et al. (1998) is an example of a systems analysis that links different modules into one framework. Only a few experts are able to run such a model, and the analyses produced by such models are used for long-term projections. Another suite of models is developed together with stakeholders, for example, the adaptive environmental management approach used to produce models for regional management of ecosys-

[1] Contemporary cultural analysis of such mathematical models tends to stress that they cannot claim universal rationality or objectivity; for like any other form of policy-supporting expertise, such models are inevitably value-laden and culturally embedded. Such analysis, though correct, makes it difficult to relive the ideals and optimism that surrounded mathematical models in early post-war decades. The atmosphere of Dutch post-war ‘applied mathematics’ is well rendered by Alberts (1998).

tems (Walters, 1986), now echoed in participatory integrated assessment (van de Kerkhof, 2001). Companionable modeling and role games (Bousquet et al., in press) and participatory Geographic Information Systems (Craig et al., 2002). Input–Output models are data driven extrapolations of economic developments (Duchin and Lange, 1995). Such models are suitable for scenario analysis in the shorter term.

We can conclude that there is a rich variety of methods available to develop computer models. This variety can be explained by the suitability of certain methods for dealing with particular phenomena of interest; but, it can also be explained by the expectations the modeler has as to how the results of the model will be used. Is the model specifically designed for policy makers, or is it also meant for the scientific arena?

1.3. Approaches in existing literature

In this section, we will briefly discuss some of the main traditions that can be distinguished in existing literature about computer models in environmental policy-making. The validity and use of such models has drawn a considerable amount of attention in various bodies of literature over the last few decades.[2] These studies can be roughly distinguished into two approaches: the approach we will call *validational*, where the main issue at stake is whether the models discussed are *valid*, i.e. good enough for the issue they model, and the approach we will call *contextual*, where computer models are studied as part of a wider social and political context, and are seen as both products and constituents of that wider context.

Validational discussions have often followed in the wake of the introduction of a new model or model type during the past three decades of environmental policy-making. Examples include the discussions about the validity of the World3 model of Meadows et al. in the early 1970s (e.g. Cole et al., 1973), and the recurring debates about the validity of computer models simulating the process of global warming during the 1990s (e.g. Emsley, 1996). The appreciation displayed in validational studies for the models they discuss may vary. Some authors will question the validity of a certain model or model type fundamentally, whereas others will agree with a model's potential, but suggest ways in which its validity could be further improved; however, all authors taking this approach share the conviction that discussing the validity and quality of computer models is meaningful, and necessary. Authors using this approach usually locate themselves as experts speaking from within the domain of the natural sciences, or the domain of modeling as such, acting on behalf of the improvement of knowledge in general and the improvement of models in particular, irrespective of whether they endorse or dismiss the specific models they discuss.

[2] For a more extensive review of the existing literature, from the perspective we will call 'contextual' later on, see Shackley (1997).

A recent development in validational discussions of environmental models has been to move beyond evaluating the validity of models only in terms of their ability to represent the outside world realistically. Instead, models are increasingly evaluated in terms of their ability to support the policy process as a *heuristic* or *learning* device. According to this new outlook, a model should not be presented to policy makers as what it in truth can never be, i.e. a truth machine; instead, it should be presented as a tool to help policy makers get to grips with the dynamics, uncertainties and judgements involved in the issue at hand. This can for instance be achieved by visualizing some of the uncertainties involved in modeling the future behavior of the environmental issue concerned, or by incorporating multiple cultural perspectives into a model (Rotmans and de Vries, 1997). An alternative or additional route that can be used to improve the heuristic qualities of models is to provide an interactive user interface, which will allow users to experiment with and learn from different model settings (e.g. Berk and Janssen, 1997; Parson, 1995; Toth, 1988). This heuristic trend in model evaluation progresses beyond a strict interpretation of 'model validation' in epistemologically realist terms. The issue at stake, however, is still the validity, the 'being right' of the models concerned; but with 'validity' no longer taken in an absolute sense. Instead, a model is now considered right for the job if it is appropriate enough, both in its mimicry of reality, or multiple realities, and as a heuristic device.

Contextual discussions of computer models do not focus on the question of whether model *x* or model type *y* is a good model for environmental problem *z*. Instead, the wider social and political context of which these models are an integral part is discussed, aiming at what could be called a *sociology* of the construction and use of computer models in environmental policy. Authors within this approach tend to locate themselves outside the domain of the natural sciences and the modeling world; they write instead as policy analysts, or are located within the 'social studies of science'.[3] Classic subject treatment in this tradition tends to be aimed at exposing the social nature and value-laden content of computer models, contesting the seemingly objective—i.e. mathematical and scientific—stature of such models. A forceful example in this genre is Keepin & Wynne's deconstruction of the International Institute of Applied Systems Analysis (IIASA) World Energy Model.[4] Results from case studies comparing different national political cultures of model construction and model use have been particularly enlightening, see for example Baumgartner and Midttun (1987) on energy forecasting, and Hajer (1995) on acid rain.

[3] For an introduction to the social studies of science perspective on the relationship between environmental science and policy, including a look at models, see Jasanoff and Wynne (1998).

[4] As presented in separate articles by Keepin, Wynne and Thompson in the *Policy Sciences* Special Issue, The IIASA Energy Study of November 1984 (Vol. 17-3), and by the joint papers of Keepin and Wynne in *Nature* of 20 December 1984 (Vol. 312) and in Baumgartner and Midttun (1987, pp. 33–57).

A recent development among contextual discussions of environmental models has been to move beyond merely exposing models as socially constructed, towards exploring the, not necessarily negative, social roles that computer models can play in the process of their construction and use. Attention is focused in such studies, on concepts like discourse coalitions (e.g. Hajer, 1995) and mediation (e.g. Shackley, 1997), and the mutually enabling roles that models may play for different actor groups involved are emphasized.

The present study combines aspects of both validational and contextual approaches to environmental models as outlined above. The study is validational in the sense that we see merit in discussing the qualities of models and in looking for possibilities to improve future model construction and use. It is contextual in the sense that we do not treat the question of models being 'right' for the job as static over time, but as dynamic and dependent on context.

In the next section, we will discuss the policy life cycle of environmental problems, and the different types of roles models can play during the policy life cycle. Examples of different model roles will be given for various environmental problems on various types of scale. In the final section of this paper we present conclusions about the relation between the roles of models and the policy life cycle, including a discussion about the adaptability of policy-oriented models.

2. The policy life cycle and the roles of models

Models addressing different types of questions can play different roles in the policy process. In order to relate these different roles to the development of environmental policy over time, we first discuss views on *life cycles* in environmental policy, after which we identify four typical roles that computer models can play. Following this, we discuss the relationship between the development of policy and the roles of models.

Various authors have suggested a representation of the policy process consisting of a number of general stages or phases.[5] Winsemius (1986), Minister of the Environment in The Netherlands between 1982 and 1986, proposed a policy life cycle for environmental issues as part of his theories on environmental management.[6] This policy life cycle describes the stages through which environmental issues progress from being discovered to being brought under managerial control. The four stages identified in this life cycle are: recognition, policy formulation, policy implementation and control. Although different authors identify different stages, the general idea underlying these views is similar. In this article, we have chosen to use the cycle proposed by Winsemius as it relates specifically to environmental problems.

The first stage of the policy life cycle proposed by Winsemius is the stage of *recognition*, where the issue is 'discovered' and put on the political agenda. This stage is often accompanied by large amounts of alarmed media attention. The second stage is the stage of *policy formulation*, where intense political debate may take place between the different parties involved. During this stage, the conditions that are necessary for change have to be developed. The third stage of the policy life cycle (that an issue however may never reach, if the parties involved cannot reach consensus on general policy strategy during the second stage) is the stage of (*policy*) *implementation*. During this stage, the general policy strategy formulated during the second stage of the cycle is translated into societal practice through mechanisms like regulations, taxes, subsidies or the promotion of new technologies. Finally, the fourth stage of the policy life cycle is the stage of *control*, where the initial environmental problem is brought under control by the newly implemented managerial regime. For instance, in the case of surface water pollution, by the operation of a nation-wide network of sewage-water treatment plants.

We recognize that a policy cycle is only a general and stylized representation of a policy process, as in reality the process is often non-linear[7] and iterative, or can even have a garbage-can like character (Cohen et al., 1972). During a policy process, new findings may lead to iterations. In climate change research, for instance, recognition of the impact of sulfate aerosols meant that further investigation was needed, yet policy formulation continued in parallel with this work. With respect to these kinds of complex policy issues it is also important to note that an intricate network of actors is involved, rather than there being a unitary decision maker. In these multi-actor situations, problem perceptions and objectives may differ widely and may also change over time. For the purpose of analysis, however, we will use the policy life cycle proposed by Winsemius as an analytical simplification of the policy process and because the *formal* policy processes for environmental issues are often designed to proceed in a structured way. Examples of these formal structures are the United Nations Framework Convention on Climate Change (FCCC) and the United Nations Economic

[5] Examples of such representations are the policy cycle used by May and Wildavsky (1978), and the phases of the policy process defined by Brewer and deLeon (1983). In the book they edited on the policy cycle, May and Wildavsky distinguish the phases: agenda setting, issue analysis, implementation, evaluation, and termination. Brewer and deLeon define the phases: initiation, estimation, selection, implementation, evaluation and termination.

[6] An English language edition was published by the Amsterdam office of McKinsey & Company, the consulting firm to which Winsemius (1990) returned after his term of office as Minister of the Environment.

[7] A life cycle model of policy development such as the Winsemian model may be called a linear model in the sense that the process it describes starts with the recognition of a given problem that is thought to exist as such in reality. From that first stage of problem recognition the arrows of action flow in one direction, towards the eventual solution of 'the' problem. Contemporary social analysis stresses that such a linear model is misleading, because the arrows of action also flow the other way around: preferred solutions and social settings select and structure the problems that will be perceived.

Commission for Europe Convention on Long-Range Transboundary Air Pollution (LRTAP).

2.1. Roles of models

In this section, we identify four different roles that computer models can typically play in environmental policy development. These roles will be illustrated with key examples of the use of computer models in environmental policy over the past three decades. The models under consideration in this section are all computer models that have been developed intentionally to support (the various stages of) an environmental policy process.

- *Role 1* (*models as eye-openers*): In this role, models help in placing a new environmental issue on the political agenda.
- *Role 2* (*models as arguments in dissent*): The advocative role of such models is to challenge opposing assessments by way of counter-expertise, and to help visualize alternative futures.
- *Role 3* (*models as vehicles in creating consensus*): In this role, models help in creating political consensus among different stakeholders.
- *Role 4* (*models for management*): In this role, models support the actual management of a particular ecosystem or a particular environmental issue. This means that the models are meant to assist in identifying concrete policy decisions and in assessing effects of the implementation of concrete policies.

Below, we will study the different model roles in more detail using various examples. Following this, the roles will be related to the policy process.

2.1.1. Role 1: models as eye-openers, perceiving a new problem

This role is well illustrated by the *World3* model, which forms the basis of the best-selling *The Limits to Growth* report to the Club of Rome in 1972 (Meadows et al., 1972). This famous model and the media attention surrounding it had a large political impact in many countries helping to place ‘the’ environmental crisis and the question of limits to economic and population growth high on the national and international political agendas.[8] Of course, these models have been criticized for being overambitious and unrealistic; however, as Edwards (1996, p. 154) has pointed out, ‘it is certainly true that through its models, popular books, meetings, and person-to-person canvassing of politicians, the Club succeeded in communicating, to both a broad public and a policy elite, its two basic heuristics: (a) that exponential growth (especially in population) cannot continue unchecked, and (b) that the world should be viewed as a set of interlocking systems that cannot be understood successfully or managed piecemeal’. Thus, the World3 model became an important vehicle in bringing the new problem perception of a global ecological crisis to national and international policy attention.

2.1.2. Role 2: models as arguments in dissent, visualizing an alternative future

The complexities of this particular role can be illustrated by the different energy models that were produced in western Europe and North America during the 1970s. In the early years of the 1970s, ‘the energy question’ emerged as a distinct environmental issue that would go on to dominate environmental debate for many years to follow. Political debate about this issue combined pragmatic economic worries about future energy supplies related to the 1973 oil crisis with two of the most hotly debated fundamental environmental issues of the decade: the dangers of nuclear power generation and the unsustainability of sustained economic growth. In this climate of heated political debate, studies modeling the future of energy demand and supply flourished in many countries, like the United States, the United Kingdom, Germany, The Netherlands and Scandinavia (Baumgartner and Midttun, 1987). Two dominant attitudes can be distinguished among the energy policy analysts involved in producing these studies, as Greenberger and Hogan (1987) have suggested: ‘traditionalists’, who were growth-orientated, in favor of nuclear power and skeptical about the near-term promise of solar energy; ‘reformists’, who were ‘very sensitive to environmental concerns’, in favor of a resource-conserving ethic, and against a primary reliance on nuclear power. Some of the most influential models produced during this period can be said to display these same characteristics, distinctly supporting either the ‘traditionalist’ or the ‘reformist’ worldview.[9] Such models tended to induce the production of contrasting models *in dissent*, supporting the opposite point of view.

In the United Kingdom for instance, the earliest energy studies of the 1970s predicted a future of huge increases in energy demand, and invited a future of increased nuclear power generation. ‘Reformist’ studies soon appeared in opposition to this, the most important of which would become *A Low Energy Strategy for the United Kingdom* in 1979 by Gerald Leach (de Man, 1987). In the United States, however, we find a reversed order of events. Here a more or less ‘reformist’ study, the Ford Energy Policy Project of 1974, started the political debate on energy modeling. This was followed by contesting studies from a more ‘traditionalist’ point of view and by additional reformist studies later that decade, the best known of which is probably Amory Lovins’ *Soft Energy Paths* of 1979 (Greenberger and Hogan, 1987).

Irrespective of their traditionalist or reformist outlook, we can conclude that many of the energy models of the later 1970s played a role *in dissent* in the energy debate,

[8] Compare Peters (1997), who shows that the large amount of attention that The Limits to Growth received in The Netherlands was related to a media hype in 1971, after the press had obtained a pre-print version.

[9] Compare Greenberger and Hogan (1987, p. 251, table 11.2).

'counter-modeling', to quote Greenberger and Hogan, earlier models with another point of view.

2.1.3. Role 3: models as vehicles in creating political consensus

Two successful examples of models in this role are: the RAINS model, used to assist policy makers in evaluating options to reduce acid rain in Europe (Hordijk, 1991; Grünfeld, 1999), and the 'Triptych Approach', a calculation tool designed to support negotiations about the distribution of CO_2 emissions within the European Union (Phylipsen et al., 1998; Nolin, 1999).

The RAINS model became a central locus of calculation within the international negotiations towards the Second Sulphur Protocol of the UN-ECE Convention on Long-Range Transboundary Air Pollution (Grünfeld, 1999). It is assumed that the eventual emission reductions agreed upon in the Second Sulphur Protocol are largely based on results obtained from scenario calculations using the RAINS model (Grünfeld, 1999). The RAINS model has thus contributed to the establishment of international political consensus on the issue of "acid rain" in the European region, and helped to get actual emission reduction policies on their way. The development of RAINS started in 1984 in international collaboration at the *International Institute of Applied Systems Analysis*. Similar to the World3 model discussed above, the RAINS model is a *systems* model, interlinking various aspects of the acid rain issue to support the analysis of different options for the reduction of relevant emissions in individual European countries. The model shows the geographical distribution of acid burdens across Europe under different scenarios to support its calculations visually and in geographically distributed detail. The RAINS model eventually occupied a center stage position in the process of political consensus creation towards the Second Sulphur Protocol. This success seems to have been based both on the model's institutional embedding (based at the 'neutral' IIASA, and with good connections to the Convention's dedicated *Task Force on Integrated Assessment Modeling* (TFIAM)) and on the aptness of the information supplied and political strategies supported by the model. This aptness was achieved by testing the model on its intended users, and by interaction in the Task Force on Integrated Assessment Modeling. According to project leader Hordijk, several reasons can be given for the success of the RAINS model; one of which was giving the model enough flexibility so as not to frighten its intended political audience of international negotiators. 'The answer has been to build a model that allows users to explore all the options they like; at the same time it offers more options than they had thought of'(Hordijk, 1991, p. 601). In order to do this, the modelers had to be familiar with the needs of the political actors involved.

In the case of the Triptych Approach, we find many similar mechanisms at work. This calculation model was commissioned by the Dutch Ministry of the Environment to support the Dutch European Union Presidency of 1997, and developed in 1996 by 'reformist' energy researchers at the University of Utrecht (Phylipsen et al., 1998). The Triptych Approach is thought to have helped in creating consensus between EU Member States to accept a significant greenhouse gas emission reduction target in March 1997, both for the EU as a whole and, through burden sharing, for its individual Member States. This tool thus contributed to the remarkable greenhouse gas emission reduction target of minus 15% for the EU as a whole during a politically crucial time-slot (Ringius, 1997; Nolin, 1999). The Triptych Approach was designed in close co-operation with Metz, the senior Dutch policy maker responsible for international climate policy at the time. This tool was designed to break the political deadlock over the issue of 'burden sharing' within the EU by calculating emissions using a sectoral approach, distinguishing, for each EU Member State, between the power producing sector, the internationally operating energy-intensive industries and the remaining domestically oriented sectors. In making this sectoral breakdown, an effort was made to incorporate important national differences into a numerical framework of calculation. In the case of the Triptych Approach, it was again the familiarity with the particular needs of the political actors involved that was a decisive factor in the success of this tool.

Both the RAINS model and the Triptych Approach have succeeded in becoming strategically located numerical tools in a process of international political negotiations. In both cases, the ingredients for success of the consensus-supporting role seem to have been: an ability to show details of distribution, crucial for a setting of internationally negotiated burden sharing, and inside access to political knowledge to aid the design of a model that was suited for the political setting involved in its content and timing (Nolin, 1999).

2.1.4. Role 4: models for management of a particular ecosystem or issue

Another role that computer models can play in the environmental policy process is that of supporting the actual 'management' of a particular ecosystem or a particular environmental issue. The most obvious examples of models in this category can be found in the management of relatively local and confined ecosystems. Management decisions for controlling ecosystems on a local scale are sometimes heavily based on detailed simulation models. Models are, for example, frequently used by the forestry industry and by fishery agencies to determine 'optimal' levels of resource extraction. These models are generally accepted by the resource managers, although sometimes criticized by the scientific community. There are some striking examples where it has turned out, after the collapse of a resource, that the models were not correct, like the ignorance shown of budworm dynamics (Baskerville, 1995) or the incorrect assumption made for fish population dynamics (Finlayson and McCay, 1998).

Models are a key-element of environmental decision support systems, which are interactive computer systems that are used to assist decision makers attempting to solve unstructured, or loosely structured, problems (Guariso and Werthner, 1989). Such systems provide problem solving tools for resource managers. Decision support systems are combinations of large data bases, simulation models and user-friendly interfaces. Once environmental managers become familiar with environmental decision support systems, the opportunity is created for their decisions to become more effective. An example of a computer model for practical resource management is RANGEPACK (Stafford Smith and Foran, 1990). RANGEPACK is a microcomputer-based advisory system for pastoral land management, developed for Australian rangelands. It includes a dynamic herd and flock model which allows the pastoralist to compare management options in the context of climatic and marketing risks for their own property. Furthermore, the model provides information on how to improve production and minimize the risk of degradation in their paddocks. Knowledge of grazing distributions in large paddocks is used to suggest the best locations for placing water facilities and fences. This package is widely used in Australia among pastoralists.

2.2. Relating the roles of models to the policy life cycle: temporal and spacial scales

If we try to combine the four stages of the policy life cycle proposed by Winsemius with the four typical roles of computer models identified above, we can locate the role of models as *eye-openers* at the first Winsemian stage of issue *recognition*. At the opposite end, the role of models for *management* can be located at the final stages of the Winsemian policy life cycle. The development of such managerial models may be part of the process of policy implementation, and their actual application may be part of the stage of managerial control. For the roles of models *in dissent* and models *as vehicles in consensus creation*, the situation is somewhat more complicated. Both these roles seem to be located primarily within the crucial second stage of policy formulation: models in dissent as part of the political debate during this stage, and consensus-promoting models as part of the process of successfully ending this stage, and moving on to the next stage.

Not every environmental issue, however, will always generate models in each of these roles. This will depend on the nature of the particular environmental issue in question, and on the political culture in which the process of policy formulation takes place.

For many environmental issues, it has not been a model that has acted as an eye-opener. Issues are often placed on the political agenda because events or even catastrophes take place. This means that actions are often only taken after an event has taken place, for example, to prevent new events from taking place or to prevent the situation from worsening. An example of a situation in which an event increased the urgency of a problem is the depletion of the ozone layer. Ozone depletion first became an environmental concern in the mid-1970s, when it was discovered that chlorine could potentially deplete the ozone layer. Although the 1985 Vienna Convention for the Protection of the Ozone Layer set a precedent in being the 'first time that nations agreed in principle to tackle a global environmental problem before its effects were felt, or even scientifically proven',[10] it was not until severe ozone depletion in the Antarctic was reported (later in 1985) that ozone depletion became an important international issue.[11] The objective of a model as an eye-opener could be to be ahead of these kinds of situations, and to indicate what could happen if no measures are taken. Paradoxically, to start developing a model in the role of an eye-opener, the modelers have to be triggered in some way to make a model of the system in the first place. Furthermore, a model will not generate the same sense of urgency as the events that take place. Another objective of a model in this role can be to perceive an event in a certain way. For instance, by perceiving temperature change as a result of the greenhouse effect, events may be noticed at an earlier stage and may be considered to be of more significance and urgency. In this way, models can play a role in placing issues (higher) on the agenda.

Dissenting models can stimulate the political debate once an issue is on the agenda. Models can provide a way of perceiving an issue from a different point of view, for instance, from an environmental point of view, rather than from an economical point of view. When taken seriously, models in dissent can help to focus the debate and to stimulate opposing parties to justify their assumptions and conclusions. It is also possible that the dissension that exists is used strategically by actors to delay or prevent decisions from being taken. Counter-models may, for example, distract attention from the political issues towards technical details Greenberger et al. (1976).

The relationship between the role of computer models and the political culture in which policies have to be formulated is of particular importance if we look at the possible roles computer models can play in the setting of *international* environmental policy formulation. At the nation-state level, environmental policy often can be formulated without the need to create consensus between every party involved in the issue. In countries with two dominant political parties that rule alternately, for instance, the party in power may more or less formulate policies unilaterally, without needing the prior consent of every single stakeholder involved. However, in the political setting of inter-governmental negotiations about joint international environmental policy, the setting is often such that a full consensus between all parties, in this case all countries, is needed. It is in this international setting that the process of consensus creation can

[10] United Nations Environment Programme, www.unep.org.

[11] Center for International Earth Science Information Network, www.ciesin.org.

become a formidable task and obstacle in the process of policy development. It is therefore no coincidence that the two examples of models successfully supporting political consensus creation discussed in the previous section are both models from a setting of *international* policy development. It is in this international setting that the need for models in this particular role seems greatest at present. However, there are also some difficulties related to this role. In this role, there is a risk of further postponement of action (e.g. Greenberger et al., 1976), because it often takes a significant amount of time to develop a model. In addition, as the policy process progresses, stakeholder complexity becomes increasingly important. The more complicated a situation is in terms of content and stakeholder complexity, the more difficult it will be to develop a model that can play a consensus role. As Greenberger et al. (1976, p. 44) state: 'The very conditions that help to create the demand (for expert advice) may also reduce the likelihood that research results will be put to use in the policy process'. Problems in which there is both much uncertainty about the available knowledge as well as dissension about the values involved and that should be used to guide the resolution of the problem are called intractable political problems in the typology used by Douglas and Wildavsky (1983). The climate problem, for example, is a clear case of an intractable political problem, for which, as yet, no single model has played a consensus role at the global level. Furthermore, even if a model plays a consensus role at this stage of the policy process, the extent to which the results can be attributed to the model as such, will be very difficult to assess.

Computer models in the first three roles discussed above are not inherently confined in the geographical scale of their subject matter or their audience. For the role of *consensus creation* we even find a tendency towards transnational subjects and audiences, as discussed above. *In contrast*, current models in the role of *ecosystem management* operate predominantly on a confined geographical scale. Under present conditions, models for environmental management seem to be feasible only at a national or sub-national scale. A management model needs an authority in charge to implement such management; whether this is the one-person authority of a forester or nation-state authority delegated to a government agency. At the international level of inter-state environmental policy formulation however, institutions of comparable management potency are still under construction. Policy-oriented environmental computer models that aim at the arena of international policy development will for this reason currently find their most 'advanced' role, for the time being, in support of international consensus creation.

2.3. Computer modeling teams can support different roles over time

As environmental problems evolve over time in the environmental policy process, modeling groups can change their strategy to play different roles during different phases of the policy cycle. An interesting example is the IMAGE[12] modeling team. The first version of IMAGE was developed by a few individuals, and provided a timely integrated picture of the greenhouse effect (Rotmans, 1990). Although IMAGE 1 was not very accurate in its quantitative details it demonstrated the 'qualitative dynamics' of the climate change problem. Once an environmental issue is recognized by policy, however, as a problem to be addressed, the various stakeholders will start their struggle for implementing, or preventing, specific policy measures. During this 'policy formulation' phase quantitative details and especially details of distributions become the central focus of the policy debate. A model like IMAGE is expected to deliver increased quantitative details accordingly, if it is to stay in tune with developing policy needs. Given the uncertain and complex nature of the climate system however, producing authoritative quantitative accuracy was and is not an easy mission. After 1992, the IMAGE model was transformed and expanded to become what is now known as the IMAGE 2 model or the IMAGE project. A renewed and enlarged modeling team, developed a new version of IMAGE which was aimed at being accepted by the core scientific community (Alcamo, 1994; Alcamo et al., 1998). This more comprehensive approach also allowed details of distribution to be presented, which is important for policy purposes.

Building up IMAGE's scientific credibility was viewed as a prerequisite for its use in policy development. After the publication of the IMAGE 2 model documentation (Alcamo, 1994), the IMAGE team wanted to explore the application of IMAGE 2 for the issues being debated and negotiated in the context of the Framework Convention on Climate Change.

In 1995, a new development was started. The IMAGE team (in co-operation with Delft University of Technology and senior policy advisers of the Dutch Ministry of Housing, Physical Planning and Environment) organized a series of workshops to which policy makers who were involved in the preparation of the climate protocol were invited (van Daalen et al., 1998). However, the comprehensive IMAGE model was not suitable for these workshops on its own, and therefore, new additional computer tools were developed such as the Safe Landing Analysis (Alcamo and Kreileman, 1996), the Interactive Scenario Scanner (Berk and Janssen, 1997) and the FAIR model (den Elzen et al., 1999). These simpler models focused on specific actual policy issues during the negotiation process, and were designed to evaluate many different options together with the policy makers. With respect to IMAGE we can conclude that using these different strategies the modeling team was able to adapt to the changing phases of the climate change policy cycle.

[12] IMAGE stands for Integrated Model to Assess the Greenhouse Effect.

3. Conclusion and discussion

We have introduced four typical roles of computer models in environmental policy-making in this paper, and explored the relationship of these roles to policy development over time. If we combine the four identified roles with a general and linear model of environmental policy development like the 'policy life cycle' of Winsemius, a simplified picture suggests that during the recognition stage of an environmental issue, computer models may be used as *eye-openers*. In the policy formulation stage, models can be used in *dissent* to articulate different (scientific and political) insights, and as tools that can be used to arrive at *consensus*, for example on specific emission or concentration targets. In the policy implementation and control stages of the policy life cycle computer models may be used as *management* tools.

This general picture becomes more textured if we look in greater depth at environmental issues of *international* scale, such as the issue of climate change. As climate change is an environmental issue for which policy formulation is primarily sought within the setting of international policy negotiations, we find that the most 'advanced' role that policy-oriented computer models can presently play in this arena is the role of promoting consensus in support of policy formulation. As the RAINS model and the Triptych Approach have shown in the past, computer models may indeed facilitate consensus building between nations. Computer models can thus be important factors in helping the policy process on an environmental issue of international scale to move beyond the stubborn stage of policy formulation. However, the problem of climate change is complex in the sense that there is a lot of uncertainty with regard to the knowledge of causal relations and effects and many different stakeholders are involved. This makes it all the more difficult to develop a model that can play a consensus role.

Developing and keeping a policy-oriented computer model in tune with policy needs is a difficult and challenging task, which can never be fully controlled. Large amounts of work on model development and model adaptation will have to precede the actual policy developments, so that an element of gambling and high-risk investment is always involved. Of particular importance is the question of whether policy-oriented models are to be *kept* adaptable to new developments in the policy arena, and if so how. Adaptation to new political needs becomes more difficult as models grow to become more comprehensive. For policy-oriented computer models on the particular issue of climate change, this question can become especially pressing, as there are an unprecedented number of physical and social processes involved in this truly comprehensive issue. Adapting an already expanded model to new policy needs may not always be an attractive option; one may sometimes prefer to develop a newly policy-tuned model from scratch, and on some occasions one may want to maintain a certain model, even if it is slipping out of tune with short-term policy needs, for the sake of longer term, less political or less predictable goals. The adaptation strategies of modeling teams may vary here, depending on earlier choices and investments made. An important issue in this respect is the question of how to balance the inclusion of physical processes versus social processes in a policy-oriented computer model, in view of the development of policy needs over time. One may argue in general that during earlier stages of the policy life cycle there will tend to be more need for information on the physical processes involved, based on expertise from the natural sciences; whereas once the problem is accepted by policy makers as a serious problem, political attention will turn to questions like how to reduce emissions in a cost-effective and politically acceptable way. Policy-oriented models on these latter types of questions are likely to involve other kinds of expertise and disciplines, like economics or policy instrumentation studies. Of course, a fully 'integrated' model like the RAINS model has its power precisely in its ability to combine expertise from all these different disciplines into a single model. Aiming at such integration within a single model, however, may not always be the most attractive strategy to follow, in view of changing policy needs and the physical and social complexity of issues such as climate change.

In sum, environmental problems experience different phases in their political development or *life cycle*. In these different phases, computer models can play different roles, and distinct types of computer models have been found to fulfill these roles.

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