

## 5. Computerized models: tools for assessing the future of complex systems?

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### INTRODUCTION

Models are commonly used to make decisions. At some point all of us will have employed a mental model, that is, a simplification of reality, in an everyday situation. For instance, when we want to make the best decision for the environment and consider whether to buy our vegetables in a large supermarket or a local farm shop, we will use our own mental model of what is good, and less good, for the environment. But it was the advent of computers that gave a boost in particular to quantitative models. They have been on the scene roughly since the Second World War. Since the 1950s, engineers have studied complex dynamic systems using computer models, inspiring biologists to apply similar techniques in their disciplines. Such models assist in understanding the behaviour of a system, that is, a limited part of reality that contains interrelated elements. This understanding generally refers to how the different elements (components) of a system interact and determine the state of the system at a certain moment, as well as how it may change over time. Once this understanding of historical and present behaviour has been achieved, models are used to forecast future states of the system.

In reality, different computer models serve different policy formulation purposes. As the literature uses a variety of often inconsistent terms to categorize computer models, in this chapter we first try to shed some light on terminology, and more importantly on different classes of computerized models and their purposes in forecasting future states of systems (Section 2). We then introduce the various ways in which computer models can be used in a policy formulation process and how this relates to other tools as described in this book (Section 3). To properly understand the role of computer models in policy formulation processes we need to have a closer look at what evidence and knowledge they deliver to such processes, which is the subject of Section 4.

After these introductory sections we are ready to have a somewhat more detailed look at practical cases in which computer models played a role in policy formulation processes to derive insights from hindsight. Modesty is justified when it comes to the use of models in such processes: while almost every scientific paper presenting a model or application in a case study claims (potential) usefulness for decision and policymaking processes, few have documented real-life applications with a demonstrated analysis of policy impact. This is not to say that models are rarely used in societal processes, but rather that analysis and documentation of the (non-)use in the literature is scarce. In Section 5 we therefore present lessons learned from a number of case studies in which models did play an important role and from this we try to achieve a deeper understanding of the utility of computer models in policy formulation, their users, and when and how models are employed in practice. Although we focus on cases where models have been used, the reasons why in many other cases they have not been used logically follow from the analysis, because one or several of the conditions for use have not been met. In Section 6 we conclude with a discussion of key factors that are important in the effective use of computerized models in policy formulation processes, and highlight possible new research on this important, policy-relevant topic.

## COMPUTER MODELS AND THEIR PURPOSES

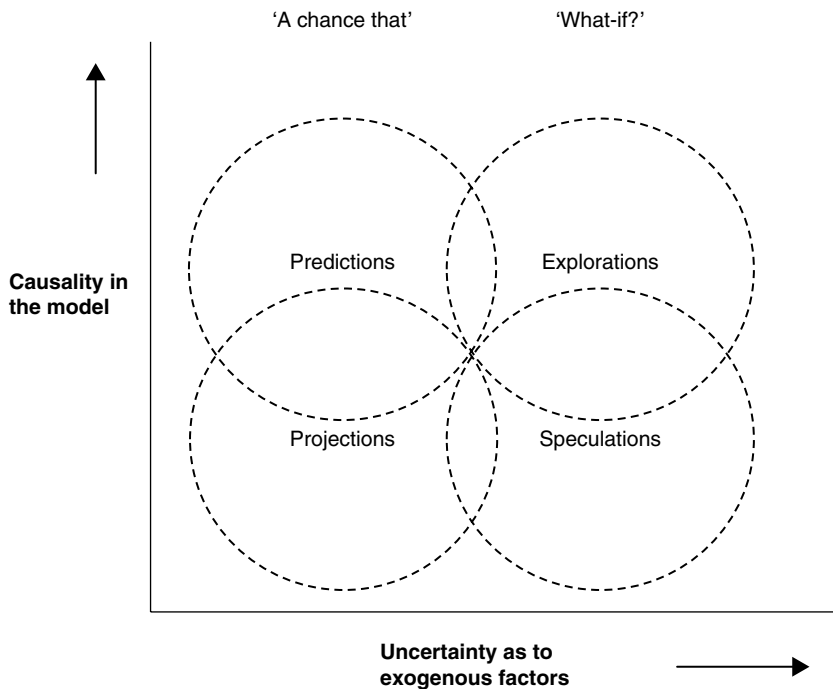
There are many types of quantitative systems models and hence many classifications of them. Here we present a few common terms and classifications that are used in the literature to label the type of methods that we will focus on in this chapter. We concentrate on computer models that aim to provide new insights into future states of fairly complex systems. Examples will be drawn from models that represent complex natural resource management (NRM) systems, where the authors have particular experience.

For studies analysing future states of systems, three rather different terms can be used (van Asselt et al. 2010): forecasting (analysing the likely ‘surprise-free’ futures, that is futures that are plausible and that logically follow from past and present trends); foresight (analysing different ‘possible’ futures); and normative future explorations (exploring different ‘desired’ futures). Forecasting and foresight studies (see Chapter 3, this volume) can also be labelled as, respectively, ‘projective’ and ‘predictive studies’; that is, they try to model the actual, likely or probable evolution of systems, taking the objectives of actors as being more or less implicit. Normative approaches, on the other hand, try to find (‘explore’) the optimal, desired or alternative solutions to a given problem by keeping

the objectives explicit. Predictive (in economic literature also often called positive) studies are generally more policy-oriented: they take system properties, including the human behaviour component, as a given and try to 'predict' the future state(s) of the system in response to alternative policies. Often, explorative or normative future studies are more resource-oriented: they analyse possible futures based on availability and limitations of (natural) resources, while assuming certain objectives of agents and optimum behaviour to realize such objectives.

Today, many models are used for the purpose of so-called integrated assessment and/or in the context of the impact assessment of policies (see Chapter 9, this volume). Here, we refer to integrated assessment as a research process, while we use impact assessment to refer to the political process of assessing the expected impact of new policies or technologies (Adelle et al. 2012). Integrated assessment has been defined as 'an interdisciplinary and participatory research process combining, interpreting and communicating knowledge from diverse scientific disciplines to allow a better understanding of complex phenomena' (Rotmans and van Asselt 1996, p. 327). Integrated assessment and modelling (IAM) has been proposed as a means of enhancing the management of complex systems and to improve integrated assessment (Parson 1995; Harris 2002; Parker et al. 2002). It is based on systems analysis as a way to consider, in a more holistic fashion, the biophysical, economic, social and institutional aspects of a system under study. The term is used for models that consider biophysical and socio-economic aspects and have multi-level capabilities, for instance analysis at regional, farm and field level. The assumption underlying IAM is that computerized tools contribute to better informed *ex ante* impact assessments of new policies and technologies, as for instance employed by the European Commission since 2003 in the EU's policy formulation process (EC 2005).

Models that aim to contribute to the impact assessment of policies need to have some predictive capacity, that is, they must be able to predict likely systems changes as a result of policy changes, and must therefore allow modelling of the responses of actors. So actor behaviour must somehow be captured in the models. In contrast, more explorative and normative models address system responses or optimum configurations with more 'what-if' type questions and scenarios coming to the fore. For example, how would the system change or what would be an optimum system configuration assuming a certain objective (or prioritization of objectives) of actors? The quality of these studies is not measured in terms of the likelihood that the outcomes of the models will actually happen, but rather in showing the ultimate consequences of different priorities or choices. Crucially, they can help to reveal trade-offs between conflicting objectives. The terms predictive and explorative can be further explained and defined



Source: van Ittersum et al. (1998) and Becker and Dewulf (1989).

*Figure 5.1 Typical model-based future studies as classified by the degree of future uncertainty and the causality in the model*

in a classification that relates future studies to systems models. It employs four classes based on two criteria (Figure 5.1). The first criterion is the level of uncertainty, with respect to assessing future values of system parameters and exogenous factors, for example in relation to land use, population growth, trade and market developments. Usually, the longer the time horizon of a study, the higher the level of uncertainty in these factors. It is here that a scenario approach (see Chapter 3, this volume) might be useful. The effects of making specific estimates for exogenous variables (for example, population growth) may be revealed in scenarios. The whole set of scenarios should represent the extremes of possible values for the uncertain parameters. The second criterion is the level of causality in the model of a given system, used to forecast possible future states. The level of causality is reflected in the type of model that is used for the study. Models may have a strong statistical/descriptive basis or a

more mechanistic/explanatory basis with information on causes of certain developments. In more mechanistic models, behaviour or possible behaviour of a system at a higher level is explained completely by characteristics of components at lower hierarchical levels. Regional and farming systems are often too complex to model mechanistically. However, it may well be possible to model certain aspects of the systems, for example the biophysical aspects, and make explicit assumptions about others, for example the socio-economic aspects, in a scenario analysis.

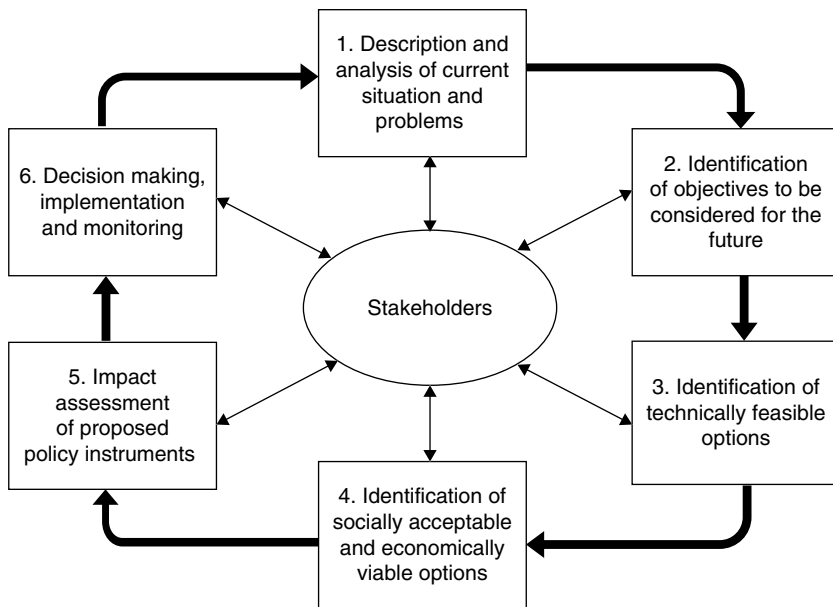
These two criteria classify model-based future studies into four categories (Figure 5.1). *Projections* are based on a low level of causality in the model employed and in fact are only useful under low levels of uncertainty. If more information on causality and relations behind a projection is available, projections may gradually evolve into *predictions*. The distinction between projections and predictions is a matter of judgement, but a prediction claims a certain degree of predictability of the described developments, whereas a projection merely transplants current knowledge and information into the future (van Latesteijn 1995). In both, extrapolations of past and current trends are used and system performance is used as an input. Use is often made of actual and historical data of an empirical and statistical nature. Predictive and projective studies are generally done for the short term (less than 10 years). If the level of uncertainty increases, a projection might evolve into a *speculation* and, if more information is available on how different processes and developments are related, a speculation changes into an *exploration* of the future (see also Chapter 3, Figure 3.1, this volume). Explorations show options for future developments given explicit assumptions about uncertain developments. They usually concern strategic (occurring over >10 years) issues.

In the terminology used by van Asselt et al. (2010), that is, forecasting, foresight and normative future studies, forecasting comes close to projections, foresights are close to predictions and normative future studies generally belong to the class of explorations. However, van Asselt et al. also use the word 'explore' to describe forecasting and foresight, illustrating the ambiguity evident in both the literature and daily practice when it comes to classifying and describing future studies using computer models.

## MODELS AND POLICY FORMULATION

### What Policy Formulation Tasks do Models Seek to Perform?

Computer models frequently aim to provide information that informs various steps in the policy cycle. A cycle in which policies are formulated



*Note:* Steps 1–5 are part of policy formulation.

*Figure 5.2 The development cycle for natural resource management policies*

is a highly complex, non-linear and iterative process. Howlett (2011) subdivides it in terms of agenda setting, policy formulation, decision making, implementation and evaluation. Computer models as discussed in this chapter are aimed primarily at supporting the stage in which options that might help resolve issues and problems recognized at the agenda-setting stage are identified, refined, appraised and formalized (Howlett 2011, p. 29). Applied to land use and natural resource management problems, the policy formulation step can be structured as in Figure 5.2 (van Ittersum et al. 2004; Dent and Ridgway 1986). Again, this is highly stylized and hypothetical compared with the reality. In the first step, the current situation and the resource base are described and analysed to make an inventory of problems (in other words, problem definition and diagnosis); creation of awareness is very important in this phase. In the second step, objectives are identified that steer policy formulation. Stakeholders should agree about a set of objectives and the way they are quantified. In the third and fourth steps, natural resource-use options are explored; especially the degree to which they satisfy a range of objectives. In the third step, the emphasis is

on biophysically feasible options, meaning that system designs are explored which are possible from a biophysical and technical point of view, while little is said about how feasible or desirable they are from a socio-economic point of view. In the fourth step, socially acceptable and economically viable options are identified. In the fifth step, policy measures are assessed in an analytical and participatory process.

It is important to mention that the term ‘policies’ as used here includes specific projects and programmes, that is, we are not only talking about, for example, a price or input subsidy policy, but also about projects to construct, for example, an irrigation scheme or a road, or an extension programme. In the sixth step, the selected options are implemented and their impact is monitored and evaluated. This can then lead to a new policy cycle and the (re-)formulation of existing policies. The cycle is centred on the stakeholders, including the different actors affected by the policies. This facilitates the endorsement of both the *process* of policy formulation and its eventual *outcomes*, and prevents the procedure becoming too top-down (Dent et al. 1994; Fresco 1994).

Explorative studies are thought to be useful in steps 3 and 4 of Figure 5.2, that is, to identify ways to realize objectives and ultimate consequences of particular objectives. In Stirling’s (2008) terms, these studies aim to ‘open up’ (as opposed to ‘close down’) the future; they must not take for granted past and present states and evolutions of the system, but indicate which (strategic) options for change exist. The required longer time horizon of such models implies greater uncertainty (see Figure 5.1). In step 3, the emphasis is on exploration of biophysically and technically feasible options, under different societal priorities; hence the studies have a relatively strong biophysical orientation. Predictive studies (Figure 5.1) can play a role particularly in steps 4 and 5. In step 4 economically viable and socially acceptable options must be identified, with the studies requiring a relatively strong socio-economic orientation. In the phase of identification of policy measures (step 5), predictive studies are introduced, particularly to estimate which policy instruments lead to the desired outcome in terms of defined indicators. This is a core activity in impact assessment procedures, as for instance employed in the European Commission.

### **How do Computerized Models Link to Other Policy Formulation Tools?**

Computer models are normally combined with other policy formulation tools to make them (more) effective in decision making processes (cf. Ewert et al. 2009). For example, scientists use participatory methods (see Chapter 2, this volume) to translate policy problems and views into researchable questions, scenarios and indicators. This is crucial for

engagement and contextualization of the modelling work and something that has been ignored too often in past modelling studies. Scenarios are employed to benchmark a policy change against a baseline situation in which policies do not change, or to explore explicit assumptions on drivers of change that are not part of the model (exogenous as opposed to endogenous variables which are part of the model) (see Chapter 3, this volume; Thérond et al. 2009). Scientists also use indicators (see Chapter 4, this volume) to characterize different dimensions, aspects and criteria of sustainability; computer models allow for their quantitative assessment (Alkan Olsson et al. 2009). Aggregated or summary indicators can also be used to aggregate and present complex outcomes of computer models. For that purpose various kinds of visualization tools can also be employed, ranging from GIS, spider webs and various kinds of diagrams.

Cost–benefit analysis (see Chapter 7, this volume) can also be part of computer models (Janssen and van Ittersum 2007; Britz et al. 2012), though an important distinction is that the models as covered in this chapter try to present objectives and indicators in their own physical units rather than expressing everything in monetary terms. To weigh different criteria or objectives, for instance economic versus environmental, multi-criteria assessment methods (see Chapter 6, this volume) may be used *ex post* (Paracchini et al. 2011), after the model has been used; the objectives or indicators quantified by the model can be weighed using MCA techniques to reveal trade-offs between objectives and to identify optimal compromises. Although this step may be appealing for stakeholders or decision makers to arrive at ‘single best options or solutions’, the danger of weighing is that differences in opinion and relevance are rendered implicit. In the end, this may hinder transparent discussions and decisions.

## WHAT KINDS OF KNOWLEDGE DO COMPUTER MODELS SEEK TO FEED INTO POLICY FORMULATION?

Scientists have choices in how they relate to decision makers. These choices have important effects on decisions or other outcomes arising from the science–policy interface. In his book *The Honest Broker*, Roger Pielke (2007) describes four roles a scientist can take in this respect: Pure Scientist, Science Arbiter, Issue Advocate and Honest Broker. A Pure Scientist is not involved in policy – (s)he publishes or presents his or her scientific work, without engaging with policymakers. A Science Arbiter responds to questions without expressing an opinion on related policy choices, in contrast to an Issue Advocate who takes a clear position and argues for specific policy



action, using scientific knowledge. Finally, the Honest Broker engages in the policy process to use scientific information to expand or clarify the scope of choice available to the decision maker. In this role, the scientist reveals the different options and their possible consequences, without taking a stance.

Following Pielke, we work from the premise that the prime and preferred role of the scientist is that of an Honest Broker. However, it is virtually impossible for a scientist to take a value-free stance in societal and political issues. Scientists often have to make choices on what to include or exclude in their analysis for reasons of data availability, importance and resource (including time) availability; such choices are often affected by normative and personal factors. Yet, a key stated aim of a great deal of science is to better inform policymaking processes – through assessing proposed options in all relevant dimensions of sustainable development, and through revealing alternative options and their consequences – while not advocating particular solutions. This requires transparency about all kinds of choices made in the research process. It also requires a degree of engagement with the decision maker to make sure all relevant alternatives are investigated, and that the scientific analysis is indeed useful and understandable.

Quantitative systems models constitute an important means of learning, in the context of professional practice connected to human values (Leeuwis 2004). Learning through experience could be labelled experiential learning (Kolb 1984) through a continuous interaction and iteration between thinking and action. Models often seek to enhance such learning and thus seek to play a heuristic role. By their very nature, computer models are strong in handling all kinds of interactions between sub-components of the system and between different processes that determine its state. This may assist in providing insight into important processes and drivers of systems behaviour, thus contributing to meaning and knowledge. Scientific and policy-oriented research relies on this use of system models for all sorts of levels, ranging from the level of the gene (as in the case of Genetically Modified Organisms) to planetary systems (as in the case of the Intergovernmental Panel on Climate Change). Models may also be used to structure thinking about implications of systems configurations that do not yet exist, thus supporting *ex ante* or *ex post* assessment and evaluation of policies. Finally, if transparent, models may enhance learning by diversifying the solution space, revealing trade-offs and synergy among objectives, and supporting the selection of ‘suitable’ alternatives. Other proposed roles of models are relational (mediation of conflicts between stakeholders or actors and contributions to community-building) and symbolic (raising awareness and putting issues on the agenda). The extent to which these high aspirations are actually delivered is discussed in the next section.

## BY WHOM, WHEN AND HOW ARE COMPUTER MODELS USED IN PRACTICE?

The aim of the remainder of this chapter is to present insight from hindsight (lessons learned) in terms of factors determining the use and usefulness of computer models in everyday policymaking. Specific references are made to experiences from land use and natural resource management (NRM) models. The work draws heavily on Sterk (2007), who investigated the use (in societal problem solving) of a number of whole farm models and a range of land use and NRM models. A synthesis paper based on her work (Sterk et al. 2011) concluded that a number of conditions need to be met before a model can be used successfully, for instance to create awareness of a problem (phase 1 in Figure 5.2), define policy objectives (phase 2) or assess proposed policies (phase 5). These factors are necessary conditions, but do not automatically lead to successful application. However, by focusing on these conditions, application of a model is not merely a matter of luck but becomes something that can be managed to some degree. The section also brings in reflections on, and lessons learned from, a major European project to develop research models for *ex ante* impact assessment (van Ittersum et al. 2008).

### Model Impact and Utility in ‘Real World’ Policy Formulation Activities?

Sterk (2007) demonstrated how land use models may contribute to societal problem solving and concludes that the uses are rather diverse, including heuristic, symbolic and relational. Cases where a land use model had an impact combined a heuristic role with at least one other, for example a relational or symbolic role (Shackley 1997; Sterk et al. 2009a; 2011). Also, the models fed into different policy formulation venues, ranging from high-level negotiations with directors of ministries, to far more technical policy analysis and support units of ministries or directorates (see below).

A heuristic role refers to learning about land use and NRM systems, but also to learning about the views, norms and values of other actors. Land use models are especially appreciated for their study of interactions between the components of systems; they allow integration and synthesis of fragmented knowledge on processes and components of the system to arrive at a more holistic view. All successful introductions of land use models described by Sterk et al. (2009a) fulfilled such a heuristic role. Another demonstrated role of land use and NRM models is relational, referring to the enhancement of mediation of conflicts between stakeholders or actors and contributions to community-building (facilitating the definition of common ground and purpose). EURURALIS (Westhoek

et al. 2006; Verburg et al. 2006) is an example of a model which had this quality. It assessed the effects on landscape of plausible changes at the European level in different political and socio-economic conditions. To this end, EURURALIS assessed scenarios of plausible changes as defined by drivers of globalization and the control of governments over societal developments. In terms of our classification (Section 2), the model had predictive qualities. In 2002, Wageningen University and Research Centre and the Netherlands Environmental Agency were asked by the Dutch Ministry of Agriculture, Nature and Food Quality to develop a partly quantitative decision support tool. Parallel to the development of EURURALIS, the Dutch Ministry of Agriculture initiated a European network of national policymakers to address the future of rural areas and to develop an EU rural policy agenda. It was similar to existing networks on water and nature conservation. Reflecting upon the role of the model in the process, an informant in the Ministry claimed the new network would cease to exist if the EURURALIS modelling work were no longer part of the network (Sterk et al. 2009a). According to the scientists and employee of the Ministry involved, the rural area directors especially appreciated the possibility of employing the EURURALIS tool as a card index and the visualization of output in land use maps because these features helped the users to get an overview of the diversity in developments and interdependencies in the rural area at both national and European levels. Respondents explicitly referred to its community-creating role, that is, the model facilitated the definition of common ground and purpose. Furthermore, its heuristic role was acknowledged, that is, EURURALIS helped the users to develop an idea of relevant aspects and interdependencies at both national and European levels.

The third demonstrated role of land use models is symbolic, that is, they may help put issues on the agenda. The *Ground for Choices* study (Rabbinge and van Latesteijn 1992) carried out by the Netherlands Scientific Council for Government Policy (WRR), is a paradigm case of a land use study of explorative nature that fulfilled a symbolic role as well as a heuristic one. It was highly successful in putting the need for further reforms to the EU's Common Agricultural Policy (CAP) onto the agenda in the early 1990s, just after the so-called MacSharry reforms initiated a process of price liberalization with direct income support measures substituting price support. The study revealed the extreme consequences of prioritizing market liberalization, rural development, environmental or nature conservation objectives in a set of agricultural land use scenarios. It showed the enormous potential of increasing agricultural production and resource use efficiency in the EU (at that time comprising only 12 Member States) when exploiting technical potentials and concentrating

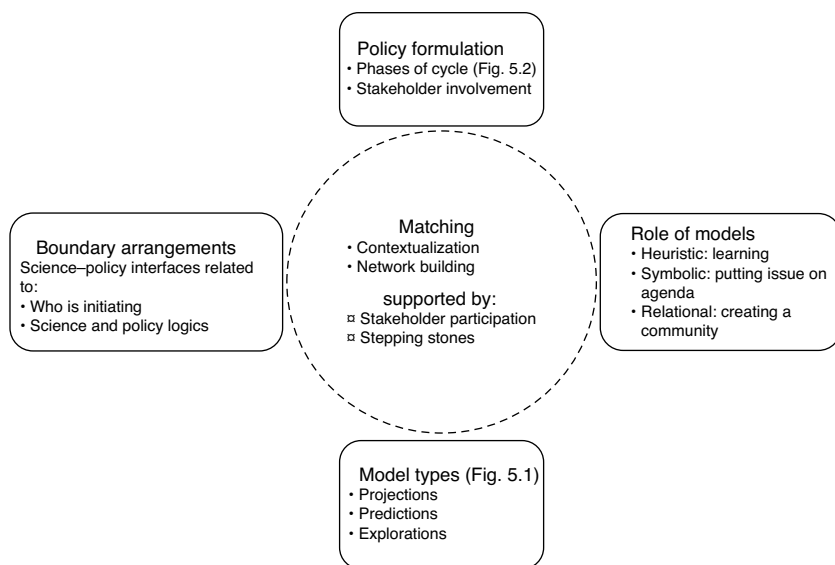
agriculture on the land with best climate and soils. The study also made clear that policy objectives matter: consequences in terms of optimum land use are very different depending on what objective, for example market liberalization or rural development (still an important aim of the CAP), is prioritized. Though the study did not directly assess policies nor lead to immediate policy changes, the WRR itself and its collaborators in the study claimed that the Dutch government and agricultural and nature conservation organizations became convinced of the need for further consideration of the options to integrate environmental, nature and forest objectives with agricultural objectives in response to *Ground for Choices*. In the years after publication of the study, the focus shifted from ‘agricultural’ to developing ‘rural’ policy. This change of mindset is a typical quality of explorative studies; one which is especially important in the early stages of policy formulation.

### **When and How are Computer Models Used in Practice?**

We argue that computer models and knowledge emerging from them *may*, but not necessarily *will*, be used, if a number of circumstances converge. More precisely, the specific phase of the problem solving or policy formulation cycle, the role of model, type of model and the so-called boundary arrangement between science and policy need to match (Figure 5.3). The chances that the computer models (or the knowledge emerging from them) actually *will* be used increase if this matching occurs in a process of contextualization and networking.

Problem solving dynamics and the main phases of policy formulation (Section 3), different roles of models (Section 4) and different types of models (Section 2) have been introduced earlier in the chapter. Boundary arrangements describe how actors conceive of the division of labour between science and policy. They characterize the institutional science–policy space and help to explain experiences of interactions between science and policy. Building on the work of Hoppe (2005), Sterk et al. (2009b) define four boundary arrangements based on two criteria: (1) who is perceived to initiate the research, that is, ‘science’ or ‘policy’, and (2) how logical and appropriate it is to integrate scientific knowledge and policy. Acknowledging the different existing boundary arrangements makes explicit the institutional space in which modellers function and the arrangements or facilitators that may assist in model introduction.

The actual matching of the four factors and the chances for model use are supported by ‘contextualization’ and ‘network building’. Contextualization is the process that encompasses the explication of underlying values and aspirations of the modeller, fitting the model to a



Source: Sterk et al. (2011).

*Figure 5.3 Conditions that favour model application in policy formulation: matching of four factors through a process of model contextualization and network building*

social and biophysical context and interpretation of the model (and its results) in relation to other knowledge sources such as expertise and the experiences of other involved actors. Network building, mostly led by the scientists, is about becoming linked to other societal stakeholders and fostering feelings of interdependency. In building a network, modellers, potential users, other stakeholders as well as the land use model itself take on roles. In the cases where land use models contributed to problem solving, substantial investments have always been made in network building and contextualization. It was not one specific actor (group) that made these investments; we came across examples where both modellers and future users took the initiative.

In the analysis of contextualization and network building processes, two ‘critical leverage points’ were identified (Sterk et al. 2011): first, participation of stakeholders and/or envisaged users in model development, and second, availability of ‘stepping stones’, the latter referring to the closer involvement of researchers or professionals other than the modeller within the policy sphere. A stepping stone is a person (or small group of people)

that functions as a guide when a modeller starts to work in an unknown problem setting or moves into a different boundary arrangement.

Participation of stakeholders in model development has been a frequently debated aspect of modelling research (for example, Parker et al. 2002; Walker 2002; Jakeman et al. 2006). The argument holds that more participation increases the relevance and commitment of the involved stakeholders and consequently leads to greater impact of modelling outside science. Crucially, the cases where a land use model contributed to problem solving exhibited some degree of participation in model development, ranging from a few meetings to discuss the problem definition and research questions, informing the envisaged users about progress and fine-tuning the research further, to collaborative data collection of modellers and stakeholders. The observed consistent employment of participatory modelling suggests that it is a viable approach, although the implementation varied.

### **Practical Lessons Learned in the Matching Process of a Large Computer Modelling Framework**

The integrated project SEAMLESS, funded by the European Commission, aimed at developing an integrated framework of models that can be employed to better inform *ex ante* impact assessments of EU agricultural and environmental policies (van Ittersum et al. 2008). It was funded by DG Research (the European Commission's Directorate-General responsible for funding and implementing European research programmes) as one of a series of integrated projects aimed at developing research tools to underpin *ex ante* impact assessment. In the case of SEAMLESS, DG Research perceived that the European Commission's Directorate-General (DG) for Agriculture (and perhaps other DGs) would have need for this type of model-based framework, to be used by or to provide information to the policy analysts and policy support units in the DGs. In the course of the SEAMLESS project, around 20 meetings took place in Brussels with DG Research and/or DG Agriculture and representatives of various other DGs to define the potential role of the project. DG Research and the research consortium defined the role as being essentially heuristic; symbolic and relational roles were never demanded nor discussed. Concrete topics on model development and contextualization – which were discussed in the course of the many interactions in Brussels – as well as the responses of the project's modellers, are summarized in Table 5.1.

Next to the 'extrinsic' factors (for example, making a policy impact) that will be further discussed below, there are of course '*intrinsic*' methodological and technical requirements of models that must be satisfied. Peer review and publication of all model components – and their integration – in international journals are a necessity to build credibility. Model

*Table 5.1 The Integrated Framework: a comparison of potential user requirements\* and the responses from the SEAMLESS project*

Requirement of (foreseen) users	Response of research project	References
Flexible and open framework	Component-based structure	van Ittersum et al. (2008); Ewert et al. (2009)
Link with the EC's Impact Assessment procedure	The framework and user interface was structured in pre-modelling, modelling, post-modelling phases	Ewert et al. (2009); Bäcklund et al. (2010)
Relevance for users with different focus and expertise (different 'policy formulation venues')	Graphical User Interface for Integrative Modeller and Policy Expert	van Ittersum et al. (2008); Ewert et al. (2009)
Transparency and consistency of the framework	Extensive documentation and adoption of ontologies	www.seamlessassociation.org; Janssen et al. (2009)
Adopt and relate to existing indicators	Indicator library and indicator framework	Alkan Olsson et al. (2009)
Information on uncertainty	User-oriented uncertainty analysis approach	Gabbert et al. (2010)
Maintenance and future of the framework and components	Establishment of a post-project SEAMLESS Association	www.seamlessassociation.org

*Note:* \*As defined and discussed in a series of workshops in Brussels.

documentation is a second obvious requirement, but is far from trivial in practice. Third, the models should preferably be freely available, that is, open source, such that those interested in the model and its code can, in principle, themselves evaluate or use the model. In a recent overview article, Britz et al. (2012) present a number of other intrinsic qualities of integrated assessment models in agriculture. These include consistent linkages between different organization levels, often the micro and macro level (in other words, farm to regional or market level), model calibration and validation and uncertainty analysis. The model description and documentation must explicate underlying assumptions. In an uncertainty analysis, consequences of model assumptions and all sorts of uncertainties as to processes and data can be investigated by the modellers. The challenges of doing this in a scientifically sound yet meaningful manner for users are far

from trivial. Gabbert et al. (2010) explored a user-oriented approach, but uncertainty analysis is clearly an intrinsic model quality that requires more attention to avoid 'black box' syndromes of research models and their application. This is a quality contributing to a successful contextualization of computer models for policy assessment.

As to the *extrinsic* factors, a number of lessons learned became apparent to the project coordinator (the lead author of this chapter) while reflecting on the process of science-policy interaction. First, research project formulation and execution require careful attention to *expectation management*. Project proposals (for Framework Programmes of the EU and other funding agencies alike) must be ambitious and promise well-defined outputs to win funding. In the case of SEAMLESS it was not possible – it was strongly discouraged by DG Research – to interact with potential users during the definition of the project. Yet the proposal had to be precise in its deliverables, and the complexity of the consortium of 30 research institutions (with over 150 scientists) required a precise work allocation and plan of work. Once the project had been approved and started, interactions with foreseen users were initiated and both the funder (DG Research) and foreseen users (mainly from DG Agriculture) strongly encouraged the project to raise its ambitions (Table 5.1) and sometimes to deviate from the original project proposal. The latter requires a level of flexibility which is sometimes difficult to attain in a research consortium in which the partners and individual scientists have their own specific roles. Also, although the project was funded primarily to achieve methodological advances, there was a continuous push to analyse 'hot' political topics. The project had to manage expectations in terms of what could be delivered in that respect, that is, a tension exists between *methodology development* and *application*. The methodology-application tension is a particular issue when the work is carried out by universities and institutes primarily motivated by research rather than commercial/policy applications.

Already at an early stage in the policy formulation interactions in Brussels, the issue of *maintenance and continuity* of the research tools was brought up by the foreseen users. While originally DG Research had suggested that it would take responsibility for continuity in the event of a successful project, it subsequently became clear that continuity was to be first and foremost a responsibility of the research consortium, despite various intermediate project reviews being very positive. As no single consortium member (university or institute) was able to maintain and apply all the computer models of the framework, it was essential to identify the key partners needed to maintain, further develop and apply the core components of the framework. Just before completion of the project, the SEAMLESS Association was established with around 10 core



members from the consortium. The budget of the Association was modest and composed of membership fees from each partner. Though DG Research favoured the establishment of an association, neither it nor DG Agriculture felt responsible for providing financial support. The establishment of the Association is precisely the type of institutional mechanism that the knowledge utilization literature (Nutley et al. 2007) argues is required to institutionalize knowledge use over the longer term.

Finally, two important overarching lessons were learned from the science–policy interface during the SEAMLESS project. First, a *stepping stone* must be created in Brussels to network and contextualize the models and their representation of systems. It seems indispensable to post an intermediate person (cf. knowledge broker – Ward et al. 2009) in Brussels, to work on the science–policy interface on a daily basis. Working on this issue remotely, in the case of the SEAMLESS project from Lund and Wageningen, is not sufficient, whatever the level of personal commitment. A second lesson learned is the crucial *role of the funder*, as well as the agency responsible for drafting the research call, in this case DG Research. Much can and should be expected from efforts of the research consortium to contextualize the research models and to ensure a proper matching of methodologies to the politically relevant questions and processes. However, the donor(s) can play the crucial role of stepping stone in a networking process which potentially greatly facilitates the contextualization and uptake of the developed models.

## CONCLUSIONS

Many computer models are being developed in research, with many either claiming political relevance or being financed precisely with that objective in mind. The challenges surrounding actual use of computer models in policy formulation are far from trivial, but are rarely investigated and documented in detail. Here, we would like to plead for more studies documenting both model use and non-use. Analysis of cases of non- or very partial use may be at least as enlightening as ‘successful’ cases, although modellers may find the results uncomfortable reading. In this chapter we have tried to conceptualize and summarize lessons learned, identifying by whom, when and how computer models are used in policy formulation, based on a number of demonstrated cases of land use and NRM where models *did* make a difference in policy formulation. We believe that some of the insights from hindsight may be generally applicable to other types of models and policy domains, but some may not be. Nevertheless, valuable general lessons can be learned.

The factors ‘problem solving dynamics’, ‘boundary arrangements’, ‘model types’, ‘roles of models’ and the ‘matching’ process allow insight regarding the who, when and how questions as to land use and NRM modelling. Based on this analysis and the further experience obtained in the example presented in Section 5, we conclude that in designing a modelling strategy with a promising opportunity for model use, equal attention must be paid to the technical requirements for model development and to the embedding of the work in a given or intended societal context. Contextualization and network building are essential to embed a model in the societal context, and to avoid modelling becoming too much of a scientific or technocratic purpose in itself.

A number of activities are particularly relevant for the matching process in various stages of the actual model development work. During the preparation, the scientists can clearly influence the proper choice of model type depending on the problem formulation dynamics and the required role of the model. Models are generally appreciated for their capability to address interactions between components of systems and between different environmental, economic and social aspects, including analysis of trade-offs. Policy questions that are likely to benefit from an integrative systems approach will allow better chances for model introduction. Studying the boundary arrangement will greatly facilitate the identification of a proper pathway for model introduction. Finally, stepping stones may be helpful when working in new or difficult boundary arrangements.

During the actual model development process, continuous attention is needed to match the possible and desired roles of the model in the specific phase(s) of policy formulation. Second, model contextualization requires attention, which implies that the underlying values and aspirations of the modellers are made explicit continuously and that these fit the social and biophysical context of the system and its stakeholders. Stepping stones in the science–policy interaction may continue to be highly instrumental in realizing this matching and contextualization.

A distinct quality of computer models is their heuristic role, that is, their potential contribution to learning, especially social learning (Muro and Jeffrey 2008; Reed et al. 2010), which can be defined as the convergence of stakeholder perspectives on the problem and possible solutions (De Kraker et al. 2011). Social learning can form the basis for integrated solutions that require collective support and/or concerted action of various stakeholders. In recent research, attempts have been made to measure social learning, with an emphasis on the role of computer models (van der Wal et al., 2014). It is our hypothesis that a more precise understanding of whether and how social learning is facilitated by models may strengthen the understanding of how they must be developed, both technically and

socially. This, together with enhanced insight into the factors determining the introduction of a model, seem crucial steps towards a better understanding and use of computer models in policy formulation processes.

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