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Actor based analysis and modeling approaches

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Abstract

Integrated assessment (IA) can be defined as the scientific discipline that integrates knowledge about a problem domain and makes it available for policy development and decision making processes. Whereas initial approaches relied mainly on models as means for integration, subsequent approaches paid increasingly attention to including the knowledge of stakeholders in the assessment process. The human dimension has thus a prominent role to play. It is a challenge to represent human behaviour in integrated assessment models. A new approach, agent based modelling, proves to be very promising in this respect. It allows representation of the complex dynamics of human-technology-environment systems and is particularly suitable for participatory approaches. Actor based analysis and modelling takes into account that decision making processes are complex and that any assessment has to take the subjective perceptions and individual framings of actors into account. The combination of integrated models and multi-scale stakeholder processes is a promising approach to assess and manage societal transformation processes in dealing with complex socio-environmental problems.

Keywords: Agent based modeling, stakeholder analysis and participation, social learning, group model building, integrated assessment, institutions, scale

1 Introduction

Integrated assessment (IA) can be defined as the scientific discipline that integrates knowledge about a problem domain and makes it available for decision making processes. Hence IA builds on two major methodological pillars:

- Approaches to analyse and integrate knowledge about a problem domain.
- Understanding of policy and decision making processes.

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Considerable progress has been made by the integrated assessment community over recent years. Initial approaches relied more or less on models as means for the integration of knowledge from different scientific disciplines to capture complex cause effect relationships (Rotmans, 1998). The decision making process was perceived as utility maximizing choice of (a) single decision maker(s) (Morgan and Dowlatabadi, 1996). The measures taken into consideration were mainly of the centralized kind, such as taxes. Such representations of the nature of decision making and the available policy instruments presuppose a simple system—much more simple than is relevant to the policy issues associated with the complex socio-environmental problems that society faces today. It became evident that integration has to encompass both scientific and local knowledge (e.g., Funtowicz and Ravetz, 1993; Pahl-Wostl et al., 1998; Jakeman and Letcher, 2001). The combination of modeling and formal analysis with stakeholder participation has gained increasing importance. In particular the European Integrated Assessment community has taken a lead role in this area. Major issues that have been discussed over the past few years include:

- How to account for and communicate uncertainties?
- How to design multi-scale integrated assessment processes and models?
- How to improve the representation of the human dimension, in particular how to combine participatory approaches with formal modeling techniques?

The perception of the decision making process that an IA feeds into has experienced a considerable change. Decision making should be based on a modern understanding of governance that is polycentric. This implies that dealing with complex problems and transitions towards sustainability requires complex processes in society encompassing many scales (Pahl-Wostl, 2002*c*; Minsch et al., 1998). Governance is multi-level, multi-actor, multi-faceted, multi-instrument and multi-resource-based (Bressers and Kuks, 2003). This has implications for the policy processes and the measures to be explored. The management of resources is for example not only characterized by a governance system, but also by a system of (formal and informal) property rights. The governance concept refers to what public authorities do and what actors around them do to influence them. Property rights are not included. Although they may have been shaped or changed by the state, they are considered to be an autonomous set of rules. Therefore, it is an important issue to explore the interaction of the two systems at different scales to understand potential implications for the sustainable management of a common pool resource.

One of the major issues in understanding policy processes relates to the question of institutions and institutional change. Institutions can be defined as rule systems governing the behaviour of human actors. The market is a formal rule system where the information about an environmental good is only inherent in its price. Complex policy processes will imply the change of rules, both formal and informal, and the role of different actors. This includes power relationships, responsibilities, formal institutional arrangements that guide individual behaviour, incentive structures and other issues. Such changes can only be brought about in participatory processes where the assessment feeds into a process of social learning.

If stakeholders are included into the assessment process, if one tries to capture their subjective perceptions and explores options for change, integrated assessment not only informs the policy process but starts to shape it. The analyst is not a detached observer but becomes part of the system and the process that is required to come up with an assessment. Bots et al. (2000) pointed out that the policy analyst should stay away from 'hard' solution-oriented models for the risk of false fixation of the problem formulation. Instead, she should acquire knowledge by making a whole range of soft perception-oriented models, trying to improve her understanding of how actors think. It is a guiding principle for the understanding of actor based analysis and modelling to capture the subjective perspectives of the actors and to combine them in a process with factual knowledge to determine solutions that are both feasible and desirable.

However, actor based analysis and modeling is a resource intensive process. Hence it is crucial to consider when it should be used, to develop rules of good practice how it should be implemented and to explore how it can be fruitfully combined with other approaches.

2 Actor-Based Analysis and Modelling

Systems analysis as practiced in natural sciences and engineering implies that the analyst explores the system, sets up a data base, develops a model and tests model predictions against system behaviour to assess the quality of the model. The model is assumed to capture cause-effect relationships. The more accurate the representation, the better the models predictive capacity. Based on such understanding of system behaviour one can design strategies for management and intervention. Social scientists and practitioners from management science have started to developed another approach the so-called "soft-systems" analysis (e.g., Checkland, 1993). Intervention and management is not based on the ability to predict and control a social system. It is based on the ability to mobilize and guide potential for change. Actor based analysis and modeling can been seen in this tradition. It takes into account the subjective perspectives of the actors involved in the process. In parallel to the modelling process one explores and sets up a process with the relevant actors on a theme. Model development and stakeholder process interact continuously. This approach takes into account that the social system under observation is changing during the process of interacting with it people may change the rules under which they operate when being confronted with their own behaviour and new facts (Johnson, 2000; Pahl-Wostl, 2002*b*).

2.1 Stakeholder and Institutional Analysis

The first step in actor based analysis and modelling is the analysis of the stakeholder network. This is a prerequisite for the design of a participatory process and the development of integrated modeling tools. Different approaches exist as to how to characterize such stakeholder networks depending on the theoretical perspective and the purpose of the analysis. A stakeholder analysis for designing an integrated assessment process should provide information about:

- Social network of all stakeholders and the rules governing their exchanges and their roles.
- Characterization of individual stakeholders (groups)—interests, goals, power.
- Decision making processes in the area of interest

It is useful to make a few definitions of variables of major interest.

- An actor is an individual or an aggregated social entity (collective actor) that has the ability to make autonomous decisions and act as a unit—e.g., a company or an association is a collective actor with overall accepted rules for collective choice and can thus be regarded as a single social entity.
- An institution is defined as a regularity of behaviour or a rule that is generally accepted by members of a social group. It is either self-policed or policed by external authority. The rule systems determine the interaction between actors. Institutions do not refer to the organizations themselves (e.g., a company is an organization whereas the market refers to the institutional context within which the companies interact).
- The scale of action determines the range within which an actor makes his/her decisions. It is the defined sphere of influence. A national government has a scale of action corresponding to national boundaries. A farmers association may act at the national scale whereas the individual farmer acts locally.
- Formal and informal constraints—norms—determine the behaviour of individuals. In general it is assumed that norms can only be enforced by sanctions since they constrain the behaviour of the individual. Hence they must be imposed. However, norms may be internalized into the value system of individuals and hence the need for sanctions is less pronounced. This is one ingredient of social capital and trust that may guide collective choice processes (e.g., Nooteboom and Janssen, 2002; Nooteboom and Six, 2003).

During the EU project FIRMA (Freshwater Integrated Resource Management with Agents) a new approach to stakeholder analysis was developed and applied to five case studies. Table 1 summarizes generic characteristics of stakeholder groups and illustrates their meaning with a few examples. The consumer

Stakeholder Group	Scale of action				Level of representation			Degree of organization			Public/ Private	
	local	regional	national	European	individual	aggregated	highly aggregated	not organized	Informal institutions	Formal institutions	public	private
Consumer Association			X		X					X		X
Group of Households		X					X		X			
Citizen	X				X			X				

Table 1: Characterization of stakeholder groups

association is a formal legal entity with its own rules of decision making. A group of households refers to households forming a neighbourhood community in a village where social ties are important. They are linked by informal social bonds, neighbourhood relationships, friendship networks that influence norms and values. The group does not represent a formal entity but is still influential for the social process. The individual citizen represents a member of an individual household.

The different categories chosen were identified to be of crucial importance for the characterization of stakeholder networks in their structure and institutional setting. Scale of action and the level of representation are important aspects for characterizing stakeholder groups and for their representation in a participatory process or in an integrated agent based model. This is illustrated in Figure 1. The notion of individual refers to the fact that the stakeholder can be represented by a single social entity—e.g., a company is in this view an individual agent with goals and strategies or the consumer association in Table 1. In contrast, a group of consumers is highly aggregated since they do not represent an entity with formal organization. Bakker et al. (1999) carried out a review of stakeholder categorisations that were used and recommended for water resources management. Every categorisation has two parts: a criterion for dividing the stakeholders, and a list of categories into which they are grouped according to the criterion. Six general criteria and associated categories were elicited (see Table 2).

Another useful instrument for stakeholder mapping is the stakeholder matrix as outlined in Figure 1 (Van der Heijden, 1996). The mapping exercise involves:

Criterion	Explanation	Categories
Scale	refers to the resolution of the stakeholders sphere of influence	global/ national/ regional/ river basin/ local
Tier	refers to whether the stakeholder has a role in planning or implementing activities in the water management system	strategic/ operational
Function	refers to whether the stakeholder sets policy, sets regulations, or operates services in the water management system.	policy/ regulatory/ operational services
Aggregation	refers to whether the stakeholder represents an individual or a group of individuals	individual/ collective
Thematic networks	groupings of stakeholders with respect to a specific task	e.g., water suppliers/ water sewage managers
Policy networks	groupings of "like-minded people that cluster around agents of action ... to promote certain policies and edge out others"	e.g., anti-smoking lobby/ construction industry lobby

Table 2: Recommended criteria for stakeholder categorisations (adapted from Bakker at al. 1999)

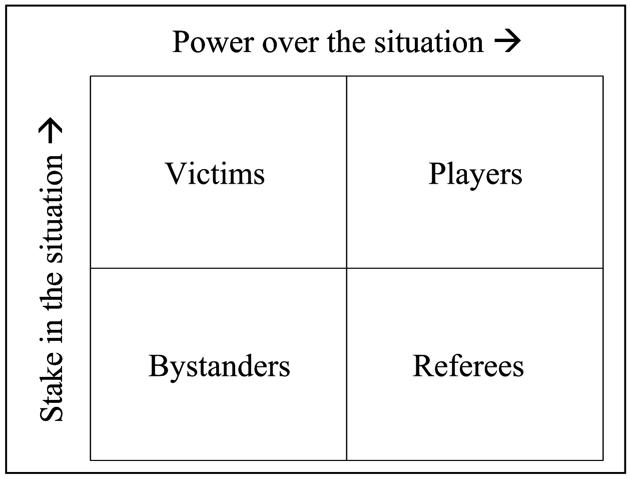

Figure 1: Stakeholder matrix. The different stakeholder groups are characterized according to their stake in the situation and their power to influence the decisions. Players have high stakes and can influence the situation—e.g., the farmers association, agricultural industry. They are crucial for the process. Victims need to be actively invoked to enable them to defend their interests—e.g., individual, non-organized farmers, citizens. Referees have power over the situation but have little stakes in the outcome. Hence they may serve as mediators, facilitators—ideally the scenario team organizing the whole process. Bystanders have no power and little stakes. They should not be included in the process.

- Listing potential stakeholders
- Classifying them on stake and power, as per the stakeholder matrix
- Projecting how they might move across the matrix in the future.
- Selecting the most important parties, in line with the overall frame of the assessment.

In addition the stakeholders are characterized by their goals and perceptions of the problem domain. Such knowledge may be elicited using specific techniques. Here it is of interest to explore how the subjective framing, the "internal" perspectives of the stakeholders deviates from the "external" view of the analyst (Bots et al., 2000; Hare and Pahl-Wostl, 2002).

2.2 Stakeholder process

The stakeholder process serves both as a source of knowledge enriching the assessment and improving the knowledge of the analyst about social processes and as core element of a problem solving approach. Processes of social learning affect relationships and mutual expectations between the various participants. Processes of knowledge exchange and information processing feed into the task oriented planning and decision making process.

Processes of social learning are assumed to be of paramount importance to establish a sound base for communication and collective decision making and to explore options for institutional change (Pahl-Wostl, 2002*c*; Craps, 2003). Processes of social learning involve

- Building up a shared problem perception in a group of actors, in particular when the problem is largely ill-defined (this does not imply consensus building but recognizing differences in perception and being able to deal with them constructively).
- Building trust as the base for a critical self-reflection, which implies recognition of individual mental frames and images and how they pertain to decision making.
- Recognizing mutual dependencies and interactions in the actor network.
- Reflecting on assumptions about the dynamics and cause-effect relationships in the system to be managed.
- Reflecting on subjective valuation schemes.
- Engaging in collective learning processes (this may include the development of new management strategies, and the introduction of new formal and informal rules, change of roles etc.)
- It is assumed that there is a continuous interaction between relational aspects important for the social network (e.g., social ties, roles of actors, establishment of an identity) and the processing of facts and problem analysis the formal decision making approach. Relational aspects refer to the shaping of a community of practice in the stakeholder group, and the feeling of belonging to a wider group of people with a shared responsibility for the common good (Wenger, 1998). Such an identity is crucial to embed local action into a wider perspective and to build the minimum level of trust where collective action, innovation and negotiation processes become possible. The processing of factual knowledge and the development of a shared problem perception is required to identify options for action and potential conflicts of interest.

The importance of such processes of social learning for integrated water resources management and the role of ICT tools are currently investigated in the European project HarmoniCOP Harmonizing Collaborative Planning (`http://www.Harmonicop.info`). One needs to carefully distinguish between different types of information and knowledge and design appropriate methods to take these into account. Participatory processes have to be tailored to the specific setting taking institutional, cultural, national factors into account.

2.3 The role of models and ICT tools

One promising approach to support such processes is agent based modelling. Agent based models allow one to represent the behaviour of human actors in a more realistic fashion. They are particularly useful for being coupled to environmental models to explore the complex dynamics of human-technology-environment systems(Janssen, 2002; Pahl-Wostl, 2002*a*; Parker et al., 2003) . Currently the development of agent based models is a very vibrant and dynamic field. The next section gives an overview over this new modeling approach. The models to be developed in the participatory setting explained in previous sections differ considerably from traditional simulation models as used in the natural sciences. Models are embedded in a process of social learning and serve as tools for communication (Degeus, 1992; Vennix, 1996; Pahl-Wostl, 2002*c*). Mental models of stakeholders are elicited with specific knowledge engineering techniques (Hare and Pahl-Wostl, 2002; Vennix, 1996; Sterman, 2000) and feed into the model building process. The types of mental models to be explored include:

- Cause-effect relationships and feedback cycles
- Perceptions of the social networks and expectations about other actors' roles and behaviours
- Subjective valuation schemes.

In such a process different types of learning take place. Mental models may be corrected in case they are factually wrong. The different actors learn about other perspectives and framing of the problem. Together the whole stakeholder group engages in a collective process of negotiation and exploration of innovative change. Such processes are considered to be of vital importance to reveal the nature of potential conflicts and to explore how to resolve them. The agent based model and the whole process of design and application serve thus different purposes. The model represents the dynamics of the system and it serves as a knowledge elicitation and representation and as a communication tool. Hence the whole question of validation of a models quality has to be judged along different dimensions and the participatory process has to be validated as well.

An agent based model in participatory agent based social simulation is informed by different processes and hence has to be validated against these different purposes. This is summarized in Figure 2:

- An ABM is derived from a factual data base (e.g., improvement of water quality after introduction of new technology) and judged against its ability to reproduce observed system behaviour (classical systems analysis).
- An ABM is informed by expert knowledge (e.g., decision making rules, subjective probabilities) and judged against the plausibility of the produced results in the stakeholder group.

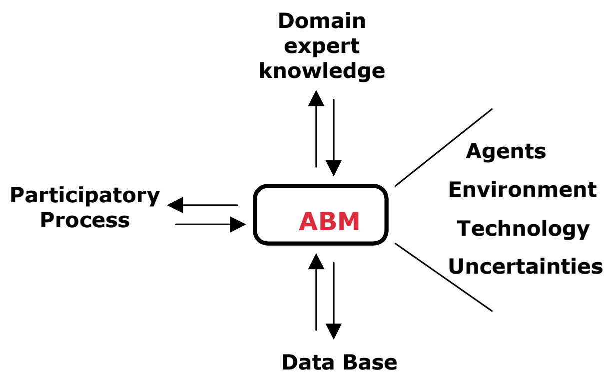

Figure 2: Different processes informing the development of an agent based model and that are important for the validation of its quality.

- An ABM serves as tool to facilitate a participatory process. New knowledge is elicited and fed back to the group. Here the model is judged against its ability to facilitate the process and foster processes of social learning.

Some models may be mainly designed as tools to support learning processes whereas others may be mainly designed to represent the complex dynamics of a socio-environmental system. Sometimes such models may be used in combination within one IA process.

3 The Potential of Multi-Agent Systems to Improve Integrated Modelling

Multi-agent-systems have their roots in distributed artificial intelligence (Ferber, 1999; Weiss, 2000). The purpose in computer science is to develop intelligent software rather than representing intelligent human beings. However, the simulation community can profit from the technological developments that were triggered by the widespread application of multi-agent-systems in software development. It is important to point out that agent based modeling is only a technique. The model developer has to make important choices regarding the design of the model and the individual agents.

3.1 Conceptual issues

Agent based modelling (ABM) allows to capture the behaviour of human beings in a more realistic fashion. An enormous advantage of ABM is the ability to assess the plausibility of the behaviour of agents, the ways in which the agents interact and the consequences of that behaviour and interaction. It is important

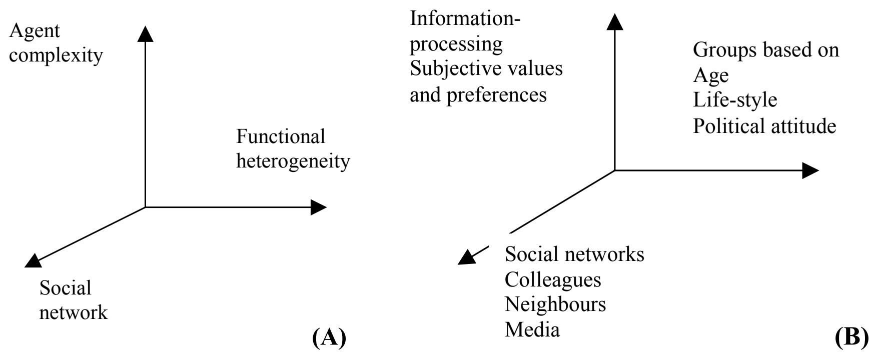

Figure 3: A. Abstract space for the three dimensions of complexity for an agent based model. B. Concrete example for consumer behaviour.

to emphasize that ABM comprises a wide range of approaches and activities. These range from spatial models with simple rule based cellular automatons to complex cognitive architectures of individual agents such as the BDI framework.

One may thus identify the three dimensions of complexity for an agent based model outlined in Figure 3. Any modeller who intends to develop an agent based model for a particular resource management problem is thus faced with choices along the dimensions of:

Agent complexity numerous approaches exist how to represent the reasoning processes of agents. They may be based on psychological theories (e.g., ACTR or SOAR), on microeconomics—rational actor paradigm and modifications thereof based on bounded rationality, complex cognitive agents architectures or simple heuristics and rule based behaviour. Many conceptual theories on human behaviour have never made it to the stage of being included in a simulation model at all. Hence making here a choice for a specific implementation of an agent based model is not a trivial issue.

Functional heterogeneity what type of functional groups should be included in a model. Economists prefer to work with the representative agent approach where a whole collective of diverse agents is represented by one average type. However, what are the effects of neglecting the diversity of agent heterogeneity, e.g., different consumer groups? Such groups may be for example be based on life-style attributes (Kottonau and Pahl-Wostl, 2004) or on different cultural perspectives.

Social network the interaction among agents is of paramount importance for the diffusion of information or behaviour. In the case of the ideal market, information transfer (via price) is immediate, central and without costs. In the real world, interactions are local, information transfer and processing is associated with costs and takes time. Networks have structure—spatial (e.g., neighbourhood in geometrical space) and social (different types of relationships, friendship groups). Often interactions are based on distributing agents on a rectangular grid. However, investigation of voter behaviour showed that the network structure based on social interactions was of major influence for simulation results (Kottonau and Pahl-Wostl, 2004). The existence of such issues is in general acknowledged, the view on their importance and how to account for them differs largely.

The choice of the appropriate agent based model depends on the goal of the modelling approach and on the complexity of the tasks the agents have to accomplish in their environment. Obviously there is a trade-off between modelling complex interactions in heterogeneous social networks and representing the complexity of the internal reasoning processes of individual agents. Up to now these two fields have developed rather independently. Either researchers have been more interested in the emergence of patterns in complex, spatial networks or they have explored in more detail complex cognitive architectures for individual agents. It will be important to foster an intense exchange between these fields to explore the importance of scale, agent representation and aggregation.

One question that should be resolved in such exchanges is for example the appropriate representation of individual and collective agents in spatial settings. Can a representation derived from the cognitive base of an individual be easily transferred to a collective agent and even more so to an aggregated group of agents? Economics assumes utility maximizing behaviour for all agents at any scale be it the individual decision maker, the representative household or the profit maximizing firm. A richer framework for the representation of decision making processes at different levels of aggregation and more investigations into the effect of aggregation are urgently needed. Figure 4 shows important dimensions that ought to be considered when aggregating agent behaviour.

Hence it must be emphasized that considerable uncertainty is inherent in the simulation of any social system. Hare and Pahl-Wostl (2001) investigated the influence of the choice of different types of agent rationality on the outcome of policy options in quite a simple system—nitrate pollution by farming agents. They discovered that the structural model uncertainty inherent in the choice of agent rationality far outweighed any uncertainty deriving from parameter uncertainties or stochastic effects coming e.g., from climate. Uncertainty based on the choice of agent rationality should be explored in a more systematic fashion.

The reasons for uncertainty inherent in any simulation of social systems are manifold. First there does not exist a sound theoretical base for representing human systems in an integrated fashion. And second, the predictability of human behaviour can be questioned in principle. Molecules follow the laws of nature and a river will not reverse its direction if faced with new information about its state. Human beings, however, may change the rules under which they operate, they may engage in a collective choice process and change their strategies within the constraints of the material boundary conditions. This implies a recursiveness that puts any traditional approaches to systems analysis into question. The analyst and the model become part of a process. Hence,

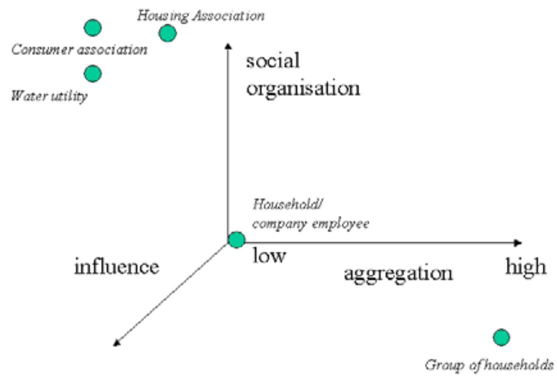

Figure 4: Different levels of aggregation affecting the spatial sphere of influence in an agent based model. "Collective agents" might be associations of companies that comprise a defined communication structure and decision making processes to come to a collective opinion/goal. For aggregations of agents such as a group of households / farms the situation is different. Here the aggregation implies that the properties of individual households can be represented by an aggregated average. This is an entirely different process of aggregation.

as pointed out in the previous section, many social simulation practitioners see model building and scenarios as a route to build a dialogue and a means for a co-production of knowledge rather than a means to develop predictive forecasts. The role of a model may be to provide the base for plausible scenarios and finally decisions are made in a process of social learning.

3.2 Examples for applications

Agriculture is an area where integrated models have been applied for quite some time as tools for developing policies and assessing their implications. Most models have been developed in the tradition of agricultural economics where simulation models of the behaviour of individual decision-makers are typically based on optimization and linear programming methods. Individual decision-making is usually aggregated at the regional or sectoral level. These models have some weaknesses. In order to evaluate the diffusion of technological innovations or the adoption of new policies it is important to explicitly capture the interaction between actors and the spatial dynamics. Otherwise transaction and information costs and the importance of processes such as imitation are not taken into account. Hence a number of models have been developed to overcome the limitations of the current generation of integrated models. Balmann (1997); Balmann and Happe (2001); Balmann et al. (2003); Berger (2001) started to extend economic models in a stepwise fashion using a farm-based linear programming approach within a cellular automata and subsequently multi-agent framework. These models are in the stage of development and have not yet been applied for policy advice. Other groups have chosen a more radical approach. A couple of French teams (Bousquet et al., 2001; Lyman et al., 2002; Etienne et al., 2003) developed models where agent behaviour is represented by simple rules and heuristics that were directly elicited from farmers in the field. These models were mainly used in participatory settings to assess current practice in agriculture and water management and promote changes mainly at local scales. It is yet too early to fully judge potential and limitation of the different approaches.

An area where the use of agent based models is very promising is land use and land cover change where it is of particular interest to explicitely represent human-environment interaction (good overviews are given by Parker et al., 2002, 2003). A number of attempts were made to couple multi-agent frameworks with GIS environments (Gimblett, 2002). Full integration is technically still quite demanding (Meinert et al., 2003). Coupled agent-GIS frameworks allow to represent spatial dynamics of individual decisions (e.g., crop choice) with a high resolution. One limitation is further given by the high data requirements. Another potential is the ability to represent the movement of agents in space taking into account spatial information. This is one reason why multi-agent-simulations find increasing applications in the area of traffic simulations.

Carpenter et al. (1999); Carpenter and Brock (2004) investigated the potential of simulation models to improve the understanding of the resilience of socio-ecological systems and the implications of different management schemes. Agent based models representing human behaviour were coupled to differential equation models of ecological systems characterized by alternate stable states. The models were of a conceptual nature and were mainly designed to improve the understanding for typical patterns of system behaviour. They were also used to communicate the implications of different stable states (one undesirable) and non-linear transitions to stakeholders to raise their awareness for irreversible effects of policies and management schemes.

4 Some Problem Domains

The approaches presented are of particular relevance where human-technology-environment systems have co-evolved over a long time period. Interactions are complex and agent based IA models can provide an improved understanding of the dynamics. Change requires processes of social learning and collective decision making and actor based analysis and modeling can support a participatory integrated assessment.

4.1 Participatory technology assessment and implementation

In industrialized countries, environmental problems have often been tackled with end-of-pipe solutions and by technical means. Such technical solutions are exported to other countries with different cultures, institutional arrangements and legislation. It is often forgotten that technology, the perception of nature, human behaviour and practices co-evolve. No part of the system can be isolated and be implanted into another context but integrated solutions have to be tailored to a new setting. This applies to exports of technologies and management practices as much as to changes of the current system. Let us have a closer look at one example the current system of urban water management. One issue that is currently discussed is a change from the prevailing system with centralized technology and control to a more integrated system with decentralized technology and control (Pahl-Wostl and Hare, 2004; Larsen and Gujer, 1997; Panebianco and Pahl-Wostl, in press). Such a change is a complex process in the whole socio-technical system affecting the role of actors, changes in responsibility, and changes in the paradigms reining the system.

Modeling plays an important role in urban water management, planning and implementation. Models serve to design the technical system that is assumed to be predictable and controllable. Models are thus an accurate representation of reality and are judged by their predictive power. The human dimension has largely been considered as being external to the technical design process. The design problem becomes more complex if socio-economic aspects and changes in the actor network have to be taken into consideration as well. However, rules of good practice for system design are governed by strong paradigms on being able to predict system behaviour and on being able to quantify and control risks. It is further assumed that big treatment plants are more cost efficient and better in their performance. Such institutional logic and inertia often prevent that alternative solutions are taken into consideration at all. Exploring alternative systems (e.g., decentralized) is definitely not only a technical problem that can be solved by providing factual knowledge and model predictions. Table 3 indicates the change in the role of the water utilities, companies and households when one moves from a centralized to a decentralized system.

It is assumed that the individual household has little interest to give up comfort and service as long as the current centralized urban water management system is reasonably cheap and functions well (Pahl-Wostl et al., 2003). However, experience of the past has shown that the design of centralized utilities is often driven by the presence of subsidies without considering costs of maintenance and efficiencies. Once a system is in place (in particular a centralized system) change is very difficult due to the sunk costs. Hence, integrated assessment should provide the tools to assess the sustainability (environmental, economic and social) of different systems in a comprehensive fashion before they are put into place. The design of appropriate systems for water supply and sanitation will be of particular relevance in developing countries to meet the targets of the Johannesburg summit and to decrease the vulnerability of the urban poor

Actor group	Centralized system	Decentralized system
Public utilities	Operating, sole responsibility	Technical service and control of household technologies
Manufacturer	Provides big systems to few clients—utilities	New market for households that are the clients
Household	Little knowledge and decision making power	Decide on technologies

Table 3: Role of actor groups in different systems.

(Pahl-Wostl and Ridder, 2003).

4.2 Adaptive water management and innovative water policies The European Water Framework Directive

The new European Water Framework Directive (WFD) is an important field for integrated assessment where the human dimension plays a major role. The WFD provides significant innovation in water policy. It requires an integrated perspective on river basin management. This has been claimed since a long time but one has to be aware that water resources management is still dominated by a more fragmented and technological approach that is often referred to as the technical/scientific paradigm in river basins (Nilsson, 2003; Milich and Varady, 1999). The WFD requires that interested parties and the public at large are included in the development of river basin management plans. This reflects a new approach to European policy and governance that should become more participatory (Anonymous, 2001). It also reflects the insight that governance is the key factor for sustainable water resource management. Modeling and participatory approaches and in particular the combination of the two will play a crucial role in achieving the ambitious goals of the WFD (http://www.harmoni-ca.info).

Regarding the participation of stakeholders, the role of models and thus also the role of expert knowledge, one can distinguish two very different approaches:

- Policy is imposed in a top-down approach. Experts have their traditional role in informing authorities with factual knowledge. Stakeholders and the public at large are informed and may be consulted at the final stages of implementing a river basin management plan.

- Policy is developed at many scales in an interactive process new institutional rules are not only imposed but are generated in a process of change. Such a process should encourage people to think more in terms of the collective as a whole rather than pursuing solely their individual interests. Experts become part of the process.

One may question the success of a type 1 approach if uncertainties and decision stakes are high. It relies on governance by contracts based on legal institutions. Under the current uncertainties in environmental conditions, economic development and technical progress governing by legal contracts has severe limitations. It is not the appropriate style of governance to foster innovation and adaptive management.

The type 2 approach portrays an ideal that may not always be realistic either given resource constraints and the presence of established traditions of governance and stakeholder relations.

Currently these issues are the theme of intense research in the European project HarmoniCOP (http://www.harmonicop.info). The project started from the assumption that the implementation process of the WFD should be guided by the notion of polycentric governance and that models and ICT tools should serve as means of communication in processes of social learning in different stakeholder groups. The project explores the current practice in different member states of the EU and will investigate the potential and limitations of stakeholder processes in a number of case studies in nine European countries. It is the goal of the project to develop rules of good practice for the design of multi-scale stakeholder processes and the application of models and ICT tools that take into account different cultural backgrounds, institutional settings and legislation.

5 Conclusions

Including the human dimension poses considerable challenges to Integrated Assessment:

- How to improve the representation of human behaviour in models?
- How to improve the embedding of models into integrated assessment processes?

Actor based analysis and modeling has been presented in more detail as a very promising approach to integrate different types of knowledge and different perspectives. It offers the scope to take into account the complexity of human-technology-environment systems and the complexity of polycentric decision making processes. It is most useful in situations where institutional frameworks are fragmented and do not promote the communication of stakeholder groups that are considered to be important for dealing with a problem in an integrated approach. Such an IA has the potential to support complex transformation processes towards sustainability. Further research and applications in different domains will improve the scientific base and generate a community of practice required to promote progress in science and to achieve the societal objectives against which any IA has to be measured.

As pointed out previously actor based analysis and modeling is a resource intensive process. In addition, stakeholder processes are difficult to manage. Hence, the design of any stakeholder process should be done with much care. Additional experience and more research is required to develop guidance on how different forms of stakeholder and public participation and integrated modeling/use of ICT tools can be combined in the design participatory integrated assessment processes. Such processes should integrate different geographical scales, different levels of resolution and be responsive to different phases in time of dealing with an environmental issue.

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