Integrated Assessment
2002, Vol. 3, Nos. 2–3, pp. 220–232

1389-5176/02/0302–3-220$16.00

Polycentric Integrated Assessment

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ABSTRACT

Transitions towards sustainability will require major changes in today's socio-economic systems. Such changes cannot be brought about by conventional policy measures. We advocate a new approach of a polycentric understanding of policy making that invokes instances of social learning at different levels of societal organization. The notion of polycentric involves the integration of different levels of human choice and geographical domains. The spatial component involves the sequence local – regional – national – global. It involves the combination of different types of human choice at different levels of societal organization (e.g., legal regulations, taxes, subsidies, local initiatives). Trying to understand what is the impact of dealing with diverse "global change phenomena" at diverse levels of organization will require new approaches to deal with human agency. Agent based modeling and its application in participatory settings is a novel promising approach to deal with such choice problems [1].

The importance of such scaling issues are explored for the problem of climate change and water resource management. Whereas water issues have primarily been approached from a regional, even local perspective, the climate problem has been addressed in the first place at the global scale with a global scientific and policy process (IPCC, Kyoto protocol). Regarding climate change one has increasingly recognized the importance of addressing the topic at the regional scale. Most choices will be made at the regional scale and will invoke short-term decisions that are not directly related to climate change. Regarding water resource management, patterns of regional water scarcity may be compensated by complementary patterns of food trade leading to major transfers of virtual water at the global scale. In both cases the coupling of different scales in space, organization and time poses major challenges for integrated assessment.

Keywords: social learning, multi-scale stakeholder processes, participatory integrated assessment, evolutionary change in social systems.

1. INTRODUCTION

Integrated assessment (IA) may be defined as the scientific discipline that integrates knowledge and makes it available for decision processes. IA gained considerable international visibility with its activities in the field of climate change. First approaches relied more or less on models as means for integration. The decision process was perceived as utility maximizing choice of a single decision maker(s). Measures taken into consideration were mainly of the centralized kind, like taxes. However, IA has made considerable progress in recent years. The issues tackled have broadened to encompass environmental problems and global change at large and new methodological challenges emerged (e.g., Rotmans [2], Rotmans and Dowlatabadi [3]). Given the fact that most global change phenomena result form the added effect of numerous activities at regional scales (e.g., Morgan and Dowlatabadi [4]), IA faces major challenges that will be summarized here by the notion of polycentric integrated assessment. Polycentric refers on one hand to the need to consider different levels of societal organization and different types of social groups and measures. A modern understanding of governance can be based on the idea of actor and policy networks that are located between state, hierarchy and market (e.g., Pappi [5], Bressers et al. [6]). Also less organized groups such as citizens play an increasingly important role that has to be taken into account in designing IA processes. On the other hand polycentric refers to the fact that IA has to take into account a range of scales in space and time. As we will see the isolation of a single scale in space and time is hardly meaningful when dealing with complex environmental problems. The paper discusses some conceptual and methodological issues related to implementing a polycentric approach to integrated assessment. This is illustrated in a number of problem domains.

2. THE DECISION PERSPECTIVE

By its definition IA has to build on some well-defined perception of decision processes. It makes a major difference

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if decision making is perceived as maximizing a single objective goal function or as a process of negotiation among a set of actors with diverging subjective interests. Many IA analyses were based on the concept of the rational actor and the institution of a market.

The rational actor paradigm is explained very briefly. More detailed explanations can be found in any textbook on micro-economics or decision-theory (e.g., Kreps [7]). A rational actor is an omniscient individual who has the total knowledge about all his possible actions, their outcomes and their utility given different states of the world. Hence, he can always make the optimal decision maximizing his individual utility. His life happens in a market environment.

However, regarding environmental issues three major problems arise in market economies, due to their limited scope in space and time:

- The environment is outside of the boundaries of the free market since most environmental services have no price and are thus not visible to the market.
- Regarding time scales, the needs of future generations are outside of the scope of market economies. The presence of a positive discount rate limits the time horizon of market economies to about one or two decades. That means the institution of a market is not responsive to environmental degradation. Decisions are based on short time scales determined by the discount rate excluding thus considerations extending further into the future.
- The absence of a process based understanding in economics renders attempts to define the spatial and temporal boundaries of an environmental problem quite futile – from an economic perspective. This comment will be dealt with in more detail in later sections.

Attempts to improve market failures arising from economic activities with respect to the environment are based in general on the internalization of external effects. External effects are defined as effects where the welfare of economic units is affected by the economic activities of other units in ways other than through markets. Since markets exchange information only via the price external effects may be internalized by introducing for example a tax. The most common approach to come to decisions in this kind of framework is based on cost benefit analysis (CBA).

CBA is used for the appraisal of public sector investment projects and other aspects of public policy. The total social benefits from a project are compared with the social costs and a decision is taken on the project by the use of the decision rule: invest if the present value of benefits exceeds the costs.

CBA was also applied to deal with mitigation options to prevent climate change (e.g., Munasinghe et al. [8]). The costs are defined as welfare forgone due to investments for measures of abatement. The benefits are defined as damage from climate change that is prevented by these measures. Quantitative estimates may be derived from a global welfare function with a single global utility maximizing decision maker (e.g., Nordhaus [9]). The problem with using a positive discount rate is obvious. Due to the time scales involved one has to deal with issues of intergenerational justice and equity that are neglected if potential future damage is discounted with the current market rate. However, the major problem of CBA is related to how it shapes the decision perspective based on traditional economic thinking that has several severe short-comings:

- The system understanding is based on the assumption of an efficient equilibrium state implying that any measures beneficial for the environment cause costs that can only be justified by prevented damage.
- Preferences and utility function are aggregated over a large number of actors to yield a representative agent.
- Evolutionary dynamics of socio-economic systems are neglected.
- There is little diversity in agents and their characteristics.

As a consequence, choice problems involving non-marginal changes in the structure of today's economies, e.g., societal transitions involving institutional change are largely outside the realm of traditional economic approaches. We have to seek for a new understanding of individual and collective action and correspondingly institutional settings and evaluate their relevance for integrated assessment.

2.1. Novel Approaches to Decision Making

Figure 1 represents the structure of reasoning relevant for decision making. The pathways of reasoning for the rational actor are depicted by bold arrows. More complex models account for the processes of change in preferences and perceptions.

The rational actor paradigm assumes for an agent infinite computational capabilities. Based on his subjective probabilities, an agent is able to derive the optimal decision optimizing his utility function in the decision space covering all possible choices and all possible states of the world. At the same time agents endowed with perfect foresight live in an extremely simple social world. Expectations about others are unambiguous, forecast is perfect and choice optimal. The individual with infinite computational capacity results in the simple equilibrium world. The imperfect social individual lives in the complex world of real human beings where expectations are contingent and path-dependent, where different perspectives and mental models exist. The perception of reality, subjective judgements and probabilities are socially constructed to a large extent.

Subjective probabilities narrowly defined in the micro-economic perception of bounded rationality depend only on the state of information [7, 10]. Two actors with the same state of knowledge should per definition have the same subjective probabilities (e.g., their subjective assessment of the market potential of a new product). In a more advanced

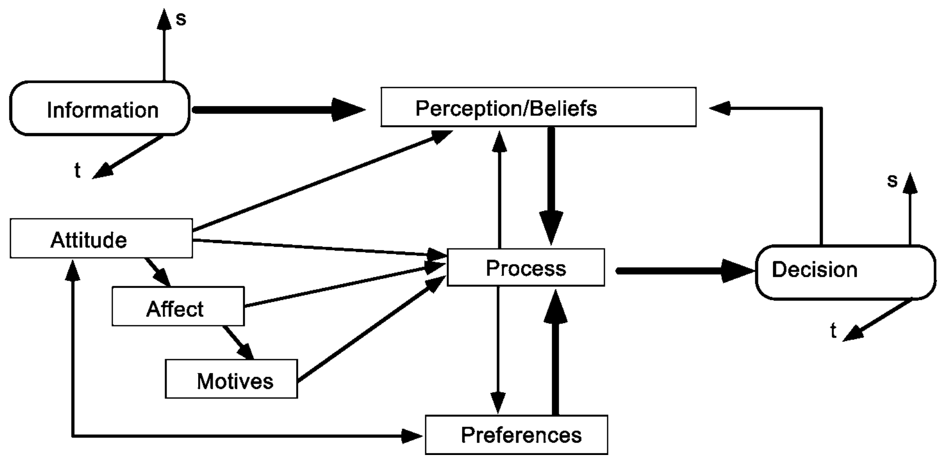

Fig. 1. Representation of the pathways relevant for decision making. The pathways of reasoning characterizing the rational actor are depicted by bold arrows. More complex models account for the processes of changes in preferences and perceptions. Further explanation in the text.

perspective one has to acknowledge that the processing of information is inherently subjective. The thin arrows in Figure 1 indicate that attitudes, affects and motives influence subjective beliefs and preferences. The input and the processing of information is time and space dependent. Personal values, previous experience, the embedding in a social network define what one may call a cognitive and time-dependent filter for the acquisition and processing of information. To account for such processes in the representation of agents in models, a combination of approaches from logic and probabilistic theory are promising (e.g., Woolridge [11]). Knowledge may be represented with so-called belief networks that allow to represent uncertain, probabilistic knowledge and its contingent structure – e.g., causal and diagnostic reasoning. Figure 2 gives an overview of the processes involved in knowledge acquisition and decision making. A cognitive filter is responsible for information processing and for developing a subjective representation of beliefs about the world. As such the representation of knowledge does not yet imply the use of any cognitive theory. It provides a coherent framework for description that allows to derive a "taxonomy" of human behaviors: e.g., the goal directed planning engineer with rule governed behavior [12], the profit maximizing investor, the need satisfying and habit driven consumer [13]. Figure 2 indicates also that such an approach allows accounting for social interactions and dependence relations among agents. For an understanding of human-environment systems the interactions between individual agency and institutions governing social interactions are of major importance.

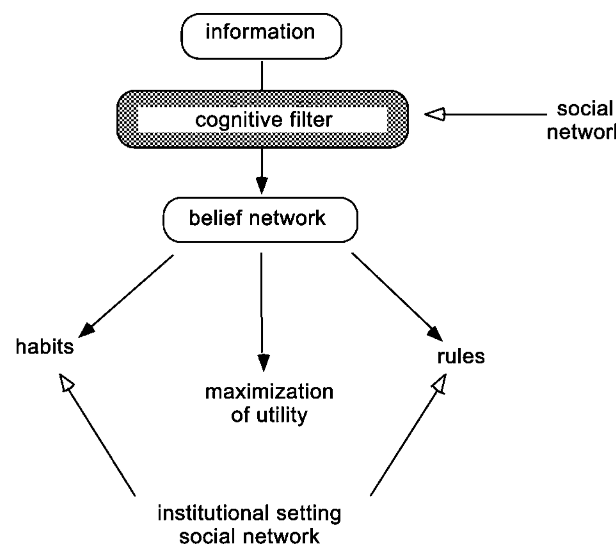

Fig. 2. A generic approach to represent decision making using belief networks for the filtering and processing of information and probabilistic reasoning. Based on such an appraoch a "taxonomy" of different behaviors may be derived (e.g., rule based, habit driven, utility maximizing). As indicated the embedding of an individual in a social network will influence information processing by shaping the cognitive filter and decision making by shaping social rules and habits.

Institutions are now a focus of research in different areas of the social sciences. New institutional economics focus on the importance of institutions for determining transaction costs and thus the competitiveness of different economic systems (e.g., Furubotin and Richter [14]). Institutional analysis in social science emphasizes the importance of institutions for patterns of societal communication, public choice processes, and the relationship between self and society (e.g., Bakker [15], Ostrom [16]). Studies in institutional analysis may provide one framework for integrating approaches from economics and other social sciences, an integration of major importance for integrated assessment in general, and integrated assessment modeling, in particular.

An institution may be defined very broadly as shared rules of human conduct (e.g., Crawford and Ostrom [17]). Rules enable individuals to form expectations concerning the actions of others. For example, if one is driving on a road one expects other drivers to respect the red light and stop. Without such shared rules of conduct life in a society would be impossible. Some institutions (laws) are enforced by legislation (e.g., traffic regulations). Others (customs) are shared by the members of a society and evolve and change in a social setting (e.g., shake hands for welcome). Rules may focus on individual decision making (e.g., risk assessment) or operate at the level of society (e.g., policy networks). They may encompass regional, national or even international scales.

The notion of scale, the integration of different scales of analysis is central to this approach. Trying to understand what is the impact of dealing with diverse "global change phenomena" at diverse levels of organization is currently one of the central tasks of institutional theorists studying global change processes [18, 19]. Cash and Moser [20] emphasized the need to develop adaptive assessment and management processes to link local and global scales. The implementation of institutional resource regimes for sustainable resource management often has to deal with the problem that the scale of established institutional settings does not match with the appropriate scale to manage the environmental system (e.g., a river basin).

How to design assessment processes, tools, methods that allow bridging different scales of analysis? How to take into account the importance of different institutional settings?

Minsch et al. [21] point out the importance of institutional innovations and a polycentric understanding of policy making for sustainable development. Current institutions were designed for stabilizing a fast growing economy not for managing change in a saturated economy. Therefore major emphasis should be given to the analysis of institutions and patterns of change. A polycentric understanding of policy is based on the idea that decision making involves processes of social learning, the shaping of expectations. In a recent study for the Enquete Commission of the German Parliament Minsch et al. [21] emphasized the need for a shift from "What" to "How" in the sustainability debate. Such a shift can be interpreted as a shift from goal to a process based decision making, from hard to soft systems approaches in analyzing decision situations (introductions to the notion of soft systems analysis can be found in Checkland [22], Checkland and Scholes [23], Flood and Romm [24]). A soft systems approach implies the analysis of subjective perceptions of an ill-defined problem situation. In questions related to sustainability problems are often ill-defined. Perceived costs and benefits vary largely among the stakeholders involved. Arguments about refining goals may be quite futile if the uncertainties associated with the path to get there are very high. The costs may for example be path and scale dependent [25]. In these cases collective decision making is of major importance. Decisions may be guided by rules that are shared by a whole collective of agents. The shaping of collective expectations may be crucial to overcome lock-in situations – an issue that will be discussed in subsequent sections of the paper.

3. THE IMPORTANCE OF SCALES

3.1. Environment Human Interactions Across Scales

The first choice of a system analyst is the appropriate level of analysis in space and time given the problem under consideration. This is not trivial for the integrated assessment of environmental problems. The notion of a complex adaptive hierarchical system is used to exemplify how the appropriate level of analysis may be defined. Figure 3 shows the three level approach generally taken into consideration. The level of analysis can be distinguished by the "typical" time scale of the processes under consideration (e.g., day), the overall scale of analysis (e.g., a decade) and the grain of resolution (e.g., hour). This applies equally to other dimensions of space or categories (e.g., individual, group, population of a state). Boundary conditions are defined as slowly varying external variables (e.g., climate changing on a time scale of decades). Underlying processes are defined as processes that are very fast and may thus be considered at an aggregated, parameterized level (e.g., processes on a time scale of minutes).

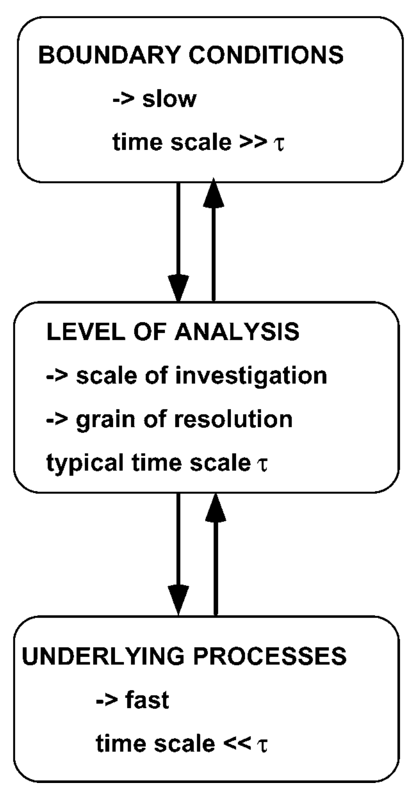

Fig. 3. Different levels in a hierarchical systems. The level of analysis is characterized by a "typical" time scale τ.

A hierarchical approach is also of major importance when one deals with the notions of stability and variability. Any comments about stability must always be made within the scales of the problem specification and with respect to a specific stability concept. The sloppy use of the notions of stability and equilibrium caused many concerns in ecosystem research. Stability was claimed as desirable property for ''healthy'' ecosystems. This view has been replaced by a more balanced perspective taking into account the importance of scale and change in any natural system (e.g., Pahl-Wostl [26, 27]). Similar concerns arise in the description of human-environment systems in the choice of the appropriate system state of reference to analyze for example environmental change, adaptive responses or management strategies. Depending on the variable under consideration, the concepts of stability and equilibrium employed and the scale of analysis, a human-environment system may be perceived as being stable or not. Further it has to be emphasized that the concept of equilibrium in economics differs largely from the equilibrium concept for natural systems. Whereas the latter is derived from the description of fundamental processes in the system, an economic equilibrium is perceived as an optimal efficient state. The lack of taking dynamics into account leads to the puzzling situation that it is irrelevant how fast a market equilibrium may be obtained or what is the appropriate scale of analysis.

The fact that little attention has been paid to scaling issues in economics may be attributed to the need that the link between space and time requires a profound understanding of the underlying processes. The virtual absence of process based thinking in economics may therefore be a reason for this lack of focus. A notable exception is the more recent research in spatial economics (e.g., Fujita et al. [28]).

The link between spatial and temporal scales can be expressed as follows:

- a process (social, biological) may be characterized by a certain time scale τ.
- a corresponding transport process may now be characterized by a certain spatial scale σ that is the spatial distance covered during the time period τ.

A typical example is the relationship between growth processes and diffusion in aquatic environments (e.g., Pahl-Wostl [26, 27]). The size of a patch depends on the spatial distance corresponding to the typical time scale of the growth process. Correspondingly – the spatial scale of the consequences of human action depend on the relationship between the time scale of the dynamic process and the spatial scale of the corresponding transport phenomena.

Human activities have induced a speeding up of processes and a shift in the relationship between spatial and temporal scales. In particular in human-environment system major transfers relate to the exchange of non-material goods where space does not matter any longer. Global change proceeds at an unprecedented time scale. This causes a problem since the speed of global change (e.g., diffusion of lifestyle and technology) exceeds any adaptation potential of natural systems. It includes also certain opportunities since fast change also allows faster management response regarding human induced activities. Regarding the considerations made about the hierarchical nature of complex adaptive systems it implies that the separation of scales and the distinction of a level of analysis cannot easily be accomplished. Global decision processes/financial and material exchanges are not necessarily much slower than decision processes/financial and material exchanges at the regional scale.

The scaling perspective is now analyzed in more detail for two different problem domains:

- climate change and the excess production of carbon dioxide.
- sustainable water resource management.

3.2. Climate Change and Water Resource Management from a Scaling Perspective in Time and Space

If one attempts to make a comparison between the typical scales of a phenomenon in space and time one needs to take into consideration that transport processes link regions over space and time. One has thus two aspects of importance – the size of the spatial domain that is covered by the transport process and the typical time scale of spatial transfers.

Let us now compare climate change and carbon dioxide production with the issue of integrated water resource management by considering the scaling relationships along the PSIR sequence pressure – state – impact – response. Figure 4 shows a comparison of the sequence PSI of the two problem domains from a space time perspective. The notions are defined as follows: pressure refers to human actions that cause a measurable change in the state of the environment. This change leads to impacts that are defined as long-term changes.

- Climate change and CO_2 production – pressure is inherently regional given by energy consumption and fossil fuel burning in different countries. Due to the fast global diffusion of technologies and life styles similar levels of high energy consumption are adopted in most countries of the world. Due to the short time scale of mixing in the global atmospheric reservoir, regional carbon dioxide production is integrated at the global scale within a few years. Hence, the decisive change in the state of the environmental system is global. The impacts of ''global'' climate change are long-term and will be experienced at regional scales caused by the regional manifestations of climate change. The most serious

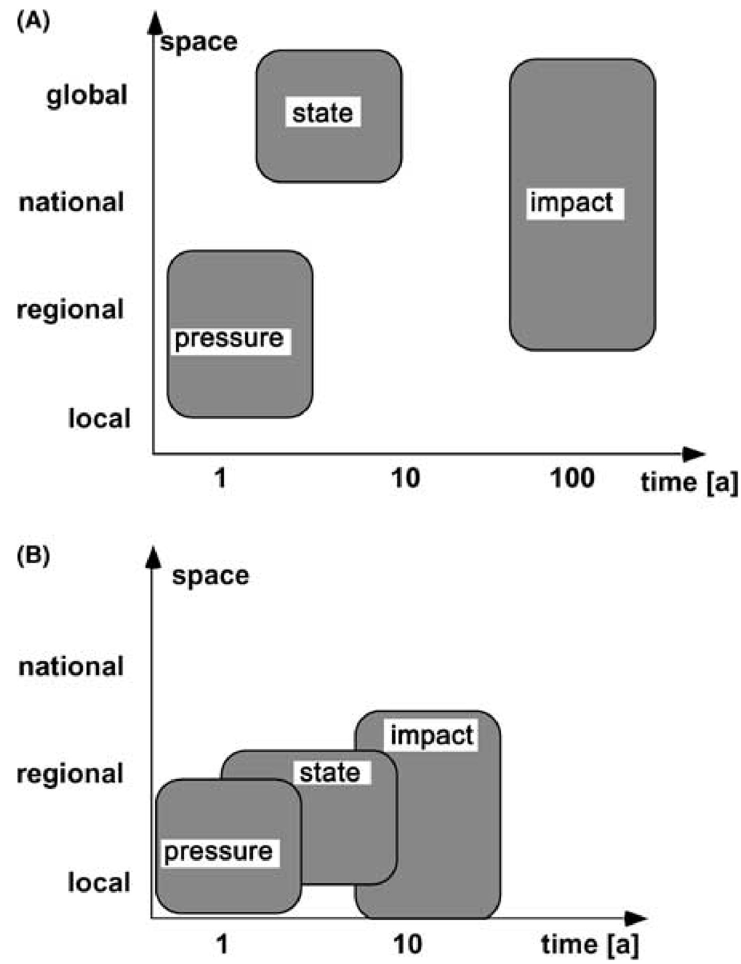

Fig. 4. Comparison of the PSI sequence of the problem domains of (A) climate change and (B) water resource management in a space time perspective. Further explanation in the text.

impacts are expected in developing countries that have contributed little to the overall problem of climate change. This causes serious concerns of equity and justice.

- Quantity and quality of water resources. Pressure is inherently local and short term (e.g., high water consumption, fertilizer use in agriculture). The state of the available water resource in terms of quantity and quality may be affected very fast. The environmental reservoirs of importance are regional aquifers. Large rivers are responsible for directed transport processes across wider spatial distances. Impacts such as the depletion of an aquifer or groundwater pollution are thus experienced mid-term at regional scales. Natural processes cause the uneven distribution of precipitation and water availability. Regional water scarcity problems are not counteracted by any transport phenomena related to the global hydrological cycle. Transboundary transport processes may lead to pollution effects (e.g., acid rain). In general, the whole problem domain is, however, much more localized.

The design of integrated assessment processes and the development of management strategies have to take into consideration the importance of scale, the importance of a polycentric approach:

- An assessment of climate change requires linking regional response options with global policy processes.
- An assessment of regional water scarcity requires searching for a global process to cope with regional problems of water shortage, a process that directs water flow to balance the natural pattern of a very uneven distribution of water resources.
- The fast global diffusion of technologies and lifestyles poses major challenges for both the assessment of climate change and the management of water resources.
- An assessment of climate change has to take into consideration that due to threshold effects and irreversible non-linear responses of the climate system precautionary action is a necessity. Adopting a reactive mode may be associated with high risks.
- An assessment of water scarcity has to take into consideration that the temporal scales and the recovery times regarding the dynamics of water resources are highly

uncertain. Also here the adoption of a reactive mode is associated with high risks.

4. CLIMATE CHANGE AND BEYOND

Given the nature of human induced climate change it is quite evident that the problem itself can only be tackled at a global scale. However, meanwhile it is also evident that early work in integrated assessment typically represented by the DICE model with a global welfare function and a single decision maker does not provide an appropriate decision perspective. Morgan and Dowlatabadi [4] summarized insights from many years of integrated assessment on global climate change. In particular they emphasized that many decisions will be made by the individual choices of millions of organizations and citizens, and these will be driven by local interests and conditions. The climate decision makers are diffuse groups spread all over the globe who will make a number of sequential climate-related decisions that are primarily driven by local non-climate considerations. Dealing with the climate change decision problem requires thus a complex process of decision making bridging scales in time, space and institutional settings. Cash and Moser [20] emphasized the need to develop adaptive assessment and management strategies. This is in line with a shift from a goal-based, optimization framework, to a process based multi-scale approach. This implies identifying a long-term target/vision (e.g., a low energy society) and short-term options that trigger the movement into the direction of the target in a fashion of sequential decision making.

It might be useful to clarify the difference between a goal and a process based approach guided by a target/vision as used here. A vision refers to a moving target guiding the self-organizing, innovative forces of a society, forces that otherwise would remain diffuse. It differs from a goal in that it is a tangible image of a future society without being subject to fierce arguments about exact definitions that characterize the operationalization of goals. An example for fierce discussions about goals is provided by the arguments about the targets (e.g., 5% reduction) for CO_2-emissions. Given the huge uncertainties surrounding the costs of the different implementation strategies some of these discussions have to be judged as futile. A vision is comprehensive and synthesizes different goals and aspirations. That implies an embedding of climate policy in a wider range of societal concerns.

Such an embedding is particularly important for considering mitigation options at the regional scale. At this scale the most common approach is to consider adaptation options only. Isolated regional action reducing carbon dioxide emissions cannot prevent regional damage from climate change caused by the global carbon dioxide budget. Hence traditional arguments of cost benefit considerations lead to the conclusion that the costs for investments into mitigation options at a regional scale cannot be justified since climate is a common good and benefits will be global [29]. However, regional action will be decisive for action at the global scale. Inherently climate policy will not be a top down process where global agreements will enforce a cascade of corresponding policies at national and regional scales. Nor will it be a bottom up process where in a type of "world movement" a new life style will emerge and spread over the globe as a whole. It will rather be an iterative process where top down and bottom up forces will mutually reinforce or as well block each other. Obviously an assessment process should aim at fostering a reinforcement and at preventing a blocking.

How can one bridge scales from the individual citizen making choices in his/her individual life style to the global policy process and the Kyoto protocol? Such questions were addressed within the CLEAR project (CLimate and Environment in Alpine Regions) in a participatory integrated assessment from a regional perspective [25]. The research focussed on the individual and his/her role as consumer adopting new products and making choices in individual lifestyle and as citizen participating in democratic processes. The direct democracy in Switzerland with its specific participation of citizens in decision processes provides an excellent environment to study such approaches.

The participatory integrated assessment used the method of citizen focus groups. A specific model and information platform on climate impacts and options was developed to inform the assessment process. Two models were developed that addressed mitigation options. An individual energy demand calculator emphasized options at the level of lifestyle choices. The options model was designed to reflect a polycentric understanding of policymaking by addressing a whole range of political measures at different levels of societal organization and different institutional settings – public policy and measures that aim at changing informal rules and social norms. Figure 5 shows the list of options that were addressed in discussions with participants of citizen focus groups. We noted two major limitations:

- bridging scales from the individual to a global policy process is not trivial. The empowerment of citizens requires that they are able to identify options in their individual area of decision making and to realize their important role as individuals in a larger context without feeling responsible for the problem as a whole [30].
- accounting for the combined effect of different types of measures that bridge scales and institutional settings (e.g., the combination of a tax and measures for education of the public) and for uncertainties in such projections is currently impossible given the analytical frameworks available. The discussion about the combination of different categories of measures had thus to remain largely at a qualitative level.

Changes in rules, norms, and shared habits are difficult to address. Given the current limitations of analytical

Market Instruments
CO_2-tax
Ecological tax reform

Fixed Targets
CO_2-emission certificates
energy barrier

Governmental Restrictions
fixed technological standards
sunday driving prohibition

Voluntary Agreements
commitments of business
global action plan

Supporting Measures
funding of research and technology
information and education

International Measures
role of Switzerland in policy process
global economy

Fig. 5. Overview of the measures catalogue included in OPTIONS, a module of the CLEAR information platform developed for the participatory integrated assessment with citizen focusgroups (see Pahl-Wostl et al. [25]).

frameworks to deal with such options the following needs are identified:

- a modeling approach that can account for cognitive and social aspects of human behavior, for different modes of communication and interaction.
- a participatory model building to deal with uncertainties and aspects of a socially constructed reality that have to be addressed.

A socially constructed reality refers here to the mutual shaping of expectations. Expectations may trigger and stabilize a certain behavioral pattern and a development trajectory of a system as a whole. In climate change one is interested in exploring development trajectories that decouple economic growth from the degradation of the environment. Evolutionary systems dynamics uses the metaphor of walking on a fitness landscape to describe the state space of a dynamic system (e.g., Pahl-Wostl [26], Kauffman [31]). The fitness landscape may be rugged or smooth. It may change its shape over time due to the consequences of walking on it! If

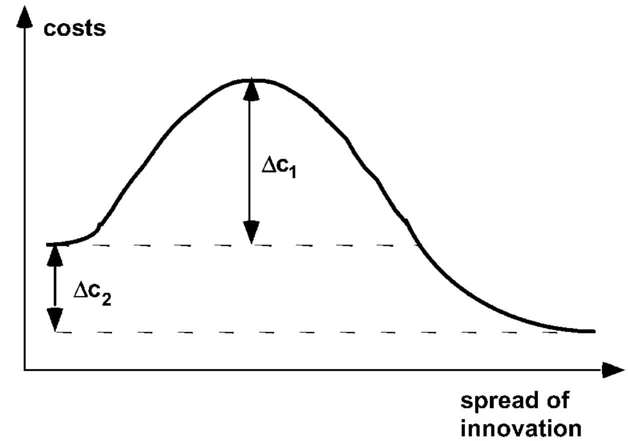

Fig. 6. Lock-in effect preventing the spread of an innovation (e.g., new technologies in mobility). The shape of the cost curve is of major importance for the transition from one regime to the next.

socio-economic development is perceived as a local search process on such a fitness landscape rather than as a global optimization process, the search path is highly dependent on past development and contingent on the perceptions of the stakeholder groups involved.

One may encounter lock in effects where the search may be constrained within the boundaries of the current attractor of system behavior. Figure 6 shows a typical cost curve characterizing a lock in effect that prevents the spread of an innovation. The shape of the cost curve is of major importance for any transition to be accomplished. Δc_1 refers to the height of the cost threshold to be overcome. Δc_2 refers to the potential decrease in overall costs once an innovation has spread over the whole system of interest. Costs refer here to an aggregate for an economic system, a community as a whole. They may refer to the scale dependent price of a new technology, the costs associated with the learning of new skills for manufacturing and handling etc. For an integrated assessment it is crucial to take into account that:

- Costs are path dependent and depend on the expectations and the patterns of choices made by the different individuals and stakeholder groups involved [25].
- The shape of the aggregated cost curve and the cost curves for individual groups may be scale dependent (see also Cash and Moser [20]).
- Individual decisions are not based on aggregated costs but on the costs perceived by different stakeholder groups.

A most obvious example for such a lock-in effect is given by patterns of energy consumption, in general, and mobility behavior, in particular. A comparison among different OECD countries is already quite informative. A US citizen has an average energy consumption of about 10000 Watts.[1]

[1]Energy consumption is expressed here in units of a power as suggested by Imboden and Jaeger [32].

In most European countries the average per capita energy consumption is at a level of about 6000 Watts. Energy efficiency defined as GDP/Watt is much higher in European countries. One reason can be attributed to the fact that the US society has largely developed during the time when the automobile was already available. This has fostered the adoption of a certain type of infrastructure and of a highly energy intensive pattern of mobility. The break out of such a lock-in situation requires a concerted action comprising national action in legislation and investment strategies, regional demographic planning, and habit breaking of consumers who are entirely adapted to a certain mobility behavior. Regarding habit breaking it is interesting to note that in Switzerland an increasing number of people live in car-free households. However, giving up the car is hardly ever a conscious decision. Due to changes in personal circumstances consumers may be forced to explore a new type of mobility behavior and discover its positive benefits. Hence their previous behavior did not reflect their optimal choice. This is an example for a lock in effect at local scale. Habits reduce costs associated with information seeking and processing, with making conscious decisions [13]. Habits are stabilized by social acceptance and lead their adopters to an identification within a social group. Novel modes of behavior emerge slowly.

The dynamics of changes in consumer preferences is an important but largely unexplored area of research. It involves processes of individual and collective learning. If one accounts for the richness of cognitive behavior at the level of the individual, scaling up is not easily accomplished [1, 13]. This poses challenges for modeling at different scales. In any system, the diversity in the characteristics of individuals and complex patterns of social interactions renders aggregation difficult (e.g., Pahl-Wostl [26]). Can behavior at the level of an aggregated consumer group be described by the same approach chosen at the level of the individual? This is the current practice of the “representative agent device” used in many CGE models, a practice that is increasingly criticized (review in Leitner et al. [33]). Analytical approaches to deal with aggregation already meet their limits with the much simpler situation of consumers obeying the rational actor paradigm. A promising possibility towards deriving descriptions across a range of scales is by way of comprehensive and rigorous simulations with agent based modeling frameworks [1].

5. SUSTAINABLE MANAGEMENT OF WATER RESOURCES

Contrasting with the issue of climate change where the request for action is largely determined by concerns about future damage, water resource management has to deal with severe current problems of shortage and pollution in different parts of the world. The situation will aggravate in the future if current practices continue (e.g., Cosgrove and Rijsberman [34]). Traditionally water related problems have been approached from a rather narrow and fragmented perspective. The EU water policy with its numerous directives targeted at single issues in isolation is a prime example of a fragmented water policy [35]. With the advent of the new European Water Framework Directive the situation changes drastically. With the European Water Framework Directive European water policy adopts a more polycentric approach. Of particular relevance for our considerations is the integration of the previously fragmented European water policy, the participation of stakeholders in adopting the management plans and the introduction of the river basin as the primary management unit.

The idea of integrated management at the basin scale has increasingly gained importance. River basins are the natural context for water resource management. They are defined by the watershed limits of a system of waters flowing into a common destination. It is not always trivial to clearly define river basins – in particular in the area of estuaries. Further, man made flows (e.g., water supply, canals) may induce transfers from one river basin to another. Despite these difficulties in clearly delineating system boundaries from an environmental perspective, river basins are important management units that are increasingly adopted in many countries in the world. This is a major advance in comparison to previous approaches. However, the basin scale hardly ever coincides with the boundaries of institutional settings. Only in a small number of countries river basin management schemes are in operation. Stakeholders are in general not organized at a basin scale since it is not a scale of social organization. The need for institutional change and innovation is obvious.

In the following two different topics are addressed to show the importance of scales and a polycentric approach to policy making for water resource management:

- Transformation processes and lock-in effects as a function of scale.
- Market based institutions from the local to the global scale.

5.1. Societal Transitions and Lock-In Effects

The interaction between a socio-economic system and water resources is largely dependent on the technologies and institutional resource regimes at the interface. Technologies are broadly defined to comprise not only a specific technique but the whole pattern of institutional settings. Lock-in effects, discussed already in the context of the issue of climate change, arise here as well. An example is given by urban water management. Figure 7 shows different interdependent components stabilizing the current system of water supply, in particular, and urban water management, in general, in many

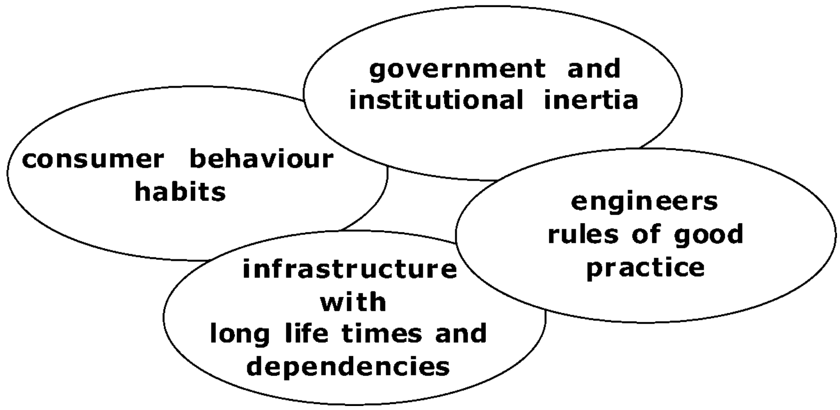

Fig. 7. Determinants for lock-in effects in urban water management.

OECD countries. A lock-in situation arises due to the long lifetimes and the high fixed costs of infrastructure. Rules of good practice in the engineering community, consumer habits and institutional inertia are further impediments to change. Such a situation has been explored for the city of Zürich where the planning of supply capacities does not reflect the need to improve flexibility for responding to change [12, 36]. Risks are prevented by high investments into technology and the establishment of several layers of security. Efficiency in both economic and ecological terms is unsatisfactory. Also here, the adoption of new technologies and new institutional arrangements is a process that can only be accomplished in a concerted action involving different stakeholder groups. In particular, citizens will play a more important role – as consumers making technological choices and as citizens making political choices.

However, the adoption of innovations is also prevented by the high degree of fragmentation of the water sector. Figure 8 shows an overview of important parts of the coupled urban-rural system. Agriculture may pollute the groundwater resources. The problem of nitrate pollution of groundwater resources and thus drinking water supplies is nowadays a pressing problem in many regions with intensive agricultural activities. Once the nitrate concentration in the well exceeds the limit, it may take a decade or more until a reduction in the amount of fertilizer application will have an effect. We encounter here a mismatch between time scales of pollution and effect. The soil reservoir has a memory of several years until the polluting effect of the water resource can be detected in the well. The system then retains a "memory" over years even when the response options at the level of the original source, agricultural practices, are drastic and immediate. In general, the immediate response strategy is either the closing down of wells for drinking water supply or the purification of drinking water with highly sophisticated and expensive technologies. Further, waste water treatment

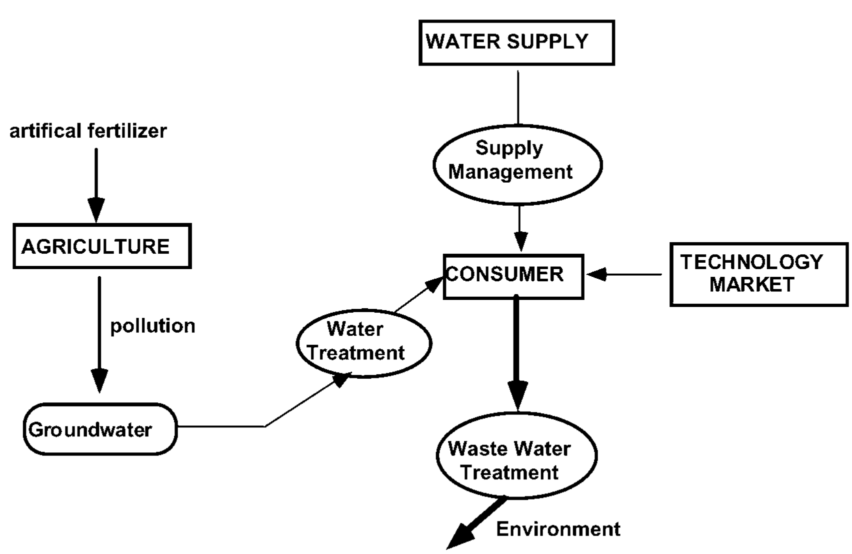

Fig. 8. Some urban-rural couplings in urban water management. A problem to innovation arises since the current institutional setting does not support to develop a common strategy for an urban-rural system and lock-in effects prevent change.

plants release additional nutrients into the environment. Each of these fields of activity is dealt with in isolation. A more comprehensive approach should take the perspective of the system as a whole and make, for example, the attempt to close nutrient cycles. However, costs and benefits vary as a function of scale. Hence one may pose the question – what is the appropriate scale to introduce an innovation? Further uncertainties in the assessment are huge. Whereas uncertainties in the dynamics of the natural resource have received a lot of attention in groundwater modeling, uncertainties in the dynamics of human behavior have largely been neglected.

Currently prevailing attitudes and technological systems spread over the whole world at an unprecedented pace. Big water companies transfer western technologies to all large cities of the world. Given the knowledge about the emergence of lock-in situations this can hardly be perceived as a desirable development.

5.2. Market Based Institutions from Local to Global Scales

The market is in general perceived as the single best institution for the efficient allocation of a scarce resource. This is one reason why regulatory reform [37] and in particular market based approaches in water resource management are receiving increasing attention [38, 39]. A multiscale approach seems to be warranted that takes additional processes such as rule governed behavior, complex patterns of interactions, imbalances between supply and demand, and negotiations into account. Let us briefly address this issue by looking at different scales of the problem of water scarcity:

- The local scale of the community → Allocation of water among different groups within a local community. The members may have different access to water. Allocation and communication patterns may be governed by cultural perspectives, and informal rules within a community. The empowerment of the different social groups needs careful considerations.
- The regional scale of a province → Allocation of water among different user groups – e.g., domestic and industrial demand, and agricultural use for irrigation. In such settings the spontaneous emergence of informal water markets has proven to be quite likely. This is the scale where new technologies may be adopted – given that their market potential and thus price have been judged from a wider perspective.
- The scale of a large transnational river basins → Allocation of water among different areas within the basin with different water availability, e.g., up- and downstream areas. Transnational management schemes and formal arrangements for trading water rights need to establish efficient institutional settings that should prevent transaction costs from becoming too high.
- The global scale → Allocation of water among different regions/nations of the world with different levels of water availability and water scarcity. The appropriate commodity for trading is given by food and thus virtual water. The local production of food would minimize transaction costs. However, institutional arrangements and coordinated investment strategies are largely missing. This is an area of major interest in current research.

An important field of action is located at the global scale by breaking one global tendency and by fostering the emergence of another. There is a need to break global tendencies of the diffusion of uniform technologies and to foster the development of technological solutions and institutional settings adapted to the characteristics of a region. The global patterns of food trade should be exploited to equilibrate differences in water supply across regions by indirect imports of water as virtual water in food (e.g., Cosgrove and Rijsberman [34], Zehnder [40]). Linking food and water policy may also help to overcome the fragmentation of institutions in the water sector. However, it is also evident that the management of water resources from the regional to the global scale requires a multi-scale perspective and modeling approaches that allow a nested approach to deal with the problem and institutional interactions across scales.

Informal markets may emerge spontaneously as spot markets with water as commodity. More formally, one may introduce water rights and in the next step water markets with tradable water rights. However, limiting the perception of market based institutions to a narrow microeconomic perspective and to price based allocation mechanisms is insufficient. Questions of kinship, access to water, power relationships need to be taken into account (e.g., Bruns and Meinzen-Dick [41]). They operate at different levels of societal organization and cannot easily be accounted for in the traditional market approach.

Informal social norms at the local level could be much more important than (formal) property rights and public policies for explaining (but also for modifying!) the behavior of water users. There is an analytical/empirical need to know more about these social norms; but there is also a political/practical need for information/persuasion instruments in order to modify users behavior. Thus, "management strategies" ("policy tools") must also take into account information/persuasion instruments (and not only planning, economic incentives and legal prescriptions). All in all, we advocate that cognitive elements (from individual perception of water problem to the assessment of the effects of more integrated water management) should be analyzed in more detail.

6. SUMMARY AND CHALLENGES FOR INTEGRATED ASSESSMENT

Assessments related to global change have to address decision problems in a polycentric approach bridging a range of different scales in space and time and levels of societal organization, dealing with different institutional settings that may not easily be scaled up or down. The analysis of the structure and dynamics of informal social rules and norms may be equally or even more important than the analysis of regulatory frameworks. This insight is based on a new understanding of policy making and institutional dynamics. One conclusion is the insight for the need to improve the representation of the human dimension in both integrated assessment models and processes. We advocate participatory agent based social simulation as new approach to account for the human dimension in such a polycentric approach to integrated assessment.

Agent based modelling (ABM) is a broad term that embraces a wide range of approaches from computational economics, cognitive psychology, artificial intelligence and computer science. ABM allows representing decision making processes explicitely and accounting for the dynamic behaviour of socio-economic systems. An agent may represent an individual and/or an organization (e.g., an association, the government). Processes of scaling up and down to represent decision making processes at different levels of aggregation are major research questions. Up to now no coherent approach has emerged. This may also not be warranted at the current exploratory stage where a number of different approaches should be followed. ABMs are particulary suited to be applied in participatory settings since they allow representing decision making processes in a more realistic fashion. Starting from stakeholder perspectives means to really include the human dimension into integrated assessment processes. The building and application of models in participatory settings is of particular importance if uncertainties and decision stakes are high [42].

An improved understanding of human environment systems can only be achieved by linking theoretical and applied research, by linking approaches focusing on agents (representation of individual human actors with cognitive function of varying complexity) and approaches focusing on system behavior (interaction of agents, institutional change). Figure 9 sketches the main areas of research. Starting from the focus of complex individual agents and acknowledging cognition as a source for complexity and uncertainty is rather new. The system's perspective has a longer tradition. Complexity arises from agents' interactions in social networks. There is a certain tradeoff between making individual agents very complex and investigating the dynamics that arise from agents' interactions. However, to understand the emergence of norms and the dynamics of institutions one has to take into account the embededness of indviduals in social networks and the internal representation of institutions (e.g., shared norms, rules) in an individual's mind.

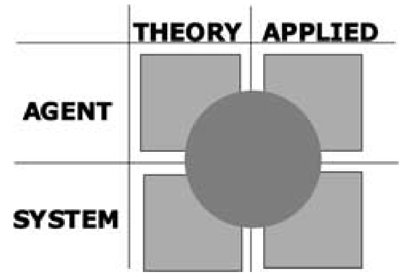

Fig. 9. Different areas of research in agent based modeling that should be explored simultaneously.

A new generation of models is required that allows a nested representation of different scales of analysis – local – regional – global and the investigation of the shaping of expectations across scales. Using agent based models, this requires improving the understanding for the representation of agent behavior at different levels of aggregation. Given the high degree of uncertainty and the decision stakes involved, the importance of participatory model development and application cannot be overstated [1, 43, 44]. In a polycentric approach to integrated assessment model building and development is an essential part of the assessment process providing thus major challenges to validation. Models should constrain the space of plausible future scenarios and provide a quantitative base wherever appropriate. At the same time they should allow exploring the whole range of plausible scenarios and the indeterminacies that emerge from the degrees of freedom inherent in human choice.

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