Tools for Stakeholder Assessment and Interaction

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1. Introduction

Stakeholders play an increasing role in environmental policy and are key actors in the supposed sustainability transition (O`Rìordan/Stoll-Kleemann 2002). Characterizing their role as well as the transition itself requires a deeper understanding of the interconnectedness of social networks and the relationship between individual and collective action. In many models, used in integrated assessment, a top-down rational controller drives the world into a desired direction, optimizing a global welfare function, notwithstanding the fact that the development of the real world is affected by numerous agents which act according to their own interests and capabilities. Sustainable development strategies often fail due to their inability to adequately take social interaction into consideration, such as dialogues, negotiations, conflicts, coalition formation and institution building. Usually collective action is seen as a problem in common pool resources (such as fishery), where unregulated resource access by a group of individuals leads to resource depletion and the violation of common interests, as can be observed in the so-called "Tragedy-of-the-Commons" (Hardin 1968, Ostrom 1990).

While such conflicts of individual vs. collective interests can be observed in many social dilemma situations, there was less attention to the possibility that joint action could rather preserve natural resources and support a sustainability transition if individuals cooperate and coordinate their actions. A key question is under which conditions one or the other form of interaction occurs and how it can be realized. The answer depends on the rules of communication and the institutional settings, as well as on the tools available during, before and after the interaction. Such tools, designed as simple or comprehensive models, and established as rules, procedures or programs, could deepen the understanding of the phenomena and manage their complexities and uncertainties. They are an issue in interactive decision-making and communication processes, such as stakeholder dialogues and negotiations, in support of sustainable development.

This article describes some of the modelling and computational tools that can play a role in complementing and supporting dialogues, including mathematical models, negotiation analysis, mediation, experimental games, agent-based models and participatory integrated assessment. Properly designed, these tools can be used as instruments during real-world dialogue or decision-making, with stakeholders being active users or objects of study. By making critical information accessible and facilitating communication in dialogue and negotiations, by structuring complex problems and providing practical models in support of decision-making and risk analysis, such tools would support stakeholders in assessing problems and expressing their views more explicitly. As educational and research tools they can improve the understanding of the issues at stake. To illustrate the use of some of the tools in environmental policy, applications in climate, fishery and water management are mentioned.

2. Stakeholder involvement in interactive decision-making

In a broad sense, stakeholders can be considered as those individuals or groups that have an interest or concern in a particular issue. There are a variety of potential stakeholders who

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[1] Forthcoming in: S. Stoll-Kleemann, M. Welp (Eds.), Stakeholder dialogues in natural resources management and integrated assessments: Theory and practice, Cambridge University Press, 2005

can be governmental or non-governmental, pursue their individual or group interests, act on local, national or global scales. Dialogues or interactive decision-making are an opportunity to bring the diversity of stakeholders together for the discussion or resolution of burning societal problems. Such processes can be quite complex, involving multiple stakeholders, issues, interests, disciplines and levels of decision-making. Stakeholder dialogues empower the parties involved and seek to reconcile and integrate divergent interests to reach agreement or consensus.

In environmental assessment and management, stakeholders participate in developing sustainable investment strategies, define work plans for implementation and finally push for and monitor the planning process. Ideally, stakeholder assessment would take into consideration the interdependence between stakeholders and the environment in which they interact, including the institutional frameworks, as characterized by rules and strategies that are embodied in regularized patterns of behaviour or procedures for conflict resolution (Priscoli 1989). With the increasing involvement of stakeholders in social and political processes, decision-making would become more interactive and complex, demanding new types of procedures and tools to manage it. While agreement would be a preferred solution in many negotiations, not all dialogues aim at a consensus. Science-based stakeholder dialogues also seek to explore different arguments and viewpoints. Knowing where the stakeholders disagree is a valuable result too and guides future research.

While a main characteristic of stakeholder dialogues is communication and exchange, not necessarily with a pre-assigned goal, interactive decision-making and negotiation (IDN) implies activities in groups of stakeholders that seek an agreement, either as a whole group, as sub-groups or individually. Generally, IDN is relevant in science, policy and management, dealing with critical issues of technical change and its impact on society, environmental management, and position finding in democratic decision-making processes that require a "critical mass" of supporters. In a specific sense, IDN refers to activities "in which a government involves citizens, societal organizations, private parties and/or other governments into the decision-making-process as soon as possible, in order to interact and/or to co-operate with them to establish the preparation, the determination, the implementation and/or the evaluation of policy".(van der Veen 1999) In this context, IDN closes the gap between the government and its citizens and enlarges the support for its policy and decisions, increasing legitimacy and responsibility and improving the chances for problem solving.

On an organizational level, the concept of "participatory governance" is complementary to hierarchical governance, which is mainly organized at the governmental macro level. At the meso and micro level citizens, together with industries and governments, debate and negotiate public issues and policies. Institutional structures facilitate communication, co-management and the sharing of responsibility. The participant composition and decision rules are crucial for participatory governance as they influence the internal power structure.[2]

IDN involves societal resources, such as time, money and knowledge, to improve the quality of decision-making and create a surplus for its participants.(van der Veen 1999) Stakeholder participation is an opportunity for individuals to influence public decisions and shape the policy process into a direction that meets their interests. Citizens can develop their capabilities and creativity, and bring about new innovative ideas for a more direct democracy. Governments, on the other hand, can demonstrate openness and transparency, enlarge their legitimacy and improve their public image. All actors can reduce prejudices about each other, realize a synergy and surplus value (win-win). IDN can be used to locate potential conflicts in an early stage and make the interaction less complex.

[2] On participatory governance in a multi-level context see Heinelt et al. 2002.

Other factors may impede the implementation of interactive decision-making. If a government is involved in a decision-making process (e.g. on national legislation or regionally in the construction of a new airport), the sharing of information and knowledge with citizens may be seen as a loss of power and control. Because of self-interest, inadequate representation, and selective participation, the democratic legitimacy of IDN can be questioned. Interactive processes can cost considerable time and efforts, without producing a reasonable or justifiable outcome. The need to reduce time and effort may diminish the efficiency and effectiveness of the whole process. For difficult and complex issues, or too many stakeholders involved, participants may feel incompetent or overwhelmed by the process. In case of severe disagreement, conflict or inadequate management, there is the risk of complete failure, i.e. the interactive process will not yield any result. In case of success, however, participation can strengthen cooperation, conflict resolution and democracy.

Whether stakeholder dialogues are perceived as successful, depends on the evaluation criteria chosen (cf. Chapter 4 Evaluating stakeholder dialogues). Even if no agreement can be achieved, stakeholder dialogues may produce net benefits, simply by the information shared. Successful stakeholder dialogue and interaction is a way of increasing the social capital and thus the productivity of society, in addition to natural, physical and human capital as used in economic theory. Social capital refers to the institutions, relationships, and norms that shape the quality and quantity of a society's interactions. These are embodied in the values, habits, and relations among persons, strengthening social cohesion and the formation of social networks.[3] Integrated sustainability strategies aim at strengthening the links between social and natural capital.

3. Tools in Stakeholder Interaction and Modelling

3.1 The stakeholder concept in management and systems science

Whether stakeholder interaction is a success or a failure may depend on the tools used during the process, which can influence the amount and efficiency of the resources used. From this viewpoint, stakeholder analysis is an issue for the behavioral, organization and management sciences. Since its first appearance in an international memorandum at the Stanford Research Institute in the early 1960s, the stakeholder concept has found increasing attention in the management literature, first of all with regard to business responsibility (Elias et al. 2000). In a first definition, stakeholders were defined as essential players for an organization as 'those groups without whose support the organization would cease to exist' (cited in Freeman 1984).

In the 1970s, the concept diversified into a wide range of fields, including organization theory, systems theory, corporate planning and social responsibility. The systems model of stakeholders emphasised participation and argued that problems should not just be defined by focussing or analysing, but by enlarging or synthesizing, addressing social issues from an open systems point of view. Ackoff (1974) argued that participation of stakeholders is essential for systems design, as they would help in solving societal problems. Many researchers were concerned with the social responsibility of business firms, including nontraditional stakeholders who were having adversarial relationships with the firm.

Since the landmark book by Freeman (1984), the stakeholder concept has become increasingly embedded in the thinking of managers and decisionmakers. The literature focused on descriptive and empirical aspects, as well on instrumental and normative aspects

[3] See Putnam (1995). Coleman (1990) describes it as 'the structure of relations between actors and among actors' that encourages productive activities.

which were integrated into the stakeholder theory of corporations. More recent issues are the dynamics of stakeholders as well as stakeholder theories and their validation. These trends indicate the growing complexity of the field, as the mix of stakeholders and their attributes may change, such as responsibility, power, legitimacy and urgency (Mitchell et al 1997).

Increasingly the stakeholder process and its organization is subject to analysis in management science. This concerns the different phases in the interaction cycle, including communication, decision-making, negotiation and joint action, as well as the framing conditions, under which it will operate, such as timing, budgeting and staffing (see last section of this article). The procedural conditions determine the rules of the game with regard to the style of exchange and its facilitation, as well as conditions for entrance and withdrawal. The roles, functions and responsibilities of the different participants are essential to maintain support for the process.

3.2 Stakeholder modelling and simulation

The analysis of stakeholder interaction is linked to social systems modelling and simulation, and much of the methodology in this area can be applied. Analysing the emergence of collective action from individual action is a dynamic field of current interdisciplinary research, combining natural and social sciences. Modelling and computer simulation can contribute to a deeper understanding and the development of new instruments for decision-making in complex environments. There is a wide range of formal methods and models that are relevant in this context:

1. *Computer simulation and dynamic systems theory* study the time evolution of trajectories in state space, in many cases driven by a set of differential or difference equations that describe local change for given initial conditions and constraints. A major focus are equilibria and stability of system dynamics, as well as phenomena such as order and disorder, chaos, self-organization and phase transitions which have a symbolic and practical relevance in the natural and social sciences.[4] Stability theory deals with methods to sustain essential system properties and equilibria against disturbances, seeking resistance against change over a given period. Dynamic models can be directly relevant for stakeholder dialogues and interactions dealing with ecological or economic system dynamics. Examples are models of weather, climate and water cycles, the growth of forests, fishery, cities or the economy as a whole. Dynamic competition models (such as the Lotka-Voltera model) describe the interaction and potential conflicts between actors or populations, often with regard to scarce resources. For a fixed parameter set in deterministic dynamic systems, implemented as computer programs, stakeholders can explore future options and scenarios in virtual experiments, simply by changing parameters and initial conditions. By adapting their control variables, they can steer the dynamics towards particular targets or keep the dynamics within given limits satisfying their interests.

2. *Decision analysis* deals with the ranking and selection of actions from a set of options, following certain rules, preferences and criteria. In the standard case, a single rational decision-maker chooses the most preferred option, by maximizing a utility or value function in a set of constraints. A wide range of methods have been developed to search for the optimum, such as decision trees, the steepest ascent/descent in a utility landscape, linear and non-linear programming (such as the Simplex method), combinatorial optimization, and others. Benefit-cost analysis seeks the most efficient way of achieving goals with limited resources. Optimal control theory determines optimal paths in dynamic systems with state-dependent feedbacks in the control set, usually by optimising constrained value functions (called Hamiltonians) via the Maximum Principle (Feichtinger, Hartl 1986). In case of multiple independent value functions, generally not all can be optimised at the same time which

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[4] With regards to applications in socio-economics see Gandolfo 1997, Grebogi/York 1997, Epstein 1997.

requires a balancing mechanism between objectives. Multi-criteria decision-making derives solution concepts such as Pareto optimality, seeking the set of combined actions that do not allow further joint improvements for all players. Despite the achievements of economics with the rational actor paradigm (RAP), rational actors have been characterised as “lonely social atoms with infinite computational capacities”, optimising their utility with every step (Pahl-Wostl 2001).[5] While they can be adequate in environments with a few number of state and control variables, the limits are more obvious in a complex environment and with human beings of bounded rationality.

3. *Game theory* extends rational decision-making to two and more players, each pursuing their own preferences and values in response to the supposed or observed decisions of other players (von Neumann/Morgenstern 1948, Owen 1982). For a small number of players and discrete options, these can be depicted as matrix games. A situation in which no player has an incentive to change its action is called a Nash equilibrium. The most well-know type is the Prisoners’ Dilemma (PD) game, describing situations in which two players individually prefer not to cooperate, even though mutual cooperation would be of advantage for both. While cooperation is potentially possible in such a game, it is excluded in zero-sum games of conflicts in which a player can only gain if the opponent looses. A key issue in conflict resolution is to create incentives for cooperation by seeking joint gains. Cooperative game theory studies the formation and stability of coalitions of players, representing larger social units, as well as the power of individuals in group decision-making, measured by indices such as the Shapley Value in voting processes. If all players’ decision criteria are taken into consideration, methods of multi-criteria decision-making are applicable in game theory. Game theory is appropriate when the goals and options of players can be clearly laid out, but becomes more difficult to handle when a large number of players interacts in a dynamic environment.

4. *Differential game models* with a few number of optimizers in controlled dynamic systems are widely used in economic theory as well as in natural resource management (see Carraro/Filar 1995, Dockner et al. 2000). More general dynamic game models describe the interaction between multiple players according to situation-dependent decision rules and reaction functions (Intriligator 1971, Tuinstra 2000). In repeated games players can learn and adapt their behavior to the strategies of other players, leading to the evolution of cooperation. In a computer competition between strategies in the repeated PD game, the Canadian psychologist Anatol Rapoport succeeded with the simple tit-for-tat strategy, which suggests to cooperate in the first place and only switch to non-cooperation if the counterpart does (see Axelrod 1984). Evolutionary games, framed by John Maynard Smith, analyse the selection among competing populations of game strategies according to their fitness in replication (Hofbauer/Sigmund 1998). Selection of strategies and decision rules in computer-based simulation models can be based on observation and include real-world actors, which offers a wide field of experimental games for educational and research purposes as well as for decision support and policy advice.

5. *Agent-based modelling* uses computer simulation to analyze complex interaction between multiple agents which follow given action rules and stimulus-response mechanisms to form complex social patterns. Using the approach of cellular automata, agents move like insects in virtual landscapes, acting as laboratories of *artificial societies* (see Epstein/Axtell 1997, Gaylord/D’Andria 1998). For a large number of homogenous agents, methods from statistical physics, non-linear dynamics and complexity science are applicable, building on the terminology of “Synergetics” (Haken 1977), such as self-organization or micro-macro phase transitions. Such approaches to collective phenomena have been transfered to interdisciplinary fields such as socio-physics and econo-physics (Helbing 1995, Weidlich 2000, Schweitzer 1997). Different from top-down models in decision-making, agent-based models are a bottom-up approach to stakeholder analysis. Observed macroscopic properties

[5] See also Welp et al. 2005. A discussion of the RAP paradigm can be found in Jaeger et al. 2001.

emerge from the behaviour and interactions of the component agents. Applications range from moving crowds and traffic systems to urban, demographic and environmental planning (see more in section 6 of this article).

6. *Qualitative reasoning* can represent heterogeneous data and dynamic behaviour under uncertainty, integrating knowledge from different disciplines on an aggregated level (Kuipers 1994). Methods of qualitative differential equations (QDEs) analyze the qualitative system properties in dynamic systems under uncertainty. Instead of an exact functional and numerical specification, it is only necessary to formulate qualitative if-then relationships. This approach is suited to classify dynamical systems and solutions with similar properties and formulate rules about the interrelationship of nature and human action which are robust to uncertainties and parameter changes. By clustering system patterns and policy options, qualitative approaches can be useful in stakeholder decision-making dialogues. Qualitative approaches found applications in environmental research through the "syndrome concept". It was developed to describe *patterns of global environmental change*, based on qualities and dynamic interactions, perceived as relevant by stakeholders and decision-makers. An example is the overexploitation of marine resources, a pattern associated with the loss of marine biodiversity, overcapitalization, and declining coastal economies (Eisenack/Kropp 2001, Kropp et al. 2002, Eisenack et al. 2004). Here statements are of the form '*if harvest increases and stock regeneration decreases, then the fish stock decreases*', or 't*he stronger the pressure of the fishing lobby, the higher the total allowable catch*'. This allows to cluster harvest regions according to qualitative properties and analyze transitions between them. It provides a basis for negotiations and institutional mechanisms to control allowable catch.

7. Another innovative – even though mathematically challenging - method is *viability theory*, which provides mathematical methods and tools to maintain a controlled system dynamics within given boundaries. To stay within the viability constraints of a system, given by objective limits or value-based judgements, reverse methods are applied for selection of admissible control variables that correspond to a feedback mechanism at the boundary conditions (Aubin 1991). The theory of viable control is a useful instrument to design and control the complex interaction between the economic, environmental and political spheres in natural resource management (see for instance Aubin 2004). The impact of changing crucial couplings is studied to improve viability in resource networks, resolving conflict between environmental damage and expected gains from resource use. Viability theory provides a powerful tool to predict the confinement of the resource dynamics to a pre-defined regime in phase space, e.g. given by tolerable windows for fish catch or guardrails for greenhouse gas concentration (Petschel-Held et al. 1999, Bruckner et al. 1999). This would allow stakeholders to identify controls necessary to stay within sustainable limits, e.g. for fish catch, and to avoid non-viable regions in which fish resources decline or fishery becomes unprofitable, taking into account uncertainties about fish stocks and catch efficiency. Computational tools for practical implementation of viability theory are under development.

A variety of further methods and tools have been developed in systems science, operations research, artificial intelligence and computer simulation which cannot be mentioned here in detail. These include for instance neural networks, expert systems, complexity theory, social network analysis, Bayesian learning and statistical methods in all variations. They are applied or potentially applicable to stakeholder assessment in environmental management (see Kropp/Scheffran 2005). Some of the mentioned tools and methods are explained in more detail in the following, in the context of environmental stakeholder assessment and interaction.

4. Tools in environmental conflict resolution and mediation

In the environmental sciences, systemic approaches (from eco-systems) and agent-based approaches (in economic-social relations) are directly linked, which facilitates the use of modelling and computational tools in stakeholder assessment. In particular, this applies to environmental conflicts over the use of natural resources, or intensified by their use. Environmental degradation and resource scarcities are relevant sources of conflict in various regions of the world (see for instance Homer-Dixon 1991; Baechler/Spillmann 1996, Carius/Lietzmann 1999, Diehl/Gleditsch 2001). Besides conflicts over exhaustible resources (minerals, fossil fuels, territory), there are also conflicts over the degradation of renewable resources, such as agricultural products, fish stocks, favorable climatic conditions, water, soil and air.

Conflict is a particular form of human interaction, resulting from incompatible objectives or actions of agents. Conflicts can emerge as a result of collective interaction among rational actors which seek their own advantage but fail to achieve potential joint gains. While conflicts are a natural part of social life, they may indicate or contribute to the inefficiency and instability of societies. Thus mechanisms for mediation and conflict resolution could stabilize social interaction and prevent environmental destruction as well as the most destructive forms of conflict. The problems causing a conflict could be denied, taking the risk of conflict escalation, or a conflict could be decided by a court. More attention should be paid to the reduction of potential conflicts and the enlargement of consensus in interactive decision-making and negotiations.

Negotiation is an interactive process in which negotiating parties try to reach an agreement on issues under dispute, usually starting with different interests and information sets. Different types of negotiations can be specified, depending on the degree of conflict, the number of parties, and their willingness to share information or find compromise (Kettunen 1999). An example is the dispute about fishing rights between countries harvesting the same fish stock. Negotiation analysis aims at understanding and supporting negotiation processes, studying negotiation procedures and properties of negotiated settlements. Besides the descriptive aspects, one objective of negotiation analysis is to develop a prescriptive theory of negotiations and provide useful advice for involved parties and negotiators (Raiffa 1982, Pruitt/Carnevale 1993).

Stakeholders can negotiate to find a solution to the conflict themselves, or with the help of a mediator. Mediation is a voluntary part of the negotiation process which aims for a common ground, with a neutral, independent person who monitors and manages the process and assists the disputing parties. During the mediated process, the decision objectives and alternatives as well as the conflict areas have to be specified, based on the preferences of the parties, to find the areas for consensus, compromise and cooperation. The solutions of mediation should find support and be acceptable and binding to all parties. If no mediated solution can be found, conflict parties can seek arbitration by an independent group of experts who analyse the conflict and propose a solution. A crucial issue is whether a solution is widely supported and whether the arbitrators have the power and authority to implement a solution to the conflict, respectively the underlying problems. Communication is an ingredient part of mediation, in dialogues, disputes or formal negotiations between stakeholders throughout the conflict. Particular tools can model the interactions in conflict and facilitate the mediation process, seeking options and strengthening the capabilities of the conflict parties towards cooperation

Environmental communication, mediation and alternative dispute resolution can contribute to finding solutions to environmental conflicts. They can complement governmental or business decision-making and legal procedures in environmental policy. Environmental mediation has received great interest during the past decade in Germany (e.g. Weidner 1998), although the number of implemented procedures is still small. Since 1990 the Social Science Research Centre Berlin (WZB) has been conducting an interdisciplinary research project on mediation procedures in the field of environmental protection, largely on conflicts arising out of waste management (Holzinger 1997).

Similar cases were also studied by Peterson (2002) who analyses and demonstrates the potentials and limits of decision-analytic tools, including value tree analysis and multicriteria methods, which have sporadically been used in environmental mediation. They can be practical instruments in support of environmental mediation, to structure the decision making process and make it transparent and comprehensible to all parties. To actually apply them, the mediation process needs to be formalised to allow for the specification of steps. In a process-orientated game-theoretic model of negotiations, parties compare their outside options with possible agreements in the mediation process. Taking into account the iterative character of negotiations in computer simulation, the alternatives and claims of the parties change perpetually. By including emotions, such as anger and envy, the approach explains the difference between rational, utility maximizing behaviour and supposedly irrational behavior, leading to an escalation of conflicts.

Each simulation consists of several negotiation rounds, during which the mediator proposes a compromise solution calculated in solution space that the parties can either accept or reject, depending on their outside options, the so-called Best Alternative To Negotiated Agreement (BATNA). The claims depend on the parties' negotiation strategies and the attitudes of the opposing parties which change in each negotiation round. The mediation ends when the parties agree to an option, it fails if an agreement cannot be reached, either because parties drop out or the conflict escalates or is deadlocked.

The potential of the approach has been investigated in detail in the case of the German city Bremen where an environmental mediation was held upon the conflict between the environmental and social acceptability of a waste disposal site (Peterson 2002). Using the simulation model, implemented in Mathematica as a programming tool, a potential compromise solution was found, even though in the real mediation no agreement was achieved. The analysis was able to explain the conflict and find possible win-win solutions, taking into account the escalation dynamics and the role of the mediator in deescalation. The simulations underline the importance of outside options as parties with higher BATNAs tend to drop out of the mediation if they have not much to gain from the negotiations.

5. Interactive methods for group decision and negotiation support

5.1 Basic approaches

Negotiation support research develops tools for finding agreement and producing solutions which would satisfy all involved parties, even in situations where the negotiating parties fail to find a satisfactory agreement by themselves. By structuring and reducing the complexity of the negotiation problem, tools can help mediators to find jointly beneficial proposals. The methodology of interactive optimization methods has its roots in decision analysis and game theory, with input from various disciplines including mathematics, social psychology, political science, management and computer science (Sebenius, 1992, Jelassi et al. 1990).

Raiffa (1982) observes that agreements made in negotiations are frequently inefficient in the sense that alternative agreements preferred by all parties were not reached.[6] An important research issue is to analyze the procedures and conditions that lead to `good' agreements. The success of negotiations can be measured with several criteria, including fairness and equality as well as rationality and efficiency (Mumpower 1991). Efficiency is usually represented by Pareto optimal solutions, which means that no feasible alternative agreement exists improving two parties at the same time. In the joint utility framework, a good agreement would maximize the (weighted) sum of the negotiating parties' utilities. Giving equal weight to the utilities of all parties would satisfy the criterion of equality.

[6] On reasons for inefficiency see Kersten/Noronha 1998.

Negotiation support research develops practical and constructive methods for efficient agreements in multi-party negotiations, reaching joint gains for all parties. Some of the approaches are described in the following, based on the survey in Kettunen 1999:

1. *Utility Function Assessment:* Various methods have been developed for constructing a decisionmaker's utility (or value) function by eliciting his/her preferences. If preferences can be expressed by utility, efficient agreements can be calculated by increasing and maximizing utility. For multiple actors, maximizing a weighted sum of the joint utility functions (also referred to as social welfare function) is a commonly used method to produce the `best' agreement. With different weights, different Pareto-optimal agreements are found. Selecting the weights for each individual utility function is a political issue, reflecting the power and preferences of actors, and runs into problems of interpersonal utility comparisons. One option is to avoid aggregation of utility functions by lexicographic preferences, an approach that requires a hierarchical ordering of preferences, like words in a dictionary.

2. *Constraint Proposal Methods* are more appropriate in cases of partial information of the decision makers' preferences, in particular when no explicit utility functions can be identified or constructed. Negotiators are asked to select their most preferred alternatives on a plane of constraints similar to a budget constraint. Based on a suitable updating scheme, new constraints are generated until the negotiators' selections coincide. Under certain conditions the process should converge to a Pareto-optimal point, which varies with changing the initial reference point. The method has been generalized to multi-party negotiations with multiple issues.

3. *Single Negotiating Text Based Methods* generate a single negotiating text which serves as a tentative agreement, suggested by a mediator or the negotiators themselves. Based on the information the parties give about their preferences, the mediator examines the old text and searches a new one which all parties prefer to the previous one. The step-by-step process, which matches many real-world problems, gradually approaches a Pareto efficient agreement which depends on the initial points chosen.

4. *Multi-criteria decision-making* in consensus seeking groups: Group decision making problems are mathematically similar to problems in multiple criteria decision making (MCDM). This implies that methods developed for supporting a single decision maker with multiple objectives could be applied in negotiation settings with multiple decisionmakers, each having their own objective. The balance of interests among the different actors is subject to an interactive negotiation process in which not just the actors' preferences come into play but their power as well and the possibility of conflict and coalition formation, shifting the weights of the different criteria. The art of mediation is to find aggregate consensus functions balancing the weights of all criteria.

5. *Group Decision Support Systems (GDSS) and Negotiation Support Systems (NSS)* take advantage of computer systems to improve communications among participants, provide group decision modeling and techniques, and include expert systems components. Different decision support tools are used in the decision-making cycle, from problem structuring to consensus seeking. Model-based computational tools are integrated into real life experiments with stakeholders, which requires the development of a user-friendly negotiation support software.

A method of improving directions has been presented by Ehtamo et al. (1999) which builds on a two-party negotiation procedure.[7] The underlying idea is to search for jointly improving directions in the issue space. Starting from their most preferred positions, the negotiators

[7] A similar idea, using heuristic rules, has been suggested by Teich et al. (1996) for two-party resource allocation negotiations.

make concessions in their subsequent offers and counter offers, until all parties have offered the same alternative and agreement is reached. The method is tested in practice by role-playing experiments in which the negotiating parties are required to answer relatively simple questions concerning their preferences.

5.2 Internet tools for negotiation analysis

The internet is a promising platform for exchange and negotiations among distributed individuals located at various places around the world. Because of their interactive nature, models of negotiation analysis are suitable for e-learning. Various e-learning material on negotiation analysis and on related fields exists, such as decision analysis, game theory and experimental games, potentially usable in stakeholder dialogues and negotiations (see the survey in Ehtamo et al. 2003). For instance, Al Roth at Harvard University has a game theory and experimental economics website, which contains electronic books on game theory and interactive applets to play different games against the computer, such as variants of the prisoners' dilemma game.[8] The Decisionarium site provides interactive multicriteria decision support with tools for individual decision making as well as for group collaboration and negotiation. Access to the Web-HIPRE value tree software allows to evaluate negotiations.[9] The Harvard Business School developed a commercial e-learning on-line negotiator, based on the book by Fisher and Ury (1981).[10]

Not many web-tools are yet used to support real decision making, negotiations and stakeholder dialogues. Specific software systems are required for remote negotiation support, providing possibilities for exchanging messages between distributed negotiating parties and implementing mathematical methods in negotiation analysis. Some recent studies have focused on using computers for teaching negotiation and e-negotiation skills for university students, providing an effective way for testing, evaluating and reinforcing acquired knowledge on negotiations. Köszegi/Kersten (2003) presented a course and experiences in multi-criteria based e-negotiations, including an electronic textbook which focuses on basic concepts of economics, game theory and social psychology, as well as case studies. Related role-playing exercises involve students to negotiate both with a NSS and face to face directly. The software tool INSPIRE has been used for teaching e-negotiations in continuously organized negotiation sessions. At the tournament International Competition for Online Dispute Resolution 2003, the participating students formed local teams to solve a negotiation case by negotiating with another team, selecting from six different NSSs.[11] These systems provide tools for communication through exchange of text messages over the Internet or allow videoconferencing. The systems INSPIRE and SmartSettle help the parties to describe their preferences by constructing additive value functions which are used in negotiation for evaluating offers and counteroffers.[12]

To promote e-negotiations, the Systems Analysis Laboratory at Helsinki University has developed e-learning material to teach e-negotiation methods for university students (Ehtamo et al. 2003). Students practiced the use of NSS in role-playing exercises via "learning by doing". A website on e-learning decision making contains material and tools for negotiation support and discusses students' experiences of its use.[13] The material consists of sections on negotiation theory, including case studies, software assignments, quizzes for self-evaluation, and multimedia presentations such as video clips, animations and color graphics.

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[8] See www.economics.harvard.edu/~aroth
[9] See www.decisionarium.hut.fi.
[10] See www.dieu.com/e-learning/Yes_The_Online_Negotiator.asp.
[11] See www.enegotiation.org.
[12] See www.smartsettle.com, http://interneg.org.
[13] See www.dm.hut.fi.

The software tool “Joint Gains” is based on an interactive multiple criteria negotiation method for solving multi-player/multi-issue negotiation problems. It is publicly available online and allows users to create their own customized negotiation cases, requiring local preference information from the parties, without using the additive value function model, and provides aid for reaching Pareto solutions. In its web-based implementation, Joint Gains can serve as an online-interactive negotiation support system for real-life negotiations as well as active learning through role-playing experiments, which allow to explore and learn about the objectives and power of different parties and the potential for coalition building (Kettunen et al. 1999). The teacher not only acts as a lecturer but also as an instructor, who guides the students to work with the material more independently than usual, and takes care for technical arrangements of the software accessibility and maintenance.

Sotware-based NSSs can be useful for education purposes, making negotiation analysis a promising field for e-learning in application areas such as political or environmental decision making, international affairs, e-business, etc. It is particulary relevant for environmental negotiations and has been used for lake-river regulation policy problems and in a workshop on environmental negotiations at the Caspian Sea area (Ehtamo et al. 2003).

6. Agent-Based Modelling

6.1 Structure and behavior of agents

An agent-based model (ABM) is based on a set of autonomous agents capable to interact with each other as well as with the environment according to rules of behavior. In this context, an agent has been defined as “*an object in a computer program that encapsulates a particular behaviour when interacting with other agents within an environment. The behaviour may be simple or complex; deterministic, stochastic or adaptive; and the system as a whole may be homogeneous (all agents are of the same type) or heterogeneous (more than one type of agent present).”* (Hood 2003) In this understanding, agents may be endowed with cognitive capabilities “to perceive signals, react, act, making decisions, etc according to a set of rules”. Cognitive agents are characterized by (Conte/Castelfranchi 1995):

- *beliefs*: what agents think to know about the world (based on experience and perception);
- *goals*: what agents would like to achieve (desired states of the world);
- *intents:* which specific actions will agents undertake to achieve the desires.

To achieve desired goals, agents may try new intents, alter their desires or change their beliefs. With regard to their action abilities, agents can be

- *autonomous*: they act independently of any controlling agency;
- *social*: they interact with other agents;
- *communicative*: they can communicate with other agents explicitly via some language;
- *pro-active*: they are driven by goals and objectives;
- *reactive and adaptive:* they observe and respond to changes in the environment;
- *rational:* they can follow a well-defined and logical set of decision rules.

Agents can both change their environment and their internal structure. Beyond the “representative agent” used in many economic models, they can learn by generating, testing and evolving models of their environments and of other agents, converting these models into rules of stylized behaviour (Pahl-Wostl 1995). They use these abilities to change their environment, interact with other agents and solve group problems. Agents need ‘sensors’ to perceive their local neighbourhood and receive or send messages.(Gilbert and Troitzsch 2000, p. 167) ABMs are used to generate macro structures from local micro mechanisms.

Depending on the agents' number, their attributes and behavioral rules in their respective environments, ABM's can be of great variety and complexity, making them hard to analyse or predict. Since they are problem-specific, they can include many details matching reality, with processes occurring at different spatial and temporal scales. Simulations have the character of experiments in virtual worlds, often with demanding computational requirements. Key challenges are to calibrate the models with data and to integrate ABMs into real-world applications such as stakeholder dialogues and negotiations.

6.2 Simulation environments and environmental simulation

Agent-based modelling and simulation is being increasingly used in environmental management. It permits the coupling and embedding of social interaction into environmental models, taking into account the adaptive, disaggregated nature of human decision making as well as collective responses to changing environments and management policies. Special modelling–simulation environments or toolkits of various kinds are available for performing experiments, which abstract from the details and can be duplicated by other researchers. One example is the TRANSIMS model which attempts to capture the details of traffic flow and its consequences, for instance for the planning of road additions in Albuquerque. SWARM is a public domain software developed at the Santa Fe Institute, simulating collections of concurrently interacting agents and offering a wide spectrum of tools used for modelling experiments in many application areas, including economics, ecosystems, anthropology.[14] Vensim provides a software environment for developing, analyzing, and packaging high quality dynamic feedback models.[15] Sensitivity testing allows to change assumptions about input values, to examine the uncertainty in selected output variables, and automatic calibration to fit historical data series. Among various applications, Vensim has been used to model the allocation of demands among competing suppliers and to track the efficiency of teamwork, based on information about skill and experience of the team member.

Hare/Deadman (2004) develop a taxonomy for environmental agent-based systems that could also serve as educational tools in environmental management. Six modelling requirements (coupling social and environmental models; micro-level decision making; social interaction; intrinsic adaptation of decision-making and behaviour; population level adaptation and multiple scale level decision-making) are linked to a set of eleven case studies, listed in Table 1.(Hare/Deadman 2004) The case studies highlight that

- social interaction tends to be implemented in algorithms imitating the behaviour of neighbours and friends;
- most popular are decision making models based on simple heuristic rules; and
- the modelling of multiple scale decision making is still in its infancy and needs to be further developed.

[14] Various materials and programmes can be found at website www.swarm.org.
[15] www.vensim.com/software.html

Table 1: Agent-based models in environmental assessment (Hare/Deadman 2004)

Name and type of model	Description	Type & number of agents
Bali model Rural water resource management	Investigates whether a specific Balinese system of water temple networks managing irrigation practices could have self-organized. A simulation is used to test the theory	Subaks (groups of farmers) (172)
SHADOC Rural water resource management	Investigates the viability of current irrigation practices in the Senegal river valley through development and interactive use of an ABM	Individual farmers, pumping station manager, water course manager (40–60)
CATCHSCAPE Rural water resource management	Investigates the viability of irrigation practices in Thailand with respect to future changes in drought conditions, changes in commodity prices, and farmer behaviour	Individual farmers, water manager (327)
Lake model Rural water resource management	Assesses farmers' adaptive responses to policy measures (i.e. taxation) for reducing phosphorus levels in a hypothetical lake	Individual farmers (100)
Thames model Urban water demand management	Investigates how social structure and learning affects the efficacy of a regulator's exhortations for consumers to save water as part of a drought management policy.	Households, policy agent (80–100)
MAGIC Flood mitigation decision support	Various "expert agents" cooperate with each other to come up with decision support advice for human flood catastrophe response teams.	Individual expert decision agents (<10)
Biomas Animal waste management	Explores possible negotiating strategies and outcomes used by simulated actors in managing the removal, transportation and processing of animal wastes.	Eleveur, Cultivateur, Transporteur, Transformateur (<10)
Rangeland model Rangeland resources management	Explores the range of collective responses of hypothetical pastoralists to regulators' policies for sustainability	Pastoralists, regulator (100)
FEARLUS Agricultural land use change	Investigates how well different social learning strategies employed by decision-makers compete in the face of a changing, heterogeneous environment	Farmer households (>40)
LUCITA Agricultural land use change	Explores how the characteristics of frontier families influence changing agricultural land use, and secondary succession, in Amazon rainforest near Altamira, Brazil	Farmer households (236)
Grand Canyon model Recreation management	Assesses impacts of river rafting trip management scenarios, where agents represent individual trips on the Colorado River through Grand Canyon National Park	Rafting trips (>50)

7. Stakeholders in Integrated Assessment

7.1 Participation and validation in Integrated Assessment modelling

Integrated Assessment models and tools are designed to aid the evaluation and decision-making process in complex nature-society environments. They provide decision-makers and stakeholders with a coherent framework to explore and reproduce future options and scenarios, addressing environmental, economic and social concerns in an integrated way. Users can interact and play with model units and other users, to better understand and anticipate opportunities and risks, facilitating decision-making under uncertainty. Integrating information from many different areas and knowledge across disciplines supports management and planning, and facilitates an informed debate of policy decisions and conflict resolution. An information management and decision support system, adapted to the user's needs, can provide scientific expertise to policy makers quickly and improve transparency. (Fordham et al. 1997). For longer time frames and at a larger scales, model-based scenarios can be used to increase understanding of the possible consequences of actions.

Integrated Assessment models range from highly aggregated models such as the DICE climate model of Nordhaus (1994), using dynamic optimisation to estimate optimal emission reductions, to process-based models, addressing details from climate to ecosystem change and human responses (Rotmans/Dowlatabati 1998). DICE has been criticized because of unrealistic assumptions based in standard economic theory (e.g. single optimizer, discount rate, simple damage function) which are hard to validate. Extensions and improvements have been suggested, including multiple actors with behavioral patterns, adaptive management and climate change mitigation (Hasselmann 1998, Weber et al. 2003).

To develop a new anticipatory IAM framework, tools are required to handle the complexity of the interactions between natural and social systems on a global scale (Moss et al. 2001). While models of some sub-systems (or modules) exist, there is no predictive theory or model on how those systems act together. However, software tools have been developed which enable the coupling of modules written in different languages.[16] Models of social systems are much less reliable and more hard to integrate. Decision-making procedures, such as cost-benefit analyses, assume the ability to identify possible future outcomes and predict their values and probability of occurrence. Some social structures reduce uncertainty and mitigate the unpredictability of processes and events, such as stock changes, disasters or terror attacks. Norms and institutions increase societal efficiency and stability but also restrain the freedom of individual action and the pace of change. Predictive social theories would be rather prescriptive as by themselves they could change the structure of the system.

A modelling approach for policy advice not only legitimizes from scientific criteria, but rather from its plausibility for the non-expert audience. Thus, integrated assessment needs to be embedded into a social process based on a dialogue with decision-makers and other stakeholders as well as the general public (cf. Ulysses-project). A participatory integrated assessment approach directly involves stakeholders in the specification and evaluation of social simulation models which help to identify the socially constructed reality, and the mental models of individual actors. They can specify the behavioural patterns and identify misspecification or implausibilities in the model.

Stakeholders can also be involved in the empirical validation of the model and its output. A program is said to be validated if it demonstrates to do in practice what it is designed to do, producing outputs that correspond to observable properties of real social systems. Given the

[16] See the Community Integrated Assessment Module (CIAM) developed at the Potsdam Institute for Climate Impact Research. For reference see the website of the European Climate Forum.

size, complexity and diversity of integrated assessment models, none of these models will be strictly correct and complete or predict the future. Models of social systems cannot be fully validated experimentally and don't have to replicate in detail every property and event of real social systems but should capture and reproduce some essential qualitative features and statistical descriptions of the phenomena. Here the link between integrated assessment and qualitative modelling becomes obvious.

Validation of participatory agent-based social simulation is a reflexive process involving both modellers and stakeholders (Moss et al. 2001). The models should be convincing to stakeholders to understand the outcomes on different levels, coarse grain as well as fine grain. A user should be able to set the level of detail and to explore the implications of parameter choices and uncertainties. A practical goal is to understand the phenomena of interest sufficiently to mitigate adverse outcomes and to enhance positive outcomes. There are very few models which give an outsider an opportunity to comprehend the model structure and dynamics with reasonable effort.

The combination of a physical model of the environment (e.g. climate) and a socio-economic model raises issues of scale in both time and space. While decision-making is local and short term, climate change, for instance, is essentially a long term and global phenomenon. Bringing these two scales together requires an iterative learning process which matches the diffusion and aggregation of local actions to global levels and the implementation of global decisions down to regional and local levels. Understanding the mutual relationship between global negotiation and local decision making processes across hierarchies is one of the key challenges of Integrated Assessment modelling.

7.2 Examples of Integrated Assessment models

An early example for integrated environmental assessment is the project ICRA (Integrated Climate Risk Assessment) which is a core component of CLEAR (Climate and Environment in Alpine Regions), developed at EAWAG in Zürich.[17] Seeking to span the interfaces between the physical, ecological, social sciences, CLEAR combines two tools: computer models for organizing scientific knowledge and focus groups for organizing a social process involving scientists and non-scientists.

The EU funded project ULYSSES has used existing IA Models, such as TARGET and IMAGE, developed by the Dutch research institute RIVM, as an input for participatory integrated assessment. In addition, the PoleStar model was used, based on regional data about urban lifestyles. ULYSSES enhances the static framework of NAIADE, the Novel Approach to Imprecise Assessment and Decision Environments which is a multi-criteria decision analysis tool and allows policy-makers to seek "defendable" decisions that reduce the degree of conflict or that lead to greater equity in their impacts.[18]

The European project FIRMA (Freshwater Integrated Resource Management with Agents) aims to integrate physical, hydrological, social and economic aspects of water resource planning. Participation of stakeholders, like planners, decision makers, consumers, suppliers and environmental NGOs, is incorporated to improve the quality of the model, to raise the interest of stakeholders and to increase their confidence in the model results. (Downing et al, 2000) The model framework combines agent-based modelling and Integrated Assessment.

- The *agent-based model* is based upon complex or cognitive agents, represented by independent sub programmes capable of reflecting on their goals and beliefs, and

[17] Cebon et al. 1998. Project descriptions of CLEAR can be found at http://CLEAR.eawag.ch and http://hdgc.epp.cmu.edu/projects/abstracts/clear-icra.html.
[18] ULYSSES and other models are described at http://zit1.zit.tu-darmstadt.de/ulysses/models.htm.

(re)acting to a changing (model) world, including the perceived behaviour of other agents. An update of beliefs, resulting from new information and changing perceptions, may lead to a change in goals and expectations about the impact of a particular strategy on the environment. Strategies are implemented and changed according to a pressure-state - response-impact (PSRI) concept, initiating a state changing process, triggered by threshold values. Behavioral changes result from rules assigned to each agent by declarative statements, written in declarative programming languages like SDML (strictly declarative macro language), MIMOSE, PartNet or others.

- The *Participatory Integrated Assessment* model uses mental models of organizations and institutions as input for the agent-based model, based on the most relevant actors and their interaction within the target system. Creating an interface between the participative process and the agent-based model allows stakeholders to develop and validate models, to learn, communicate and negotiate about planning strategies and policy measures (interviews, dialog methods, focus groups).

The integrated approach seems to be particularly suited to model the interaction between the natural environment and human actors, incorporating social dynamics from the early stages of planning activities.. The combination of models and the simulation setup is a step forward to a decision support system (DSS) that enables modellers and planners, decision makers and stakeholders to deal with a complex setting of interrelated issues. The consequences of human activities can be studied in an interactive, consistent and dynamic way. It allows to explain reasons for particular actions and their consequences on the environment as well as on other actors within a specific target system like a river basin. In applications such as climate change adaptation and natural resource management, physical parameters are taken into consideration, like river bed geometry, land use change or flood probability as well as external and internal pressures like climate change or demand for housing, and surprises. Agents can shape their landscape and react to events like floods, droughts or pollution. Here threshold values are significant, such as the height of dykes, carbon emission or fish harvested. The model also deals with agent–agent interaction, including communication and negotiation about planned activities, conflicts and coalition formation. Communication between stakeholders and modellers is an essential part of the entire modelling process. Increasingly the internet is part of participatory group learning (Hare et al. 2001).

8. Integration and Outlook

As was discussed in this article, there are various tools and resources applicable to stakeholder assessment and interaction. Increasingly these tools become integrated in a manner that is useful for real-world decision-making. To achieve full integration is however a demanding task, given the complexity of the underlying problems. An integrated approach would seek to match the complex relation between environmental and socio-economic systems and the diversity of agents. An issue that is missing in most of the studies is the transition between heterogenous individual actors and collective units that emerge from the dynamic interaction, in the form of coalitions, networks and institutions. Understandig the conditions for a self-organized sustainability transition among multiple heterogeneous actors is an issue of great importance for successful stakeholder interaction.

To structure the analysis and identify the usefulness of the various tools, it is adequate to describe the policy decision-making and management process involving stakeholders as a multi-step process, including the following phases:

1. Situational analysis and problem structuring
2. Option identification and scenario modelling
3. Concept development and criteria-based evaluation
4. Decision-making and negotiation

5. Planning and action
6. Monitoring and learning

In each of these phases, which form a repeated cycle with connecting processes such as evaluation, communication, capability building, information, simulation, validation, some of the tools mentioned in this article are particularly useful to support multi-stakeholder policy assessment (see the link between phases and tools in Figure 1). Analyzing a particular situation, drawn from information about the environment, is important to understand the problem that stakeholders are dealing with. Here all kinds of sensors, measuring the key variables that characterize a particular problem, and other methods for data gathering and analysis are at hand, including interviews, questionnaires, polls and statistical methods using the data as input, including Bayesian Learning. To work on a problem, it is essential to understand the dynamic interactions among systems variables, elements and actors, using a wide range of methods from system dynamics and complexity science as well as agent-based modeling. Computer simulation has developed into the dominant tool to explore selected scenarios and identify the most relevant options to choose from. Using computer-based visualization techniques, even complex phenomena can be presented to stakeholders.

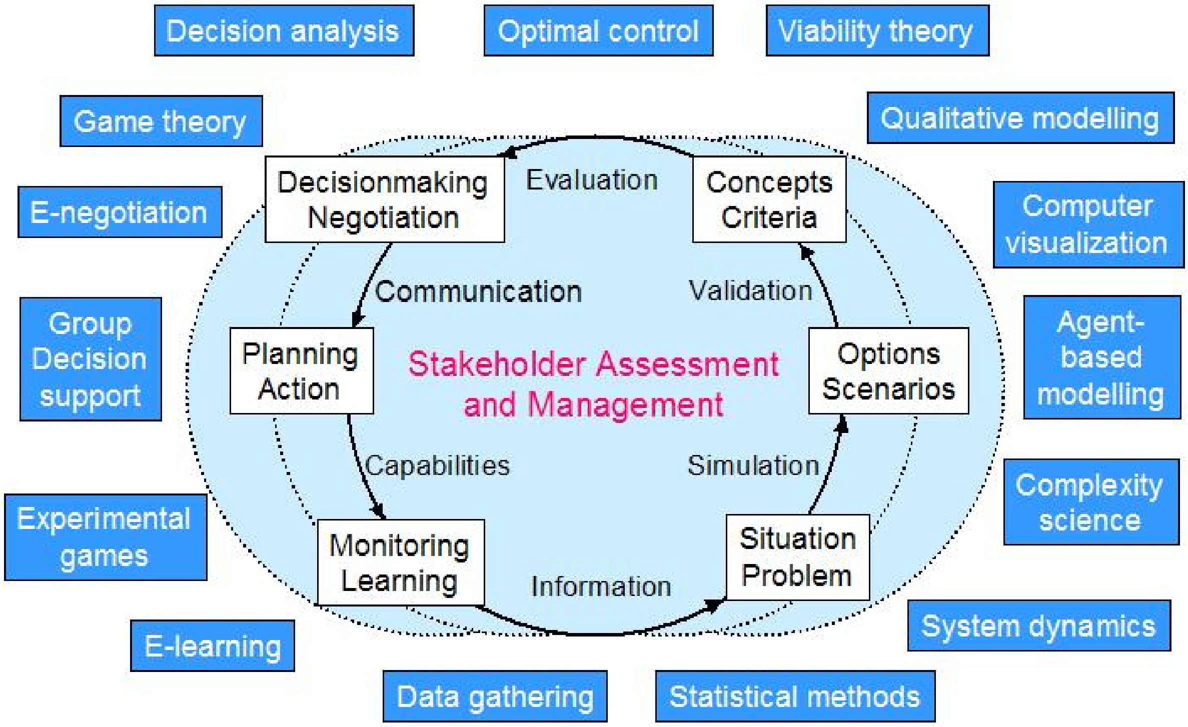

Figure 1: The Stakeholder cycle and tools for stakeholder assessment and management

To select from the menu of validated options, stakeholders need to develop concepts for the future they want to design, and criteria to evaluate these concepts as well as the actions to take. By abstracting from unnecessary details which often cannot be validated, qualitative modelling tools support the reduction in complexity required for the design of concepts that can be understood and implemented. Viability theory translates value judgements into system states and trajectories that are to be achieved or avoided. The established approach of optimal control seeks to find those solutions that are perceived as the best to realize the concept according to the criteria chosen.

The highest burden of responsibility occurs during the decision-making and negotiation phase as well as during implementation because there the transition from concept to reality is actually made. Here the variety of tools developed in decision theory are relevant, including multi-criteria methods. Game theory is appropriate either for a few number of players or for coalition formation in negotiations. Increasingly game theory deals with dynamical problems. The internet can used for e-negotiations among distributed parties. Group-decision support are relevant in the whole process of decision-making and negotiations among several actors as well as setting up of work plans and their implementation in joint actions taken, making best use of the available resources and capabilities of the individual actors. Experimental games, established as board games or more advanced computer games, facilitate experiments that explore the possible interactions among players in the real world and provide learning experience for the participants, in particular if they are updated with real-world data. Here the continuous monitoring of the environment is a precondition for learning, which can be supplemented by internet-based e-learning. Providing the information gathered throughout the process as an input for situation and problem analysis closes the interaction cycle which thus can be repeated.

Throughout the cycle various tools can support stakeholder interaction and performance. Some tools are complementary, others overlapping which allows an exchange of methods. An integrated approach provides a conceptual framework for stakeholder analysis that combines various tools, such as decision theory and optimal control, agent-based modeling and dynamic games. Key to this is the way an actor is designed. Many models use a reduced-form actor that is either driven by maximizing utility and minimizing costs, following given behavioral rules and adapting to others, or seeking positions within viable boundaries. Real human beings however show each of these patterns, with a different emphasis in different contexts. Understanding the conditions and transitions between contexts and model settings in a more integrated model framework is a challenge which is also relevant for stakeholder assessment and interaction.[19]

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[19] For an approach to design a more comprehensive framework of action and interaction of multiple agents see Scheffran 2000, 2001; Scheffran/Stoll-Kleemann 2003.

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