Draft of 3-20-2005. This version is slightly revised from the version made available for the Panel's February 2005 workshop. The Bibliography section has been expanded and now should include all citations in the paper.

Decision Analytic Tools and Participatory Decision Processses

D. Warner North and Ortwin Renn

Background "State of the Science" Paper

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on Public Participation in Environmental Assessment and Decision Making

1. Introduction

Inviting stakeholders and representatives of the public to be part of the decision making process in environmental management has been a major objective in European and American environmental policy arenas. The US National Academy of Sciences has encouraged environmental protection agencies to foster citizen participation and public involvement for making environmental policy making and risk management more effective and democratic (NRC 1996a). The report emphasizes the need for a combination of assessment and dialogue which the authors of this National Academies report have termed the "analytic-deliberative" approach.

We start with a simple characterization of an environmental decision situation (see basic overview in Dodgson et al. 2000) as a set of alterative *options* or *choices*, from which follow *consequences.* The relationship between the choice made, and the consequences that follow from this choice, may be straightforward or *complex*. The science supporting environmental policy is often complicated, across many disciplines of science and engineering, and also involving human institutions and economic interactions. Because of limitations in scientific understanding and predictive capabilities, the consequences following a choice are normally *uncertain*. Finally, different individuals and groups within society may not agree on how to evaluate the consequences – which may involve a detailed characterization of what happens in ecological, economic, and human health terms. We shall describe consequences as *ambiguous* when there is this difficulty in getting agreement on how to interpret and evaluate them.

Environmental assessment and environmental decision making inherently involve these difficulties of *complexity, uncertainty, and ambiguity* (Klinke and Renn 2002). In some situations where there is lots of experience, these difficulties may be minimal. But in other situations these difficulties may constitute major impediments to the decision making process. To understand how analysis and deliberation interact in an iterative process following the NRC 1996a report, we must consider how these three areas of potential difficulty can be addressed. We believe that it is useful to separate questions of evidence with respect to the likelihood, magnitude of consequences and related characteristics (which can involve *complexity* and *uncertainty*) from valuation of the consequences (which we are labeling *ambiguity*). For each of the three areas there are analytical tools that can be helpful in identifying, characterizing and quantifying cause-effect relationships. We shall be examining these tools in the context of analytic-deliberative processes, following the recommendations of the 1996 report.

This paper explores the potential of analysis, and in particular, decision analytic methods and techniques, in conjunction with public deliberation on environmental decision making. We believe analysis can be a valuable complement to deliberation and we present our views on how decision analysis can be helpful to enhance and inform deliberative processes. The paper provides an introduction to concepts and motivation for using analysis in combination with deliberation. We have also included references that provide much more detail on how these methods are used on environmental policy decisions and recommendations on how these tools should be used. The first section explores the role of analysis within a larger framework of deliberation, the second section provides a brief overview of the benefits and problems with decision analytic tools. The third section discusses the potential application of these tools in deliberative, and particularly, participatory processes. The last section describes five specific tools that we recommend be considered, with references describing applications of these tools.

1.1 Philosophy of Decision Analysis: Three Types of Approaches

Decision analysis (DA) provides insights into three areas (Slovic et al. 1977; Skinner 1999):

a) how human beings or organizations identify, evaluate and select choices when making decisions (*descriptive* DA);
b) how decision making can be structured in logical steps that need to be addressed in some way when humans make decisions, including ignoring them (*typological or systematic* DA) and

c) how, inspired by the goal of instrumental rationality, humans should proceed when making decisions (*normative* or *prescriptive* DA).

In addition to DA, social scientists investigate the factors that influence decision making processes or that determine different routes and strategies for decision making with respect to individuals as well as organizations (behavioral decision *theory*). Decision theory (DT) provides valuable insights for testing normative models of DA with respect to the appropriateness, effectiveness, efficiency and other criteria of good governance in different domains. What may turn out to be appropriate for one domain (for example, consumer choices in purchasing products), may be totally inappropriate for another domain (for example, decisions about environmental policies).

What do these three forms of DA entail? Normative DA is focused on analytical procedures and tools for supporting decision making and for assuring logical consistency in how results are obtained from inputs into the analysis (Howard 1966, 1968, North 1968, Fishburn 1981: Behn and Vaupel 1982; von Winterfeldt and Edwards 1986: 15ff.). Logical consistency in dealing with complex problems can be achieved through using mathematical modeling such as probability theory as a formal logic for dealing with uncertainty. The difficult part is the interface with the real world – the inputs and modeling assumptions. Assessment of these inputs must be based on both observational data and on human judgments. These include judgments about uncertainties, which may be subdivided into aleatory (in the sense of statistical randomness) and epistemic (such as which of several competing scientific theories may be true.) There may be uncertainties about the parameters of models and the assumptions that define which model will be used. Judgments are also needed about valuing consequences including risk preference, time preference, and tradeoffs (the areas of multi-attribute utility analysis and cost-benefit analysis), and judgments about what options are possible (the set of available options often reflect legal and political structures as well and technical possibilities).

How to understand and capture human judgment is the realm of descriptive DA and behavioral decision theory, as applied to individuals and to groups up to and including national governments and international institutions (overview in: Einhorn and Hogarth 1981; Yates 1990; Dawes 2001b). This line of research illuminates the actual decision making processes by individuals, organizations and groups and highlights the mechanisms, biases, and intuitions that lead to judgments about options. Psychological research has focused on the inherent reasoning processes when facing behavioral choices. This includes the processing of information such as probabilities (Kahneman, Slovic, and Tversky, 1982), the intuitive mechanisms of making inferences, the process of dealing with cognitive stress and dissonance and the coping mechanisms when experiencing conflicting evidence claims or value assertions. Sociological and other social science studies have been investigating social and cultural constraints for identifying and generating options, the framing process of identifying and defining problems and procedures for their solution, norms and rules of evaluating expected outcomes within different social and cultural contexts, the perceived legitimacy of selection and evaluation schemes and the institutional and organizational interpretations of decision making in different cultures and political domains (Heap et al. 1992: 62ff.; Hofstede 2003). The contribution of many disciplines within the humanities is to provide evidence for the variety of decision making processes in history, literature or other representations of human activities.

All these descriptions feed into the building of analytical theory construction. The main objective, as with any other scientific endeavor, is to understand causal connections between independent variables such as personality, social bondage and cultural affiliation to decision making structures and preferences. In addition, these insights enlighten the construction of normative advice, as its effectiveness relies on behavioral insights into decision making in order to improve decision making processes, especially those involving decisions on behalf of a group. Social and behavioral sciences research has much to teach normative analysts about how to assess uncertainty in the form of probabilities and how to deal with value assessment of consequences, including the difficult tradeoffs between economic and environmental objectives. Such research can substantially improve normative decision analysis in support of environmental decision making.

The third DA approach, the typological, can be generically captured in a sequence of steps, as given in Table I. In the typological model, the analytic parts comprise estimations of negative or positive consequences associated with each option (magnitudes) and the assignment of probabilities to each outcome (Phillips 1979: 4). The deliberative component refers to the desirability of outcomes. Once the desirability has been established, it is then specified as a cardinally measured utility providing a hierarchical order from beneficial to adverse effects.

In this background paper we are interested in exploring the opportunities for using DA in environmental deliberations and reviewing the existing evidence from decision theory. We explore what different forms and methods of DA can deliver what in real life situations with respect to predefined goals. The starting point is therefore normative, i.e., it looks into the potential opportunities of DA based on typological models of decision making. In a second step we review the existing experiences with these DA-based approaches and methods with respect to their performance in combination with deliberative forms of decision making.

Generic Steps of the Decision Analysis Approach	**Example: Municipal Solid Waste Disposal**
Structure the problem and specify goals for the choice situation ahead	Priorities: reduce waste generation, encourage voluntary re-use and recycling, mandate recycling, incineration and landfills.
Extract appropriate value-dimensions from stated goals	Equity of risk exposure, compensation, cost effectiveness, minimize impacts
Define criteria and indicators for each value dimension (or attribute)	Meta-criteria: health risks, environmental risks, social and cultural risks.
Assign relative weights to each value dimension	Health risk = 40%; environmental risk = 35%; cost = 25%
Describe alternatives or options that seem to meet the criteria	Option A: Regional recycling centers and an expanded landfill. Option B: a new landfill in community W.
Measure how well each decision option performs on the criteria	Geological borings, probabilistic risk assessments, collect statistical data, elicit citizen‘s responses
Assess probabilities for each possible outcome	Option A: health risk = 11; eco risk = 21; cost = 82. Option B: health risk = 34; eco risk = 75; cost = 20
Sum each decision option's utility on each criterion multiplied with the weight of each value dimension	Option A = 32; Option B = 45
Do a sensitivity analysis to incorporate changes in the criteria composition, outcome generation, assignment of weights and probability assessments	Option A (28,32, 56); Option B (16, 45, 47)

Table I. Generic steps in a decision analytic approach (taken from Jaeger et al. 2001: 51).

1.2 Normative DA: Analytical Aids for Making Good Decisions

We define a good decision as a decision that is rational in the sense of being logically consistent with what we know (information), what we want (values and preferences), and what we can do (choices, options, or action alternatives). This definition has major implications:

a) analysis does not precede deliberation, as often postulated in the literature, but is an integral part of the deliberation process (NRC 1996a: 79ff);
b) DA consists of a set of formal requirements that one should follow when pursuing instrumental rationality (i.e. selecting from a set of available options the one option that promises to maximize one's own goals or corresponds best with one's own preferences);
c) the normative advice given in DA is a priori superior to any other structure of decision making under the goal of instrumental rationality (von Winterfeldt and Edwards 1986: 21f.);
d) normative DA applies to all decision making contexts regardless whether the decision is made by a villain, benevolent dictator, democratic body, participatory group, an organization or an individual (Fishburn 1981).

The key term in this context is "instrumental rationality". DA does not give any advice of how to delineate goals or preferences. If decisions require reflection about underlying values, preferences, and visions, normative DA can point out a proper place for such a discussion in the overall deliberation process, it can offer techniques for structuring and exploring the implications of conflicting values and visions, but it cannot provide a "rational" decision rule of how to generate values and preferences and how to resolve conflicts about them (Shafir and LeBoeuf 2002). The same is true for conflicts based on personal relationships, affects, and emotional judgments. Most DA advice includes the need for addressing these underlying factors and to make them more explicit. Yet, it does not offer any formal procedure to deal with personal or emotional conflicts when making decisions (Loewenstein et al. 2001).

In environmental decision making instrumental rationality is only one among different rationalities that are important and relevant. Yet there is no doubt that instrumental thinking about what works, and what effects do we expect from what option, and whether these effects are desirable or not based on a given set of goals and preferences, is an important and substantial component of a "good" decision process. At the same time, however, it is not the only aspect that one needs to consider. This is the main reason for the combination (and integration) of analysis and deliberation. Methods of deliberation have been developed to address issues of conflicting values, visions and preferences (Renn 2004: 301ff.). They offer tools for dealing with personal and emotional associations linked with options and their expected consequences. A deliberative process can help a group to share perspectives and different viewpoints about an issue and to discuss what the members of the group want.

With increasing levels of complexity and statistical uncertainty, analytical tools become increasingly important. With increasing levels of remaining uncertainties and ambiguities, deliberative tools become increasingly important. Both types of reasoning are certainly needed in the environmental domain. This domain is characterized by high complexities about causes and effects (non-linearities, synergies, multitude of intervening variables, etc.), uncertainties about potential consequences (long delay between causes and effects, inter-individual variation, stochastic nature of cause-effect relationships, etc.) and ambiguities (definition of adverse effects, tolerability of human interventions, images of nature and wilderness, etc.). Due to this high degree of complexity, uncertainty and ambiguity, a combination of thorough analysis and informed deliberation is clearly useful and important for decision and policy formulation in the environmental area.

1.3 Analytic-deliberative Processes: Towards a Procedural Integration

This paper focuses on the analytical part of this process, yet provides also recommendations for structuring the deliberative part without offering solutions or decision rules if non-instrumental aspects are at stake. Other theoretical frameworks such as the Theory of Communicative Rationality (Habermas 1970; 1987a; Webler 1995), theories of social judgment (Hammond 1996) or value-focused perspectives (Keeney 1992) need to be consulted when looking into forms of dealing with normative, expressive or affective conflicts.

The possibility to reach closure on environmental issues rests on two conditions: first, all participants need to achieve closure on the *underlying goal* (often legally prescribed such as prevention of health detriments or guarantee of an undisturbed environmental quality, for example purity laws for drinking water); secondly, they need to agree with the implications derived from the *present state of knowledge* (whether and to what degree the identified hazard impacts the desired goal). Dissent can result from conflicting values as well as conflicting evidence. It is crucial in environmental decision making to investigate both sides of the coin: the values that govern the selection of the goal and the evidence that governs the selection of cause-effect claims.

Strong differences in both areas can be expected in most environmental decision making contexts. So it is necessary to explore *why* people disagree about what to do – that is, which decision alternative should be selected. As pointed out before, differences of opinion may be focused on the evidence of what is at stake or which option has what kind of consequences. For example:

What is the evidence that an environmental management initiative will lead to an improvement, such as reducing losses of agricultural crops to insect pests – and what is the evidence that the management initiative could lead to ecological damage – loss of insects we value, such as bees or butterflies, damage to birds and other predators that feed on insects – and health impacts from the level of pesticides and important nutrients in the food crops we eat?

Other differences of opinion may be about values – value of food crops that contain less pesticide residue compared to those that contain more, value of having more bees or butterflies, value of maintaining indigenous species of bees or butterflies compared to other varieties not native to the local ecosystem, value ascribed to good health and nutrition, and maybe, value ascribed to having food in what is perceived to be a "natural" state as opposed to containing manufactured chemical pesticides or altered genetic material.

Separating the science issues of what will happen from the value issues of how to make appropriate tradeoffs between ecological, economic, and human health goals can become very difficult. The separation of facts and values in decision making is difficult to accomplish in practical decision situations, since what is regarded as facts includes a preference dependent process of cognitive framing (Tversky and Kahneman 1981) and what is regarded as value includes a prior knowledge about the factual implications of different value preferences (Fischhoff 1975). Furthermore, there are serious objections against a clear cut division from a sociological view on science and knowledge generation (Jasanoff 1996). Particularly when calculating risk estimates, value-based conventions may enter the assessment process. For example, conservative assumptions may be built into the assessment process, so that some adverse effects (such as human cancer from pesticide exposure) are much less likely to be underestimated than overestimated (National Research Council 1983). At the same time, ignoring major sources of uncertainty can evoke a sense of security and overconfidence that is not justified from the quality or extent of the data base (Einhorn and Hogarth 1978). Perceptions and world views may be very important, and difficult to sort out from matters of science, especially with large uncertainties about the causes of environmental damage.

A combination of analytic and deliberative processes can help explore these differences of opinions relating to complexity, uncertainty, and ambiguity in order to examine the appropriate basis for a decision before the decision is made. Most environmental agencies go through an environmental assessment process and provide opportunities for public review and comment. Many controversial environmental decisions become the focus of large analytical efforts, in which mathematical models are used to predict the environmental, economic, and health consequences of environmental management alternatives. We are not advocating that extensive analysis be used in all cases. Rather we view analysis per se as an indispensable complement to deliberative processes, regardless whether this analysis is sophisticated or not. Even simple questions need analytic input for making prudent decisions, especially in situations where there is controversy arising from complexity, uncertainty, and ambiguity.

1.4 Evidence and Values: Distinct Functions, Yet Difficult to Distinguish

Analytical tools assist decision makers and others involved in, and potentially affected by, the decision (i.e., participants, stakeholders) to deal with complexity and many components of uncertainty, and to address issues of remaining uncertainties and ambiguities. Using these methods promises consistency from one decision situation to another, assurance of an appropriate use of evidence from scientific studies related to the environment, and explicit accountability and transparency with respect to those institutionally responsible for the value judgments that drive the evaluation of the alternative choices. Collectively the analytical tools provide a framework for a systematic process of exploring and evaluating the decision alternatives – assembling and validating the applicable scientific evidence relevant to what will happen as the result of each possible choice, and valuing how bad or how good these consequences are based on an agreement of common objectives.

The value judgments motivating decisions are made explicit and can then be critiqued by those who were not involved in the process. To the extent that uncertainty becomes important, it will be helpful to deal with uncertainty in an orderly and consistent way (Morgan and Henrion 1990). Those aspects of uncertainty that can be modeled by using probability theory (inter-target variation, systematic and random errors in applying inferential statistics, model and data uncertainties) will be spelled out and those that remain in forms of indeterminacies, system boundaries or plain ignorance will become visible and can then be fed into the deliberation process (van Asselt 2000; Klinke and Renn 2002).

Analysis is a process for decomposing a decision problem into pieces, starting with the simple structure of alternatives, information, and preferences. Normative DA is a formal framework for quantitative evaluation of alterative choices in terms of what is known about the consequences and how the consequences are valued. Hammond et al. (1999) and Skinner (1999) provide introductions to decision analysis concepts and analytical tools. Raiffa (1968), von Winterfeldt and Edwards (1986), Yates (1990), Plous (1993), Clemen (1996), and are among the large number of college-level texts available on decision analysis, in which the major steps are described and their implications discussed. The volume by Morgan and Henrion (1990) focuses on the analysis of uncertainty, in particular for public policy applications.

2. Decision Analytic Approaches: Opportunities and Challenges

2.1 *The First Component: Analysis*

In many policy arenas in which problems of structuring human decisions are relevant, the tools of normative decision analysis have been applied. Especially in economics, sociology, philosophical ethics, and also many branches of engineering and science, these methods have been extended and refined during the past several decades. (Edwards 1954, Howard 1966, 1968, North 1968, Howard, Matheson and North 1972, North and Merkhofer 1976, Behn and Vaupel 1982, Weber 1983, Pinkau and Renn 1998, van Asselt 2000, Jaeger et al. 2001)

The procedures and analytical tools of normative DA provide a number of *possibilities* to improve the precision and transparency of the decision procedure. However, they are subject to a number of limitations. The opportunities refer to:

- Different action alternatives can be quantitatively evaluated to allow selection of a best choice. Such evaluation relies both on a description of uncertain consequences for each action alternative, with uncertainty in the consequences described using probabilities, and a description of the values and preferences assigned to consequences. *(explicit characterization of uncertainty and values of consequences)*
- The opportunity to assure transparency, in that (1) models and data summarizing *complexity* (e.g., applicable and available scientific evidence) (2) probabilities characterizing judgment about *uncertainty,* and (3) values (utilities) on the consequences are made explicit and available. So the evaluation of risk management alternatives can be viewed and checked for accuracy by outside observers. *(outside audit enabled of basis for decision)*
- A complex decision situation can be decomposed into smaller pieces in a formal analytical framework. The level of such composition can range from a decision

tree of action alternatives and ensuing consequences that fits on a single piece of paper, to extremely large and complex computer-implemented models used in calculating environmental consequences and ascribing probabilities and values of the consequences. More complex analysis is more expensive and is less transparent to observers. In principle, with sufficient effort any formal analytical framework can be checked to assure that calculations are made in the way that is intended. *(decomposition possible to include extensive detail).*

On the other hand, there are important limitations:

- Placing value judgments (utilities) on consequences may be difficult, especially in a political context where loss of life, impairment of health, ecological damage, or similar social consequences are involved. Utility theory is essentially an extension of cost-benefit methods from economics to include attitude toward risk. The basic tradeoff judgments needed for cost-benefit analysis remain difficult and controversial, and often, inherently subjective. *(difficulties in valuing consequences)*
- Assessing uncertainty in the form of a numerical probability also poses difficulties, especially in situations there is not a statistical data base on an agreed-on model as the basis for the assessment. *(difficulty in quantifying uncertainty, assigning probabilities)*
- The analytical framework may not be complete. Holistic or overarching considerations or important details may have been omitted. *(analytical framework incomplete)*
- Decision analysis is built upon an axiomatic structure, both for dealing with uncertainty (i.e., the axiomatic foundation of probability theory), and for valuing consequences (i.e., the axiomatic basis for von Neumann-Morgenstern utility theory). Especially when the decision is to be made by a group rather than an individual decision maker, rational preferences for the group consistent with the axioms may not exist (the "Impossibility" Theorem of Arrow, 1951). So in cases of strong disagreements on objectives or unwillingness to use a rational process, decision analysis methods may not be helpful. *(limits on applicability)*

Decision analytic methods should not be regarded as inherently "mechanical" or algorithmic," in which analysts obtain a set of "inputs" about uncertainty and valuing consequences, then feed these into a mathematical procedure (possibly implemented in a computer) that produces an "output" of the "best" decision. Normative DA can only offer coherent conclusions from the information which the decision maker provides by his/her preferences among consequences and his/her state of information on the occurrence of these consequences. Where there is disagreement about the preferences or about the information, DA may be used to implore the implications of such disagreement. So in application, there is often a great deal of iteration (sensitivity analysis) to explore how differences in judgment should affect the selection of the best action alternative.

Normative DA thus merely offers a *formal framework* that can be effective in helping participants in a decision process to better understand the implications of differing information and judgment about complex and uncertain consequences from the choice among the available action alternatives. Insight about which factors are most important in selecting among the alternatives is often the most important output of the process, and it is obtained through extensive and iterative exchange between analysts and the decision makers and stakeholders. The main advantage of the framework is that it is based on logic that is both explicit and checkable – usually facilitated by the use of mathematical models and probability calculations. Research on human judgment supports the superiority of such procedures for decomposing complex decision problems and using logic to integrate the pieces, rather than relying on holistic judgment on which of the alternatives is best (this is not only true for individual decisions, see Heap et al. 1992: 36ff.; Jungermann 1986; but also for collective decisions, see Heap et al. 1992: 197ff.; Petit 1991). One should keep in mind, however, that "superior" is measured in accordance with indicator of instrumental rationality, i.e. measuring means-ends effectiveness. If this rationality is appropriate, the sequence suggested by DA is intrinsically plausible and obvious. Even at the level of qualitative discussion and debate, groups often explore the rationale for different action alternatives. Decision analysis simply uses formal quantitative methods for this traditional and common-sense process of exploring the rationale – using models to describe complexity, probability to describe uncertainty, and to deal with ambiguity, explicit valuation of consequences via utility theory and other balancing procedures such as cost-benefit or cost-effectiveness analyses. By decomposing the problem in logical steps, the analysis permits better understanding of differences in the participants' perspective on evidence and values. DA offers methods to overcome these differences, such as resolving questions about underlying science through data collection and research, and encouraging tradeoffs, compromise, and rethinking of values.

Based on this review of opportunities and shortcomings we conclude that decision analysis provides a suitable structure for guiding discussion and problem formulation, and offers a set of quantitative analytical tools that can be useful for environmental decisions, especially in conjunction with deliberative processes. Yet it does not replace the need for additional methods and processes for including other objectives such as finding common goals, defining preferences, revisiting assumptions, sharing visions and exploring common grounds for values and normative positions.

How does analysis contribute in modern environmental assessment and decision making? There has been increasing use of quantitative models and analytical methods, but not yet a lot of agency experience using decision analysis in support of environmental decision making, especially using the analytical-deliberative framework described in NRC 1996. None of the case studies in this 1996 report involved a full use of state-of-the-art tools for either the deliberative processes or decision analytic tools as decision aids. Further research and experienced gained in application will be desirable. A new report from the National Research Council (2005) recommends top priority to research in the decision sciences to improve the analytical tools and deliberative processes needed for good environmental decision making. We heartily agree. We also note that analytical and deliberative processes must be adapted to the legislative and institutional framework laws within which federal agencies must function.

The Office of Management and Budget (OMB 2003) has recently encouraged cost-benefit analysis and assessment of probabilities from scientific experts on important uncertainties for regulatory decisions with impacts of $1 billion or higher. Experience with such methods is limited. There is more experience in applications to business decisions in private industry (Clemen, 1996; Howard and Matheson 1989) and in areas of engineering such as safety analysis (NAE 2004).

2.2. The Second Component: Deliberation

Environmental policies are normally contested in a pluralist society facing different value systems and worldviews. Who can legitimately claim the right to select the values or preferences that should guide environmental decision making, in particular when health and lives of humans are at stake? One of the answers to this question can be derived from the theory and practice of discursive deliberation.

The term deliberation refers to the style and procedure of decision making without specifying which participants are invited to deliberate (NRC 1996; Rossi 1997). For a discussion to be called deliberative it is essential that it relies on mutual exchange of arguments and reflections rather than decision-making based on the status of the participants, sublime strategies of persuasion, or social-political pressure. Deliberative processes should include a debate about the relative weight of each argument and a transparent procedure for balancing pros and cons (Tuler and Webler 1999). In addition, deliberative processes should be governed by the established rules of a rational discourse. In the theory of communicative action developed by the German philosopher Jürgen Habermas, the term discourse denotes a special form of a dialogue, in which all affected parties have equal rights and duties to present claims and test their validity in a context free of social or political domination (Habermas 1970; 1987b). A discourse is called rational if it meets the following specific requirements (cf. McCarthy 1975; Habermas 1987a; 1991; Kemp 1985; Webler 1995; 1999). All participants are obliged to:

- seek a consensus on the procedure that they want to employ in order to derive the final decision or compromise, such as voting, sorting of positions, consensual decision making or the involvement of a mediator or arbitrator;

- articulate and critique factual claims on the basis of the "state of the art" of scientific knowledge and other forms of problem-adequate knowledge; (in the case of dissent all relevant camps have the right to be represented),

- interpret factual evidence in accordance with the laws of formal logic and analytical reasoning,

- disclose their relevant values and preferences, thus avoiding hidden agendas and strategic game playing,

- process data, arguments and evaluations in a structured format (for example a decision-analytic procedure) so that norms of procedural rationality are met and transparency can be created.

The rules of deliberation do not necessarily include the demand for stakeholder or public involvement. Deliberation can be organized in closed circles (such as conferences of Catholic bishops, where the term has indeed been used since the Council of Nicosia) as well as in public forums. It may be wise to use the term “deliberative democracy” when one refers to the combination of deliberation and public or stakeholder involvement (see also Cohen 1997; Rossi 1997).

What needs to be deliberated? First, deliberative processes are needed to define the role and relevance of systematic and anecdotal knowledge for making far-reaching choices. Second, deliberation is needed to find the most appropriate way to deal with uncertainty in environmental decision making and to set efficient and fair trade-offs between potential over- and under-protection. Third, deliberation needs to address the wider concerns of the affected groups and the public at large.

Why can one expect that deliberative processes are better suited to deal with environmental challenges than using expert judgment, political majority votes or relying on public survey data?

- Deliberation can produce common understanding of the issues or the problems based on the joint learning experience of the participants with respect to systematic and anecdotal knowledge (Webler et al. 1995; Pidgeon 1997);

- Deliberation can produce a common understanding of each party‘s position and argumentation and thus assist in a mental reconstruction of each actor‘s argumentation (Warren 1993; Tuler 1996). The main driver for gaining mutual understanding is empathy. The theory of communicative action provides further insights in how to mobilize empathy and how to use the mechanisms of empathy and normative reasoning to explore and generate common moral grounds (Webler 1995).

- Deliberation can produce new options and novel solutions to a problem. This creative process can either be mobilized by finding win-win solutions or by discovering identical moral grounds on which new options can grow (Renn 1999).

- Deliberation has the potential to show and document the full scope of ambiguity associated with environmental problems. Deliberation helps to make a society aware of the options, interpretations, and potential actions that are connected with the issue under investigation (Wynne 1992; De Marchi and Ravetz 1999). Each position within a deliberative discourse can only survive the crossfire of arguments and counter-arguments if it demonstrates internal consistency, compatibility with the legitimate range of knowledge claims and correspondence with the widely accepted norms and values of society. Deliberation clarifies the problem, makes people aware of framing effects, and determines the limits of what could be called reasonable within the plurality of interpretations (Skillington 1997).

- Deliberations can also produce agreements. The minimal agreement may a consensus about dissent (Raiffa 1994). If all arguments are exchanged, participants know why they disagree. They may not be convinced that the arguments of the other side are true or morally strong enough to change their own position; but they understand the reasons why the opponents came to their conclusion. At the end the deliberative process produces several consistent and --in their own domain-- optimized positions that can be offered as package options to legal decision-makers or the public. Once these options have been subjected to public discourse and debate, political bodies such as agencies or parliaments can make the final selection in accordance with the legitimate rules and institutional arrangements such a majority vote or executive order. Final selections could also be performed by popular vote or referendum.

- Deliberation may result in consensus. Often deliberative processes are used synonymously with consensus-seeking activities (Coglianese 1997). This is a major misunderstanding. Consensus is a possible outcome of deliberation but not a mandatory requirement. If all participants find a new option that they all value more than the one option that they preferred when entering the deliberation, a ”true” consensus is reached (Renn 1999). It is clear that finding such a consensus is the exception rather than the rule. Consensus is either based on a win-win solution or a solution that serves the “common good” and each participant‘s interests and values better than any other solution. Less stringent is the requirement of a tolerated consensus. Such a consensus rests on the recognition that the selected decision option might serve the “common good” best but on the expense of some interest violations or additional costs. In a tolerated consensus some participants voluntarily accept personal or group-specific losses in exchange for providing benefits to all of society. Case studies have provided sufficient evidence that deliberation has produced a tolerated consensus solution, particularly in siting conflicts (one example in Schneider et al. 1998). Consensus and tolerated consensus should be distinguished from compromise. A compromise is a product of bargaining where each side gradually reduces its claim to the opposing party until they reach an agreement (Raiffa 1994). All parties involved would rather choose the option that they preferred before starting deliberations, but since they cannot find a win-win situation or a morally superior alternative they look for a solution that they can "live with" knowing that it is the second or third best solution for them. Compromising on an issue relies on full representation of all vested interests.

In summary, many desirable products and accomplishments are associated with deliberation (Chess et al. 1998). Depending on the structure of the discourse and the underlying rationale deliberative processes can:

- enhance understanding,
- generate new options,
- decrease hostility and aggressive attitudes among the participants,
- explore new problem framing,
- enlighten legal policy makers,
- produce competent, fair and optimized solution packages and
- facilitate consensus, tolerated consensus and compromise.

3. The Use of Decision Analytic Tools in Deliberation

3.1 The Integration of Decision Analytic Tools in Deliberation

In a deliberative setting, participants exchange arguments, provide evidence for their claims and develop common criteria for balancing pros and cons. This task can be facilitated and often guided by using decision analytic tools (overview in Merkhofer 1984). Decision theory provides a logical framework distinguishing action alternatives or options, consequences, likelihood of consequences, and value of consequences, where the valuation can be over multiple attributes that are weighted based on tradeoffs in multi-attribute utility analysis (Edwards 1977). A sequence of decisions and consequences may be considered, and use of mathematical models for predicting the environmental consequences of options may or may not be part of the process (Humphreys 1977; Bardach 1996; Arvai et al. 2001):

a) The structuring potential of decision analysis has been used in many participatory processes. It helps the facilitator of such processes to focus on one element during the deliberation, to sort out the central from the peripheral elements, provide a consistent reference structure for ordering arguments and observations and to synthesize multiple impressions, observations and arguments into a coherent framework. The structuring power of decision analysis has often been used without expanding the analysis into quantitative modeling.

b) The second potential, agenda setting and sequencing, is also frequently applied in participatory settings. It often makes sense to start with problem definition, then develop the criteria for evaluation, generate options, assess consequences of options, and so on.

c) The third potential, quantifying consequences, probabilities and relative weights and calculating expected utilities, is more controversial than the other two. Whether the deliberative process should include a numerical analysis of utilities or engage the participants in a quantitative elicitation process is contested among participation practitioners (Gregory et al. 2001). One side claims that quantifying helps participants to be more precise about their judgments and to be aware of the often painful tradeoffs they are forced to make. In addition, quantification can make judgments more transparent to outside observers. The other side claims that quantification restricts the participants to the logic of numbers and reduces the complexity of argumentation into a mere trade-off game. Many philosophers argue that quantification supports the illusion that all values can be traded off against other values and that complex problems can be reduced to simple linear combinations of utilities. One possible compromise between the two camps may be to have participants go through the quantification exercise as a means to help them clarify their thoughts and preferences, but make the final decisions on the basis of holistic judgments (Renn 1986). In this application of decision analytic procedures, the numerical results (i.e. for each option the sum over the utilities of each dimension multiplied by the weight of each dimension) of the decision process are not used as expression of the final judgment of the participant, but as a structuring aid to improve the participant's holistic, intuitive judgment. By pointing out potential discrepancies between the numerical model and the holistic judgments, the participants are forced to reflect upon their opinions and search for potential hidden motives or values that might explain the discrepancy.

3.2 Assisting Participants in Eliciting and Structuring Values

Most decision analysts agree that applying the concepts from decision analysis requires specific tools that help participants to use the decision analytic framework most productively. This is true both for eliciting values on the consequences and for organizing information – issues of complexity and uncertainty in the prediction of the consequences for the various options under consideration. The main criteria for choosing such tools for value elicitation are (Keeney 1988, 1992):

- adequacy of tools to represent participants' values and preferences;
- adequacy of tools to distinguish between inviolate values (principles) and relative values (for which trade-offs can be made)
- incorporation of cognitive, affective, normative, and expressive arguments into the elicitation process
- assistance to participants to clarify their value and preferences structure and to find strategies to balance perceived pros and cons
- compatibility of structuring and evaluating tools with the reasoning process of all participants
- intelligibility of all operations for all participants.

Obviously some of these criteria are in conflict with each other. The better a tool represents non-linear patterns of thinking and evaluating, the less intelligible are the respective mathematical operations for a non-skilled participant. The more a tool reflects the whole horizon of statements (cognitive, affective, normative, and expressive) the less straightforward is the process of amalgamation and integration of concerns. It therefore depends on the case, the qualification of the participants and the situation to decide which of the many tools that decision analysis provides for participatory processes should be selected for which purpose.

3.3 Assisting Participants in Generating, Structuring and Evaluating Evidence

The tools needed on the informational aspects involve another set of criteria, including:

- Have all evidence claims been fairly and accurately tested against commonly agreed standards of validation (methodological rigor)?
- Has all the relevant evidence in accordance with the actual state of the art in knowledge been collected and processed (comprehensiveness and representativeness)?
- Was systematic, experiential and practical knowledge and expertise adequately included and processed (incorporation of all relevant knowledge claims)?

- Have all conflicts about evidence been resolved using accepted means of validation, testing and methodology that have been approved by the respective scientific or knowledge communities?
- Were all normative judgments inherent in evidence claims made explicit and thoroughly explained? Were normative statements deduced from accepted ethical principles, legally prescribed norms or accepted conventions within the knowledge community?

Of specific interest are the claims about cause-and-effect relationship between the options under consideration and the consequences – what will happen, given the choice made in the decision. The use of models and statistical analysis is well known among scientists, but some participants may not agree with the assumptions, choice of parameters, algorithms and model structure chosen for the scientific models, and scientists may not agree among themselves (Funtowicz and Ravetz 1993; Koenig and Jasanoff 2001). Uncertainty compounds the difficulty – adverse consequences may be agreed to be possible, but scientific understanding is not yet sufficient to make predictions that are accepted as valid by all experts in the relevant scientific disciplines (Merkhofer 1987; Jaeger 1993).

It is essential to acknowledge in the context of environmental decision making that human knowledge is always incomplete and selective and thus contingent on uncertain assumptions, assertions and predictions (Functowicz and Ravetz 1992). It is obvious that the modelled probability distributions within a numerical relational system can only represent an approximation of the empirical relational system with which to understand and predict uncertain events. It therefore seems prudent to include other, additional, aspects of uncertainty (Morgan and Henrion 1990; van Asselt 2000: 93-138). Although there is no consensus in the literature on the best means of decomposing uncertainties, the following appears to be an appropriate means of distinguishing the key components of uncertainty (Klinke and Renn 2002):

- target variability (based on different vulnerability of targets)
- systematic and random error in modelling (based on extrapolations from animals to humans or from small samples to large populations, from large dose to small dose, statistical inferential applications, etc.)
- indeterminacy or genuine stochastic effects (variation of effects due to random events, in special cases congruent with statistical handling of random errors)
- system boundaries (uncertainties stemming from restricted models and the need for focusing on a limited amount of variables and parameters)

- ignorance (uncertainties derived from lack of knowledge)

All these different elements have one feature in common: they reduce the strength of confidence in the estimated cause and effect chain. If uncertainty plays a large role, in particular indeterminacy or lack of knowledge, then the calculation of probabilities becomes more problematic, and the validity of the end results may be more questionable. For decision making purposes, additional information may be needed such as a subjective confidence level in the probability estimates, potential alternative pathways of cause-effect relationships, and other means for making more explicit the evidentiary basis underlying the probability calculations.

In this situation the deliberation process may involve soliciting a diverse set of viewpoints, and judgments need to be made on what sources of information are viewed as responsible and reliable. Publication in scientific journals and peer review from scientists outside the government agency are the two most popular methods by which managers or organizers of deliberative processes try to limit what will be considered as acceptable evidence. Other methods are to reach a consensus among the participants up front which expertise should be included in the deliberation or to appoint representatives of opposing science camps to explain their differences in public. In many cases, participants have strong reasons for questioning scientific orthodoxy and would like to have different science camps represented. Many stakeholders in environmental decisions have access to expert scientists, and often such scientists will take leading roles in criticizing agency science. Such discussions need to be managed so that disagreements among the scientific experts can be evaluated in terms of the validity of the evidence presented and the importance to the decision. It is essential in these situations to have a process in place that distinguishes between those evidence claims that all parties agree on, those where the factual base is shared but not its meaning for some quality criterion (such as “healthy” environment), and those where even the factual base is contested (Foster 2002).

Another point of consideration is the issue of presenting scientific results. Participants without scientific training may feel disadvantaged by presentation of information in scientific terminology, and by extensive use of models, mathematics, and statistics. The point here is not that one should simplify to be comprehensible to a lay audience (which may be important for communication with stakeholders, but not for an environmental decision making process that uses mathematical logic as an appropriate means for dealing with great scientific complexity). The point is rather that the assumptions and conditions that may constrain the validity and applicability of the models should not remain hidden behind the image of exact figures and algorithms (Klein 1997). These assumptions and conditions should be made explicit and be subject to questioning and challenge by the participants. It may be advisable for those responsible for the deliberative process to work closely with scientists and analysts so that information is made available in a format that guarantees that all assumptions, underlying values and norms and scientific conventions (such as using the 95th percentile for significance testing) become transparent and are open for criticism.

4. Empirical Evidence for the Benefit of DA in Deliberative Processes

4.1 Problems of Testing

The literature on DA provides a large set of arguments and plausible reasoning in favor of using DA in deliberative processes. They reach from the benefit of providing a consistent and coherent structure to decision making processes (Keeney and Raiffa 1976; Shoemaker 1982; McDaniels and Thomas 1999) to the benefit of assisting participants in ordering their own preferences, integrating factual and normative information and making people aware of their own trade-offs and value conflicts (Shoemaker 1982; Hammond et al. 1999, Keeney 2004). There is, however, not much in the literature when it comes to empirical evidence that these claims are true. The main reason for this lack of empirical evidence is the difficulty of testing these claims in a meaningful way. Nobody can afford to have two parallel deliberative processes running one with and one without analytical assistance. In addition, deliberative processes that are thoroughly evaluated by social scientific means are rare, as organizers of these processes are likely to refrain from such evaluations. They are mostly concerned that "the process works", i.e., leads to the results that the organizers would like to see. An independent review or evaluation is often not desired. As a consequence of this situation, there are only two sources of empirical validation of the normative claims: laboratory results (or insights based on hypothetical surveys) and evaluations of deliberative processes based on subjective estimates of participants and some external criteria such as effectiveness, efficiency, fairness, competency, and others (Rowe and Frewer 2000; Stirling 2000-2001; Renn 2004: 334ff.). These evaluations do not include comparisons with control groups, but rely on plausibility when making comparisons with situations without analytical input. These two sources of evidence are described in the next two sections.

4.2 Empirical Results of DA in Laboratory Settings

Behavioral research has produced a large amount of empirical insights into how people make decisions and how information from third parties is processed (Kahneman and Tversky 1974; Fishhoff et al. 1977; Einhorn and Hogarth 1981; Arkes 1991; Koehler 1996; Thaler 1999). One of the major insight has been that individuals do not follow the line of reasoning that DA would propose as the most logical and plausible path towards rational choice.

Most people pursue specific pathways of reasoning when faced with hard choices. These mechanisms of processing information, dealing with uncertainty and selecting options are called intuitive heuristics (Ross 1977; Dawes 2001a). They are particularly important for environmental decision making, since they relate to the mechanisms of processing probabilistic information. Early psychological studies focused on personal preferences for probabilities and attempted to explain why individuals do not base their judgments about options on expected values, i.e. the product of probability and magnitude of the (positive or negative) outcomes of each option under consideration (Pollatsek and Tversky 1970; Kahneman and Tversky 1974; Lopes 1983). One of the interesting results of these investigations was the discovery of systematic patterns of probabilistic reasoning that are well suited for most everyday situations. People are risk averse if the stakes of losses are high and risk prone if the stakes for gains are high (Kahneman and Tversky 1979). Furthermore, many people balance their risk taking behavior by pursuing a risk strategy that does not maximize their benefits, but assures both a satisfactory payoff and the avoidance of major disasters (Luce and Weber 1986).

One example of such a satisficing strategy is to use combinations of options that are able to compensate for each other's losses. This specific deviation from maximizing expected utilities has been adopted as a normative guideline by portfolio theory used by investors in the stock market. According to this theory, investors should select a portfolio of stocks in which the risks of losing money on one share is correlated with the probability of gaining money for another share (mathematically through co-variance analysis). This example and many other show that deviations from the rule of maximizing one's utility are not so often a product of ignorance or irrationality but an indication of one or several intervening context variables that often make good sense if seen in the light of the context and the individual decision maker's values (Brehmer 1987; Gigerenzer 1991).

More specific studies on the perception of probabilities in decision making identified several biases in people's ability to draw inferences from probabilistic information. These biases refer to (Festinger 1957; Kahneman and Tversky 1979; Ross 1977; Koehler 1996):

- *Availability:* Events that come to people's mind immediately are rated as more probable than events that are less mentally available.

- *Anchoring effect:* Probabilities are adjusted to the information available or the perceived significance of the information.

- *Representativeness:* Singular events experienced in person or associated with properties of an event are regarded as more typical than information based on frequencies.

- *Avoidance of cognitive dissonance:* Information that challenges perceived probabilities that are already part of a belief system will either be ignored or downplayed.

Although these biases constitute clear violations of logical rules, they might have been overrated in the literature (Fischhoff et al. 1982). Many laboratory situations provide insufficient contextual information to provide enough cues for people on which they can base their judgments (Lee 1981; Lopes 1983). Relying on predominantly numerical information and being unfamiliar with the subject, many subjects in these experiments retrieve to "rules of thumb" in drawing inferences. In many real life situations, experience of and familiarity with the context provide additional information to calibrate individual judgments, particularly for nontrivial decisions (Heimer 1988; Gigerenzer 1996). Nevertheless, organizers of deliberative processes need to be aware of these biases because they are found in deliberative reasoning and may be one of the underlying causes for the problems of reaching consensus on evidence and its implications. Assessment of probabilities for use in decision analysis should be carried out using methods that minimize biases (Spetzler and Staël von Holstein 1975, Wallsten and Busdescu 1983).

Thomas Dietz and Paul Stern have been suggesting a revised model of decision making that seems to be more consistent with what has recently been learned about the evolution of human cognition, the existence of psychological heuristics, and the importance of social influences (Dietz and Stern 1995). Dietz and Stern make four different, but connected joists at the typological DA model. First, with a glance to the literature on human and social evolution, they note that the relatively complex array of mathematics that the DA model presumes of people is not consistent with what we know about human cognition. People simply are not very adept at multiplying probabilities by expected utilities of n different action alternatives, at least not without external aids. Human cognition, they point out, has developed along another track. What humans are good at is pattern recognition, classification, and the application of rules of thumb. In short, people are “skilled taxonomists” rather than “powerful calculating machines.” According to Dietz and Stern, people tend not to be as thorough-going as the DA model assumes. Rather than systematically consider each action alternative, people are more likely to categorize similar action alternatives and make judgments about whole sets according to rules of thumb. This claim has been echoed by many social psychologists such as Simon (Simon 1955; 1982; review in National Research Council 1986) and more recently Gigerenzer (Goldstein and Gigerenzer 1999; Gigerenzer 2001).

Second, they refer to the literature on bounded rationality and intuitive heuristics that was mentioned and described above. The third argument that Dietz and Stern make for their new model of individual choice also has to do with how humans simplify complex decision making. Drawing on Schwartz‘s model of norm activation, Dietz and Stern assert that individuals consider the worthiness of different possible outcomes until one triggers a moral response. Norm activation presumes that, for each individual, there are compelling norms. These supersede the consideration of other values and thus “drive” the decision. According to Dietz and Stern, these decision-activating-norms may not be single values, but rather value clusters. Again, following up in the idea of classification and simplification, they propose that people consider possible decision outcomes not in terms of a myriad of single values, but of sets of values called clusters. They propose three value clusters in relation to environmental issues: egoistic, altruistic, and biospheric.

Fourth, they draw upon the social movement literature to bring in the ideas of framing and social influence. Again they turn to the experience of everyday life and note that one of the fundamental assumptions of DA needs to be reconsidered. People do not make choices in social isolation. Instead, they actually seek out the advice of their friends, spouse, children, and peers. They make themselves available to persuasion by media, authority figures, and others. Indeed, even if they do not seek out others‘ advice, people cannot escape social influence. Any search for information, grounding or perspective is likely to encounter the motivations of other individuals. People frame descriptions and advice in strategic ways. As an example, Dietz and

Stern point to results from contingent valuation studies which show that by merely rewording a survey question, the results can be significantly changed (Guagnano et al. 1994).

More insights about individual and group decision making processes could be mentioned here but the main point has become obvious already. People do not follow the normative guidelines that DA would propose. Is a normative decision rule appropriate if intuitively individuals choose different routes for making these decisions? Does it make sense to superimpose a structure on decision making that differs from what participants would do without such force? Deviation from intuition and common sense is not an argument against the use of DA. Yet one needs to prove that following the normative rule brings better results than following the intuitive routes.

The experiments by Gigerenzer demonstrate that tasks that require reasoning along the lines of instrumental rationality and do not --as he puts it-- require a strong cooperation between human hardware and software (as for example in making a decision where a baseball will land) are better served by the normative DA than by having people use only deliberative or intuitive methods for selecting and justifying choices (Gigerenzer 1991). Other evidence shows that once subjects understand the logic and the sequence of DA they feel better about their choices and believe that the selection of options is more reasonable than a selection process that they had taken intuitively (Fischhoff et al. 1982).

In essence, it is clear that individuals do not follow the sequence of typological or normative DA. However, if the task includes typical instrumental means-ends relationships and the participants are trained and enabled to use the DA tools adequately, they seem to perform better (in terms of measuring effectiveness and efficiency) and are also subjectively more inclined to be satisfied with their decision process and outcomes (measured in the decrease of post-decisional regret) than without this assistance (Bell 1982).

4.3 Evidence from Evaluation Studies

Although the literature is full of good advice on how to conduct deliberative processes and to include analytical reasoning in these processes, the empirical basis for such advice is weak (Comparative empirical reviews in: Talbot 1983; Bingham 1984; Buckle and Thomas-Buckle 1986; Creighton 1991; Frey and Oberholzer 1996; Moore 1996 and Rowe and Frewer 2000). In addition, most empirical analyses are based on one model or one type of application. Several applications such as hearings, mediation, citizen advisory committees and expert panels have received substantial empirical attention while others such a citizen juries or consensus conferences are rarely subjected to systematic evaluation. Basically missing are comparative evaluations of hybrid procedures, the only type of procedures that can satisfy the requirements of an analytic-deliberative process (Renn 1999). It is therefore essential for further research and model evolution to organize systematic evaluations of these processes and compare the results of these evaluations.

Most evaluative criteria refer to the subjective satisfaction of the actors involved in the process. Subjective satisfaction is certainly an important, but insufficient criterion for evaluating success or failure of deliberations (Rohrmann 1992; Webler 1995). People will tend to rate processes positively if they are heavily invested in them -- emotionally or just by sacrificing their time. In addition, many processes are able to convey a good feeling but may lead to a very unsatisfactory outcome and the other way around. There is obviously a need for objective indicators of evaluation that relate to the product and the process independent of the subjective interpretation of the persons involved (Wondollek 1985).

There are only few examples of non-subject centered approaches to evaluating deliberative processes. Ray Kemp used Habermas' definition of the ideal speech situation as a measure against which to compare the discourse that occurred in the public inquiry process to permitting the British uranium reprocessing facility (Kemp 1985). Daniel Fiorino developed performance criteria for public participation from the theory of participatory democracy and evaluated several generic models of participation (1989a; 1990). Frank Laird has supplemented Fiorino's criteria with another set from the theory of pluralist democracy and evaluated the same models (1993). Although not developed for the purpose of evaluation, the competing values theory by Quinn and Rohrbaugh (1981; 1983) provide another set of interesting criteria for measuring the success or failure of deliberative processes. These criteria are related to four potential organizing principles: flexibility and control on one hand, and internal versus external focus on the other hand. These conflicting principles are associated with corresponding criteria: legitimacy, participatory quality, accountability, and efficiency. Similar criteria were suggested by Renn (2004: 336.): these criteria refer to fairness, competence, legitimacy, and efficiency.

All studies based on these criteria do not provide sufficient proof that feeding analytical knowledge into the process and structuring deliberations according to DA improves the process quality and the outcome. Renn has tested different forms of knowledge presentation to citizen panels and concluded that videotapes of experts with conflicting positions were the most productive means of initiating a debate about evidence and its implications (Renn 1989). In addition, evaluations of citizen panels demonstrated that the structuring according to an ideal DA sequence was welcomed by most participants and received positive grades from a vast majority of participants (Buser 1995; Roch 1997; Vorwerk and Kämper 1997). Other authors such as Tim McDaniels and Robin Gregory claim that the success in terms of conflict resolution and problem solving depends on the appropriate selection of tools (McDaniels 1996; Gregory 2004). Depending on the nature of the problems, some DA tools seem to be more appropriate and productive than others.

In order to explore the scope of these tools, five tools will be described below, the first two for value elicitation and the remaining three for dealing with complexity and uncertainty.

5. *Five Examples of Decision Analytic Tools for Deliberative Processes*

Value-tree-Analysis: A value-tree identifies and organizes the values of an individual or group with respect to possible decision options (Keeney et al. 1984; Keeney et al. 1987). In the process of structuring a value-tree, representatives of different stakeholder groups are asked to identify their criteria and objectives for evaluating different options. Values in this context are abstractions that help organize and guide preferences (von Winterfeldt 1987).

A value-tree structures the elicited values, criteria, and corresponding attributes in a hierarchy, with general values and concerns at the top, and specific criteria and attributes at the bottom. Depending on the political context and the nature of the decision to be made, the values of the various stakeholder groups may vary considerably. By giving each group the right to assign a weight of zero to each criterion that they regard irrelevant, it is possible to construct a joint or combined value-tree that accounts for all viewpoints and can be verified by all participants (Keeney et al. 1984).

Many users of the value-tree technique (i.e., von Winterfeldt 1987) take value trees as a first step in the sequence of decision making. In this line, they elicit performance measurements for each option on each criterion or ask for the assignments of trade-offs between the various independent criteria. Other argue that both tasks are extremely prone to strategic game playing and would likely end in a process by which each group would be able to rationalize its latent preference for one of the decision options available. They would use the qualitative value trees as input for further discussions based on other less strategically sensitive techniques.

MAU-Analysis: A second example for using formal decision analysis tools refers to the elicitation of values, criteria, and attributes and the assignment of relative weights to the different value dimensions. The procedures used for this purpose are derived from *Multiattribute Utility Theory* (Fischhoff et al. 1982; von Winterfeldt and Edwards 1986). The respondents are first asked to use the criteria of the joint value-tree to rate each decision option on each criterion. The participants are free to add new values to the tree, but they may not delete any of the criteria elicited from the stakeholder groups. They also can modify the presented option or add a new option to the list. Finally, each criterion is weighted against each other criterion, resulting in a matrix of relative weights and utility measures for each option and each criterion. Both tasks, the transformation of the expert data in utilities and the assignment of trade-offs are performed individually and in small groups.

Sensitivity Analysis: Most comparisons of the consequences of alternative environmental management alternatives involve projection of what will happen to an environmental system over time under each of the alternatives or options. Sometimes these projections are simply estimates based on expert judgment, but increasingly, mathematical models of environmental systems (forests, wetlands, river basins, etc.) are used to make the projections. Projections either from models or from the judgment of experts depend on the assumptions and the data being used to make the projections. So a very useful means for gaining insights into which factors are most important in making the decision is to carry out a systematic sensitivity analysis to data inputs and model assumptions. Sensitivity analysis is done by asking about how the projections would change if alternative assumptions and input data are used. Make up a list, and for each input or model assumption on the list, ask how the evaluation of the alternatives would change if this factor were different, within a range judged to be reasonable. Sensitivity analysis is therefore equivalent to a list of "what-if" questions. What if there is a drought? Or a flood? In a study of a river basin, a series of wet years or dry years might be examined as alternatives to an assumption of average precipitation and resulting stream flows. Does the evaluation of the management alternatives change as the precipitation levels vary from wetter to drier? If so, further study may be warranted for this factor now identified as sensitive for the decision being studied. Often models have a great many assumptions and input parameters. Outside review of the model by experts in the relevant technical disciplines may be useful in identifying assumptions and inputs that might be sensitive. When the input is uncertain and important, then it may be useful to proceed to the next tool we shall discuss – assessment of uncertainty in the form of a probability distribution for an uncertain factor. But often an important aspect of sensitivity analysis is to determine that many inputs to the model (or in the absence of a model, factors affecting the environmental system) are **not** critical in the sense of having a strong impact on the evaluation of which decision is best. Then discussion and debate can then move away from the factors that are not critical, and concentrate on the factors that appear to be more important to the decision. Patil and Frey (2004) in a recent publication on sensitivity analysis methods in food safety conclude that food safety models should be designed to facilitate sensitivity analysis, and that sensitivity analysis methods are a valuable tool in supporting food safety regulation. Such conclusions seem also appropriate for other areas of environmental assessment and decision making.

Characterizing Uncertainty in the Form of Probabilities: An important analytical tool in decision analysis is the use of probabilities to characterize uncertainty (Savage 1954; Raiffa 1968). Use of statistics as the basis for probabilities is widespread throughout science. Use of probability to characterize uncertainty in the absence of statistical data has returned to widespread academic legitimacy during the past 50 years. The basic idea is a simple one – probability theory can be used to reason about uncertain events – and indeed, is the only logically consistent way to reason about uncertainty (Cox 1961; Jaynes 2003). The application can be simple and informal – ask a source of information for a judgment about the likelihood of a future event in terms of a probability.

> When the value of an uncertain quantity is needed for policy analysis, and limits in data or understanding preclude the use of the usual statistical techniques to produce probabilistic estimates, about the only remaining option is to ask experts for their best professional judgment.
>
> (Morgan and Henrion, 1990, cited in NRC 2002 at the conclusion of Chapter 5, the "Uncertainty" chapter)

Those carrying out and interpreting probability assessments should understand the subtleties of human judgment about uncertainty (Kahneman et al. 1982, Spetzler and Staël von Holstein 1975, Wallsten and Budescu 1983). Most people are familiar with the practice of expressing judgments about the probability of an uncertain future event in terms of a numerical probability. Such probabilities (sometimes stated as "odds¨) are routinely cited for sporting events, outcome of future elections, etc. One tradition (Savage, 1954, Raiffa, 1968) in decision theory regards such probabilities as subjective judgment, expressed in terms of willingness to place a bet, or be rewarded on the outcome of the uncertain event, compared to a uncertain outcome where the probabilities are known on the basis of statistics or on symmetry considerations, such as in flipping a coin, rolling a die, or spnning a ball into a roulette wheel. Another tradition in science (Jeffreys 1961, Cox 1961, Jaynes 2003) holds that probability theory is a logic for inference, and that probabilities should reflect the available evidence relevant to the uncertain event or variable. Our experience is that it is useful to encourage people to discuss uncertainty by using numerical judgments on probability, but to recognize such judgments may be imprecise. Important uncertainties may warrant careful assessment by multiple experts under carefully designed protocols.

We summarize briefly below two important areas of environmental policy analysis where substantial efforts to use such methods are underway: the health impacts of criteria air pollutants and global climate change. The interested reader should consult the references for more extensive discussion of the progress achieved.

The US Environmental Protection Agency (EPA) has carried out probability assessment on the health effects of criteria air pollutants, such as ozone, lead, and most recently, fine participate matter. Use of probability methods has been suggested by the Office of Management and Budget (OMB) in a report to Congress (2003) and by a National Research Council report, *Estimating the Public Health Benfits of Air Pollution Regulation* (2002). The OMB report cites its new revised regulatory analysis guidelines, which recommend that agencies use formal probabilistic methods be used in all large (over $1 billion) regulatory decisions; some of us (North 2003) commented on the draft of this report saying that time and further research are needed for agencies to gain experience in such methods. The National Academies 2002 report also recommends formal proababilistic methods to EPA. Chapter 5 of this report, “Uncertainty,” provides a detailed review of EPA’s methods in characterizing uncertainty in the health effects of air pollutants, including EPA’s use of formal probabilistic assessments from health experts, and recommends that EPA revise and improve its practices in this area. EPA has made plans to improve its uncertainty analysis. EPA carried out in late 2003 a “pilot” expert elicitation of probabilities on health impacts of fine particulate matter. Preliminary presentation of the methodology and results were recently presented at a professional society meeting (Walker 2004). A review by a Special Panel of EPA’s Science Advisory Board in May 2004 commended EPA for its ambitious plans to carry out improved uncertainty analysis following the recommendations of the 2002 NRC report, but the review noted that EPA plans and achievements were not yet far enough developed so that this SAB Panel could effectively review them (EPA SAB 2004).

Elicitation of probabilities and probabilistic analysis are being used on global climate change. Identification of key uncertainties is an important part of the Third Assessment Report of the International Panel on Climate Change (IPCC 2001). Morgan and Keith (1995) carried out a assessment of judgment from 16 experts in the form of probability distributions on the extent of global temperature rise that would occur with a doubling of atmospheric carbon dioxide levels. Stephen Schneider and others have written extensively on the need for using probability methods for analysis on global climate change (Schneider 2002, North and Schneider 2004).

Value-of-Information Analysis. A highly useful but not frequently used aspect of using quantitative probability methods is that of value-of-information methods. If uncertainty can be resolved before the commitment to a decison alterntive, rather than afterward, the value of the decision situation may be much greater, because what would be by hindsight a mistake may be avoided. The concept is explained in early decison analysis text such as Raiffa, 1968. An application to environmental policy at the Presidential level on weather modification was carried out in the early 1970s (Howard et al. 1972). Yukoda and Thompson (2004) recently compiled a list of published applications of value-of-information analysis to environmental policy decisions. A section on value-of-information analysis is contained in OMB 2003.

An Example of the Use of Value-of-Information Calculations. We shall give an example of value of information calculations from application to environmental policy at the Presidential level on weather modification, carried out in the early 1970s (Howard, Matheson and North, 1972). The main (epistemic) uncertatinty was whether cloud seeding would reduce the maximum winds and therefore the damage caused by a hurricane. There were good data on the aleatory uncertainty, how the maximum wind speed (and therefore damage potential) of a hurricane grows or diminishes over time. There were three scientific hypotheses, only one of which could be true: (1) seeding makes a hurricane less damaging (on the average over many hurricanes), (2) seeding has no effect on the damage caused by the hurricane, and (3) seeding would (on the average over many hurricanes) make a hurricane more damaging. Experimental data and expert judgment were combined to give probabilities of 49% to (1) and (2) and 2% to (3).

In the absence of further information, the alternative of seeding a hurricane approaching a coastal area was caclulated to give an expected reduction of about 20% less property damage. However, reducing property damage was not the only criterion – hurricanes are highly variable in intensity, and a seeded hurricane might intensify. (The probability was calculated to be about 1 chance in 6.) Intensification after seeding might create adverse political, legal and social consequences for those in the government who ordered the seeding: An aroused public might perceive that this action by the government made a "natural disaster" worse! A "government responsibility" cost was therefore assessed, with a high negative value (judged equal to an addition of up to 50% of property damage value, depending on the degree of intensification after seeding). With this government responsbility negative value added to property damage, the alternative of seeding is calculated to be only slightly better (5%) than not seeding the hurricane. This matched the intuition of some government officials, who felt that hurricanes about to hit a coastal area should only be seeded after the experimental evidence that seeding reduced hurricane intensity was overwhelming. So the analysis recognized and incorporated a difficult value judgment – a seeded hurricane is no longer a natural disaster, but altered by human action, with people held responsible for this action if something unexpected and bad happens. The analysis focused not just on "should the US government seed a hurricane approaching the US coast," but also on what it would be worth to resolve the uncertainty on which of the hypotheses is correct: Would seeding reduce hurricane wind speed and therefore the damage caused by hurricanes? Or would cloud seeding do nothing, or even make the hurricane more destructive?

Conisder the decision to seed or not to seed, with present information and with much better information. Suppose the uncertainy can be completely resolved on which of the three scientific hypotheses is correct. If seeding on the average reduces hurricane damage, then the best decision will be to seed. If seeding has no effect or makes hurricanes more damaging, then the best decison is not to seed. The value of better information is calculated by comparing the expected value (more precisely, expected utility) of the decision with current information with the expected value (utility) of the decision situation with better information – but before the better information is known, so we must use probabilities for what the information will turn out to be. The expected value calculation is as follows for making the decision after the uncertainty on which hypothesis is true has been resolved. First, this epistemic uncertainty is resolved we learn which of the three hypotheses is true. And we have the probabilites on the three possibilities: seeding reduces damage: 49%, seeding has no effect: 49%, seeding increases damage: 2%. For each of these possbilities, calculate the expected value of property damage (and government responsibility cost and a small cost to carry out the seeding if the decision is to seed, which is the best decison for the first hypothesis). We multiply each of these results taking the best decision with the new information, times the probability of getting that information, to calculate the expected value of the decision situation with full resolution of the epistemic uncertainty. Then we compare this result to the best decision without the new information – with current uncertainty, described by the probabilities on which hypothesis is correct. The expected improvement in the decision from learning which hypothesis is true before deciding, rather than after, is about 12% of property damage – and this result is an average over aleatory uncertainty on how individual hurricanes vary in intensity over time.

The 12% reduction is a very large number, given that some hurricanes have caused up to about $10 billion in property damage. If government responsbility cost is not included, the value of the information drops by about an order of magnitude. This is because the probabilites used in the analysis implied it was very unlikely (2%) that seeding would on average increase property damage, but a lot more likely (17%) that the first seeded hurricane may intensify between the time it was seeded and the time it impacted a populated coastal area. So the bulk of the value of the information about which scientific hypothesis is correct comes from avoiding the government responsbility of seeding a hurricane if the hypothesis that seeding reduces damage is NOT true – which had a probability slightly over 50%. The main insight from this analysis was the importance of the government responsibility issue, which then became the subject of further legal investigation, as reported in Howard et al. 1972. The analysis also highlighted that value of information was very high compared to the research budget for hurricane research.

It is also possible to calculate the value of experiments that revise the probabilites for the scientific hypotheses. Two experimental hurricane seedings had previously been carried out – a wind reduction of 31% was observed after one seeding, and 15% after another seeding. Were these reductions due to the seedings, or just natural fluctions in hurricane intensity? This pair of experiments provided strong, but not conclusive, evidence in favor of the hypothesis that seeding reduced the wind and hence, property damage. (This previous evidence was factored in to the probabilities discussed above.) The analysis calculated the value of future experimental seedings by looking at how the resulting data (i.e., observed wind change after future seedings) would further change the probabilities on the three scientific hypotheses (via Bayes' Rule, a basic relationship among probabilities). The appropach to valuing experiments is similar, but more complex computationally than for full resolution of uncertainty – one calculates probabilites for the set of possible experimental data that could be obtained, then examines what is the best decision (i.e., that which minimizes expected property damage plus government responsbility cost and the small cost of carrying out the seeding), given each of the possible experimental results. Then one calculates an overall expected value for the decision situation after the seeding experiment, by multplying the expected value with the best decision alternative for each experimental result, times the probability of that experiemtal result will be obtained, and summing over all the possbilities. Then compare the value of the decision situation after the seeding experiement to the expected value of the best decision without the additional information; the difference is the expected value of the information from the experiment. Details and decision tree diagrams are found in Howard, et al. (1972).

Another Example Illustrating Probabilistic Methods: Disposition of Nuclear Waste. One of the most difficult and controversial environmental decisions facing the United States and other nations with civilian and military nuclear power programs is what to do with high-level radioactive waste. In this decison area, the extent of complexity, uncertainty, and ambiguity can be viewed as very high, and so there has been extensive use of analytical tools.

The EPA approval for an operating license for the Waste Isolation Pilot Plant (WIPP) for transuranic waste in Carlsbad, New Mexico followed decades of formal analysis using elaborate models for transport of radioactive materials and extensive probabilistic analysis, under the heading of "performance assessment". A good summary of the history, underlying science, and process up to the point of EPA's granting of the license to place radioactive waste in the WIPP repository is found in National Research Council, 1996b. This report points out opportunities that were missed in the use of performance assessment. A more recent NRC report (2001) addresses spent nuclear reactor fuel and other high-level waste. Chapter 6, "Scientific and Technical Issues in Radioactive Waste Management" of this latter report discusses proper use of models, probability methods, and performance assessment, emphasizing the importance of iterative process and of checking the assumptions in complex mathematical models of radioactivity transport. This report explicitly endorses the analytic-deliberative approach from the NRC 1996a report, with important ideas from this report summarized in a sidebar on page 130.

6. Conclusions

The objective of this paper was to address and discuss the use of decision analytic tools and structuring aids for participatory processes in environmental management. Organizing and structuring discourses goes beyond the good intention to have all relevant stakeholders involved in decision making. The mere desire to initiate a two-way-communication process and the willingness to listen to stakeholder concerns are not sufficient. Discursive processes need a structure that assures the integration of technical expertise, regulatory requirements, and public values. These different inputs should be combined in such a fashion that they contribute to the deliberation process the type of expertise and knowledge that can claim legitimacy within a rational decision making procedure (von Schomberg 1995). It does not make sense to replace technical expertise with vague public perceptions, nor is it justified to have the experts insert their own value judgments into what ought to be a democratic process.

Decision analytic tools can be of great value for structuring participatory processes. They can provide assistance in problem structuring, in dealing with complex scientific issues and uncertainty, and in helping a diverse group to understand disagreements and ambiguity with respect to values and preferences. Decision analysis tools should be used with care. They do not provide an algorithm to reach an answer as to what is the best decision. Rather, decision analysis is a formal framework that can be used for environmental assessment and environmental decision making to explore difficult issues, to focus debate and further analysis on the factors most important to the decision, and to provide for increased transparency and more effective exchange of information and opinions among the process participants. The basic concepts are relatively simple and can be implemented with a minimum of mathematics (Hammond et al. 1999). Many participation organizers have restricted the use of decision analytic tools to assist participants in structuring problems and ordering concerns and evaluations, and have refrained from going further into quantitative trade-off analysis. Others have advocated quantitative modeling as a clarification tool for making value conflicts more transparent to the participants.

The full power of decision analysis for complex environmental problem may require mathematical models and probability assessment. Experienced analysts may be needed to guide implementation of these analytical tools for aiding decisions. Skilled communicators and facilitators may be needed to achieve effective interaction between analysts and participants in the deliberative process whose exposure to advanced analytical decision aids is much less, so that understanding of both process and substance, and therefore transparency and trust, can be achieved.

Many environmental agencies are making use of decision analysis tools. We urge them to use these tools in the context of an iterative, deliberative process with broad participation by the interested and affected parties to the decision. The analytical methods, the data and judgment, and the assumptions, as well as the analytical results should be readily available and understood by the participants. The Office of Management and Budget is encouraging decision analysis methods (OMB 2003). We believe that both the agencies and the interested groups within the public that government agencies interact with on environmental decisions should all gain experience with these methods. Improper or premature use of sophisticated analytical methods may be more destructive to trust and understanding than helpful in resolving the difficulties of complexity, uncertainty, and ambiguity.

6. Bibliography

Arkes, H. R.: "Costs and Benefits of Judgment Errors: Implications for Debiasing." *Psychological Bulletin,* 110, (1991), 486-498.

Arrow, K.J.: *Social Choice and Individual Values* (Yale University Press: New Haven 1951, second edition 1963)

Arvai, J., Gregory, R., and McDaniels, T.: "Testing a Structured Decision Approach: Value Focused Thinking for Deliberative Risk Communication." *Risk Analysis,* 21, No. 6 (2001), 1065-1076.

Asselt, van M.B.A.: *Perspectives on Uncertainty and Risk* (Kluwer: Dordrecht and Boston 2000).

Bardach, E.: *The Eight-Step Path of Policy Analysis* (Berkeley Academic Press: Berkeley 1996).

Behn, R.D. and Vaupel, J.V.: *Quick Analysis for Busy Decision Makers* (Basic: New York 1982).

Bell, D. E.: "Regret in Decision Making under Uncertainty." *Operations Research,* 30 (1982), 961-981.

Bingham, G.: *Resolving Environmental Disputes: A Decade of Experience* (The Conservation Foundation: Washington, D.C. 1984).

Brehmer, B.: "The Psychology of Risk." In: W.T. Singleton and J. Howden (eds.): *Risk and Decisions* (Wiley: New York 1987), 25-39.

Buckle, L.G. and Thomas-Buckle, S.R.: "Placing Environmental Mediation in Context: Lessons from 'Failed' Mediations." *Environmental Impact Assessment Review*, 6 (1986), 55-70.

Buser, M.: *Die Wertbaumanalyse im Projekt Aargau: eine kritische Bestandsaufnahme.* Manuscript. Swiss Institute of Technology (Zürich 1995).

Caruso, D.: "No Risk Is an Island." *Harvard Business Review*, (February 2005), 40-41.

Chess, C.; Dietz, Th. and Shannon, M.: "Who Should Deliberate When?" *Human Ecology Review,* 5, No. 1 (1998), 60-68.

Clemen, R.: *Making Hard Decisions: An Introduction to Decision Analysis* (Duxbury Press: Belmont, California 1996).

Coglianese, C.: "Assessing Consensus; The Promise and Performance of Negotiated Rule Making." *Duke Law Journal,* 46 (1997), 1255-1333.

Cohen, J.: "Procedure and Substance in Deliberative Democracy." In J. Bohman and W. Rehg (eds.): *Deliberative Democracy. Essays on Reason and Politics* (MIT Press: Cambridge 1997), 407-437.

Cox, R.T.: *The Algebra of Probable Inference* (Johns Hopkins Press: Baltimore, Maryland 1961).

Creighton, J.: "A Comparison of Successful and Unsuccessful Public Involvement: A Practioner's Viewpoint." In: C. Zervos (ed.), *Risk Analysis: Prospects and Opportunities* (Plenum Press: New York 1991), 135-141.

Dawes, R.M.: *Everyday Irrationality: How Pseudoscientists, Lunatics, and the Rest of Us Fail Think Rationally*. (Westview Press: Boulder 2001a).

Dawes, R.M.: *Rational Choice in an Uncertain World.* (Original published by Harcourt, Brace, Jovanovich). Second edition. (Sage Press: San Diego 2001b).

De-Marchi, B. and Ravetz, J.R.: "Risk Management and Governance: A Post-Normal Science Approach." *Futures,* 31 (1999), 743-757.

Dietz, T. and Stern, P.: "Toward a Theory of Choice: Socially Embedded Preference Construction." *Journal of Socio-Economics,* 24 (1995), 261-279.

Dodgson, J.; Spackman, M.; Pearman, A.; Phillips, L. D.: *Multi-Criteria Analysis: A Manual*. Department of the Environment, Transport and the Regions (London School of Economics: London 2000).

Edwards, W.: "The Theory of Decision Making." *Psychological Bulletin,* 51 (1954), 380-417.

Edwards, W.: "How to Use Multi-attribute Utility Measurement for Social Decision Making." IEEE Transactions on Systems, Man, and Cybernetics, SMC-7 (1977), 326-340.

Einhorn, H.J. and Hogarth, R.M.: "Confidence in Judgment: Persistence of the Illusion of Validity." *Psychological Review,* 85 (1978), 395-416.

Einhorn, H.J. and Hogarth, R.M.: "Behavioral Decision Theory: Processes of Judgment and Choice." *Annual Review of Psychology*, 32 (1981), 53-88.

Festinger, L.: *A Theory of Cognitive Dissonance* (Stanford University Press: Stanford 1957).

Fishburn, P.: "Subjective Expected Utility: A Review of Normative Theories." *Theory and Decision*, 13 (1981), 139-199.

Fischhoff, B. (1975): "Hindsight Versus Foresight: The Effect of Outcome Knowledge on Judgment under Uncertainty." *Journal of Experimental Psychology: Human Perception and Performance,* 1 (1975), 288-299.

Fischhoff, B., Slovic, P., & Lichtenstein, S.: “Knowing with Certainty: The Appropriateness of Extreme Confidence.” *Journal of Experimental Psychology: Human Perception and Performance,* 3 (1977), 552-564.

Fischhoff, G.; Goitein, B. and Shapiro, Z.: “The Experienced Utility of Expected Utility Approaches.” In: N.T. Feather (ed.): *Expectations and Actions: Expectancy-Value Models in Psychology* (Lawrence Erlbaum: Hillsdale 1982), 315-340.

Fiorino, D. J.: “Environmental Risk and Democratic Process: A Critical Review.” *Columbia Journal of Environmental Law,* 14, No. 2 (1989), 501-547.

Fiorino, D. J.: “Citizen Participation and Environmental Risk: A Survey of Institutional Mechanisms.” *Science, Technology, & Human Values*, 15, No. 2 (1990), 226-243.

Foster, H.: *The Role of Experts in Risk-Based Decision Making*. HSE Risk Assessment Policy Unit. WEB Manuscript. www.trustnetgovernance.com/library/pdf/doc2.PDF. Trustnet-Paper (London 2002).

Frey, B. und Oberholzer-Gee, F.: “Fair Siting Procedures: An Empirical Analysis of Their Importance and Characteristics.” *Policy Analysis and Management,* 15 (1996), 353-376.

Funtowicz, S.O. and Ravetz, J.R.,: “Three Types of Risk Assessment and the Emergence of Post-Normal Science.” In S. Krimsky and D. Golding (eds): *Social Theories of Risk*, (Praeger: Westport 1992), 251-273.

Funtowicz, S.O. and Ravetz, J.R.: “Science for the Post-Normal Age.” *Futures* 25, No. 7 (1993), 739-755.

Gregory, R.S.: “Valuing Risk Management Choices”. In. T. McDaniels and M.J. Small (eds); *Risk Analysis and Society: An Interdisciplinary Characterization of the Field.* (Cambridge University Press: Cambridge 2004), 213-250.

Gregory, R., McDaniels, T., and Fields, D.: “Decision Aiding, Not Dispute Resolution: A New Perspective for Environmental Negotiation." *Journal of Policy Analysis and Management,* 20, No. 3 (2001), 415-432.

Gigerenzer, G.: “How to Make Cognitive Illusions Disappear: Beyond ‘Heuristics and Biases.’” *European Review of Social Psychology*, 2, (1991), 83-115.

Giegerenzer, G.: “On Narrow Norms and Vague Heuristics: A Reply to Kahneman and Tversky”. *Psychological Review,* 103 (1996), 592-596.

Gigerenzer, G. and Selten, R.: “Rethinking Rationality.” In G. Gigerenzer and R. Selten (eds.): *Bounded Rationality: The Adaptive Toolbox. Dahlem Workshop Report*. (MIT Press: Cambridge 2001), 1-12.

Goldstein, D.G., and Gigerenzer, G.: “The Recognition Heuristic: How Ignorance Makes Us Smart.” In: G. Gigerenzer, P. M. Todd and the ABC Research Group (eds.): *Simple Heuristics That Make Us Smart*. (Oxford University Press: Oxford 1999), 37-58.

Guagnano, G.A.; Stern, P.C. and Dietz, T.: “Willingness to Pay for Public Goods: A Test of the Contribution Model.” *Psychological Science,* 5 (1994), 411-415.

Habermas, J.: “Towards a Theory of Communicative Competence.”' *Inquiry,* 13 (1970), 363-372.

Habermas, J.: *Theory of Communicative Action. Vol. II: Reason and the Rationalization of Society* (Beacon Press: Boston 1987a).

Habermas, J.: *The Philosophical Discourse of Modernity* (Polity Press: Cambridge 1987b).

Hammond, K.R.: *Human Judgment and Social Policy* (Oxford University Press: Cambridge 1996).

Hammond, J.; Keeney, R. and Raiffa, H.: *Smart Choices: A Practical Guide to Making Better Decisions* (Harvard Business School Press: Cambridge 1999).

Heap, S.H.; Hollis, M.; Lyons, B.; Sugden, R. and Weale, A.: *The Theory of Choice: A Practical Guide* (Blackwell: Oxford 1992).

Heimer. C.; “Social Structure, Psychology, and the Estimation of Risk.” *Annual Review of Sociology ,* 14, (1988), 491-519.

Hofstede, G.: *Culture’s Consequences: Comparing Values, Behaviors, Institutions, and Organizations across Nations*. Second Edition (Sage: Newbury Park 2003).

Howard, R.A., “Decision Analysis: Applied Decision Theory.” *Proceedings of the Fourth International Conference on Operational Research* (D.B. Hertz and J. Melese, eds., Wiley-Interscience: New York 1966. Reprinted in Howard and Matheson, 1989, 581-589.

Howard, R.A.: “The Foundations of Decision Analysis.” *IEEE Transactons on Systems Science and Cybernetics,* Vol. SSC-4(3) (1968), 211-219. Reprinted in Howard and Matheson, 1989, 97-113.

Howard, R.A.; Matheson, J.E. and North, D.W.: “The Decision to Seed Hurricanes.” *Science*, 176 (1972) 1191-1202. http://www.northworks.net/hurricanes.pdf

Howard. R.A. and Matheson, J.E. (eds): *The Principles and Applications of Decision Analysis.* Two Volumes (Strategic Decisions Group: Menlo Park, California 1989).

Humphreys, P.: “Application of Multi-Attribute Utility Theory.” In: H. Jungermann and D. de Zeeuw (eds.): *Decision Making and Change in Human Affairs* (Reidel: Dordrecht 1977), 165-205.

Intergovernmental Panel on Climate Change, *IPCC Third Assessment Report*, 2001. www.grida.no/climate/ipcc_tar/

Jasanoff, S.: “Beyond Epistemology: Relativism and Engagement in the Politics of Science.” *Social Studies of Science,* 26, 2 (1996), 393-418.

Jäger, J.: “Current Thinking on Using Scientific Information in Environmental Policy Making.” *Environmental Modelling & Assessment* 3 (1998), 143-154.

Jaeger, C.C.; Renn, O.; Rosa, E.A. und Webler, Th.: *Risk, Uncertainty and Rational Action* (Earthscan: London 2001).

Jaynes, E.T.: *Theory of Probability* (Cambridge University Press, New York, 2003).

Jeffreys, H.: *Theory of Probability,* 3rd edition. (Clarendon Press: Oxford, 1961).

Jungermann, H.: "The Two Camps of Rationality." In. H.R. Arkes and K. R. Hammond (eds.): *Judgment and Decision Making: An Interdisciplinary Reader* (Cambridge University Press: Cambridge 1986), 465-471.

Kahneman, D. and Tversky, A., "Judgment under Uncertainty: Heuristics and Biases." *Science,* 185, (1974), 1124-1131.

Kahneman, D. and Tversky, A., "Prospect Theory: An Analysis of Decision under Risk." *Econometrica* , 47, (1979), 263-291.

Kahneman, D.; Slovic, P. and Tversky, A.: *Judgment under Uncertainty: Heuristics and Biases* (Cambridge University Press: New York 1982).

Keeney, R.L.: "Structuring Objectives for Problems of Public Interest." *Operations Research,* 36, (1988), 396-405.

Keeney, R.L.: *Value Focused Thinking: A Path to Creative Decision Making* (Harvard University Press: Cambridge 1992).

Keeney, R.L.: "Framing Public Policy Decisions." *International Journal of Technology, Policy, and Management*, 4, No. 2 (2004), 95-115.

Keeney, R.L.: "Making Better Decision Makers." *Decision Analysis*, 1 No. 4, (December 2004), 193-204.

Keeney, R.L., and Gregory, R.S.: "Making Smarter Environmental Decisions." *Journal of the American Water Resources Association*, 38, (2002), 1601-1612.

Keeney, R.L., and McDaniels, T.L.: "A Framework to Guide Thinking and Analysis Regarding Climate Change Policies." *Risk Analysis*, 21 (2001), 989-1000.

Keeney, R.L. and Raiffa, H.: *Decision with Multiple Objectives: Preferences and Value Tradeoffs* (Wiley: New York 1976).

Keeney, R.L.; Renn, O.; and von Winterfeldt, D., and Kotte, U,: *Die Wertbaumanalyse. Entscheidungshilfe für die Politik* (HTV Edition "Technik und Sozialer Wandel": Munich 1984).

Keeney, R.L.; Renn, O.; and von Winterfeldt, D.: "Structuring West Germany's Energy Objectives." *Energy Policy,* 15, No. 4 (August 1987), 352-362.

Keeney, R.L., and von Winterfeldt, D., "Managing Nuclear Waste from Power Plants." *Risk Analysis*, 14, (1994), 107-130.

Kemp, R., "Planning, Political Hearings, and the Politics of Discourse." In: J. Forester (ed.): *Critical Theory and Public Life* (MIT Press: Cambridge 1985), 177-201.

Klein, G.: "Developing Expertise in Decision Making." *Thinking and Reasoning* 3, No. 4 (1997), 337-352.

Klinke; A. and Renn, O.: "A New Approach to Risk Evaluation and Management: Risk-Based, Precaution-Based and Discourse-Based Management." *Risk Analysis,* 22, No. 6 (December 2002), 1071-1994.

Koehler, J. J.: "The Base Rate Fallacy Reconsidered: Normative, Descriptive and Methodological Challenges." *Behavioral and Brain Sciences,* 19, (1996), 1-53.

Koenig, A. and Jasanoff, S.: *A Comparison of Institutional Changes to Improve the Credibility of Expert Advice for Regulatory Decision Making in the US and EU.* A Study for the European Commission (EU: Brussels 2001).

Laird, F.: "Participatory Analysis: Democracy and Technological Decision Making." *Science, Technology, and Human Values* 18, No. 3 (1993), 341-361.

Lee, T.R.: "The Public Perception of Risk and the Question of Irrationality." In: Royal Society of Great Britain (ed.): *Risk Perception ,* Vol. 376 (Royal Society: London 1981), 5-16.

Lopes, L.L.: "Some Thoughts on the Psychological Concept of Risk." *Journal of Experimental Psychology: Human Perception and Performance,* 9, (1983), 137-144.

Loewenstein, G.F.; Weber, E.U.; Hsee, C.K. and Welch, E.S.: "Risk as Feelings." *Psychological Bulletin,* 127 (2001), 267.286.

Luce, R.D. and Weber, E.U.: "An Axiomatic Theory of Conjoint, Expected Risk." *Journal of Mathematical Psychology* , 30, (1986), 188-205.

McCarthy, T.: "Translator's Introduction." In: J. Habermas: *Legitimation Crisis* (Beacon Press: Boston 1975).

McDaniels, T.: "The Structured Value Referendum: Eliciting Preferences for Environmental Policy Alternatives." *Journal of Policy Analysis and Management,* 15, No. 2 (1996), 227-251.

McDaniels, T.: "Creating and Using Objectives for Ecological Risk Assessment and Management." *Environmental Science and Policy,* 3, (2000), 299-304.

McDaniels, T. and Thomas, K.: "Eliciting Public Preferences for Local Land Use Alternatives: A Structured Value Referendum with Approval Voting." *Journal of Policy Analysis and Management,* 18, No.2 (1999), 264-280.

Merkhofer, M.W. (1987). "Quantifying Judgmental Uncertainty: Methodology, Experiences, and Insights." *IEEE Transactions on Systems, Man, and Cybernetics*. 17, No. 5 (1987), 741-752.

Merkhofer, M.W.: "Comparative Analysis of Formal Decision-Making Approaches." In: V.T. Covello, J. Menkes. und J. Mumpower (eds.): *Risk Evaluation and Management* (Plenum: New York 1984), 183-220.

Morgan, M.G. and Keith, D.W.: "Subjective Judgments by Climate Experts," *Environmental Science and Technology*, 29, No. 10 (1995), 468A-476A.

Morgan, M.G. and Henrion, M.: *Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis* (Cambridge University Press: Cambridge, UK, 1990).

Moore, C.: "Defining 'Successful' Environmental Dispute Resolution: Case Studies from Public Land Planning in the United States and Australia." *Environmental Impact Assessment Review,* 16 (1996), 151-169.

National Academy of Engineering, *Accident Precursor Analysis and Management: Reducing Quantitative Risk Through Diligence* (National Academy Press: Washington, D.C. 2004). http://books.nap.edu/catalog/11061.html

National Research Council, Committee on Institutional Means for Assessing Risk to Public Health, *Risk Assessment in the Federal Government: Managing the Process* (National Academy Press: Washington, D.C. 1983). http://books.nap.edu/catalog/366.html

National Research Council, Committee on Decision Making and Problem Solving, *Research Briefing Panel on Decision Making and Problem Solving.* (National Academy Press: Washington, D.C. 1986). http://books.nap.edu/catalog/911.html

National Research Council, Committee on Risk Characterization, *Understanding Risk: Informing Decisions in a Democratic Society.* (National Academy Press: Washington, D.C.1996a). http://books.nap.edu/catalog/5138.html

National Research Council, Committee on the Waste Isolation Pilot Plant, *The Waste Isolation Pilot Plant: A Potential Solution for the Disposal of Transuranic Waste.* (National Academy Press: Washington, D.C. 1996b). http://books.nap.edu/catalog/5269.html .

National Research Council, *Disposition of High-Level Waste and Spent Nuclear Fuel: The Continuing Societal and Technical Challenges* (National Academy Press: Washington, D.C., 2001). http://books.nap.edu/catalog/10119.html .

National Research Council, *Estimating the Public Health Benefits of Air Pollution Regulation,* (National Academy Press: Washington, D.C. 2002). http://books.nap.edu/catalog/10511.html.

National Research Council, *Decision Making for the Environment: Social and Behavioral Research Priorities,* (National Academy Press: Washington, DC, 2005). http://books.nap.edu/catalog/11186.html

North, D.W.: "A Tutorial Introduction to Decision Theory." *IEEE Transactions on Systems Science and Cybernetics,* Vol. SSC-4, No. 3, (1968), 200-210. Reprinted in Howard and Matheson, 1989, 117-127.

North, D.W.: Comments on Draft of OIRA/OMB Report to Congress, 2003, http://www.whitehouse.gov/omb/inforeg/2003report/294.pdf. See in this respect also www.epa.gov/sab/pdf/eeac1198.pdf .

North, D.W. and Merkhofer,M.W.: "A Methodology for Analyzing Emission Control Strategies.“ *Computers and Operations Research*, 3 (1976), 185-207.

North, D.W. and Schneider, S. “Global Climate Change: A Survey of the Science and Policy Implications.” Presentation at the Stuttgart, Germany *Congress on Global Climate Alteration and Energy Policy,* October 11, 2004, in press for the conference proceedings. www.northworks.net/w_pub_stuttgart.htm

Office of Management and Budget, Office of Information and Regulatory Affairs, *Informing Regulatory Decisions: 2003 Report to Congress on the Costs and Benefits of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities* (Government Printing Office: Washington, D.C. 2003). http://www.whitehouse.gov/omb/inforeg/2003_cost-ben_final_rpt.pdf

Patil, S.R. and Frey, H.C.: “Comparison of Sensitivity Analysis Methods Based on Applications to a Food Safety Risk Assessment Model.” *Risk Analysis* 24, No. 3 (2004), 573-586.

Pettit, P.: “Decision Theory and Folk Psychology.” In: M. Bacharach and S. Hurley (eds.): *Foundations of Decision Theory: Issues and Advances* (Blackwell: Cambridge 1991), 147-175.

Phillips, L.D.: *Introduction to Decision Analysis.* Tutorial Paper 79-1 (London School of Economics and Political Science: London 1979).

Pidgeon, N.F.: “The Limits to Safety? Culture, Politics, Learning and Manmade Disasters.” *Journal of Contingencies and Crisis Management,* 5, No. 1 (1997), 1-14.

Pinkau, K. and Renn, O. (eds.): *Environmental Standards. Scientific Foundations and Rational Procedures of Regulation with Emphasis on Radiological Risk Management.* (Kluwer: Dordrecht and Boston 1998).

Plous, S.: *The Psychology of Judgment and Decision Making* (McGraw-Hill: New York 1993).

Pollatsek, A. and Tversky, A.: “A Theory of Risk.” *Journal of Mathematical Psychology,* 7, (1970), 540-553.

Quinn, R.E. and Rohrbaugh, J.W.: “A Competing Values Approach to Organizational Analysis.” *Public Productivity Review,* 5 (1981), 141-159.

Quinn, R. E. and Rohrbaugh, J. W.: “A Spatial Model of Effectiveness Criteria: Towards a Competing Values Approach to Organizational Analysis.” *Management Science*, 29 (1983), 369-381.

Raiffa, H.: *Decision Analysis: Introductory Lectures on Choices under Uncertainty* (Addison-Wesley: Reading 1968).

Raiffa, H.: *The Art and Science of Negotiation.* 12th edition (Cambridge University Press: Cambridge 1994).

Renn, O.: "Decision Analytic Tools for Resolving Uncertainty in the Energy Debate." *Nuclear Engineering and Design,* 93, No. 2 and 3 (1986), 167-180.

Renn, O.: "Risk Analysis: A Need to Communicate." *Forum for Applied Research and Public Policy,* 2 (Summer 1989), 86-92.

Renn, O.: "A Model for an Analytic-Deliberative Process in Risk Management." *Environmental Science and Technology,* 33, No. 18 (1999), 3049-3055.

Renn, O.: "The Challenge of Integrating Deliberation and Expertise: Participation and Discourse in Risk Management." In. T. McDaniels and M.J. Small (eds); *Risk Analysis and Society. An Interdisciplinary Characterization of the Field.* (Cambridge University Press: Cambridge 2004), 289-366.

Roch, I.: *Evaluation der 3. Phase des Bürgerbeteiligungsverfahrens in der Region Nordschwarzwald.* Research Report No. 71 (Center of Technology Assessment: Stuttgart 1997).

Rohrmann, B.: "The Evaluation of Risk Communication Effectiveness." *Acta Psychologica,* 81 (1992), 169-192.

Ross, L.D.: "The Intuitive Psychologist and his Shortcomings: Distortions in the Attribution Process." In: L. Berkowitz (eds.): *Advances in Experimental Social Psychology*, Vol.10 (Random House: New York: 1977), 172-220.

Rowe, G. and Frewer, L.J.: "Public Participation Methods: A Framework for Evaluation." *Science, Technology & Human Values,* 225, No. 1 (2000), 3-29.

Rossi, J.: "Participation Run Amok: The Costs of Mass Participation for Deliberative Agency Decisionmaking," *Northwestern University Law Review,* 92 (1997), 173-249.

Savage, L.J.: *The Foundations of Statistics* (Wiley: New York, 1954).

Schneider, S.: "Can We Estimate the Likelihood of Climate Changes at 2100?" *Climate Change,* 52 (2002), 441-451.

Schneider, E.; Oppermann, B. and Renn, O.: "Experiences from Germany: Application of a Structured Model of Public Participation in Waste Management Planning." *Interact. Journal of Public Participation,* 4, No. 1 (July 1998), 63-72.

Shafir, E. and LeBoeuf, R.A.: "Rationality." *Annual Review of Psychology*, 53 (2002), 491-517.

Shoemaker, P.J.: "The Expected Utility Model: Its Variants, Purposes, Evidence, and Limitations." *Journal of Economic Literature,* 30 (1982), 529-563.

Simon, H. A.: "A Behavioural Model of Rational Choice." *The Quarterly Journal of Economics,* Vol LXIX (1955), 99-118.

Simon, H.A.: *Models of Bounded Rationality.* Vol. I-III. (MIT-Press: Cambridge 1982).

Skillington, T.: "Politics and the Struggle to Define: A Discourse Analysis of the Framing Strategies of Competing Actors in a 'New' Participatory Forum." *British Journal of Sociology,* 48, No. 3 (1997), 493-513.

Skinner, D.C.: *Introduction to Decision Analysis*. Second Edition (Probabilistic Publisher: New York 1999).

Slovic, P.; Fischhoff, B. and Lichtenstein. S.: "Behavioral Decision Theory." *Annual Review of Psychology,* 28 (1977), 13-28.

Spetzler, C. S., and Staël von Holstein, C-A.: "Probability Encoding in Decision Analysis." *Management Science* 22 (1975) 340-352.

Stirling, A.: "Participatory Processes and Scientific Expertise: Precaution, Diversity and Transparency in the Governance of Risk." In: International Institute for Environment and Development (ed.): *Participatory Learning and Action,* (International Institute for Environment and Development: Brighton, Winter 2000-2001).

Talbot, A.: *Settling Things: Six Case Studies in Environmental Mediation.* (Conservation Foundation: Washington, D.C. 1983).

Thaler, R.: "Mental Accounting Matters." *Journal of Behavioral Decision Making*, 12, (1999), 183-206.

Tuler, S.: *Meanings, Understandings, and Interpersonal Relationships in Environmental Policy Discourse*. Doctoral Dissertation (Clark University: Worcester 1996).

Tuler, S. and Webler, Th.: "Designing an Analytic Deliberative Process for Environmental Health Policy Making in the U.S. Nuclear Weapons Complex." *Risk: Health, Safety & Environment,* 10, Vol. 65 (Winter 1999), 65-87.

Tversky, A. and Kahneman, D.: "The Framing of Decisions and the Psychology of Choice." *Science,* 211 (1981), 453-458.

USEPA, Science Advisory Board: *Review of the Revised Analytical Plan for EPA's Second Prospective Analysis – Benefits and Costs of the Clean Air Act 1990-2020,* An Advisory by a Special Panel of the Advisory Council on Clean Air Compliance Analysis, Report to the EPA Administrator, May 2004. www.epa.gov/sab/pdf/council_adv_04004.pdf

von Schomberg, R.: "The Erosion of the Valuespheres. The Ways in Which Society Copes with Scientific, Moral and Ethical Uncertainty." In: R. von Schomberg (ed.): *Contested Technology. Ethics, Risk and Public Debate* (International Centre for Human and Public Affairs: Tilburg 1995), 13-28.

von Winterfeldt, D.: "Structuring Decision Problems for Decision Analysis." *Acta Psychologica ,* 45 (1980), 71-93.

von Winterfeldt, D.: “Value Tree Analysis: An Introduction and an Application to Offshore Oil Drilling.” In: P.R. Kleindorfer and H.C. Kunreuther (eds.): *Insuring and Managing Hazardous Risks: From Seveso to Bhopal and Beyond* (Springer: Berlin 1987), 439-477.

von Winterfeldt, D., and Edwards, W.: *Decision Analysis and Behavioral Research* (Cambridge University Press: Cambridge 1986).

Vorwerk, V. and Kämper, E.: *Evaluation der 3. Phase des Bürgerbeteiligungsverfahrens in der Region Nordschwarzwald.* Working Report No. 70 (Center of Technology Assessment: Stuttgart 1997).

Wallsten, T.S. and Budescu, D.V.: “Encoding Subjective Probabilities: A Psychological and Psychometric Review.” *Management Science*, 29 (1983) 151-173,

Walker , K.D. et al.: 4 papers presented at the symposium: “Scientific Issues in the Regulation of Fine Particulates.” *Society of Risk Analysis Annual Meeting,* Palm Springs, California, December 7, 2004.

Warren, M.E.: ”Can Participatory Democracy Produce Better Selves? Psychological Dimensions of Habermas Discursive Model of Democracy.” *Political Psychology,* 14 (1993), 209- 234.

Webler, Th.: “‘Right’ Discourse in Citizen Participation. An Evaluative Yardstick.” In: O. Renn, Th. Webler and P. Wiedemann (eds.): *Fairness and Competence in Citizen Participation. Evaluating New Models for Environmental Discourse* (Kluwer: Dordrecht and Boston 1995), 35-86.

Webler, Th.: “The Craft and Theory of Public Participation: A Dialectical Process.” *Risk Research,* 2, No. 1 (1999), 55-71.

Webler, Th. and Renn, O.: “A Brief Primer on Participation: Philosophy and Practice.” In: O. Renn, Th. Webler and P. Wiedemann (eds.): *Fairness and Competence in Citizen Participation. Evaluating New Models for Environmental Discourse* (Kluwer: Dordrecht and Boston 1995), 17-34.

Wondollek, J.M.: “The Importance of Process in Resolving Environmental Disputes.” *Environmental Impact Assessment Review*, 5 (1985), 341-356.

Wynne, B.: "Risk and Social Learning: Reification to Engagement." In: S. Krimsky and D. Golding (eds.): *Social Theories of Risk* (Praeger: Westport 1992), 275-297.

Yates, F.: *Judgment and Decision Making* (Prentice Hall: Englewood Cliffs 1990).

Yokota, F. and Thompson, K.M.: “The Value of Information in Environmental Health Risk Management Decisions: Past, Present, and Future.” *Risk Analysis,* 24, No. 3 (2004), 635-650.