Participatory Modelling and Decision Support for Natural Resources Management in Climate Change Research

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Summary

The ever greater role given to public participation by laws and regulations, in particular in the field of environmental management calls for new operational methods and tools for managers and practitioners. This paper analyses the potentials and the critical limitations of current approaches in the fields of simulation modelling (SM), public participation (PP) and decision analysis (DA), for natural resources management within the context of climate change research. The potential synergies of combining SM, PP and DA into an integrated methodological framework are identified and a methodological proposal is presented, called NetSyMoD (Network Analysis – Creative System Modelling – Decision Support), which aims at facilitating the involvement of stakeholders or experts in policy - or decision-making processes (P/DMP). A generic P/DMP is formalised in NetSyMoD as a sequence of six main phases: (i) Actors analysis; (ii) Problem analysis; (iii) Creative System Modelling; (iv) DSS design; (v) Analysis of Options; and (vi) Action taking and monitoring. Several variants of the NetSyMoD approach have been adapted to different contexts such as integrated water resources management and coastal management, and, recently it has been applied in climate change research projects. Experience has shown that NetSyMoD may be a useful framework for skilled professionals, for guiding the P/DMP, and providing practical solutions to problems encountered in the different phases of the decision/policy making process, in particular when future scenarios or projections have to be considered, such as in the case of developing and selecting adaptation policies. The various applications of NetSyMoD share the same approach for problem analysis and communication within the group of selected actors, based upon the use of creative thinking techniques, the formalisation of human-environment relationships through the DPSIR framework, and the use of multi-criteria analysis through a Decision Support System (DSS) software.

Keywords: Modelling, Public Participation, Natural Resource Management, Policy, Decision-Making, Governance, DSS

JEL Classification: Q5

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1 Introduction

In recent years, the management of natural resources has become an issue of increasing complexity for several reasons. First of all, one should recognise that the problems themselves are of an intrinsic complexity, deriving from the very nature of ecosystems and in particular of those in which natural drivers interact with ever changing human activities. Secondly, we observe that environmental issues are always subject of diversified – and often conflicting – interests (economic, social, cultural ones). Moreover, the general public has shown increasing attention for environmental matters, and thus groups and even individual citizens are willing to be better informed and directly involved in planning and decision-making. Natural resource management (NRM) has thus become concerned with the integration of scientific knowledge and economics with social problems, such as conflict management, the settlement of disputes and the mitigation of divergent interests and values. Fundamental uncertainties and the risk of irreversible environmental changes make NRM a more challenging task, since they give rise to different perspectives about the nature, policy implications, or even the existence of a problem.

Science is not always able to give unambiguous responses to complex problems and phenomena such as climate change, biodiversity loss, and environment-related diseases, thus competing values and contradictory beliefs increasingly dominate the policy-making discourses. In this situation, growing attention has been paid to designing transparent planning/management processes, using interdisciplinary, pluralistic, and inclusive methodologies, with the ultimate objective of achieving more robust and informed decision-making.

The current situation raises the need for new or improved integrated approaches in which the knowledge of diverse disciplines is combined in a single methodological and operational framework. As stated above, the "traditional" knowledge in physical/environmental sciences upon which NRM has been based in the past, should then be integrated with sound economic methods (this being the field of nowadays consolidated disciplines, such as environmental economics), but also with methods borrowed and adapted from sociology, information and communication sciences and other disciplines. Three areas are of greater interest for supporting those integration efforts with robust methodological approaches and tools: simulation modelling (SM), public participation (PP) and decision analysis (DA).

- SM embodies the disciplinary scientific knowledge of phenomena – physical or otherwise – and as such it is crucial in analysing socio-ecosystems for NRM processes. It can be useful to explore and project into the future the effects of (new) policies, or of other drivers, such as climate change, and, with adequate interfaces, SM may support communication between the various disciplinary experts, and with a broader public of interested people.
- At the heart of the PP paradigm is the will to balance the rights of majorities and minorities in public decisions, and the belief that inefficient policies and practices in environmental management are often a consequence of top-down approaches, failing to integrate stakeholders' concerns, aspirations and constraints (Byrne and Davies, 1998).
- DA encompasses methods and normative frameworks to structure decision problems, generate/elicit and aggregate preferences (value judgements) on different aspects of pursued polices. DA plays a fundamental role when multiple actors are

involved in the decision process, by introducing robustness and transparency and in mitigating the biases caused by humans' limited capacity to compare multiple benefits and make trade-offs explicit.

There is a vast literature focusing on each of these three areas, promoting various methodological approaches as means to seize the challenges posed by complex environmental problems, either within each single discipline, or combining several disciplines. Yet, the application of each of the proposed approaches is prone to flaws and shortcomings which may have significant impacts on the final results of the policy, planning or decision-making processes, ultimately determining their success or failure.

In the present work we will support the thesis that a significant improvement in climate change policies and the practice of NRM can come from the integration of SM, PP and DA. We postulate that accepting the challenge of addressing the key limitations of the three methodological approaches in an integrated manner, rather than in isolation, will provide an opportunity to implement the principles of sustainable development in policy/decision making, and, in particular will allow to combine the search for inter-generational equity with the projection of plausible futures, as affected by the evolution of the main human and environmental drivers, including climate.

The paper aims firstly at reviewing theoretical and methodological aspects (Section 2) and secondly at presenting an operational approach developed to integrate SM, PP and DA in NRM (Section 3). In particular, in Section 2, we review the potentials and the most important limitations in the context of SM, PP and DA, alongside with the methodological variety which characterises these approaches. Section 2 concludes by identifying the potential synergies of combining SM, PP and DA into an integrated methodological framework. In Section 3 we outline a proposed framework for participatory modelling and decision support, in which, we argue, it is feasible to address disciplinary shortcomings and provide operational guidelines for policy support. Experiences gained in several recent research projects in the field of NRM in general, and water resource management in particular, are referred to for concreteness' sake. Section 4 concludes the paper.

2 Modelling, participation and decision support

2.1 Simulation models and the management of natural resources

Models are common in a range of disciplines and different frameworks of knowledge production. In general, models can be used to (i) measure and represent; (ii) describe structure, behaviour and pattern; (iii) reconstruct past or predict future developments; (iv) generate and test theories and hypotheses; (v) surface, encode, transfer, evaluate and interpret knowledge; (vi) guide development and assessment of policies; and (vii) facilitate collective learning and settlement of disputes (Beven, 2002; Jakeman *et al.*, 2006; Morton, 1990; van Daalen *et al.*, 2002). Models' roles are almost as diverse as their uses and modelling paradigms employed. Multiple commonly used interpretations of the term "model" (Massoud *et al.*, 1998; Meadows and Robinson, 1985; Norton, 1986) lead to different, though interrelated, attainments of models and modelling pursuit. This variety is understandable, given models' critical importance as instruments for scientific investigation and decision-making (Morrison and Morgan, 1999; Pielke, 2003). Not even the focus on formal, mathematically formulated models reduces the variety much.

Because of the vast range of different modelling techniques and philosophies, it is difficult to generalise the challenges surrounding the applications of models in natural resources management. In this section, at the risk of oversimplifying the matter, we highlight only some problems currently facing the NRM modelling community, and in particular we refer to the limitation of models which are encountered at the interface between modelling and decision and policy-making. More comprehensive discussions about the role of modelling at the science-policy interface can be found elsewhere (Argent *et al.*, 2006; Beven, 2002; Letcher *et al.*, 2006; McIntosh *et al.*, 2005; Refsgaard *et al.*, 2005; Scholten *et al.*).

To a large extent all models aim at explanation (Jakeman et al., 2006). But models which are good at explaining a system's causal mechanism, behaviour or pattern are not always built to predict. On the other hand not all prediction models perform well on explanation (discovering causal relationship), either as a consequence of insufficient understanding of the system, or due to inaccurate formalisation. Friedman (1953) argues that the only approach to assess the quality of a model is whether it yields predictions that are good enough for the purpose in hand and that are better than predictions from alternative models. A vast literature is available about the assessment of models' performances and the cited statement by Friedman, even if debated, maintains a general validity. Climate change modelling, by focusing on the analysis and projections of future developments, is practically impossible to validate, if not on past records, thus raising a broadest debate about its usefulness to inform the present policy choices, with remarkable consequences on human activities.

The above raises the critical issue of the role of the modelling discipline outside the research context, in the areas of policy support and decision-making (Pielke, 2003). Although both research and policy simulations are driven by the same aim, i.e. anticipate outcomes and consequences, their use and motivation are different. Fundamental research is typically curiosity-driven, often unpredictable in terms of its course and outcomes, concerned with testing of scientific hypotheses. Researchers are interested at discovering salient, unknown features at the frontier of knowledge. As a consequence, scientific studies may be framed or yield results which are too narrow, not transferable and of limited use for practical policy-making. Policy makers, on the other hand, deal with wider contexts, characterised by large uncertainties, communication problems, social conflicts. Models are expected in those cases to yield not only reliable, but also socially robust knowledge.

The mismatch between models available and the needs – expressed or inferred – of policy makers has traditionally been attributed to two possible explanations: either to policy makers not being able to understand scientific models, or to scientists not being able to provide the right tools for tackling the issues in question. Thus one of the main challenges related to the applicability of models to "real world" issues is the appropriate communication between scientists and policy makers, which may facilitate more effective collaboration and encourage mutual appreciation. Models encode simplified knowledge, preserving the relevant features while discarding the unnecessary complexities. This is both a strength and weakness, because the choice of what is relevant, and the way this choice is made, is highly subjective and context-dependent, and, therefore, it must be communicated transparently. This raises the problem of communication, dealt with in Hare (2005), who showed a direct relationship between the level of understanding and the confidence in model results, and the uptake probability by potential users in decision process. Unfortunately, as stated by Beven (2006), models developed by experts are often presented to interested parties without disclosing their limitations in general, and uncertainty in particular, thus diminishing credibility.

As a consequence, despite the theoretical potential, the uptake of simulation models in decision and policy-making appears limited.

Relations between models and other computer tools on the one hand, and the intended users and broader public on the other, are of great relevance, in that they can either facilitate or hamper their uptake in the real world. The topic is vast, and cannot be dealt with in detail here. Two aspects are nonetheless worth mentioning in the context of this paper, before moving to discussing the aspects related to PP: (i) the role of subjectivity in modelling, and (ii) the knowledge owned by subjects involved in the decision process, that is not – ready to be – implemented in models.

Subjective judgments are indeed not unusual in natural resources management, and for instance in ecological modelling. As pointed out by Reckhow (2003), even the mechanistic process-based models usually rely on subjective judgments by the experienced users as a basis for mathematical formulations and the choice of parameter values. He concludes that explicit use of – scientific – subjective judgments should be accepted and made explicit by adopting Bayesian probability networks.

Knowledge owned by subjects involved in the process (experts or stakeholders) is also very relevant to complement those gaps that are generally encountered in the integration of multi-disciplinary models and in the acquisition of required data and information. The ability to implement expert knowledge in the process is therefore of fundamental importance.

The need thus emerges for defining a robust methodological approach for managing the collaboration of multiple actors within the modelling and decision-making process. This is usually approached within the field of public participation methods.

2.2 Public participation: from simulation models to participatory modelling

The idea of public participation *per se* is not new: its origin in the field of environmental management and sustainable development is traditionally traced back to Agenda 21 (UN, 1992a), which identified “information”, “integration” and “participation” as key factors for the achievement of sustainable development, to be implemented through the use of participatory planning approaches. Since Agenda 21, PP has been introduced in many international conventions for environmental management, as well as regional and national policies (Pimbert, 2004). For instance, the 1991 Espoo Convention deals with public participation in environmental impact assessment (UN, 1991); the 1992 Helsinki Convention (UN, 1992b) introduced a requirement for information disclosure regarding transboundary watercourse pollution data; the 1994 UN Convention to Combat Desertification (UN, 1994) states that extensive participation is required for acting against the spread of desertification and land degradation. More recently, the EU Water Framework Directive (EC, 2000) introduced the need for extensive public consultation and the encouragement of active public involvement in water planning and management (Article 14).

The rationale underlying public participation in decision-making is simple and intuitive: the “public” is more likely to accept a policy when it is consulted beforehand, or when it takes active part in its definition. Thus, supporters of the PP paradigm assert that concerted decisions can lead to management choices which are better adapted to local conditions, are easier to implement, and less likely to cause or sustain conflicts and instabilities. Furthermore, as mentioned above, participatory approaches show the potential to improve decision-making, by ensuring that decisions are based on shared knowledge and visions, as well as experiences and scientific evidence, or subjective but informed judgments.

Starting from the 1980s and well into the 1990s, a variety of methodologies for public participation have been developed, each more or less appropriate depending on the level of public involvement sought. Passive participation, for instance, only requires information about plans and decisions to be communicated to the public at large – in a manner that is clear and easy to understand, and in the appropriate language. Decisions in those cases are already taken by the authorities (Allen *et al.*, 2002; Pretty, 1995). At the other extreme, active participation requires stakeholders to receive useful background information, and to take part in shaping and developing joint action plans with institutions. A full review of the various methodologies for public participation is beyond the scope of this paper, but a synthesis of the main approaches at various depth of public involvement is reported in Table 1 (Dalal-Clayton and Bass, 2002).

In recent years, however, fundamental criticisms to the PP paradigm have been voiced by practitioners and researchers – both in terms of PP implementation and its theoretical underpinning. Participatory approaches may not be socially and culturally suitable in some contexts (Hailey, 2001), for example when the governing group is not willing or ready to relinquish part of its decision-making power. Linked to the issue of power management is that of *representation*: who should take part in the process is not clearly defined, nor are there agreed upon mechanisms to help select among stakeholders – individuals or groups (Swyngedouw *et al.*, 2002). On the other hand, actors may not be willing to take part in decision-making, for example because they do not believe the decision makers will take their views into account, or simply because not interested.

Despite all these critiques to public participation and the lack of consensus over methodologies for actors' involvement, a strong emphasis on deliberative decision-making remains, even at the legislative level. It is therefore clear that we should expect a remarkable expansion in the adoption of PP practices in policy and decision-making in the coming years. In general it is evident that without an appropriate and consolidated implementation framework, public participation can have unintended negative consequences – often diametrically opposed to the expected benefits of participatory approaches – and become an instrument for control.

By combining the need for improved modelling practices (dealing with both scientific evidences and subjective knowledge) and robust participatory approaches (allowing to extend the group of people involved in the decision-making process outside a small number of experts – including modellers – and decision makers), *participatory modelling* emerges as a possible solution to problems common to both SM and PP.

By the term "participatory modelling" we designate a process in which the formulation of a conceptual model and its formalisation is carried out by disciplinary experts with the direct involvement of stakeholders. Various techniques are available in this field, such as cognitive mapping, causal loop diagrams, creative system thinking and brainstorming, etc. The participatory formalisation of the underlying model (i.e. the socio-ecosystem affected by the problem in question) allows the identification of the main components of the system and their linkages, typically by adopting system analysis formalisation in form of stock (state variables), flows (of energy, matter, information) and causal links (e.g. feedback loops).

Participatory modelling provides a common basis of shared knowledge upon which discussions and deliberations about the issue in question can be established later on, provided that the technique adopted to elicit actors' views, and the ability of the facilitator to limit the risks and shortcomings of participatory processes, are adequate.

There is therefore a clear need for transferring methodologically sound approaches to practitioners involved in the decision/policy-making spheres, but it is also necessary to develop and disseminate tools supporting practical implementations in DA. Decision Support Systems (DSS) are a category of methods and computer tools, often mixed or confused with simulation models, intended for that scope and dealt with in the following Section.

2.3 Decision analysis and support

Decision analysis methods help avoiding biases in judgement and making decisions more compatible with normative axioms of rationality for situations involving multiple, conflicting interests and beliefs. In this paper we refer to decision analysis as a set of procedures, methods, and tools for identifying, clearly representing, and formally assessing the important aspects of a decision to be taken.

Decision or policy-making in the field of NRM usually features the choice within a set of reasonable alternative solutions, i.e. a set of possible policy measures, or of alternative plans. In case of climate change research, choice problems typically regard the definition of mitigation or adaptation policies and measure and the selection of the preferred ones, i.e. those that perform better in terms of the preferences of policy makers and stakeholders and provide the best potentials, and scientific strength.

When dealing with complex dynamic socio-ecosystems and future projections, choosing one policy measure from a set of alternatives is limited by our capacity to process all relevant information and to manage trade-offs between competing values and objectives. Difficulties obviously dramatically increase when multiple actors are involved in the P/DMP.

A vast variety of methods have been proposed to cope with the need of synthesizing various sources of information, opinions, expectations and aims when assessing different policy options. Those encompass any normative decision techniques including cost-benefit analysis, cost effectiveness analysis, cost utility analysis, multiple-criteria analysis, game theory, utility theory, risk benefit analysis, operation research (Toth, 2000).

Numerous decision methods are available, in particular to elicit the preferences of individuals and to aggregate them across different objectives (intra-personal aggregation) and across different actors (inter-personal aggregation). Decision models result from the systematic exploration and negotiation of a 'problem', including its existence, boundaries and structure. They comprise alternative courses of actions (policies or policy measures); decision goals – translated into more tangible evaluation criteria, against which the policies are weighed; and preferences, which describe how well the policies satisfy the objectives. The preferences or trade-offs are value judgements, frequently not readily observable, which need to be revealed or approximated. Such uncovered preferences are context-specific and depend on the description and framing of a problem. For example, to assess the environmental costs of irrigation, one would have to consider the value of wetlands and riverine ecosystems deprived by water abstraction.

The extent to which specific decision models are considered consistent and 'rational' depends on the compliance of the elicited preferences with the model's assumptions and its ability to overcome cognitive biases, or integrate different perspectives and preferences. Methods may differ considerably in terms of (i) the underlying theory and assumptions (e.g. monetary valuation, utility theory, value function approaches, outranking techniques, Bayesian statistics, participatory deliberation); (ii) the approach pursued (e.g. generation of trade-offs versus elicitation of value judgements; *a priori* methods versus progressive or interactive methods, etc.), (iii) the assumed form of preference function (e.g. non-additive versus additive, linear versus nonlinear), (iv) the way value judgements are elicited (e.g. direct assessment versus elicitation of trade-offs), and (v) the extent to which the method accommodates different perspectives and problem structures. Detailed discussions about the strengths and flaws associated with specific decision methods can be found elsewhere (Bell and Sheail, 2005; Berthoz, 2004; Eisenfuehr and Weber, 2003; French, 1995; Kangas and Kangas, 2004; Larichev, 1992; Liljas and Blumenschein, 2000; Mingers and Rosenhead, 2004; Poyhonen and Hamalainen, 2001; Ryan, 1999; van den Bergh *et al.*, 2000).

Which method is more appropriate depends on the set of assumptions that seems most valid for a given situation and person, or group of people – the choice of method is in fact frequently influenced by the beliefs of those identifying policy options. Disagreements are inevitable when multiple possible methods are available to address any given decision problem, thus the theoretical background and assumptions of different methods should be carefully considered when selecting the most suitable approach. To minimise biases, several methods could be applied in parallel, thereby identifying similarities and highlighting inconsistencies. This could be seen as an educational exercise, whereby the decision makers learn more about their own preferences (Hobbs and Horn, 1997). Indeed, according to French (1995), critical self-reflection is at least as important as the outcome reached through DM. Furthermore, the integration of DA and PP can lead to better informed, more comprehensive underlying structures, and to the identification of exhaustive – and perhaps innovative – policy options to tackle the identified decision problem.

2.4 The need for comprehensive integrated frameworks

The problems discussed in the previous sections and their solutions are to large extent complementary. Well designed participatory processes create positive conditions for predictive models being understood and trusted. Models whose structure reflects needs and governing drivers of policy-making are more likely to yield reliable and socially robust knowledge, which in turn increases the prospects for policy success. Taking advantage of these achievements, decision analysis can help all actors to understand (and represent in explicit form) values, and negotiate divergent interests for seeking compromise.

It is known that public participation is susceptible to unintended negative consequences, but the combination of various tools such as experts' opinion, stakeholders' identification, analysis of position and relations can reduce the associated risks. Social network analysis can anticipate potential conflicts and relations that need explicit management, as well as key "alleys" and "opponents" of a policy proposal. This information is crucial for subsequent participatory modelling and decision analysis processes.

A combination of predictive, formal modelling based on "hard science" with soft methodologies to analyse policy problems (such as cognitive mapping) can surface and incorporate contextual (local) knowledge, and improve the suitability and applicability of models to the policy problem and decision-making contexts. Scientifically sound techniques based upon a combination of PP, SM and DA, transparent and flexible enough to fit the specific needs, may have a positive impact on the commitment of policy makers, and well structured participatory processes may preserve their commitment during the whole policy-making and implementation progress.

An underlying cyclical structure may be identified, starting from a triggering factor, which initiates the decision-making process; passing through a series of steps, which can take on several names in the literature (e.g. problem exploration, design of alternative options, etc.); and culminating with a final product, which is, in theory, "the" decision (one policy measure, or set of measures, which is valued as "optimal"). In practice the output is more often an intermediate result (e.g. a ranking of possible solutions) to be further discussed or used to inform political decisional bodies, or implemented in an adaptive management process.

Various tools and methodologies can be implemented, in parallel or sequentially, with the shared aim of improving decision-making processes, but their application needs to be coordinated within a comprehensive and unifying framework. In the following sections a methodological framework intended to address the issues raised in the previous sections, and developed by the authors as a result of a series of research projects in the field of NRM, is presented.

3 The NetSyMoD approach for supporting informed decisions in NRM

3.1 The framework

The difficulties encountered in bridging the gap between science and policy by simply providing suitable computer tools, even if freely available, adequately documented, multi-lingual, etc., pushed to stronger emphasis to be placed by the research community in the development of methodological frameworks aimed at providing operational protocols for the adoption of ICT tools, including DSS's, in the P/DMP.

In recent years one of these frameworks has been developed with the contribution of the authors in which the P/DMP is organise as a series of steps initiated by the identification of a decisional problem, and followed by the analysis of the actors involved, the in depth analysis and structuring of the problem itself, participatory modelling techniques, the design of the DSS, the analysis of alternative options and culminating with the implementation of the preferred action(s), and following monitoring taking subsequently to possible iterations and adaptive strategies (Figure 1). That framework, characterised by the adoption of specific variants of participatory techniques and modelling and specific tools has been named NetSyMoD, which stands for Network Analysis – Creative System Modelling – Decision Support.

NetSyMoD was designed as a flexible and comprehensive approach, which makes use of a suite of methods and support tools, aimed at facilitating the involvement of stakeholders or experts in environmental decision-making processes. Decisions and evaluations are here intended in a broad sense to include any process in which a choice or a judgement has to be made by examining the available information on a given problem. The problem itself, the information, the choice set and the judgements are defined with the contribution of different actors, who may be various experts in the disciplines relevant for the solution of a certain problem, and/or stakeholders and policy makers that are formally or informally involved in decision-making.

It is clearly out of the ambition of NetSyMoD to provide a single standardised approach for every possible decision case in NRM, it provides nonetheless a generic structured approach, facilitating the operational implementation of existing decision and information support tools (DIST) (McIntosh *et al.*, 2006).

The following sections will describe the framework more in detail, by providing first information about the theoretical background and secondly the description of the operational methods and tools proposed[1].

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[1] Phase 6 (Action taking and monitoring) is not treated here, since it is subsequent to the decision process in strict sense, at least in its first iteration.

3.2 Phase 1: Actors' analysis: roles, opinions and interests

The selection of participants is one of the most critical steps in participatory processes, as it will determine the legitimacy and quality of the process. There is a need to balance the involvement of a large number of stakeholders against the need to ensure their legitimacy and representativeness, and to manage their interactions. This is the underlying guiding principle driving the selection of the methodologies, namely a combination of techniques for stakeholders' identification and relational analysis.

We propose to start such process by establishing a task force group (TFG), i.e. a team formed by people interested in the decision process and its outcomes, motivated and supported by one or more experts of the approach to be implemented. The TFG is expected to implement a sequence of steps in an iterative manner, as depicted in Figure 2. At the first meeting of the TFG the geographical boundaries of the problem – and thus the area of reference – are defined, allowing the identification of all actors with a legitimate claim. The actors' group can be identified through the "snowball" sampling technique: the TFG selects a small number of readily identifiable actors, the "seeds". These are then asked to name all other important individuals/organisations that have, or could have, considerable influence in the decision process, or in its implementation. To minimise strategic incentives to manipulate membership of the interest group, a team approach to seeds identification is preferred, to provide a more objective perspective of stakeholders/experts' position and interests. The proposed general criteria for the selection of the seeds are: (i) vertical comprehensiveness, that is, consider all the actors directly or indirectly involved in the decision-making process at all the different levels of governance (national, regional, local); (ii) horizontal comprehensiveness, i.e. consider all the actors (public institutions, NGOs, etc) which are directly or indirectly affected by the decision; and (iii) cross-sectoral comprehensives, i.e. include representatives of all major social groups.

It is often not desirable or appropriate to involve a large group of individuals in participatory planning, as it becomes more and more difficult to manage their interactions and obtain a concerted decision. Therefore, the selection of key stakeholders represents a crucial step in the P/DMP. For this purpose, it is useful to carry out a Social Network Analysis (SNA), a methodology which enables the TFG to translate core concepts of social and behavioural theories into a formal language, based on relational terms (Wetherell *et al.*, 1994). In the proposed approach, SNA is articulated into three main steps: (i) data collection; (ii) data analysis; and (iii) validation of results.

Data collection entails the definition of a questionnaire which can be administered either through a mail survey, or face to face interviews; the actual interviews for data collection, and data coding. The questionnaire is designed to elicit: (i) stakeholders' relations, including the typologies and frequency of interactions among individual members of the group; (ii) stakeholders' view of the problem, that is, their position with respect to the issue under investigation; (iii) and any other relevant concern. One could, for instance, begin the identification of alternative options as proposed by individual actors, or a preliminary list of indicators that could be used to assess policy options, and their relative weights according to individual respondents, as a direct input into the Analysis of Option phase.

Data analysis forms the basis for advices to the final step of NetSyMoD. In this phase, actors' e*quivalence* is assessed through the use of graph and positional analyses and, as a result, the key stakeholders to involve in the later stages of participatory modelling are identified (one or two representative actors per equivalence class). A *power analysis* is also undertaken, to determine the synergies and interactions emerging in the network –

and with particular reference to the key stakeholders. Several centrality measures can be used as proxy for power (Freeman, 1979), we usually prefer “betweenness centrality” or the “Bonacich measure” (Mizruchi and Potts, 1998) as best representing power within the social network[2]. Finally, an analysis of the *value drivers and divides* is to be carried out to identify potential and actual conflicts among actors. Measures of cohesion, such as weighted distance measure, are suggested in order to provide a more rigorous analysis of an otherwise qualitative conflicts assessment.

Validation of the outcomes of the analyses should be performed by the TFG, and prepares the results for direct input in the successive stage of NetSyMoD, the Creative System Modelling workshop.

3.3 Phases 2 and 3: problem analysis and creative system modelling

Key stakeholders, identified in the Actor Analysis phase, usually hold different perceptions and beliefs about what the causes of the problem are, or how they should be addressed with the decision to be taken. As depicted in Figure 1, two steps are needed at this stage: individual perspectives are first explored in the Problem Analysis phase and then further elaborated and formalised in the Creative System Modelling by means of dedicated workshop activities, in order to facilitate collective learning and the building of a shared conceptual model. Problem Analysis allows the identification of the most relevant aspects of the decision, including legal and institutional ones, and, in particular:

1. a list of most relevant drivers governing the perception of the problem;
2. a preliminary list of possible solutions to be assessed;
3. a preliminary set of scenarios regarding the future development of the main drivers and cause-effect relations;
4. an extensive list of indicators against which the performance of the possible solutions (alternative options) can be measured.

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The Problem Analysis phase is conducted by the TFG with the needed support of experts in various disciplines and provides a scientifically robust ground of knowledge and information about the problem. The degree of, and the approach for, actors’ involvement varies from case to case. A workshop can be useful for this purpose, in which all the actors contribute to the building of the shared knowledge system. Typically, the focus is on aspects of the decision which support the framing of subsequent, more detailed, analytical phases, such as the building of alternative future scenarios to compare and contrast alternative solutions to the problem. In other cases, the questionnaires used for stakeholders’ analyses can also be used to collect their views and opinion on one or several of the information typologies listed above.

Once a preliminary description of the problem, including to a certain extent tentative lists of drivers, options, indicators and scenarios, has been developed within the group of actors involved, the process can move to the third phase of Creative System Modelling (CSM), in order to approach the analysis of the dynamics of the socio-

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[2] Betweenness centrality views an actor as being favoured in a social network to the extent that he/she falls on the path connecting two other actors (by counting the number of couples on whose connection path an actor falls). The Bonacich measure of centrality instead considers both the connections of a node, and the connections of the other nodes in its neighbourhood.

ecosystem affected by the decision in question. For CSM we intend a form of participatory modelling that may be supported by various techniques (e.g. cognitive mapping, causal loop diagrams, etc.), allowing to develop a formal model (either qualitative or quantitative) with the contribution of the group of people identified in the Actors' Analysis, based upon the knowledge elicitation carried out in the Problem Analysis phase.

Creative System Modelling provides not only a common ground for the mutual understanding among the parties involved, but also a scientifically sound basis for the development of effective decision support systems. For example, the CSM workshop may serve the purpose of consolidating or identifying evaluation criteria preliminarily explored through the questionnaires in the Actors Analysis phase, and eliciting individual and group weights, necessary for the evaluation of policy options through multicriteria analysis.

Depending on the specific case at hand and on the amount of work carried out in the previous phase, CSM can be targeted to one or both of the possible tasks (see examples in Figure 4):

1) building a shared causal model of the problem, by formalising the relevant cause-effects chains within the DPSIR conceptual framework (i.e. Driving Forces, Pressures, State, Impacts, Responses) (EEA, 1999), which has been expanded into the "Scenario Analysis and DPSIR Framework" (ScenDPSIR), for managing complex scenario driven problems, such as climate change issues;
2) developing shared scenario visions, depicting the potential evolutions of the system over time, or under different policies.

Several approaches are available to explore various viewpoints, beliefs, values, and knowledge related to the problem at hand. The cognitive mapping approach is a methodological option, which emphasises surfacing deeply held beliefs in form of mental models. Combining mental model elicitation techniques with participatory workshops facilitates social learning among the group of actors involved, and favours compromise building and a constructive attitude to conflict resolution. Cognitive maps comprise internally represented concepts, and relationships among concepts, that an individual uses to interpret new events. In practice, the key actors identified in the previous steps of the NetSyMoD approach are involved in a workshop where the most suitable cognitive mapping technique for the specific case is applied. Many alternative techniques are available, for example, techniques based on the Hodgson's hexagons approach (Hodgson, 1992) or causal scenarios, intended as a cognitive structure to aid in making causal attributions or judging likelihood (Kahneman and Tversky, 1982; Read, 1987; Tversky and Kahneman, 1973). These deeper structures can be modelled with system analysis methods to help exploring the dynamics of how different end states might come about.

A shared vision of the reality (i.e. the socio-ecosystem and its main dynamics) is needed for the correct evaluation of options and this can be done by developing a common mental model using techniques that facilitate the process of participatory modelling and elicitation of knowledge and preferences from actors, thus building a common understanding of the problem. It is clearly not necessary to reach unanimity, but it is certainly important that, at a minimum, commonalities and divergences about the drivers, the main phenomena to be considered and the related impact are elicited and made explicit. Experience acquired in several applications of the proposed approach has shown that the DPSIR framework provides an intuitive interface, which can be effectively used as a means for categorising the contributions of the various stakeholders within a common conceptual framework. The resulting simplified cognitive map of the problem at hand can be used as a starting point for a deeper analysis, or as an upper level interface to which the multiple visions of the actors can be referred. DPSIR evidences conceptual limits when the analysis focus goes beyond the local socio-ecosystem and it involves also external driver, like climatic variables, affecting both human and environmental elements of the system. In the latter cases a new category of nodes has to be introduced, i.e. "Scenario drivers", representing all the factors external to the system which may affect either directly or indirectly human activities (D's and P's), or the state of the environment (S, like in the case of the changes of temperature and rainfall), or the responses (R's) by local decision makers (e.g. in the case of new policies at upper hierarchical level). Therefore an extended version of the framework has been developed, called ScenDPSIR.

While planning the CSM workshop the TFG and in particular the workshop facilitator must establish a clear set of objectives and should anticipate the potential workshop stages, bearing in mind the ultimate objectives of the process. Worth mentioning at this stage is a problem which is often encountered in participatory processes of this kind: stakeholders often have limited time availability, with the consequent need to implement effective strategies for their involvement through various means, such as questionnaires, interviews, etc., while limiting the group activities within acceptable time frames. In the applications of the NetSyMoD approach a one-day workshop is usually organised, tailored to the specific needs of the case.

A practical agenda to help plan the workshop envisages beginning with an enrolment phase (see Figure 5), in which the facilitator explains the CM approach chosen and its goals, and introduces participants to the workshop's techniques through interactive games. During the brainstorming, individuals contribute ideas, either anonymously and simultaneously, or through an open, semi-structured, discussion. It is the role of the facilitator to guide the formalisation of the cognitive map and its causal links according to the ScenDPSIR framework as a precursor to the development of simulation models embedded in the DSS tool, as described in the following section. To facilitate the adoption of the DPSIR conceptual framework, the brainstorming phase is usually managed in two steps, focusing on two questions presented to the participants. The first asks their reactions in terms of the main drivers (Driving forces) ruling the system and the processes and mechanisms associated to them that have relevance for the problem analysed (Pressures). The second question is about the identification of environmental and impact indicators to be considered (State and Impacts, respectively). When enough contributions have been made, the concepts are preliminarily clustered and shown back to the group. Scenario analysis and drivers can be carried out to identify relevant drivers to be formalised in the ScenDPSIR. In this way, the group identifies a set of key concepts, together with a preliminary list of key indicators. Relationships among concepts/indicators can be indicated by influence diagrams with arrows connecting those clustered ideas that are causally related, and a sign attached to the arrow can be used to state whether the influence is positive or negative. Then feedback loops can be created. Further concepts are added as participants review contributions and piggyback one another's ideas in a plenary session.

Beam projectors or boards with adhesive tags may contribute significantly to the effectiveness of the workshop, allowing participants to monitor the development of the shared vision(s) of the problem. Concepts might be colour coded according to their type (problem, opportunity, strategic aim, etc.), helping with visualising or navigating the cognitive maps and aiding memory and thinking processes. A simplified example of cognitive mapping from a case study dealing with irrigation planning is reported in Figure 6. It shows – a sample of – the Hodgson hexagons produced during the brainstorming phase emerging from the contributions of workshop participants (I), subsequently clustered by the facilitator in II, to allow the framing of the items identified by the participants in the DPSIR causal framework as depicted in III, finally converted in a functional conceptual model, including also scenario drivers in IV.

3.4 Phases 4 and 5: DSS design and analysis of alternative options

In the DSS Design Phase builds upon the knowledge developed in the CSM workshop in terms of the cause-effect relations of the socio-ecosystem, and preliminary identification of alternatives, scenarios and indicators to be analysed. This allows for a more precise identification of information needs, that are usually provided later by the runs of distinct or integrated assessment models (IAM), representing the expected outcomes of the alternative options (i.e. the Responses to the problem in question), according to one or more possible scenarios.

The DSS Design consists in the identification of procedures and software tools capable of managing the data required for providing informed and robust decisions in the following phase of Analysis of Options. This is necessary to manage and communicate the information flow between various process phases, including exchange, transformation, integration, validation and documentation of gathered knowledge. It is not necessarily the case that a single piece of software is to be developed – which is indeed only feasible in large projects with significant budgets. Rather, one should design a toolbox of integrated tools (models, spatial data management systems, etc.), together providing the specific functionalities needed by the DSS. Figure 7 provides a representation of the main steps of the two phases, according to the approach implemented in mDSS (Giupponi, 2007) a tool developed for the purpose of framing the decision process in a (Scen)DPSIR conceptual model and facilitating the integration of different data sources (model outputs in particular) and allowing their implementation in the Analysis of Options Phase. Originally built on the Simon's design of decision process, involving "conceptual or intelligence", "design" and "choice" phases (Simon, 1960), it further develops to endorse the more iterative and loop-like (spiral) flow of decision process which characterises the NetSyMoD approach.

The decision analysis is normally carried out during either a second session, following immediately the CSM workshop, or later after quantitative elaborations have been carried out. In the first case the actors involved provide their own qualitative evaluations, in the second, which could be also a follow up of the first, quantitative indicators provided by modelling activities are used. In both cases an analysis matrix (AM) is built by processing indicator values to convert spatio-temporal data in synthetic values to be stored in the matrix cells, having options in the columns and decisional criteria in the rows. The AM thus stores the performances of the alternative policy options (e.g. alternative policy measures), evaluated individually against each decision criterion. At this stage the raw performance measured with different units and/or scales across the criteria is determined.

At that stage of the Analysis of Options, multi-criteria analysis (MCA) provides a framework for decision analysis, consisting of steps and procedures for a piecewise conceptualisation of the problem involving multiple objectives and criteria, and a set of techniques aiming at elicitation, introspection and aggregation of decision preferences (Figueira *et al.*, 2005a). Consequently, MCA represents added value to both (i) the decision process (by helping the decision-maker know more about the decision problem and explore the alternatives available) and (ii) the decision outcome (by helping elicit value judgements about trade-offs between conflicting objectives).

Preference analysed by MCA can be imagined as a choice or ranking of alternatives and criteria (Hwang and Yoon, 1981). Basically, all MCA decision rules aggregate partial preferences describing individual criteria into a global preference and rank the alternatives. The decision rules chosen for implementation in the mDSS software are (i) Simple Additive Weighting (SAW); (ii) Order Weighting Average (OWA) (Jiang and Eastman, 2000); (iii) the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Hwang and Yoon, 1981); and (v) ELECTRE (Bella *et al.*, 1996; Figueira *et al.*, 2005b; Mahmoud and Garcia, 2000; Salminen *et al.*, 1998; van Huylenbroeck, 1995). In addition, several techniques for elicitation of weights are included such as pairwise comparison, direct rating and hierarchical weighting.

MCA techniques are suitable to uncover preferences held by individuals and aggregate them across different objectives (intra-personal aggregation) and across different actors (inter-personal aggregation). The full potential of MCA comes in through its combination with deliberative techniques based on active involvement of all actors. The term deliberation here refers to the style and procedure of decision-making, characterised by mutual exchange of ideas and reflections among all participants invited to deliberate (Renn, 2006) and a balance-seeking process between conflicting arguments and claims.

Moreover, it should be remembered that the ultimate aim of MCA is not only to help find a solution to a multicriteria problem, but also to give the decision-maker an opportunity to learn about his/her own preferences and those of the involved stakeholders. In other words, the process of finding a solution is at least as important as the outcome of the process. In the case of persistent conflicts even after the deliberative problem conceptualisation, the analysis has to include also conflict mitigation/resolution using inter-personal preference aggregation, or, simply, the different viewpoints must be stated and parallel evaluation procedures can be performed to assess whether or not the diversity of opinions would lead to different results in terms of choice. The mDSS software is equipped with simple tools to face situations in which several decision makers or different stakeholders are involved in a group decision-making context. Routines are thus provided to compare the differences between the weights expressed by individual decision makers/interest groups. When the rankings are different the users can apply a variety of different techniques including weighted average (Marchant, 1998), and its modifications, Condorcet winner (Gehrlein, 1998; Tataru and Merlin, 1997) to combine them into a single compromise ranking. When the users want to investigate the main discrepancies in assigning the weights among different interest groups, a graphical representation for comparing the weight vectors of different users is provided, to highlight the main conflicts of opinion and, therefore, enable the identification of possible compromise solutions.

4 Concluding remarks

An appropriately framed participatory process can provide significant improvements in various fields and, in particular, in natural resources management. In fact, without appropriate implementation methods, public participation, and even more participatory modelling, can be ineffective or have unintended negative consequences. Therefore, the need emerges for providing new methods and tools to support practitioners (competent administrations, consultants, etc.), facing the evolution of environmental legislation towards participatory planning and decision-making.

The NetSyMoD framework presented in these pages has been tested in different case studies, with varying degrees of success. A comprehensive report about the results from the case studies is beyond the scope of this paper, but some remarks can nonetheless be mentioned here.

One of the main rationales behind NetSyMoD is that skilled professionals may find it a useful generic framework, that can guide the process of decision-making and provide practical solutions in terms of methods and application tools for its various phases. An important assumption is that a system analysis approach may provide the common background and perspective for the various expertises/viewpoints to be involved in the process.

The emphasis of NetSyMoD is on integrating and implementing within the same framework different state-of-the-art approaches in the field of modelling, from the more traditional use of simulation models in the decision process through the development of *ad hoc* decision support systems, to the more innovative creative thinking approaches for participatory modelling. In particular participatory modelling is expected to provide not only a common ground for mutual understanding among the parties involved, but also a scientifically sound basis for system analysis and the development of operational models and effective decision support systems.

The proposed framework is intended to go beyond a mere combination of different methods and techniques by (i) facilitating the choice of the most appropriate technique (or set of techniques to be applied simultaneously) for a given situation; and (ii) reducing the risk of duplication of efforts and exploiting the synergies existing among different methodological approaches, by reducing redundancy and making use of insights gained at one stage of the process in all others stages, where required. The opportunity to solve disciplinary limitation in synergy with their strengths is crucial, but not the only motivation for linking participatory processes, predictive models and decision analysis. In many situations, none of them is sufficient on its own to address complex environmental problems. Generally, to support environmental policy-making, more is needed than a single approach or tool can deliver. Experience, trust, relations yielded during the policy process, are as important as the knowledge acquired. The success (however it is defined) is a cumulative result of all methods and tools applied, plus the skills and motivations of the involved people.

A crucial role in participatory processes is played by the task force group and, in particular by the facilitators, but also the motivations of competent administrations should not be forgotten and in particular their willingness to change and to experiment new methods and, more generally, the willingness to let transparency pervade the various phases of the P/DMP.

Various challenges are faced by both the research community and the potential users of new methods and tools in the near future. Concerning the development prospects for the research side, it is worth mentioning efforts targeted to:

- investigating more efficient approaches for the communication and dissemination of the products of research projects;
- designing strategies for tool development in which the need for providing solutions to broad categories of potential users is balanced with the capabilities for tailoring to the specific needs of local end users;
- identifying more efficient forms of collaboration between research institutions and managers of natural resources (land and water), in order to provide solutions increasingly targeted to the specific needs of practitioners;
- identifying forms of (distance) learning means to train potential users and thus facilitate the adoption of new methods and technologies.

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Table 1: Examples of participatory methodologies (adapted from (Bass *et al.*, 1995).

Level of involvement	Methodologies
Participants listening only	Unilateral information transfer from a government public relations campaign or open database.
Participants listening and giving information	Public inquiries, media activities, 'hot-lines', e-mail networks.
Participants being consulted	Working groups and meetings held to discuss policy options and development strategies, Environmental Impact Assessment (EIA).
Participation in analysis and agenda-setting	Multi-stakeholder groups, round tables and commissions, focus groups, seminars and workshops, EIA, Strategic Impact Assessment (SEA).
Participation in reaching consensus on the main strategy elements	National round tables, focus group, parliamentary/select committees and conflict mediation, EIA/SEA.
Participants directly involved in final decision-making on the policy, strategy or its components	Participatory Rural Appraisal, Participatory Learning and Action, …

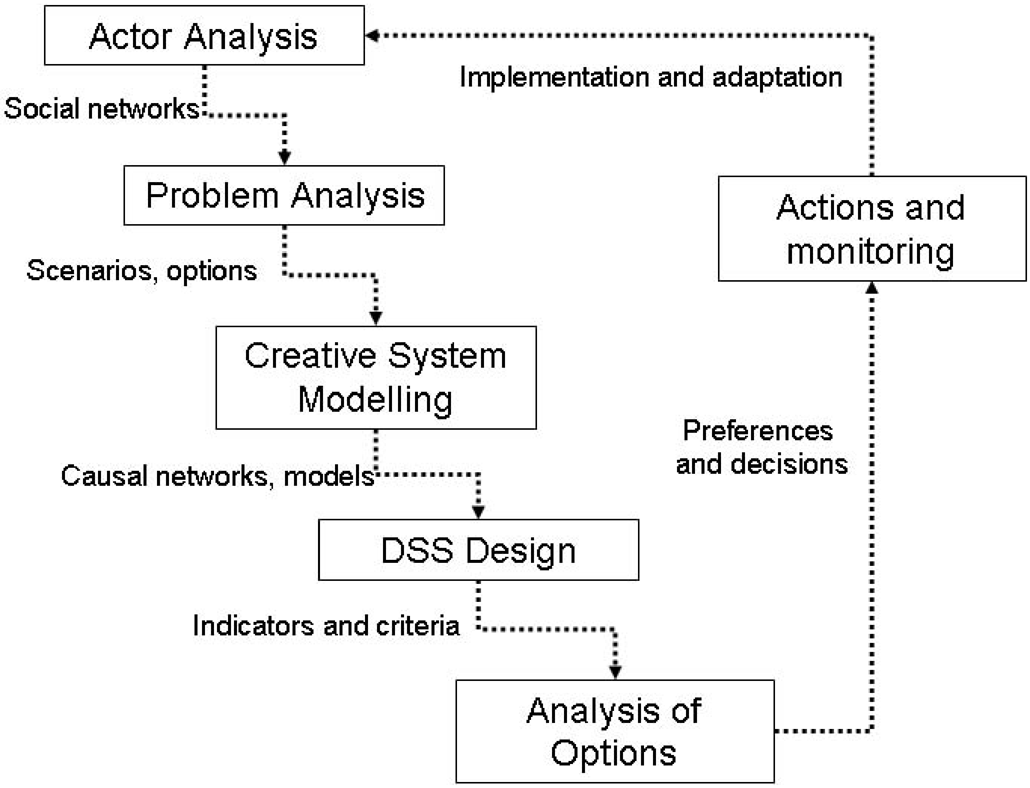

Figure 1. The main phases of decision making processes as formalised by the NetSyMoD framework.

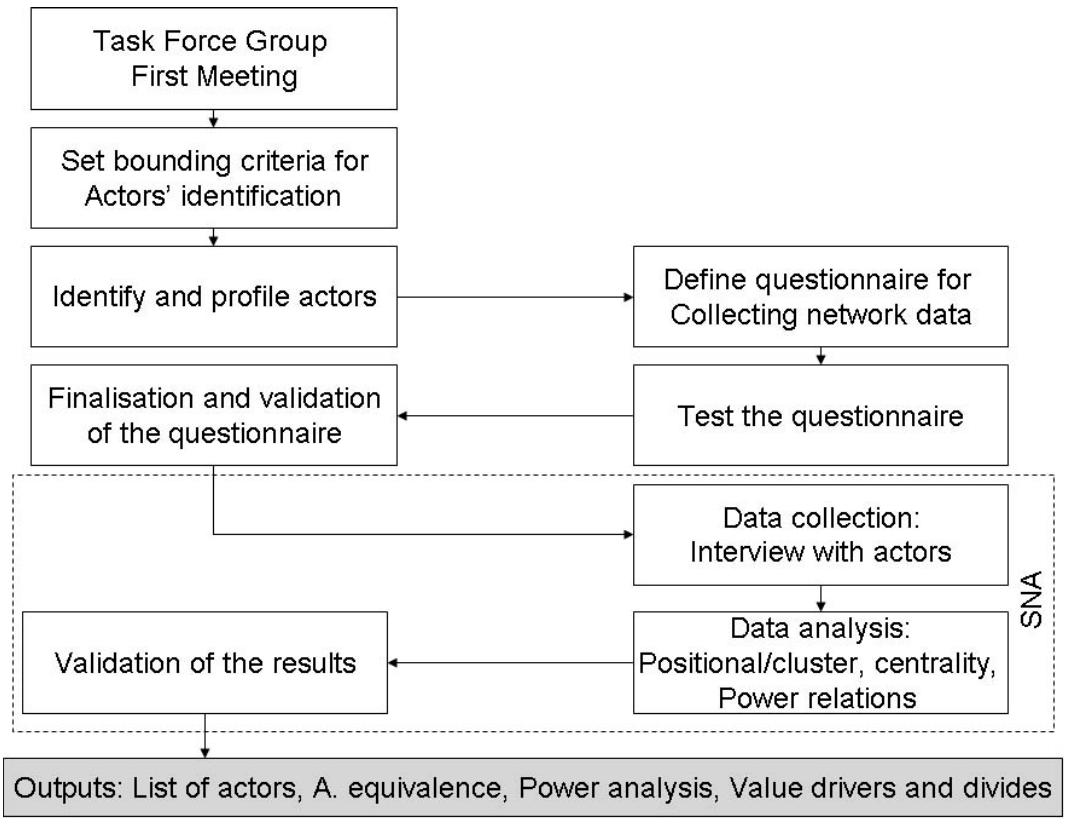

Figure 2. Diagram of the main components of the Actors' analysis phase.

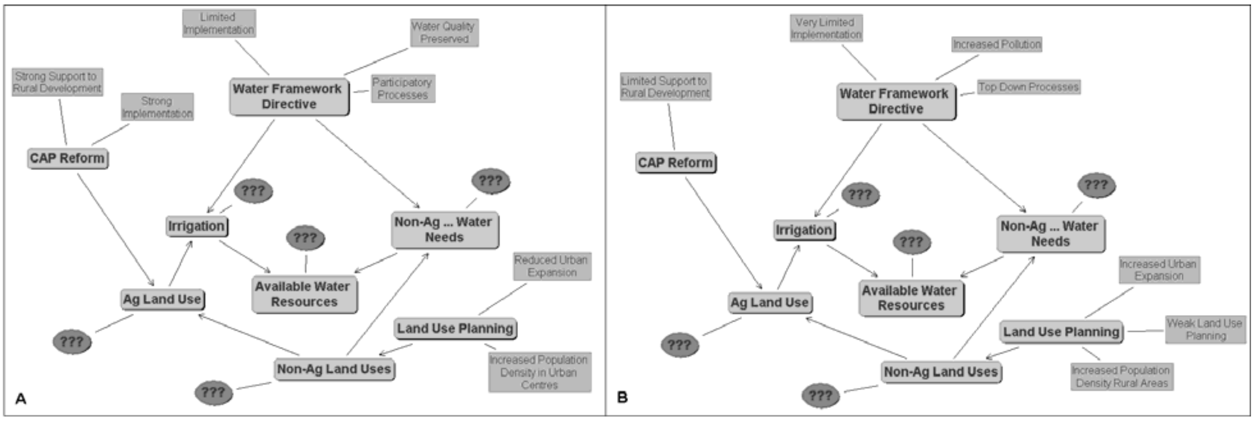

Figure 3: Example of cognitive maps used to launch brainstorming with stakeholders about future scenarios in the CSM about the reorganisation of irrigation in the Treviso Province (Italy), from the ISIIMM project (http://www.isiimm.agropolis.org/). Question marks identifying aspects to be explored during the brainstorming.

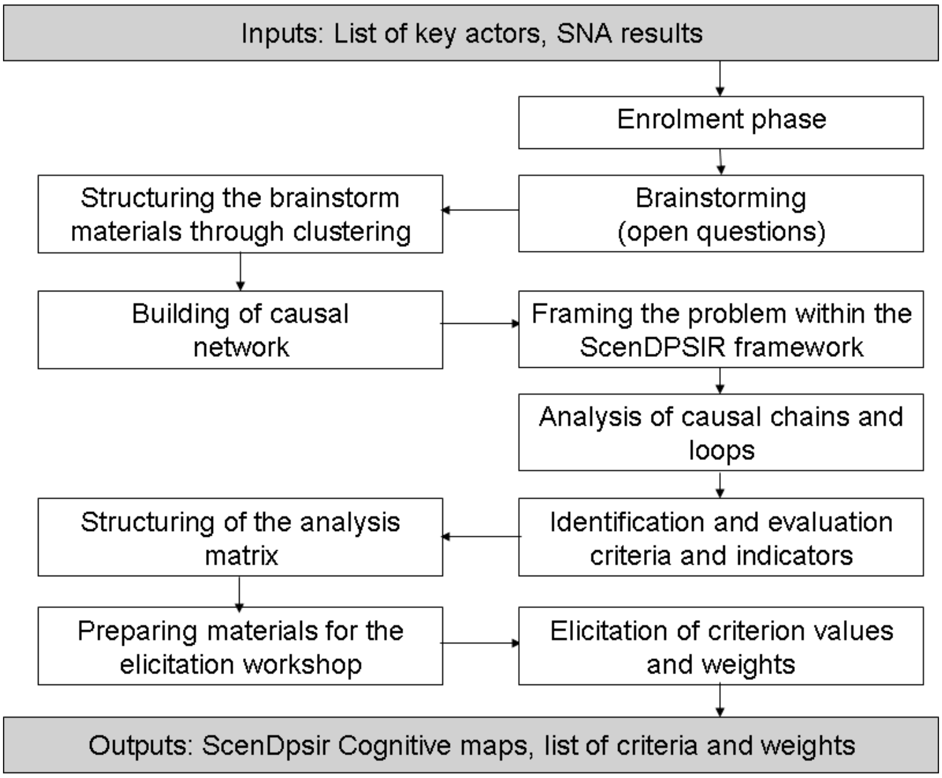

Figure 4: The diagram of the CSM workshop with group activities on the right, with the TFG activities on the left hand side.

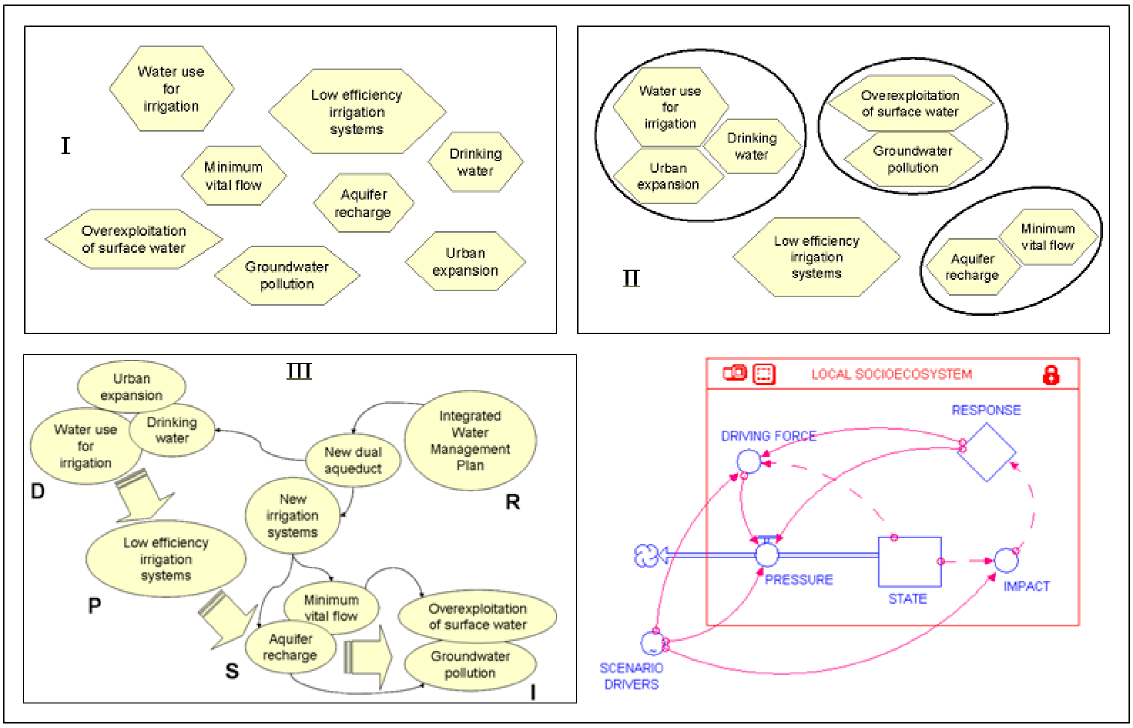

Figure 5: A simplified example of results of brainstorming and building of causal loops in the CSM phase. Knowledge elements acquired in the brainstorming phase (I), are clustered (II) and framed within the DPSIR conceptual framework (III), further developed within a dynamic ScenDPSIR model and formalised in simulation models and in the DSS software.

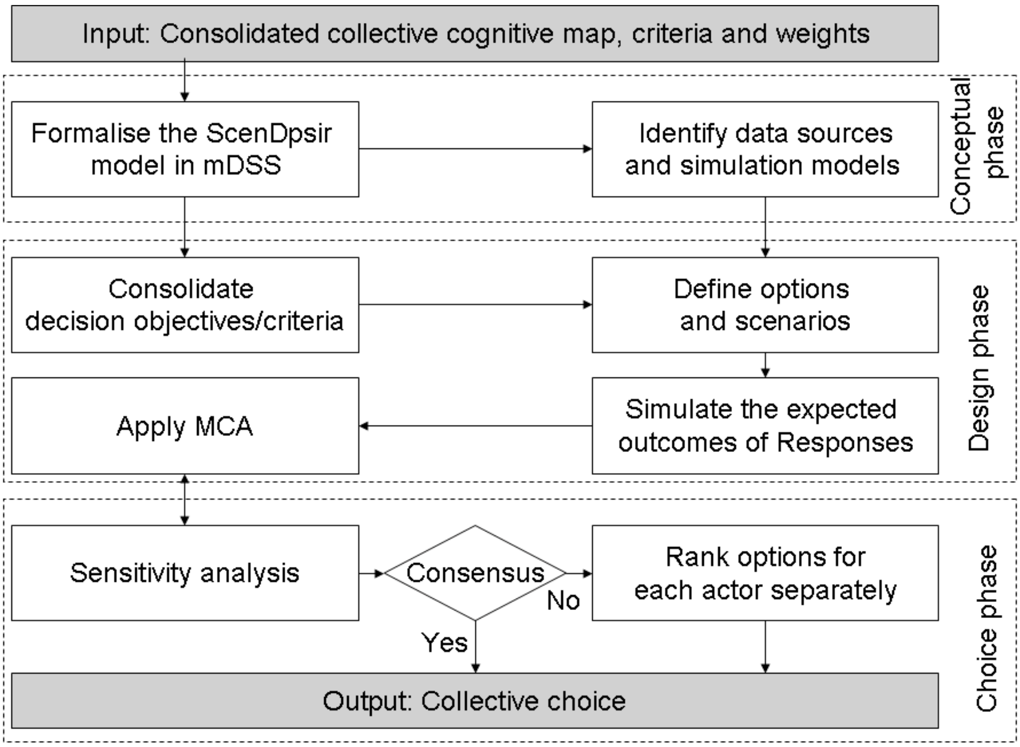

Figure 6: The diagram of the main steps within the DSS Design and Analysis of Options phases. Boxes with dashed lines identify the three main analysis phases within the mDSS software.

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KTHC	*Knowledge, Technology, Human Capital* (Editor: Gianmarco Ottaviano)
IEM	*International Energy Markets* (Editor: Matteo Manera)
CSRM	*Corporate Social Responsibility and Sustainable Management* (Editor: Giulio Sapelli)
PRCG	*Privatisation Regulation Corporate Governance* (Editor: Bernardo Bortolotti)
ETA	*Economic Theory and Applications* (Editor: Carlo Carraro)
CTN	*Coalition Theory Network*