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Participatory assessment of adaptation strategies to flood risk in the Upper Brahmaputra and Danube river basins

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ABSTRACT

A methodological proposal aimed at improving the effectiveness of interactions between the scientific community and local actors for decision-making processes in water management was developed and tested to two case studies, in Europe and Asia: the Upper Danube (Danube) and Upper Brahmaputra (Brahmaputra) River Basins. The general objectives of the case studies were about identifying and exploring the potential of adaptation strategies to cope with flood risk in mountain areas. The proposal consists of a sequence of steps including participatory local workshops and the use of a decision support systems (DSS) tool. Workshops allowed for the identification of four categories of possible responses and a set of nine evaluation criteria, three for each of the three pillars of sustainable development: economy, society and the environment. They also led to the ranking of the broad categories of response strategies, according to the expectations and preferences of the workshop participants, with the aim of orienting and targeting further activities by the research consortium. The DSS tool was used to facilitate transparent and robust management of the information, the implementation of multi criteria decision analysis and the communication of the outputs. The outcomes of the implementation of the proposed methods and DSS tool are discussed to assess the potential to support decision-making processes in the field of climate change adaptation (CCA) and integrated water resources management (IWRM).

1. Introduction

According to the last assessment report released by IPCC in 2007, the climate has been changing over the last decades and will continue to change even if greenhouse gas emissions are reduced to meet the targets of the Kyoto Protocol (IPCC, 2007a; Mace, 2005). The environmental, social and economic costs of extreme weather events are already rising in both poor and rich countries.

Climate change impacts are expected to be unevenly distributed across the planet and some areas, like mountains covered by glaciers, will be subjected to major stresses. Projected climate change for the 21st century in the mountains of the world is two to three times greater than the change observed in the 20th century: all mountains are expected to warm significantly (Nogués-Bravo et al., 2007).

There is evidence based on observations that glaciers have been retreating and decreasing in volume, and that mountain snowpack is also decreasing. As a consequence the water storage capacity of the mountains has been decreasing over time (Nogués-Bravo et al., 2007; Stewart, 2009). The hydrologic cycle is thus changing and more dramatic changes are expected (Nogués-Bravo et al., 2007), up-stream and down-

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stream, with summer droughts which might be longer (Stewart, 2009), together with decreased water availability (Messerli et al., 2004; Viviroli et al., 2007), especially when lowlands are arid, as is the case of systems like the Himalayas (Viviroli and Weingartner, 2004; Messerli et al., 2004). Though physically distant from each other, the populations of different parts of the world will be facing similar problems.

According to the Stern Review (Stern, 2006), it is no longer possible to prevent the climate change that will take place over the next two to three decades, and adaptation to climate change is therefore essential to protect our societies and economies from its impacts. Poor and developing countries in particular, which are only marginally responsible for anthropogenic climate change, will be the most affected by the expected impacts (Heltberg et al., 2009). Climate change is therefore also an equity issue and adaptation policies should continue to have a role in international negotiations and (Mace, 2005) scientific research.

Adaptation has been on the agenda since the Earth Summit in Rio (1992) and reference to adaptation can also be found in the United Nations Framework Convention on Climate Change (UNFCCC, 1992) and the Kyoto Protocol (1997). According to UNFCCC Annex II, countries that ratified the convention made a legally binding commitment to fund adaptation in developing countries (www.unfccc.int; Mace, 2005). However, it is not until the Marrakech Accords (2001) that adaptation policies and projects have gained importance (Schipper and Lisa, 2006) and in the Fourth Assessment Report of the IPCC (2007a), as well as in the Stern Review (2006), we find reference to a demand for research on adaptation, mitigation, and development.

Adaptation policies, however, can be very challenging, and negating their right importance would imply strengthening inequalities, thus burdening those countries and those sectors that will bear the heaviest impacts of climate change, such as water provisioning in river basins fed by glacier melt (Mace, 2005). Innovative water management approaches are, therefore, urgent and they must involve the study of adaptation to future scenarios (EC, 2009).

Integrated water resources management (IWRM) is the most popular paradigm adopted by legislation and plans in many parts of the world (GWP, 2000). The success of this paradigm is due to the recognition of the need to deal with the impacts of climate change on water resources in a holistic manner. Generally speaking, in fact, when dealing with the social-ecological system, it is often impossible to cope with one impact without affecting the other elements of the system: therefore the solutions are best sought in a holistic framework (Folke et al., 2002). Moreover, since the impacts are felt in a variety of sectors, and the result is bigger than the mere sum of the single impacts, responses can be developed in an integrated manner (Heltberg et al., 2009). Considering specifically water the IPCC acknowledges the fact that climate change will impact water availability, for example because of a reduced flow in watersheds fed by glaciers or snowmelt, which is the situation of the case studies presented in this article (IPCC, 2007b). Water scarcity sparks conflicts, which some think might be better addressed in an IWRM setting, where conflicting uses can find a compromise solution (WWC, 2006).

Participatory processes are one of the prerequisites of IWRM plans and projects. They further mutual learning between scientists and stakeholders, new opinions can be expressed, problems can be addressed, technical expertise shared, agreements reached, and compromise solutions found if all vested interests are voiced (Renn, 2006). Stakeholders' involvement is essential, because stakeholders hold the necessary information that could facilitate the exploitation of scientific knowledge with high social relevance (de la Vega-Leinert et al., 2008; Griffin, 2007; Reed, 2008).

In parallel to the increasing emphasis on public participation in IWRM, there is also an increasing attention to the need for efficient tools to support the management of those processes and to the role that could be played by information and communication technologies (ICT), mathematical simulation models and decision support system (DSS) tools, in particular. In the context of climate change research the first category of tools may provide scientifically-based scenarios and projections – prerequisites for any planning activity – while DSS tools may provide the ground for bridging the scientific contributions (i.e. by further elaborating model outcomes) and decision/policy-making processes, including managing the participation of different actors (e.g. policy makers, local experts, dwellers, etc.) in a scientifically sound and transparent way. Despite the theoretical potential, traditional modelling techniques have shown limited impacts on policy-making, especially with respect to complex systems such as those involved in natural resource management. DSS tools have quite often performed similarly. One of the problems most often mentioned is the limited or late involvement of stakeholders and potential users (Geurts and Joldersma, 2001), which contributes significantly to the limited uptake of modelling tools and outcomes. The conventional division of roles between the academy and 'outsiders', where scientists supply conceptual frameworks, theories, methods which are then available for use by various actors in society, such as politicians, civil society, etc., is not accepted anymore (Scott Cato, 2009) and new relationships between science, politics and society are necessary.

One of the main challenges in attempting to bridge the gap between science and policy in the water management sector nowadays lies in the development of new tools combining the potentials of advanced ICT tools and robust participatory approaches (Mysiak et al., 2005). Such instruments could be identified as decision support methods and tools providing participatory modelling functionality, in which the exploration of the problem and the formulation of a conceptual model and its formalisation are carried out by disciplinary experts with the direct involvement of stakeholders in a way that is coherent with the so-called "hard science" modelling approaches to be adopted (Sgobbi and Giupponi, 2007). The computer-based tool is surely one important component, but, as recently pointed out in a comprehensive review and survey on this topic (Giupponi et al., 2011) the future of DSS should envisage a broader and more robust combination of the tool(s) and the process of structuring problems and aiding decisions, including adequate instruments for dissemination and training. In an idealized view DSS should thus act as mediators between science and policy/decision making and as catalysts of trans-disciplinary research.

This article illustrates some of the methods and findings of the Brahmatwinn Project,[1] with a specific focus on the approach developed for demonstrating the potentials of innovative decision support processes and tools.[2] They are presented for their potential as a methodological and operational reference for the management of decision processes in a participatory context for the development of IWRM plans, including climate change perspectives and adaptation needs.

The project was carried out through the collaboration of an international research consortium of European and Asian institutions and it focused on two – ''twinned'' – river basins in the two continents: the Danube and the Brahmaputra. The choice of these study areas stemmed from the idea, later confirmed by the research results, that the two upper river basins, even if very distant from geographical and socio-economic viewpoints, would have commonalities, since they are both fed by glaciers potentially impacted by climate change. This hypothesis was confirmed during the project, which showed how climate change (CC) scenarios downscaled for the case studies (Dobler et al., 2011), point out how intensified weather events in both areas are expected to cause an increase in rainfall in the wet season and of droughts during the dry periods. Climate change could thus exacerbate the uncertainty of water availability and quality, and the occurrence of extreme events, as Brahmatwinn climatologists have suggested.

For the purposes of the project, five case studies have been analysed: two in the Upper Danube River Basin (Danube) – the Lech RB and the Salzach RB (Austria and Germany) – and three in the Upper Brahmaputra River Basin (Brahmaputra) – the Assam State of India, the Wang Chu RB (Bhutan) and the Lhasa RB (Tibet, China).

The FEEM[3] research group – to which the authors of this paper belong – developed a methodological proposal aimed at strengthening the communication and collaboration within the research consortium and with local communities of the end users of project outcomes. The proposal enabled exchange of knowledge and feedbacks between the twinned river basins, and among scientists and local actors[4] (LAs). A programme of local workshops in the two river basins was thus defined in parallel to the other research activities in various disciplinary fields (dynamic climatology, hydrology, sociology, economics, etc.) relevant for the integrated assessment of climate change impacts and the development of adaptation strategies.

The paper is organized as follows: Section 2 describes the methodological framework adopted, the information base and the DSS design. Section 3 presents the results of the application to the Brahmatwinn project. Section 4 discusses the outcomes achieved and draws some conclusive remarks.

2. Methods

2.1. *The methodological framework*

The approach adopted for the analysis of alternative adaptation responses is developed upon the NetSyMoD[5] methodological framework (Giupponi et al., 2008) for the management of participatory modelling and decision processes in the field of environmental management.

NetSyMoD is organised in six main phases. The first three (*Actors' Analysis, Problem Analysis, Creative System Modelling*) were implemented in the initial activities of the project and are not described here. They provided the Brahmatwinn research with (a) a list of the local actors to be involved in the participatory activities; (b) an in-depth analysis of general problems related to water resources management in the two upper river basins, with the participation of the communities of parties interested in the case study areas; (c) mental model representations of the problems, i.e. qualitative descriptions of the causal links among the various components of the local socio-ecosystems by means of cognitive maps clustered in order to be consistent with the DPSIR framework (EEA, 1999); and (d) extensive data sets deriving from hard science modelling activities, consisting mainly in spatial and temporal data sets describing climate change scenarios and their expected consequences in the study areas.

This NetSyMoD methodology relies on the DPSIR framework (driving forces, pressures, state, impacts, and responses), as a comprehensive and simplified conceptual framework for the formalisation of man-environment problems. An extended version of DPSIR is adopted to overcome some of its recognised weaknesses, responding to the necessity, remarked by Svarstad et al. (2008) of expanding the DPSIR framework to incorporate social and economic concerns. In the proposed approach Exogenous Drivers are added, to consider all those driving forces that act as external forcing variables to the system representing the study case: for example climate change, or international markets or policies, which are beyond the sphere of the potential effects of the decisions in question. The extended DPSIR framework is used as a communication interface, categorising the various components of the projects (in particular multiple kinds of information and knowledge) and facilitating the identification of the main causal relationships, thus framing the need for data processing procedures and modelling capabilities.

The fourth and fifth phases, *DSS Design* and *Analysis of Options*, are aimed at involving the actors and disciplinary experts in the design and evaluation of a set of alternative

[1] Project title: Twinning European and South Asian river basins to enhance capacity and implement adaptive management approaches. (Brahmatwinn). Project no: GOCE -036952. Research funded by the European Community, SUSTDEV-2005-3.II.3.6: Twinning European/third countries river basins.

[2] A comprehensive and concise presentation of the results of the whole Brahmatwinn project is presented in a recent issue of Advances in Science & Research Open Access Proceeding at www.adv-sci-res.net/7/1/2011/.

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[4] We use the term local actor (LA) to identify all the people involved in the case study activities instead of the more commonly used term stakeholder, to emphasise the fact that they were local experts or policy makers, without the ambition to assess their representativeness with robust procedures, such as social network analysis.

[5] NetSyMoD (www.netsymod.eu/) stands for network analysis, creative system modeling and decision support.

responses, in this case four broad categories of flood risk mitigation strategies, and are those reported in this paper. The last phase, *Actions and Monitoring*, is beyond the scope of the research project and it refers to the implementation of the decision taken by the competent administrations.

In particular, the *DSS Design* phase develops upon the conceptual models provided by the previous *Creative System Modelling* phase and consists of specifications in terms of elaboration and management procedures at the interface between the scientific outcomes of the project and the preferences and expectations of local actors. The *Analysis of Options* implements the results of those elaborations and consists in a series of participatory events supported by an *ad hoc* decision support system software (mDSS; Giupponi, 2007). The mDSS tool provides the framework for decision analysis at the interface between scientific outcomes and the preferences of the involved actors, with a set of techniques aiming at the elicitation and aggregation of decision preferences and through the implementation of multi criteria decision analysis (MCDA; Figueira et al., 2005). MCDA techniques are adopted to assist a decision maker, or a group of decision makers, in identifying the preferred alternative out of a range of alternatives in an environment of diverging and competing criteria and interests (Belton and Stewart, 2002).

In order to implement those two phases, the participation of local actors (LAs) in the two case studies was achieved through a series of workshops, in which brainstorming techniques were initially used to elicit the most relevant local issues and the most promising responses – potential or in place – to cope with flood risk in a climate change perspective. In parallel, disciplinary experts of the project were involved in an exercise to develop a catalogue of indicators, categorising the widest collection of data provided through analyses and modelling of various kinds and facilitating the communication of the expected outcomes in advance to the interested parties. Local issues raised by the involved actors express the demand of knowledge, while the delivery of information planned by the researchers represents the planned supply of knowledge. The two should in theory match to allow for an effective transfer of knowledge and local impact of the project. This aspect is unfortunately, quite often either neglected in many international research efforts, or considered only in the final phases of the activities, thus dramatically limiting the potential research outcomes. An innovative solution designed to cope with this problem was the implementation of a series of activities carried out in parallel with both the researchers and the local actors belonging to the two case study areas, culminating with the delivery of an extensive integrated indicator table (IIT).

The IIT represented the main interface to the knowledge base developed by the Brahmatwinn Project allowing the combination and comparison of the supply and demand of information (see Fig. 1 for the IIT structure and functions and Supplementary on-line Materials for details). On the left side of the table a hierarchical classification of the information relevant to the whole research project is reported, starting with the level of greatest aggregation, i.e. the four ''Themes'' (Environment, Economy, Society and Governance). The ''Themes'' are sub-divided into ''Domains'', which are further segmented into ''Sub-domains''. Such a categorisation of

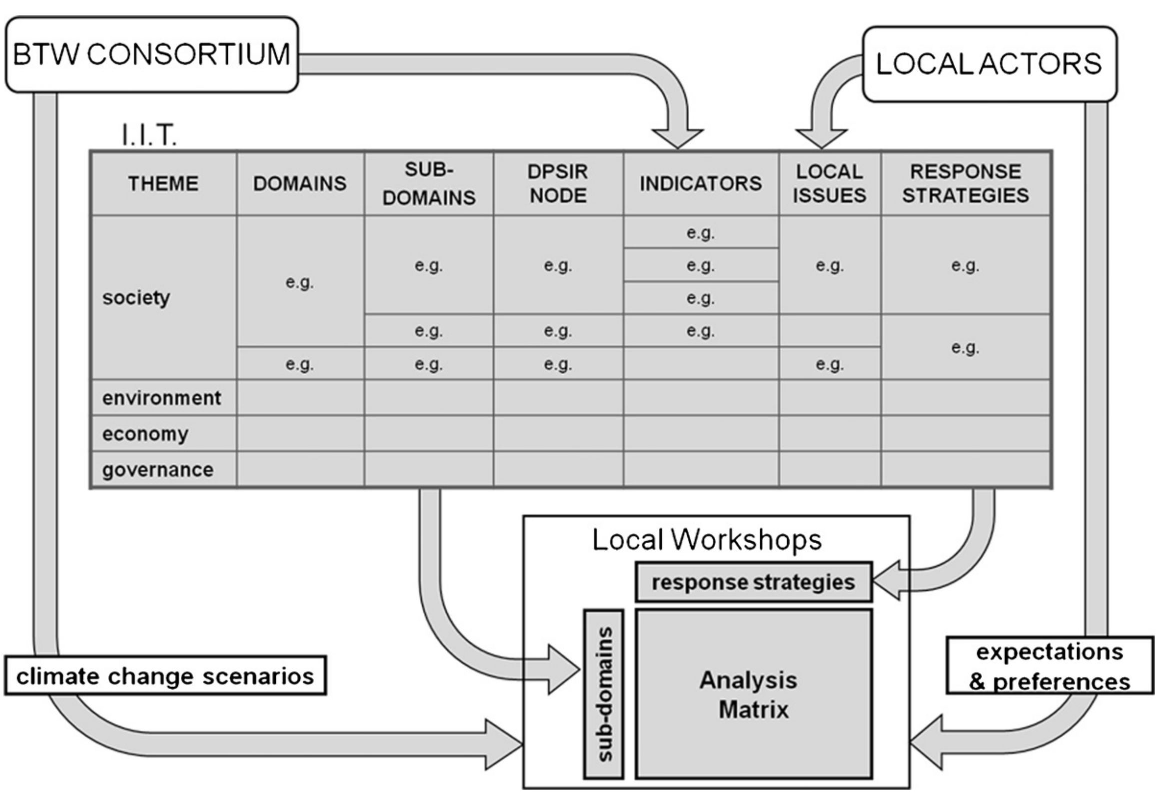

Fig. 1 – The interactions between local actors and the consortium of researchers of the Brahmatwinn (BTW) Project: interfaces and fluxes of information in support to participatory workshop conducted for the analysis of options in terms of strategies to cope with evolving flood risks within climatic change scenarios.

relevant information for the project was developed with a Delphi technique in a series of steps, in which all the project partners were involved. At the highest level of detail ''Indicators'' were identified by partners (one or more per Sub-domain) as the means of providing a quantitative assessment of the various typologies of information dealt with by the project. The left hand side of the IIT thus represents a comprehensive catalogue of the information provided in the project and intended to be useful for supporting the identification of response strategies at local level.

On the right hand side of the IIT, the issues identified by local actors during the workshops dedicated to the NetSyMoD phases of *Problem Analysis* and *Creative System Modelling* are assigned to related ''Sub-domains'', thus providing an interface between the potential supply of information from project activities, and the demand from potential beneficiaries. In general it was possible to create such correspondence, but in some cases, as exemplified in Fig. 1, it appeared that either the consortium was ready to provide information not immediately relevant to local issues or the local actors were raising issues not dealt with by the project, thus identifying the existence of knowledge gaps.

As described below – and depicted in Fig. 1, information categorised within the IIT was at the basis of the organisation of workshops aimed at analysing the expectations and the preferences of LAs in terms of future strategies, to orient the final steps of analysis of the project, with the help of the mDSS software. Therefore, sub-domains were also assigned to the five nodes of the DPSIR framework, for maintaining the coherence with such conceptual framework and preparing for the utilisation of the mDSS tool (see Fig. 2).

In collaboration with project partners the possible IWRM strategies to cope with flood risks in future climate change scenarios in the two areas were categorised into four broad categories of Responses (according to the DPSIR definition), in order to involve LAs in the process of targeting and finalising the remaining project activities:

1. ENG-LAND: Engineering Solutions and Land Management (e.g. dam construction, river network maintenance, soil conservation practices, etc.);
2. GOV-INST: Investments in Governance and Institutional Strength (e.g. accountability and transparency in government actions, enforcement of existing regulations, flood insurance, etc.);
3. KNOW-CAP: Knowledge Improvement and Capacity Building (e.g. awareness-raising activities, dissemination of scientific knowledge, training of public employees, etc.);
4. PLANNING: Solution based on planning instruments (e.g. design and implementation of relief and rehabilitation plans, hazard zoning, etc.).

2.2. *The DSS design and analysis of options*

Building upon the information acquired in the participatory activities carried out in the first two years of the project and referred to in the first three NetSyMoD phases, two workshops were organised, one in Salzburg, Austria (Danube) and one in Kathmandu, Nepal (Brahmaputra), with the aim of testing the proposed methodology. In order to guarantee the comparability of the results of the two river basins, both workshops were structured using the same procedure, designed with the purpose of building a common language and understanding of the problems within the groups of LAs, and between them and the research consortium. The workshops were organised in two half-day phases (afternoon of day 1 and morning of day 2) and their outline is briefly described below.

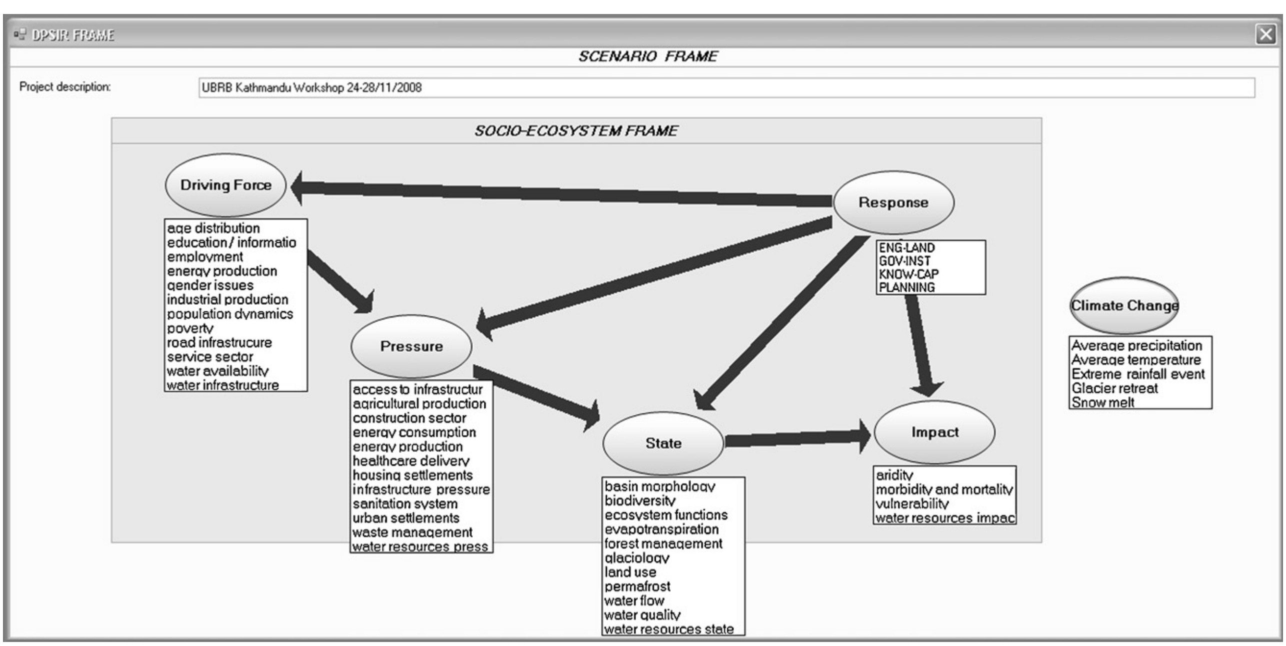

Fig. 2 – The conceptualisation of the information base stored in the IIT within the extended DPSIR framework (screenshot of the mDSS software).

The workshops started with the **presentation** of the goals and of the preliminary results of the downscaling of climate change (CC) scenarios, by means of storylines developed by the project climatologists (Institute for Atmospheric and Environmental Sciences of Johann-Wolfgang Goethe University, Germany), focusing on the possible effects of CC on local water resources over the coming 40 years.[6]

Having introduced the problem and the scenarios, a **brainstorming** session was conducted to elicit and consolidate the sets of possible responses within the four main categories that had been defined during the previous project meetings. This section created the basis for the correct implementation of the ensuing steps, and led to the identification of subcategories and specific actions, within the proposed four major categories of responses.

Having consolidated the identification of responses, participants were asked to select the **criteria** for the evaluation of responses, from the sub-domains listed in the IIT. Each participant was asked to rank the three most important, within three separate lists for the economic, social and environmental domains, in terms of relevance for evaluating the responses (40 criteria in total were listed in the IIT).

Once identified the nine most important evaluation criteria (three per each sustainability theme considered), participants were asked to provide **weights** expressing their relative relevance. The criteria-weighting procedure was based on the method proposed by Simos (1990) and revised by Figueira and Roy (2002), which involves the aid of sets of cards. This method was very appropriate for these workshops, because it supports the planned application of the Electre III method (Belton and Stewart, 2002) and because it provided a simple and effective approach for weighting, without the need of a computer lab, which was not always available.

Criteria and responses defined the entries of the **Analysis Matrix** (9 rows and 4 columns for criteria and response categories, respectively) and, together with the weight vectors, they were used for the subsequent evaluation exercise, by means of the MCDA methods provided by the mDSS software. Participants were asked to fill in the matrix, responding to the question "What is the potential effectiveness of the responses (columns) in coping with the issues expressed by the criteria (rows)?". In practice, they evaluated the potential effectiveness of each response (columns) in coping with the issues expressed by the criteria (rows) by means of a Likert scale (from 1 to 5 ranging from "very high expected effectiveness" to "very low expected effectiveness").

A second Likert scale was added in every cell to analyse the degree of confidence and **uncertainty** related to LAs opinion (IPCC, 2005), i.e. a rough idea about the uncertainty related to the judgement provided for every combination of response category and assessment criterion. In the forms distributed to workshop participants, the concept of uncertainty was specifically related here to their perceptions of the limits in the predictability of the effectiveness of the responses.

The compilation of the AM concluded the first part of the NetSyMoD workshop. All the data collected were coded with a spreadsheet software and then passed to the mDSS tool, for Multi-Criteria Analysis (MCA) and Group Decision-Making (GDM). The mDSS software allowed for the comparison of the alternative options using MCA techniques, by operating parallel evaluation processes, representing the preferences of each participant. In practice, the qualitative evaluations contained in the Analysis Matrix were transformed into normalized scores that expressed the performances of the responses in real numbers ranging between 0 and 1, and subsequently processed by means of the ELECTRE III **decision rule** (Belton and Stewart, 2002), allowing the aggregation of partial preferences describing individual criteria into a global preference and the ranking of the alternative strategy categories. ELECTRE adopts a pairwise comparison of the alternatives, so it is computationally rather demanding, but very simple to be applied by practitioners. The preference (P) and indifference thresholds (Q) were parameters defined by the research team as an input, while no veto threshold (T) was introduced in the analysis, because not pertinent to the selected indicators and analytical context.

Results of individual outranking procedures were subsequently combined in a **Group Decision-Making** procedure by means of the Borda rule (de Borda, 1953).

All the results of the data processing were reported to the participants in a final plenary session of the NetSyMoD workshop.

3. Results

The two workshops in the Danube and Brahmaputra were conducted in parallel without exchanges of information between the two communities of LAs. Even so, five out of nine selected criteria are common to the two cases revealing that in the two river basins, though characterised by different geographical locations, ecological, social and economic dimensions, LAs approach decisions about future strategies in a similar way, i.e. by basing the decision upon a similar set of criteria.

A valuable outcome of the twinning approach, therefore, has been the delineation of some crucial aspects related to flood risk and climate change adaptation strategies in the two river basins. Vulnerability was one of the highest weighted criteria, demonstrating the relevance of the issue and, in general, the concern on the two basins' ability to cope with the adverse effects of climate change in the future. Vulnerability is a hotly debated concept, but according to the IPCC (2007b), vulnerability is determined by the exposure to climate change, by the physical setting and sensitivity of the impacted system, and by its ability to adapt to change. Following this definition, an interpretation of LAs' opinions expressed during the workshops can be provided.

The exposure to climate change risks is clearly related to *Basin Morphology*, that is the physical characteristics of the drainage area, which could appear an obvious consideration, but, on the contrary, it highlights here that the design of

[6] Climate change scenarios provided climate simulations using three IPCC-SRES scenarios (A1B, A2 and B1; IPCC, 2000) and the COMMIT scenario (i.e. the consequence of committing world economies to limit GHG concentrations at 2000 levels), five data sets (GPCC, UDEL, CRU, EAD, F&S) and four models (ERA40, CLM-ERA40, ECHAM5, ECHAM5-Γ).

Table 1 – Criteria selected by LAs from the Integrated Indicators Table (IIT) and their weights.

	Criteria selected at the Danube WS	Weight	Criteria selected at the Brahmaputra WS	Weight
SOC.1	Housing settlements	0.138	Poverty	0.125
SOC.2	Population dynamics	0.097	Population dynamics	0.132
SOC.3	Infrastructure pressures	0.133	Infrastructure pressures	0.100
ENV.1	Vulnerability	0.144	Vulnerability	0.145
ENV.2	Basin morphology	0.091	Basin morphology	0.125
ENV.3	Ecosystem functions	0.143	Forest management	0.113
ECO.1	Agricultural production	0. 099	Agricultural production	0.103
ECO.2	Construction sector	0.111	Energy production	0.101
ECO.3	Energy consumption	0.043	Employment	0.056

actions and strategies lacks careful consideration of the specificity of the area. *Population Dynamics* is contemplated as one of the most important driving forces to be studied to cope with flood risk. Population size and growth, the distribution across urban and rural areas, population concentration, the distance between settlements and riverbanks, are examples of some of the aspects to be evaluated in the strategy design. Also the role of *Agriculture Production* has to be carefully considered by policy makers. Critical issues are related to irrigation infrastructure and extension, ratio of commercial agricultural land per household, household agriculture dependence as a primary source and cropping patterns and diversity. Finally, the pressure caused on *Infrastructure*, according to the LAs, has to become one of the central points of flood risk reduction strategies. Attention has to be paid to the extent of potential damages caused by floods to human infrastructures, like dams and reservoirs; aspects like the probability of dam break, the reservoir-induced seismicity, the downstream stream bed retrogression, the upstream reservoir sedimentation volume and submergence area have to be studied and integrated in the policy focus.

Besides the emergence of such similarities, the exercise of criteria selection also evidenced the significantly different relevance attributed to a series of proposed criteria out of the lists of proposed sub-domains. In the Brahmaputra, to which mainly low-income countries belong, ''*Poverty*'' was picked as the most relevant criterion, highlighting how the poverty level and low life standards strongly affect the significance of flooding damages in the area.

It is, indeed, recognized that poverty is directly related to vulnerability to climate change, since it is a determinant of adaptive capacity. Countries with limited economic resources are likely to have also poor infrastructure, fragile institutions, low levels of technology, reduced skills, limited access to information and to resources, and consequently little capacity to adapt. Poverty is both an important determinant of endogenous environmental risk, and hence indirectly of socioeconomic vulnerability, and an important constraint of adaptive capacity (Brouwer et al., 2007). Hence, poverty reduction policies would indirectly reduce the exposure to flood risk.

It is also interesting to notice that ''*Forest management*'' was selected in the top-3 environmental sub-domains only in the Brahmaputra. In the Danube, instead, LAs concentrated their votes on ''*Housing settlements*'', showing a different perspective in the European area when considering flood risk. According to LAs, the flood risk in the Danube seems to be affected mostly by housing concentration, high population density and the concentration of residential constructions in areas exposed to flood risk. With respect to the economic criteria, ''*Agriculture production*'' was considered as one of the most relevant in both river basins. This confirms that, according to the LAs' opinion, agricultural systems, irrigation infrastructures and land use in general are crucial and can contribute to either aggravate or reduce the risk of flooding.

Having identified the set of nine evaluation criteria, workshop participants then defined their relative importance by attributing criteria weights (Table 1), providing information about the relative relevance to be given to the criteria in the final ranking of alternatives. Besides the difference in the relative importance of each criterion, it is interesting to observe that in both river basins LAs tend to hold environmental and social criteria in greater regard than economic ones. We can easily see this by summing up criteria weights for each dimension: the environmental dimension was considered the most important, accounting for 38% of the total weights, followed by the social (36–37%) and lastly by the economic one (25–26%).

The calculation of weights by means of average aggregation, however, can homogenise and flatten the values. Aggregate values can therefore hide important information, such as divergence and convergence of participants' opinions. The discordance in the weight evaluations clearly reflects the different perceptions and objectives of LAs, and reveals the presence of possible conflicting interests among them. The elicitation of weights is therefore a very crucial phase, because weights can strongly influence the results (Belton and Stewart, 2002). In fact, in theory, an equal representation and integration of all the issues at stake should be guaranteed in participative exercises. In our case, after analysing the distribution and the spread of individual preferences for each criteria weight using Box and Whisker plots (see Fig. 3), we were able to verify that in general, among the Danube participants, there was a reasonable concordance in weight attribution, while, on the contrary, among Brahmaputra respondents we observed high discordance in weight evaluations.

This result pointed out the need for a sensitivity analysis, for the Brahmaputra case, to monitor how changes in the weight sets could influence the final ranking. Sensitivity analysis, indeed, is necessary to improve the quality of

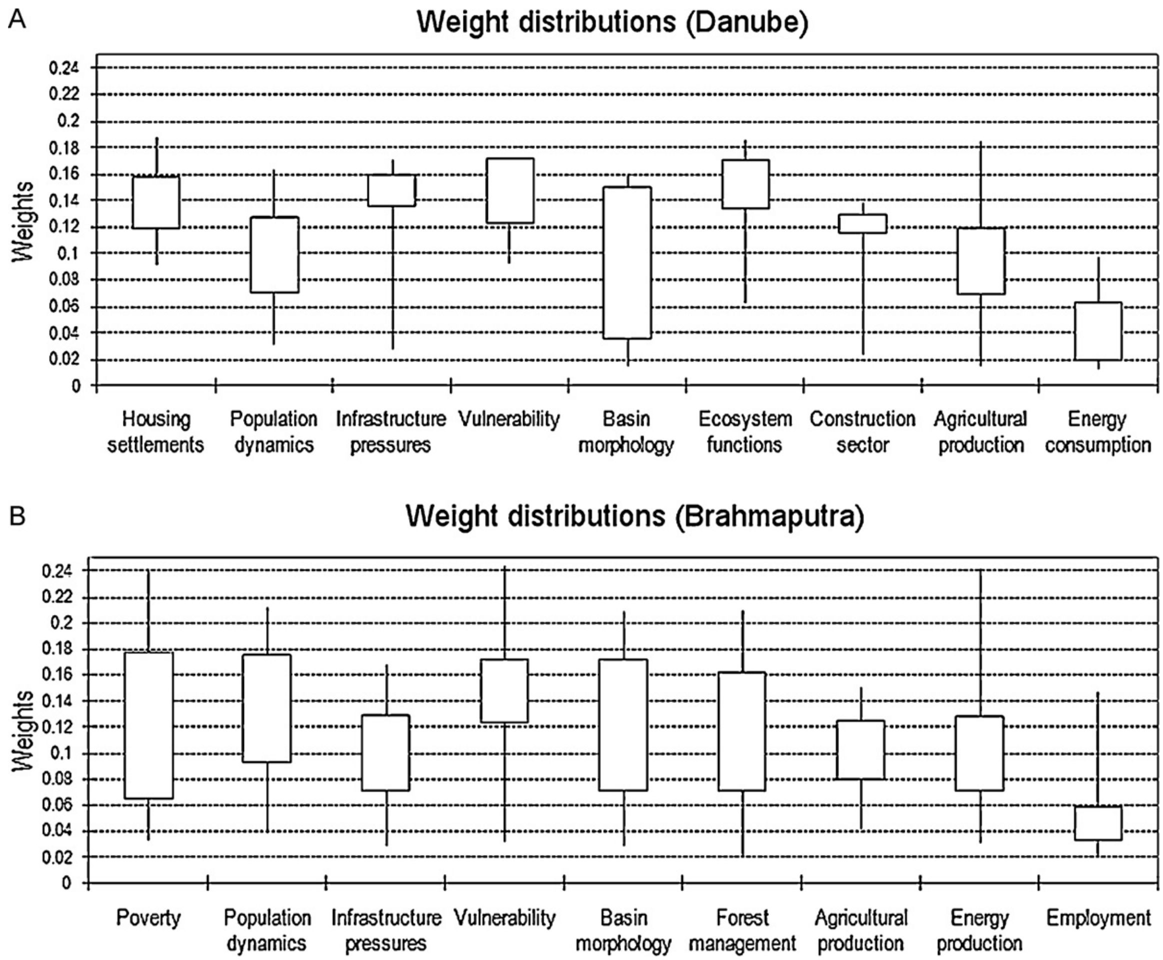

Fig. 3 – Box and whiskers plots of the dispersion of weights provided by local actors of the UDRB (a) and UBRB (b).

environmental decisions and verify the robustness of the results (French and Geldermann, 2005; Cloquell-Ballester et al., 2007), and it should, therefore, be recommended in all the cases of implementation of the proposed approach in the practice of decision making. In this exercise the sensitivity analysis of weights was performed by exploring the effects of incrementing and diminishing one weight at a time by 25%, 50% and 75%, and rescaling all the others while maintaining the original proportions among them. The sensitivity analysis results are discussed further on in the article.

The following step was the elaboration of the Analysis Matrix (AM) for each river basin, aggregating and averaging the information collected from each individual AM of participants. Two average AMs resulted (Table 2).

From the observation of preliminary data, the results in both the Danube and Brahmaputra showed that none of the categories of strategies clearly dominates the others. All the average criterion scores (bottom rows) or responses (columns farthest to the left) are in a range between ‘‘very high effectiveness’’ and ‘‘medium effectiveness’’, meaning that all the responses are considered to be potentially effective to cope with flood risk and important to deal with the selected environmental, social and economic criteria.

This result is not too surprising. Indeed, throughout the participatory process developed along the entire project, LAs gradually shared their knowledge and perceptions of the various aspects discussed around adaptation strategies to climate change. This process enhanced a shift in LAs views of the problem, from a more individualistic perspective to a common understanding of the interdependence of its multiple dimensions and, thus, of the related policies to cope with. This emphasizes the role of scientists in supplying such a communication platform and confirms the great potential of this methodology to boost knowledge sharing and mutual learning between scholars and LAs.

A supplementary validation of these results is given by the analysis of confidence scores attributed by LAs to their evaluations. The LAs were asked, indeed, to indicate the degree of confidence related to their answer (normalised scale of confidence ranging between 1 ‘‘Very high confidence’’ and 0 ‘‘Very low confidence’’). All the answers were given with a confidence above the normalised value of 0.5 and very close to the highest one (i.e. 1.0).

The last part of the analysis consisted in calculating the ranking of alternative responses by applying the MCA capabilities of the mDSS software. The partial scores describing the performance of each alternative response with respect to each single criterion were thus aggregated, considering the elicited weights and following the decision rule adopted (i.e. ELECTRE III). On average, LAs of both river basins evaluated the

Table 2 – Analysis Matrix – average values of LAs' evaluations on the potential effectiveness of each response in coping with the issues expressed by the criteria (rows) by means of a Likert scale ranging from 1 "Very high effectiveness" to 5 "Very low effectiveness".

Analysis Matrix (Average values)		PLANNING	KNOW-CAP	GOV-INST	ENG-LAND	Average
Danube RB						
SOC.1	Housing settlements	2.00	2.43	2.57	2.71	**2.43**
SOC.2	Population dynamics	2.86	3.00	2.29	3.29	**2.86**
SOC.3	Infrastructure pressures	2.43	2.14	2.57	2.00	**2.29**
ENV.1	Vulnerability	2.33	2.67	2.50	2.67	**2.54**
ENV.2	Basin morphology	2.71	2.57	3.43	3.29	**3.00**
ENV.3	Ecosystem functions	2.86	2.43	2.29	3.43	**2.75**
ECO.1	Construction sector	2.14	3.29	2.57	2.43	**2.61**
ECO.2	Agricultural production	2.86	3.14	2.71	2.57	**2.82**
ECO.3	Energy consumption	2.86	2.43	2.57	2.86	**2.68**
	Average	**2.56**	**2.68**	**2.61**	**2.80**	
Brahmaputra RB						
SOC.1	Poverty	2.43	2.62	2.00	3.33	**2.60**
SOC.2	Population dynamics	1.76	2.52	2.33	3.19	**2.45**
SOC.3	Infrastructure pressures	2.00	2.86	2.67	2.19	**2.43**
ENV.1	Vulnerability	1.71	2.43	2.24	1.95	**2.08**
ENV.2	Basin morphology	2.38	2.67	3.10	2.43	**2.64**
ENV.3	Forest management	1.86	2.10	2.10	1.95	**2.00**
ECO.1	Agricultural production	2.15	2.50	2.48	2.29	**2.35**
ECO.2	Energy production	2.19	3.00	2.43	2.10	**2.43**
ECO.3	Employment	2.43	2.57	2.43	3.52	**2.74**
	Average	**2.10**	**2.58**	**2.42**	**2.55**	

PLANNING solution as the most effective one. The remaining categories show different preferences and ranking in the two basins: in the Brahmaputra the second ranked category is ENG-LAND (e.g. dam construction, river network maintenance, soil conservation practices, etc.), there is no preference between investments in GOV-INST (e.g. accountability and transparency in government actions, enforcement of existing regulations, flood insurance, etc.) and KNOW-CAP (e.g. awareness-raising activities, dissemination of scientific knowledge, training of public employees, etc.). The LAs of the Danube instead ranked ENG-LAND as strictly dominated (not preferred) by all the other alternatives, with GOV-INST and KNOW-CAP ranked third and fourth, respectively.

Given the broad meaning of the categories of strategies considered and the exploratory context of the exercise with a relatively high number of stakeholders involved, dramatic differences in the performances were not expected and the differences of the performances were not of great interest. The robustness of the ranking was instead a main issue, because the following steps of the project went into a more detailed analysis of possible strategies within the preferred category identified at this stage.

The robustness of the results was explored and confirmed firstly with a sensitivity analysis of weights, which showed an overall stable performance. In the Brahmaputra basin, all the verified variations of weights (from ±25%, and ±50%) did not induce an overturning of the ranking, confirming PLANNING as the preferred option and ENG-LAND as the second ranked category. In the Danube basin the ranking was confirmed with variations of weights by ±25%, while it was observed that a variation by +50% of the criterion *Population Dynamics,* or of the criterion *Infrastructure Pressure* by −50% would determine a change of the ranking. These variations are indeed very high, so that the results can still be considered robust enough, nevertheless it should be mentioned that in those cases the GOV-INST became the preferred category, thus pointing out a slightly different perspective of the Danube stakeholders.

Moreover, in order to explore the possible effects of averaging the preferences of multiple actors in terms of both analysis matrices and weight vectors, the data collected from each LA were also processed separately thus obtaining multiple final rankings of options. All the rankings obtained were subsequently processed in mDSS using the Group Decision-Making (GDM) capabilities, by means of the Borda Rule. The Borda rule counts how many times each category of responses is preferred to each of the other options by interviewed LAs, and sums up the so called "votes in favour".[7] According to Borda mark (Table 3), we observed that the PLANNING category is the dominating solution (most preferred one) in both basins, with 10 votes in the Danube and 38 in the Brahmaputra, respectively.

For the purposes of the exercise within the activities of the Brahmatwinn Project, the results were robust enough to orient the attention of the researchers toward analysing in greater detail the strategies for mitigating flood risks in a climate change perspective within the broad category of PLANNING. Discussions with LAs were useful to better define strategies and actions which should be considered within the preferred category of PLANNING measures, and assessed in a more detailed second round of analysis supported by mDSS (not reported in this paper).

In both basins the attention was driven to: improving the implementation of existing land use plans; establishing protected areas along rivers; designing new catchment development plans; coordinating regional and community

[7] The votes in favour, in Borda mark, consider strictly preferences and do not count indifference.

Table 3 – Group Decision Making marks. The first number refers to the N. of votes in favour, while "I" refers to the votes of indifference.

	PLANNING	ENG-LAND	KNOW-CAP	GOV-INST	Sum of votes in favour	BORDA Mark
Danube						
PLANNING	–	3 (I = 0)	4 (I = 0)	3 (I = 2)	**10**	**1°**
ENG-LAND	4 (I = 0)	–	1 (I = 0)	2 (I = 0)	**7**	**3°**
KNOW-CAP	3 (I = 0)	5 (I = 1)	–	1 (I = 3)	**9**	**2°**
GOV-INST	2 (I = 2)	5 (I = 0)	3 (I = 3)	–	**10**	**1°**
Brahmaputra						
PLANNING	–	10 (I = 6)	16 (I = 3)	12 (I = 5)	**38**	**1°**
ENG-LAND	5 (I = 6)	–	9 (I = 4)	8 (I = 6)	**22**	**2°**
KNOW-CAP	2 (I = 3)	8 (I = 4)	–	8 (I = 6)	**18**	**3°**
GOV-INST	4 (I = 5)	7 (I = 6)	7 (I = 6)	–	**18**	**3°**

level planning; evaluating and harmonizing existing hazard plans; restricting the construction in risk areas; realizing flood risk mapping and zoning and vulnerability mapping. In the Danube river basin LAs also pointed out strategies oriented toward designing and implementing IWRM plans, underlining the need for a common government platform of the basin, and strategies focused on the planning of retention areas and urbanisation processes. In the Brahmaputra basin, LAs also focused their attention on strategies related to disaster risk management act and plan, for an earlier intervention and community preparation to flood occurrence.

4. Discussion and conclusions

The NetSyMoD methodological framework developed for the integrated participative activities of the Brahmatwinn Project, with the involvement of both researchers and local actors, facilitated in general communication and exchanges of experiences between the twinned river basins, and among scientists of different disciplines and local actors, through a continuous interaction and feedback process. In particular, the participative process proposed contributed significantly to ensuring that the scientific knowledge and approaches offered could meet the perceptions and needs of local people and decision makers, who would ultimately be the end-users of the project's outputs. The process also enabled the management of the different roles needed according to French and Geldermann (2005): researchers giving insights on how the future might unfold, with local actors providing judgements on the expected feasibility and effectiveness of the responses to cope with flood risk. In this case adaptation responses to climate change have, therefore, been evaluated by those adapting, i.e. local actors as suggested by de França Doria et al. (2009).

These findings show great potential for addressing further research efforts more effectively. In the case of the Brahmatwinn Project the results reported herein allowed for more targeted final activities, including a subsequent round of Analysis of the options focused on a set of possible strategies within the broader category of "Planning" approaches.

Looking at LAs' contributions during the brainstorming phase of the workshops, we can interpret the preference given to "Planning" in a general way: there needs to be some kind of response developed a priori, so that when flooding occurs local authorities and communities know how to behave during and after the emergency, e.g. the design of relief and rehabilitation plans and disaster risk management. Also, in a stricter sense, LAs referred to the need of physically identifying and mapping hazard areas, such as flood risk zoning, and, more generally, land-use planning. The emergence of "Planning" as the most promising response in both basins might therefore mean that not only do LAs think that "Planning" is most needed in absolute terms, but also that it is currently the most deficient of the four categories presented. In the Danube, LAs acknowledged that change in land-use planning after major flooding events – even if partial – had been a key factor for the prevention of damage in more recent flood events.

Examples of change are the projects implemented for the renaturation of the river banks, which, according to some LAs, should be extended to other areas. However, LAs have also expressed the need to evaluate, harmonize, and implement existing plans. On the other hand, in the Brahmaputra the importance given to population density and poverty (i.e. second and third most important criteria) is related to the fact that many settlements are found in high risk areas, which are sometimes the only place where poor people can afford to live. The concern for encroachment on Brahmaputra's banks as one of the factors limiting the possibility of risk reduction voiced in the workshop confirms this hypothesis. LAs of the Brahmaputra have expressed the need for land-use planning to deal with concerns for urbanisation processes along the river banks, which should be prohibited and people already living there should be resettled.

The results were also circulated within the research consortium to direct the attention of modellers to the subsequent phases of the project, with the idea of providing a quantitative assessment of the strategies within the assessment framework described here. However, the ambition to substitute LAs' expectations elicited through the Likert scale at the workshops, with quantitative assessments provided by models proved to be beyond the capabilities of the project, mainly because of time constraints. It should therefore be recommended that when approaches deriving from the one proposed here are adopted, the work plan be carefully defined with adequate time length and with the possibilities of (re)orienting hard science modelling according to the issues and the expectations elicited from the stakeholders.

Besides the methodological framework, also the mDSS software raised great interest among the participants, who were involved in the project activities since its initial phases, exposed to preliminary results and asked to contribute to orient the final phases of the project. Several participants appreciated the use of public domain software in particular, because it allowed the reuse of the approach proposed in local decision problems. In the scientific literature elements such as the timely involvement of stakeholders and the free availability of tools for reuse in local cases and elsewhere have been quite often proposed, but rarely applied in practice.

In this regard the results of this research are encouraging, because they advance our understanding of adaptation to climate change in river basins, and in particular they demonstrate how strategic planning can be implemented in practice, with the support of freely available tools. Starting with the brainstorming in each workshop we were able to elicit and develop a number of responses, needed or in place, to cope with flood risk and future scenarios. LAs of both basins were able to identify responses based on their knowledge and understanding, but also based on other responses identified in previous workshops, either in the same or in the other basin. This was possible thanks to the fact that besides the two workshops described in this article five others were held, i.e. a total of seven workshops took place according to the sequential and iterative process envisaged by the NetSyMoD framework.

In general, the experimental application of the NetSyMoD approach to the study areas provided a means to concretely carry out the twinning of the two river basins, shedding light on the commonalities and distinct features. This study approach led to structured and very effective discussions concerning adaptation responses to flooding in those areas, and allowed for the collection of a significant amount of insights and lessons, drawn from the involvement of local actors. From the evaluation questionnaires collected at the end of the events, we had no evidence of problems concerning the opportunities to freely and equally express opinions, possible biases, or about the process being guided by a dominant discourse, which may delegitimize some of the stakeholders only because they do not subscribe to a preliminarily defined agenda (Griffin, 2007).

As a final remark it should be remembered that the participatory processes described above were at least to some extent, academic simulations of social processes, since they were carried out within the activities of a research project; this implies that the results must be considered mainly for their role in methodological test and demonstration. For this reason, crucial aspects of real world applications were not dealt with by the project, such as the statistically sound identification of representative local actors. Having clarified this at the outset with the participants involved, these activities provided at least two very important opportunities and one caveat: (1) testing and refining methods and tools to be applied in real world decision processes, and (2) disseminating information about scientific developments and the availability of methods and tools to potential users of the project results. Regarding the caveat, it should be remembered that participatory activities should be carefully planned, designed and managed and that methods and tools are not enough – skilled professionals are needed too. This points to the need for future training efforts specifically targeted to provisioning the participatory processes to be implemented in IWRM and climate change adaptation processes with professionals of adequate capabilities.

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Appendix A Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.envsci.2011.05.016.

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