PARTICIPATORY MODELLING TO SUPPORT DECISION MAKING IN WATER MANAGEMENT. A CASE STUDY IN THE MIDDLE GUADIANA BASIN, SPAIN.

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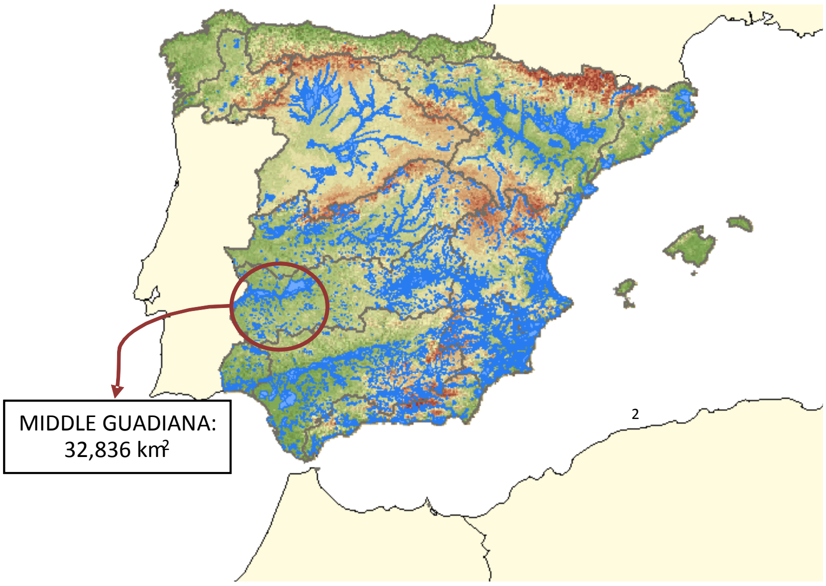
1. Introduction

The objective of this research was the implementation of a participatory process for the development of a tool to support decision making in water management. The process carried out aims at attaining an improved understanding of the water system and an encouragement of the exchange of knowledge and views between stakeholders to build a shared vision of the system. In addition, the process intends to identify impacts of possible solutions to given problems, which will help to take decisions.

This research has been applied to the Guadiana river basin. This river is located in the central Iberian Peninsula and covers 67,000 km^2 of which 83% lies in Spanish territory (Llamas et al., 2010). The area exhibits a semi-arid climate, with high variability of precipitations leading to an irregular water recharge along the year and between years. The Spanish part of the Guadiana basin is divided into 3 sub-basins: the upper Guadiana, which covers mainly Ciudad Real province, the middle Guadiana, located mostly in Badajoz province, and the lower Guadiana in Huelva province. Our study has been focused on the middle sub-basins, corresponding to 50% of the whole basin (see figure 1).

Figure 1: Location of the Guadiana basin, in Spain.



Source: SIA-MARM (2008)

Total irrigated surface in the Guadiana basin accounts for 413,300 ha, being 31% of this area located in Badajoz province (middle Guadiana). Agriculture has a great importance in the area, both as economic sector and as a water-consuming sector. This sub-basin has beneficiated from public plans for the development of irrigation, but presents in turn high volumes of water used, being modernization of irrigation systems one of the main challenges in the area, together with an improvement of water governance.

2. Methodological background

When addressing management problems, especially in the field of natural resources, the current trend is the development of integrated policies considering all factors related to the resource use and aiming at the sustainability. In this line, the European Union has developed the Water Framework Directive (WFD), establishing the general guidelines for water management in the EU countries. This framework represents a new perspective of water management, including a shift from supply to demand management, an obligation to consider the cost-effectiveness of measures and the requirement to include stakeholders in the design of river basin management plans. The WFD is inspired on the Integrated Water Resources Management (IWRM) concept, which was developed during the 1990s and is defined by Global Water Partnership as "a process which promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (Global Water Partnership, 2000). There are other definitions of the concept (Biswas, 2004; Biswas, 2004), but all of them claim the need to consider the complexity of water systems, where multiple factors and multiple actors are involved in multiple regional and time scales, and the need to involve stakeholders in the resource management (Pahl-Wostl, 2007; Rault and Jeffrey, 2008; Sgobbi and Giupponi, 2007).

The incorporation of IWRM principles in the WFD is a common feature with other current legislations (Welp, 2001), and it includes the consideration of the importance of participation, which is one of the main principles and a compulsory feature of water management in the European legal framework (De Stefano, 2010; European Commission, 2000; European Commission, 2003; European Commission, 2003).

Participation is understood as the involvement of members of the general public in policy-forming activities, under several mechanisms intentionally instituted on that purpose (Beierle and Cayford, 2002; Rowe and Frewer, 2004). According to Johnson (2009), Smith Korfmacher (2001) and Webler and Tuler (2001), there are three major reasons for stakeholder involvement: involving the public in decisions that affect them, improving scientists' understanding of facts and values by local specialized knowledge, and assuring an easier implementation thanks to a better educated public.

These motivations are on the basis of the WFD participatory requirements. First of all, stakeholder participation enables sharing information from different points of views and building a common understanding of the system. In addition, stakeholder involvement in decision making is improving public acceptance of water management plans, which becomes more probable when stakeholders have participated in the design of those plans. In short, public participation improves the durability and quality of decisions, it creates a better informed public, better acceptance of decisions, and a reduction of conflicts and costs of implementation, by creating transparency for the public (Jonsson, 2005; Lamers et al., 2010).The higher implication of such public leads to higher probabilities of achieving social learning. However, the implication level will depend on the availability of resources, and a lack of resources, of rules, of in-depth involvement of stakeholders, or a lack of professional supervision of the process are possible reasons to avoid the success of a participatory process.

Stakeholder participation is especially important to address complexity of environmental problems, such as water resources management (Welp, 2001; Antunes et al., 2009), where physical and biological systems are combined with the multiple perspectives, needs, values and concerns associated with human use. This entails the need for the development of participatory tools which are capable to overcome complexity and uncertainty (Pahl-Wostl, 2007). In addition, successful participation of stakeholders in natural resources management requires tools to support decision making which are transparent and flexible (Henriksen and Barlebo, 2007), aimed at eliciting knowledge from the different stakeholder groups and working as a platform to carry out the debate. At the same time, we need the selected methodology to support planning and decision making. Those two objectives, respectively social learning and decision making support, are identified in literature (Lynam et al., 2010; Martínez-Santos et al., 2010; Ramsey, 2009; Simon and Etienne, 2010; Voinov and Bousquet, 2010), and should be considered together, as the first helps the second (Lynam et al., 2010; Martínez-Santos et al., 2010; Simon and Etienne, 2010; Voinov and Bousquet, 2010).

In our case, we need a tool which is built with stakeholders and can help taking decisions, such as decision support tools (DST), that is, computer-based tools which can be used to create and assess management alternatives, as well as to enable knowledge communication between stakeholders. At the same time, addressing water management in an IWRM approach requires the use of integrated tools which are capable of taking in consideration the different aspects of water use. With this regard, one challenge is going from qualitative information (which is often the available one) to quantitative (Welp, 2001). An interesting approach is the integration "formal methods" (mainly mathematical models) with stakeholder based approaches (Giordano et al., 2007). Those are not mutually exclusive but complementary, and their integration can help reaching better quality of decisions than traditional approaches.

One of the most interesting approaches to address IWRM requirements is participatory modelling, understood as a "process in which the formulation of a conceptual model and its formalization is carried out by disciplinary experts with the direct involvement of stakeholders" (Jonsson, 2005; Jonsson, 2005; Sgobbi and Giupponi, 2007; Sheppard, 2005). With this approach, we can provide a common basis for the elicitation of knowledge and a ground for discussion, an improved understanding of the system while capturing the complexities of the water system and serving as a support for decision making. In any case, but especially when dealing with computer models, participation from the early stages helps understanding (Rowe and Frewer, 2000).

Voinov and Bousquet (2010) make an overview of participatory modelling techniques, emerged as a result of the occurrence of two parallel phenomena: the development of system dynamics modelling and the trend to include participation requirements in different laws. Within the umbrella of participatory modelling methods, we can find different approaches: Participatory Modelling (PM), as a generic term, referring to the inclusion of participation in traditional formal modelling, such as hydrologic or economic models (Langsdale et al., 2009; Martínez-Santos et al., 2008; Videira et al., 2010); Group Model Building (Andersen et al., 1997; Andersen et al., 2007; Richardson et al., 1997; Vennix, 1999), mainly based on the use of CLD, where collectively participate in building the dynamic model; Mediated Modelling (Antunes et al., 2006; Van den Belt, 2004), also based on system dynamics but more focused on environmental applications; Companion Modelling (Becu et al., 2008; Bousquet et al., 2005; Campo et al., 2010; Gurung et al., 2006; Simon and Etienne, 2010), which involves a combination of agent-based models and role-play games and stands on the principles of transparency and adaptiveness; Participatory Simulation, also based on role-play games and agent-based modelling, but where stakeholders do not participate in modelling building and just in simulations; Shared Vision Planning, mainly used in applied studies of the US Army Corps of Engineers, in water management; Collaborative Learning, where stakeholders are put to work together and they learn from each other, through information exchanges.

The most appropriate tool will depend on the specific context and objectives of the particular case we are dealing with. In our case, we are facing complexity and important uncertainties related to data, which come from different sources. Decisions on water management alternatives should be taken based on environmental and socio-economic criteria. A special interest was taken in representing the agricultural sector in detail, covering the specificity of the different farm types and being able to show the differential effects of management measures on such farm types. Bayesian networks (BN) cover all these requirements of capturing complexities, uncertainties and being a good support for stakeholder involvement. Considering the decision making aid purpose, we preferred a model which provided quantitative results to facilitate comparison of different alternatives. Finally, the possibility to combine different types of data made BN our choice, as it has often been in participatory decision making contexts (Crocke et al., 2007).

Apart from the selection of the most suitable tool, the participatory process itself has to be carefully designed. A successful participatory modelling process should be kept flexible to be able to build a common understanding, open in time and space to be able to represent changing environmental systems. Five principles should guide these processes (Johnson, 2009; Smith Korfmacher, 2001): transparent modelling process, continuous and appropriately representative involvement, influence on modelling decisions, and clear role of modelling in watershed management. The implementation of the process should include, as well, some fundamental tasks (Gregory, 2000): (1) framing the decision, (2) defining the objectives, (3) establishing alternatives, (4) identifying consequences, (5) clarifying trade-offs. These stages have been followed in the Guadiana river basin, where we have selected a participatory modelling approach using Bayesian networks (BN).

3. Material and methods

This paper reports the construction of an Object-oriented BN for the middle Guadiana river basin. This model has been built with the active involvement of the key stakeholders. The result has been the representation of the water system which is, at the same time, a decision support tool aimed to help selecting the best management options face to a series of environmental and socio-economic constraints.

Bayesian networks are acyclic, directed graphs representing a system through the main variables, the possible values they can adopt and the relationships between variables in terms of conditional probabilities (Bromley, 2005; Cain, 2001). The mathematical basis of this type of models is Bayes' theorem, which is expressed as follows:

$$P(A_i / B) = \frac{P(B / A_i)P(A_i)}{\sum_{i=1}^{n} P(B / A_i)P(A_i)}$$

Based on this theorem, probabilities of all variables to be in their possible states are calculated given certain initial conditions. When some new evidence is introduced, the new probabilities are determined.

The graphical design and calculations have been done using Hugin commercial software (Hugin Expert A/S, 2008; Hugin Expert A/S, 2008).

Bayesian networks present several characteristics which make them appropriate in our context (Batchelor and Cain, 1999; Bromley et al., 2005; Cain et al., 1999; Jensen and Nielsen, 2007): they can deal with different types of variables and different types of data, that is, they are adapted to complex systems. When the model is finished, different scenarios can be simulated, allowing the quantitative assessment of the outcomes. But one of the main advantages of this tool is the explicit consideration of uncertainties through probabilities. When they are used in a participatory process, the fact of having to discuss about the qualitative representation and about the quantitative aspects of the system can help fostering the debate and providing transparency (Zorrilla et al., 2010).

The process started with a selection of relevant stakeholders, a series of stakeholder meetings and inter-meeting work including the following steps (based on (Bromley, 2005; Henriksen et al., 2007)):

(1) definition of the problem and context
(2) identification of variables, actions and indicators
(3) design of a preliminary network
(4) data gathering form available sources
(5) definition of the states of variables
(6) construction of the conditional probability tables
(7) validation and evaluation

Steps 1-3 correspond to the qualitative phase of the modelling process and steps 4-7 correspond to the quantitative phase. Despite the linear design of the process, it has been implemented in an iterative way, coming back to previous steps when stakeholders or researchers pointed out the need to review the structure or data previously defined.

One remarkable characteristic of this participatory tool is its flexibility regarding the possible data sources; it is possible to use a combination of data coming from statistics, stakeholder opinions, empirical observations, models... With this respect, it has been important in our research the combination of the BN with economic models and with crop models. Being agriculture the main water consumer in the basin, we wanted to capture the details on the agricultural activity regarding the relationship between water use, yields and economic results for the farmers. On this purpose, the economic non-linear mathematical programming model represented the farmers' behaviour, capturing their response in terms of water use and selection of cropping patterns face to different water policy and climate scenarios. In addition, a crop model, Aquacrop (Geerts et al., 2010; Raes et al., 2009; Steduto et al., 2009), was used to derive yield response to water functions. The combination of the BN with the economic and crop models has allowed us to carry out simulations with those models, capturing this way the detailed consequences of the different management options for the different farm types.

The process was held between May 2008 and February 2011. Stakeholders selected were contacted by phone and by e-mail. The group included: the planning group of the Guadiana river basin authority, the agriculture department of the Extremadura regional government, representatives of the main irrigation communities of the sub-basin, environmental conservation groups, researchers and academics. The process has consisted on three meetings specifically organized for the development of the Bayesian network and, previous to the development of the Bayesian network itself, two preliminary meetings organized with the aim of eliciting the problem to be address and exploring among the different stakeholder groups the existing views of the middle Guadiana system. Table 1 shows the details of the number, dates, format and content of meetings.

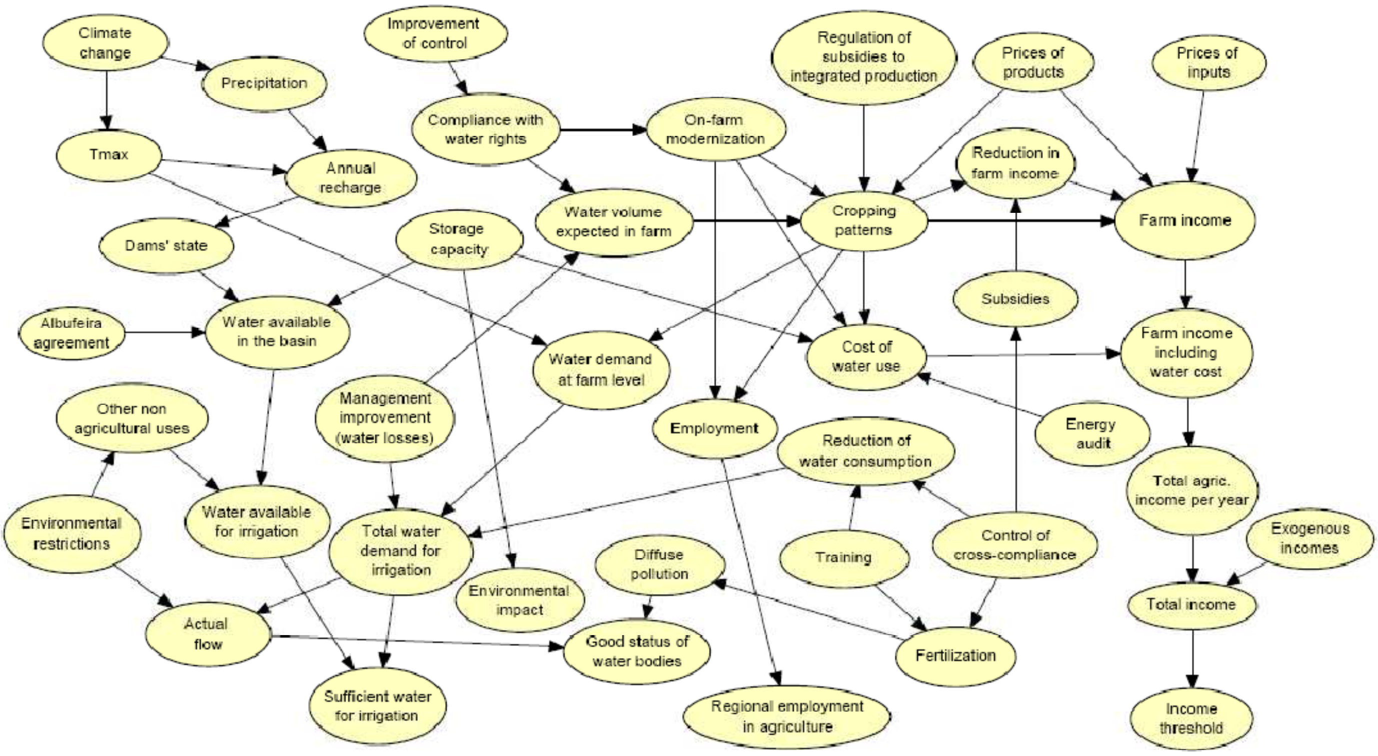
Table 1: meetings held within the middle Guadiana participatory process.

MEETING	DATE	FORMAT	OBJECTIVES	No. ATTENDEES
1.Preparatory meeting (I)	May 2008	Plenary meeting	Elicit main problems in the basin, main factors involved in water use	18
2.Preparatory meeting (II)	March 2009	Plenary meeting	Agree in a common view of the basin context	24
3. Definition of the system	May 2010	Plenary meeting	Identify the most relevant variables in the system, including potential actions and indicators	5 (of 4 SH groups)
4. Validation and completion	November 2010	Group interviews	a) Validate the preliminary network b) Obtain missing data, and c) Check if the states defined by the data collected were close to reality	11 (of 4 SH groups)
5. Evaluation	February 2011	Plenary meeting	Check, collect feedback and evaluate the preliminary results	

4. Results

After the whole participatory modelling process, a model was produced for the sub-basin, representing the water system and very much focused on the agricultural water use, responsible of more than 90% of total water consumption. Figure 2 shows a summary of the model.

Figure 2: Summary of the BN representing the middle Guadiana water system



The result has been a quite complex model, with a higher number of variables (43 nodes), maybe due to two reasons: the water system in the MG is based on surface water, presenting a complex regulatory system and a high number of interrelated elements. In addition, the MG presents an imperfect governance situation, where symptoms, causes and relationships are not clear.

A typology of farms was established and an individual BN was developed for each farm type. Those individual BNs were similar but differed in some of the probability tables, and were aggregated afterwards using an object-oriented network approach (Carmona et al., forthcoming; Dawid et al., 2007; Koller and Pfeffer, 1997; Molina et al., 2010), which allows the representation of particular characteristics of the different farms types. This is important for decision making, as we can test at the same time the effects of the different water management strategies on the different farm types and on the common environment.

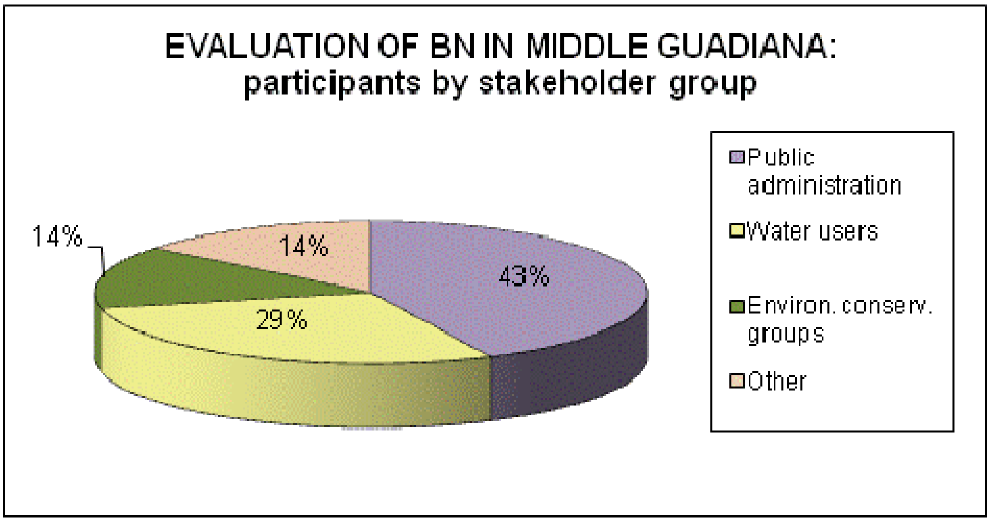
The scenarios simulated and the variables chosen as indicators to evaluate the appropriateness of the measures tested are: (1) change in environmental flow restrictions, (2) several climate change scenarios, and (3) the increase of the enforcement capacity of the River Basin Authority to make farmers comply with water volume restrictions, considering several levels of compliance. The indicators selected in the comparison of scenario simulation results were mainly farm income, employment, the environmental impact of hydraulic works and the good state of water bodies.

We will not go into detail on the results of the different scenarios. As the objective here is to report the usefulness of this approach in terms of stakeholder participation, we will rather focus on the evaluation of the process itself.

The evaluation of the participatory process has been done based on several methods: evaluation questionnaires filled by stakeholders, informal interviews with stakeholders and the own perception of researchers.

The evaluation questionnaires were distributed at the end of the processes. Stakeholders filled them anonymously, and the questions covered a series of topics, based on aspects considered as important in literature (Beierle, 1998; Beierle and Konisky, 2000; Lynam et al., 2007; Rowe and Frewer, 2000; Rowe and Frewer, 2004; Von Korff, 2006; Webler et al., 1995; Webler and Tuler, 2001). Figure 3 shows the composition of the respondents.

Figure 3: responses of the evaluation questionnaires by stakeholder group



The questionnaires for the evaluation of the BN participatory had some open questions, but the largest part of it was formulated in the form of positive assertions about desired outcomes, with which stakeholders had to express their agreement or disagreement. These assertions included in the questionnaires referred to two aspects: the process itself and the performance of the BN as participatory tool:

A. About the process:
   - My interests/views have been included in the BN
   - The BN building process has been useful for me
   - The process helped understanding of each other's concerns
   - The process has helped me improve understanding of the basin's problems
   - The process has helped me improve understanding of interrelationships between water management factors
   - The process has helped improving data transparency
B. About the tool:
   - BN is a good method for planning and management, as it includes all interests
   - BN have helped to focus discussions
   - BN built reproduce reality
   - Visual representation helps understanding the system functioning

Details on the results of the questionnaires are given in figures 4 and 5.

Figure 4: results of the evaluation questionnaires on the participatory process in the middle Guadiana basin.

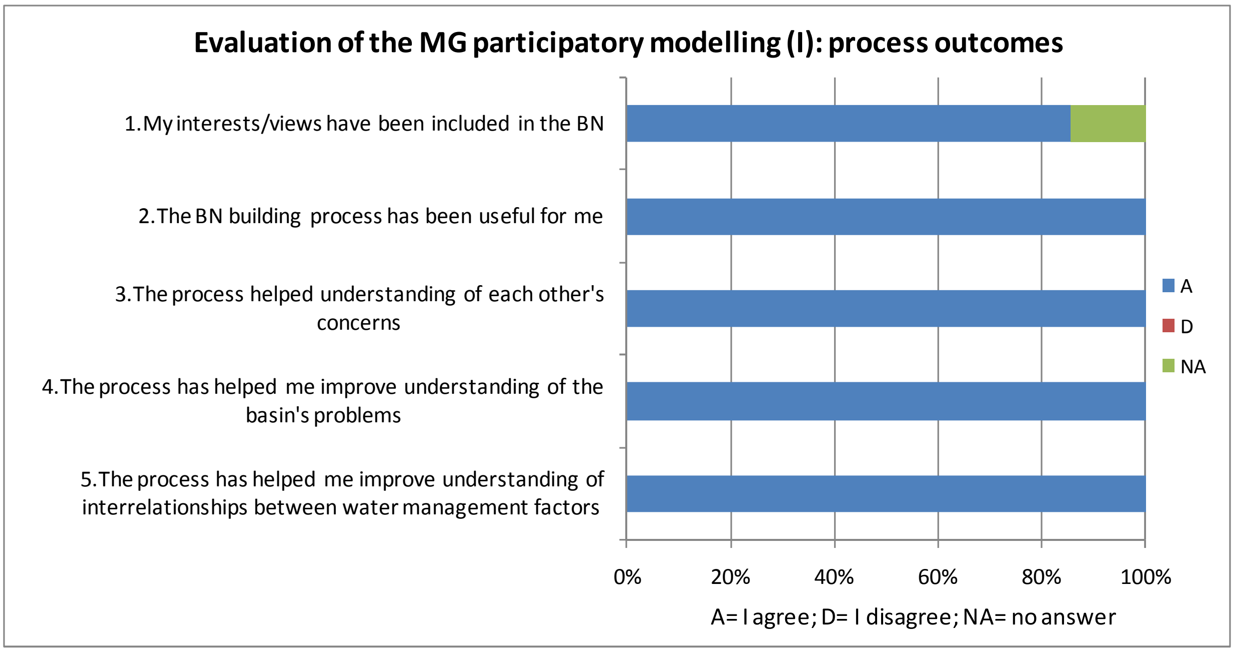
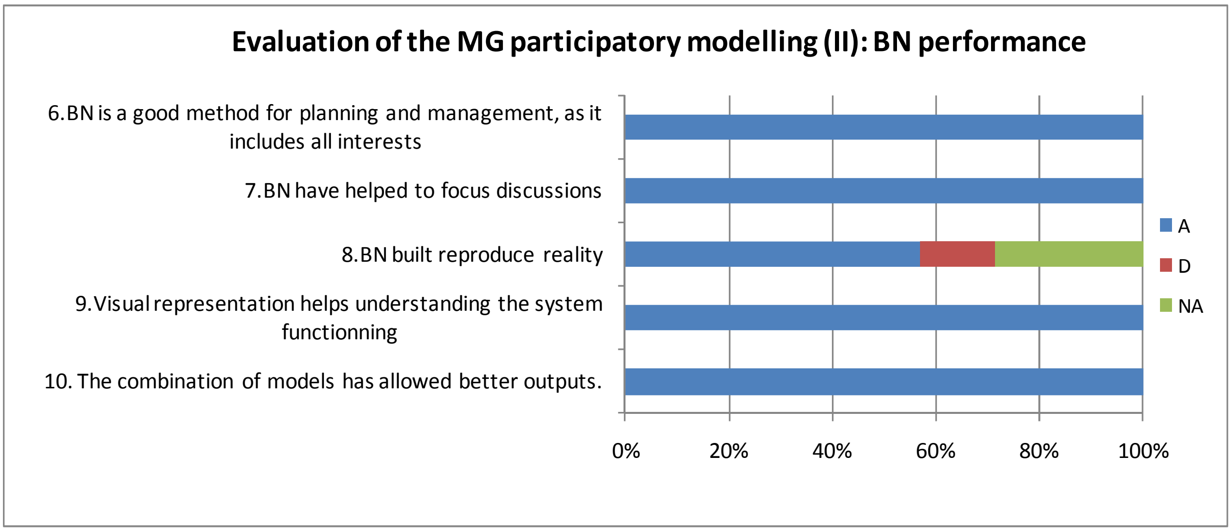


Figure 5: results of the evaluation questionnaires on the participatory process in the middle Guadiana basin.



The answers to the questions have been very positive, presenting a percentage of ‘agree’ responses close to 100, especially in the process evaluation. The only assertion that has been questioned to a certain extent is the capacity of the tool to represent reality. In the open questions, some of the stakeholders expressed the difficulty of finding a reliable database to fill the conditional probability tables, and did not fully agree with some of the simulation results.

Some other general comments came up during the meetings and can be relevant for the evaluation of the participatory modelling process:

- They graphical interface and the software availability to solve calculations in scenario testing were pointed out several times as remarkable characteristics of the methodology selected, that is, of the Bayesian networks. Some of the stakeholders showed interest in obtaining the software to have a look at it after the meetings.
- Participants from the RBA showed a great interest in the possibility to update the BNs obtained so as to be able to use them in the future, including other basins in Spain.

- The combination of BN with economic and crop models and the construction of an Object-oriented BN structure capturing the differences between farm types gained a high interest among stakeholders.

5. Discussion and conclusions

Looking at the evaluation results, we can conclude that, in this type of participatory processes, aimed to support decision making, the process itself is more important that the specific outcomes (like in Lynam et al., 2002). However, the numerical output is highly appreciated, as it facilitates comparison of different scenarios.

Secondly, the ability to involve stakeholders other than policy makers has proved to be positive, despite doubts expressed by Cain et al. (2003). The inclusion the different views in the model is regarded by stakeholders as a beneficial characteristic of the process. This supports other authors' statement about the importance to incorporate stakeholder values into decision making (Bacon et al., 2002; Lynam et al., 2007).

The ability of BN to structure the participatory process and focus discussion is also a result of the questionnaires, together with the usefulness of their graphical interface, confirming Cain et al. (2003) and Henriksen and Barlebo (2007) outcomes.

One drawback of BN is related to the construction of the conditional probability tables, which is found difficult and tedious, and sometimes stakeholders wonder about the accurateness of these initial data. It is at least a positive thing the possibility to investigate qualitative relationships with stakeholders and then translating them into probabilities by researchers.

Finally, the combination with other types of models giving details on specific aspects (economic, agronomic) is found to improve the final results my stakeholders. In addition, the evaluation of variables at different scales and interactions between different types of farms seemed very useful, proving an additional benefit of Object-oriented Bayesian networks compared to a simple one.

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