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STRUCTURING NEGOTIATION AND PARTICIPATORY DECISION MAKING PROCESSES FOR INTEGRATED WATER RESOURCES MANAGEMENT

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PhD EVALUATION COMMITEE REPORT ON THE THESIS PRESENTATION OF

MARCELLA MAIA BEZERRA DE ARAÚJO URTIGA

"STRUCTURING NEGOTIATION AND PARTICIPATORY DECISION MAKING PROCESSES FOR INTEGRATED WATER RESOURCES MANAGEMENT"

RESERARCH AREA: PRODUCTION MANAGEMENT

The PhD evaluation committee with the following examiners, coordinated by the first, considers the PhD candidate **MARCELLA MAIA BEZERRA DE ARAÚJO URTIGA, APPROVED**.

Recife, October 25th of 2017.

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ABSTRACT

Models are proposed to handle participatory decision processes in watershed committees (WSCs) in Brazil. In summary, the focus is on three different decision problems regarding water management, namely: i) conflicts regarding the use of water, usually regarding water allocation and pollution; ii) prioritizing and choosing alternatives to address a specific watershed problem; iii) and choosing among combinations of alternatives, rather than a single alternative, considering how an individual alternative can complement or substitute another alternative in the same combination of alternatives. Regarding the first decision problem, a WSC has to arbitrate conflicts with respect to the multiple uses of water. The decision makers (DMs) involved in the dispute have to negotiate an agreement. A framework is proposed to assist in identifying issues that can transform a distributive negotiation into an integrative one. This is managed by identifying values that are shared among DMs. Values can be created by using techniques from Value-Focused Thinking to analyze DMs' value systems and, subsequently, aggregating individual information in a tree of objectives that represents all DMs' objectives. The framework promotes cooperation and reduces conflicts by having DMs interact with the same purpose, which is to mutually increase the beneficial results of the negotiation. It also assists DMs to visualize an integrative negotiation with different issues of their interest to be negotiated, thus allowing them to think about tradeoff relations. In relation to the second problem, a WSC considers a set of alternatives to solve problems faced by the watershed they represent. For this purpose, this study proposes a model that assists the group decision process by structuring objectives, identifying criteria to evaluate alternatives and identifying alternatives based on the DMs' objectives. The DMs evaluate the alternatives using an individual value-function. Afterwards, the individual value-functions are aggregated into a group value-function so as to rank the alternatives based on the DMs' preferences. With this model, the DMs are able to take part in the decision-making process from starting to understand the problem, identifying objectives, creating alternatives, until the process of choosing attributes and selecting alternatives. Thus, the model promotes the DMs' engagement throughout the whole decision-making process. The third and last decision problem tackled in this study concerns the fact that WSCs faces situations where a solution of a problem is to choose a combination of alternatives instead of choosing a single alternative. In this case, it is important to consider how alternatives together meet the DMs' objectives. The possible combinations of alternatives are systematically generated using an option form approach. DMs individually rank combinations based on their preferences by providing ordinal information in an interactive way, thus reducing the cognitive burden of making many comparisons or defining tradeoffs. In this approach, each DM expresses his or her preferences using logical preference statements regarding combinations of alternatives by what is called an alternative prioritizing approach. A group recommendation is obtained after aggregating the final individual ranks using the Weighted Voting System by Quartile. A case study for each model is presented to illustrate their applicability.

Keywords: Water resources management. Group decision making. Problem structuring. Value-focused thinking. Combination of alternatives. Watershed committees.

RESUMO

Modelos são propostos para auxiliar decisões participativas em comitês de bacia hidrográfica (WSCs) no Brasil. Em suma, o foco está em três problemas de decisão diferentes relacionados à gestão de recursos hídricos, são eles: (i) gestão do uso da água, principalmente em relação à alocação e poluição da água; ii) priorização e escolha de alternativas para abordar um problema específico enfrentado por bacias hidrográficas; iii) escolha entre combinações de alternativas, em vez da escolha de uma única alternativa, considerando como uma alternativa pode complementar ou substituir outra na mesma combinação de alternativas. Em relação ao primeiro problema de decisão, um WSC deve arbitrar conflitos em relação aos múltiplos usos da água. Os decisores (DMs) envolvidos na disputa pelo uso da água devem negociar um acordo. Um framework é proposto para auxiliar na identificação de questões que podem transformar uma negociação distributiva em uma integrativa, através da criação de valor, baseado no método Value-Focused Thinking. O framework promove cooperação e reduz conflitos ao ter DMs interagindo com o propósito de aumentar mutuamente os resultados da negociação. Ele também auxilia DMs a visualizar uma negociação integrativa, em que diferentes questões de interesse estão envolvidas, permitindo-lhes pensar sobre relações de tradeoff. Em relação ao segundo problema, um WSC considera um conjunto de alternativas para resolver problemas enfrentados pela bacia hidrográfica que eles representam. Para este propósito, este estudo propõe um modelo que auxilia o processo de decisão do grupo, ao auxiliar a estruturar objetivos, identificar critérios para avaliar alternativas e identificar alternativas com base nos objetivos dos DMs. Os DMs avaliam as alternativas usando uma função valor individual. Posteriormente, as funções valor individuais são agregadas em uma função valor do grupo, de modo a ordenar as alternativas com base nas preferências dos DMs. Com este modelo, os DMs podem participar do processo de tomada de decisão desde seu início, ao entender e definir o problema, identificar objetivos, criar alternativas, até o processo de escolha de atributos e seleção de alternativas. Assim, o modelo promove o envolvimento dos DMs em todo o processo de tomada de decisão. O terceiro e último problema de decisão abordado diz respeito ao fato de que WSCs enfrentam situações em que a solução de um problema é escolher uma combinação de alternativas em vez de escolher uma única alternativa. Neste caso, é importante considerar como as alternativas em conjunto atendem aos objetivos dos DMs. As possíveis combinações de alternativas são geradas sistematicamente usando uma abordagem chamada de *Option Form*. Os DMs classificam individualmente as combinações de alternativas com base em suas preferências, fornecendo informações ordinais de forma interativa, reduzindo, assim, o fardo cognitivo de terem que fazer muitas comparações ou definir relações de *tradeoff*. Nesta abordagem, cada DM expressa suas preferências sobre as combinações de alternativas pelo que é chamado de *Altervative Prioritizing Approach*. Uma recomendação de grupo é obtida após a agregação das avaliações individuais do DMs usando o Sistema de Votação Ponderada por Quartil. Um estudo de caso para cada modelo é apresentado para demonstrar sua aplicabilidade.

Palavras-chave: Gestão de recursos hídricos. Tomada de decisão em grupo. Estruturação de problemas. Value-Focused Thinking. Combinações de alternativas. Comitês de bacia hidrográfica.

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1 INTRODUCTION

Since the 1990s, many countries have followed in the footsteps of the European Union by adopting an integrated approach to planning and managing the use and protection of water resources (DENG et al., 2016). Brazil, China, India, Argentina are among the 40 countries that have adopted what is called an integrated water management (IWM) approach. IWM principles include perceiving fresh water as finite, yet essential to sustain development, life and the environment. Thus, it has to be managed sustainably bearing in mind its multiple uses not only currently and in the short and medium term but also by future generations. IWM also considers that water management should include the participation by the community, users, and policy-makers at all levels (HASSING et al., 2009).

An IWM approach takes into consideration that the uses of water recourses are interdependent. They serve multiple competing uses such as those that meet urban household needs, and those of industry, agriculture and the energy sector (particularly with regard to cooling in power plants) (ROMANO et al., 2015). The way that water is used by one segment of society will affect its quality and availability for other uses. This is what happens when, for example, there is a high demand for water for the purposes of irrigation and it results in polluted drainage flows, which then leads to there being less water for human consumption and for industrial ends. When people and industry pollute water, this negatively affects the environment and can result in the agricultural sector having less water available for growing crops (GLOBAL WATER PARTNERSHIP, 2010).

In Brazil, Federal Law No. 9.433/97 sets out the National Water Resources Plan (NWRP) (MMA, 2006). This plan calls for participation, decentralization and integration in water management. This means that decisions regarding water resources must be reached in a participatory process which will include the local community and other different segments of society (CARVALHO; MAGRINI, 2006; URTIGA; MORAIS, 2015b). The decisions are made by a group, usually by having the decision-makers (DMs) take a vote, or by a negotiation process in which the DMs seek to find an agreement between the parties involved. In Brazil, for example, there are Watershed Committees (WSCs), which are responsible for taking decisions at the basin level. One of the responsibilities of a WSC is to arbitrate conflicts over the use of water. A WSC is the first level of arbitration in a water-related conflict. The DMs involved in the dispute have to negotiate an agreement. If the parties are not able to arrive at an agreement or one of the parties does not agree with the decision, it should be taken to another administrative body, named a Water Resources Council, which is hierarchically above the WSC

(ANA, 2011). There is always the possibility of taking the problem to the courts; however, the judiciary system has a different process compared to that of the administrative bodies. It usually takes longer for a legal decision to be taken, which means that it is preferable that the DMs reach an agreement in the administrative bodies.

In the literature, there are several studies that discuss decision-making methodologies in water management and planning. For example, the problem-structuring method Soft Systems Methodology (SSM) was used in a case study of the Adayar Basin, India, and illustrated how a problem structuring method can be implemented in conjunction with the method Analytic Hierarchy Process (AHP) method (SAATY, 1987), in order to model complex problems when multiple DMs are considered (SURIYA; MUDGAL, 2013). In relation to disputes caused by the need for multiple uses of water, the model developed by KILGOUR et al. (1987) called Graph Model for Conflict Resolution (GMCR), which evaluates the movements of DMs in a given dispute and identifies a possible resolution for the conflict, is used to study several real conflicts which involve negotiating the use of water (HE et al., 2014b; HIPEL et al., 1997, 1999). In a game theory approach, (RAUSSER; SIMON, 1992) developed a non-cooperative multilateral bargaining model that is an extension of the Stahl-Rubinstein bargaining model (RUBINSTEIN, 1982; STÅHL, 1977), which considers two DMs (who are usually called players in game theory) and one issue to be negotiated, and has finite number of interactions between DMs. Thereafter, RAUSSER; SIMON (1992) propose a generalization of the Stahl-Rubinstein model that takes into account multiple DMs, a multidimensional space of issues to be negotiated, and an infinite space of interactions between players. ADAMS; RAUSSER; SIMON (1996), apply the non-cooperative negotiation model of (RAUSSER; SIMON, 1992) to resolve disputes over the use of water in California among agents who represent interests that argue for the urban use of water, its use in agriculture, and environmental interests in California. Other studies take a more cooperative approach to resolving conflict involving water resources. HIPEL et al. (2013) propose a cooperative model of water allocation that considers all the characteristics of a river basin, bearing in mind that every process is a system within systems. The model assists DMs in the search for an efficient and fair allocation of water among users of the basin and entertains hydrological, environmental, social and economic considerations. The model is applied in a catchment area located in Alberta, Canada. Other studies on participatory watershed management and planning include those by BUTLER and ADAMOWSKI (2015), CARMONA et al. (2013), GIORDANO et al. (2007), NASRABADI et al. (2013), ROBLES-MORUA et al. (2014); URTIGA and MORAIS (2015a).

This thesis proposes models to handle participatory water management in Brazil. In spite of the progress presented in the literature, it is important to develop specific approaches that promote cooperation among DMs in situations of disputes arising from the multiple uses of water. For such, a framework is proposed in Chapter 3 that aims to identify issues that can transform a distributive negotiation into an integrative negotiation, which is especially important in the case of water allocation. This is achieved by identifying values that can be shared among DMs. The creation of values is possible by making an individual analysis of the DMs' value systems using techniques from Value-Focused Thinking (VFT) (KEENEY, 1996) and, subsequently, aggregating individual preference information in a tree of objectives that represents all DMs. A second problematic is approached in Chapter 4, which is choosing alternatives to address a specific problem within a watershed. Based on technical reports and on stakeholders' opinions given in public meetings, WSCs make decisions, usually by taking a vote. WSCs also define goals for water quality; decide on priorities for the use of water; decide how they are going to charge for such use; determine how to invest the funds available on the watershed they represent; and are also responsible for monitoring the implementation of policies defined within the WSC (ANA, 2011). In this context, a WSC considers a set of alternatives to solve problems faced by the watershed they represent (e.g., those problems might include water pollution and degradation of the watershed) which are usually chosen by having the DMs participate in a simple voting system. It is important that DMs take informed decisions and that they reflect about their objectives in order to choose alternatives that represent those objectives. To do so, this thesis proposes a model that assists a WSC during a decision-making problem, from the moment that the process begins, namely by identifying the problem, structuring objectives, identifying criteria to evaluate alternatives and identifying alternatives based on the DMs' objectives. After this initial phase, an additive model that allows the DM to evaluate alternatives individually, by means of a value-function is used. Afterwards, a group value-function aggregates the individual value-functions so as to recommend the alternative that best represents all DMs. A third and last problematic is tackled in this study in Chapter 5, which takes into account the fact that a solution to a problem might be to choose a combination of alternatives instead of choosing a single alternative (RAJABI et al., 1998; YIN et al., 1999). This raises questions on how to represent DMs' preferences over combinations of alternatives. This context can be observed, for example, when a WSC has to approve a revitalization project for the watershed it represents. In this case, it is important to consider how alternatives collectively meet DMs' objectives. Thus, a method for modeling DMs' preferences over combinations of alternatives is proposed. This method results in a ranking of combinations of alternatives. A final ranking for the group is provided by using a voting procedure.

In summary, this thesis focuses on three different decision problems regarding water management in Brazil, which are: i) conflicts regarding the use of water, usually regarding water allocation and pollution (Chapter 3); ii) choosing an alternative to address a specific watershed problem (Chapter 4); and iii) choosing combinations of alternatives, rather than a single alternative, by considering how an individual alternative can complement or substitute another alternative in the same combination of alternatives (Chapter 5).

Although the studies are designed to focus on water management in Brazil, they can be used by other groups of DMs working in the same context in other countries, or in a different context, as long as the decision problems have similar characteristics. In such cases, some adjustments might be necessary.

1.1 Motivation and Justification

Efficient water resources management is extremely important for the development of a country, especially in those in which there are semi-arid regions and where the availability of water is very limited and scarce, thereby affecting the quality of life, health and income of the population. In participatory decision-making, such as in WSCs, individuals from different economic sectors and social classes are present, who are chosen to reflect the whole range of interests, the fundamental basis for democratic decision-making. Although Brazil has a progressive and important law for sustainable water management, decisions are still unbalanced, and for example, the opinions of individuals who hold higher technical knowledge may overrule other opinions. This also reflects an unequal representation due to socio-economic circumstances and therefore, the decision-making process might not appropriately represent the interests of marginalized communities. This often discourages the participation of different groups in society from taking an active part in WSCs (PERKINS, 2004; PORTO et al., 2000). However, one of the objectives of participatory management is precisely to ensure that the interests, concerns and desires of various sectors of society are represented in a WSC, so that decisions take into consideration the integrated aspect of water resources in order to achieve more sustainable management.

Thus, the importance of this research study is justified in the sense that DMs' objectives and preferences are taken into account in a transparent and structured way, in order to help all DMs to feel that they are adequately represented in the decision-making process. In addition, the proposed study promotes DMs' participation throughout all the decision-making process by stimulating dialogue, exchange of information and cooperation in order to assist DMs to successfully manage water resources.

Furthermore, this thesis takes into account some specific characteristics of water resources management, which include the following:

- Water resources management takes into consideration multiples issues, besides the economical one, such as environmental and social matters, which cannot always be evaluated monetarily. Thus, multicriteria methods are appropriate when different issues, which are usually in conflict with each other, need to be considered and for which these methods use subjective and qualitative evaluation. Furthermore, multicriteria methods allow the DMs' rationality to be used in the decision-making process by means of structuring DMs' preferences. To take into account these characteristics, the models proposed in this thesis use a multicriteria approach.
- Water management problems are usually complex due to the impact of the decisions on life in society with regard to several issues such as income, health, leisure, and food supply. These problems include there being multiple DMs, with not only multiple objectives to be considered, but also multiple criteria and alternatives. Thus, to achieve more effective recommendations in a decision process, the DMs should reflect on what is happening in the environment, who is being affected, what the concerns of these people are and how to add different perspectives to the problem. There are methods that can assist structuring negotiation and group decision problems, called Problem Structuring Methods, which are also included in this thesis. The information DMs receive is more reliable when methods are used to aid decision-making instead of decisions being taken only intuitively, without having a structured process (SAATY, 2005).

1.2 Objectives

1.2.1 Main Objective

The main objective of this thesis is to propose models for structuring negotiation and participatory decision-making processes to assist DMs in collectively managing and planning water resources.

1.2.2 Specific Objectives

To achieve the main objective of this work, the following specific objectives are addressed in this thesis:

- To structure a decision problem after identifying all relevant factors to reach a solution such as who the DMs involved are, what their objectives are and what attributes will represent those objectives to evaluate solutions;
- To prompt DMs into thinking creatively in order to identify and structure their objectives;
- To help promote a cooperative environment to ease conflicts between DMs;
- To promote group synergy in order to enrich DMs' perceptions and ideas regarding the problem they are facing;
- To reduce the gap of knowledge between DMs by presenting them with a broader, yet deeper, view of the decision problem.
- To create a list of issues that can be negotiated among the DMs in order to allow tradeoffs and bargaining for an integrative negotiation process;
- To identify which objectives the DMs hold in common, as well as which attributes can be selected to help the group evaluate alternatives;
- To identify alternatives based on the objectives of the group of DMs;
- To propose a method for representing and aggregating DMs' preferences when choosing an alternative or a combination of alternatives.

1.3 **Outline of the Thesis**

Besides the Introduction, this thesis is organized into 5 other chapters, as shown in Figure 1.1. Chapter 1 presents the theoretical background including the methodologies on which this thesis is based. It also presents an overview on water resources management in Brazil to provide more information to the reader about the context explored in this thesis. Chapter 3 presents a framework for structuring negotiation processes. Chapter 4 presents a model for structuring and aggregating preferences of a group of DMs, in order to select an alternative. Chapter 5 presents a methodology for modeling and aggregating DMs' preferences in the problematic of selecting a combination of alternatives. Chapter 6 rounds off the thesis with conclusions, final comments and suggestions for future lines of research.

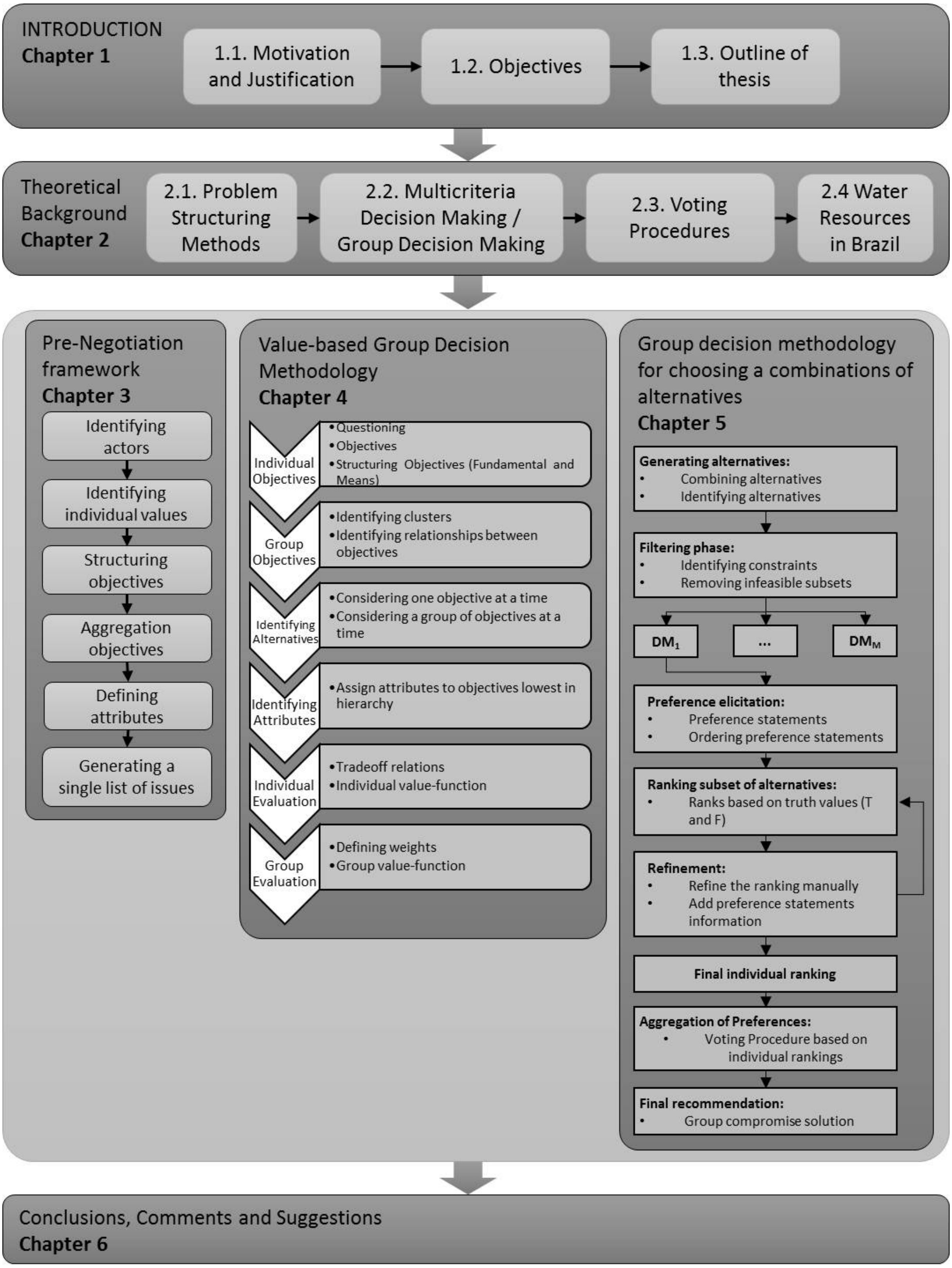

Figure 1.1 Structure of the Thesis

2 THEORETICAL BACKGROUND AND LITERATURE REVIEW

A review of the literature and the methods used to develop this thesis is presented. Reviews of the literature, that focus on more specific subjects, are also presented at the beginning of Chapters 3, 4 and 5, which are the chapters that comprise the key contributions of the thesis.

2.1 Problem Structuring Methods

According to EDEN (1988), problem structuring is a process of interactive learning that seeks to build a formal representation of a problem that unites objective and subjective aspects of DMs' views. Problem Structuring Methods (PSM) can help identify the relevant factors while modeling the decision problem, prior to the decision-making itself. Some methods, in addition to modeling the problem, also furnish DMs with a final recommendation. Unlike more traditional decision methods that use sophisticated mathematical models, quantitative inputs provide more accurate answers, PSM modeling is more focused on value judgments and on participation, while the model is being developed (KEISLER et al., 2014).

There are several PSMs in the literature, some of the best known are: Soft Systems Methodology (SSM) (CHECKLAND, 1981; CHECKLAND; HOLWELL, 1997), Strategic Options Development, Analysis (SODA) (EDEN; ACKERMANN, 2001), Value-Focused Thinking (VFT) (KEENEY, 1992) and the Strategic Choice Approach (SCA) (FRIEND; HICKLING, 2005).

SSM is a PSM built to analyze complex problems. Its methodology is based on continuous learning. The method prompts the DMs into a process of asking and answering questions in order to identify alternatives. The questions lead to new ideas that create a learning system. The process takes place by searching for solutions and comparing alternatives (CHECKLAND, 1981; CHECKLAND; HOLWELL, 1997). SODA is a PSM that helps DMs to define the problem of interest and gives them guidance during the decision process. The method uses cognitive maps and workshops to model the problem and understand and incorporate DMs' perceptions into a model (EDEN; ACKERMANN, 2001). VFT has a more proactive way of looking at a decision problem. According to KEENEY (1992), what should guide the decision process are values. From these values, opportunities can be identified. Thus, the decision process begins with a DM focusing his or her thoughts on values; from these values, the related objectives are identified, and from these, the alternatives are identified and it is these that point a way to achieving the objectives. SCA is a method designed to help develop and plan strategies in complex decision-making. It comprises four stages: i) shaping, which entails selecting the decision areas that are the most urgent ones to be focused on; ii) designing, which includes discussing what alternatives could be usefully evaluated by way of addressing the decision areas which were prioritized in the previous stage; iii) comparing, which means comparing the alternatives with selected criteria; and iv) choosing, which is when the DMs further analyze combinations of alternatives that looked promising in the previous stage by considering uncertainties and it is also when they decide on strategies for the present and for the future (FRIEND; HICKLING, 2005).

2.1.1 The Use of Value-Focused Thinking

The VFT method suggests the following steps in a decision making process for identifying and structuring objectives (HAMMOND; KEENEY, 1999):

- Step 1: List all concerns, considerations and criteria related to the decision making: In this step several techniques can be used to increase the list, such as to think about the best and worst alternative and to talk to people who have faced similar situations.
- Step 2: To convert general concerns into goals. In this step, the DM converts the concerns and aspirations obtained in the first step into goals. The clearest way to express a goal is by composing a short phrase consisting of a verb and an object. At this stage, it is desirable to have a long list of objectives where those that are similar should be combined and grouped into categories.
- Step 3: To split ends and means to identify the fundamental objectives. After categorizing the goals, the objectives are separated into end objectives and means objectives.
- Step 4: To clarify the meaning of each goal. In this step, for each objective found the analyst asks the DM: what does this really mean? This question helps identify aspects that are part of the objective and broadens the understanding of the objective. This procedure helps to establish the objectives more precisely and to understand how they can best be achieved.
- Step 5: To test objectives. At this stage, the goals are tested to see if they truly reflect DM's objectives. To do so, one can use the list of objectives found to evaluate potential alternatives and see if the results are consistent.

The process of identifying values begins with identifying objectives, which must be done with the analyst interviewing the DMs and stakeholders (KEENEY, 1994, 1996). The task of identifying and structuring objectives is difficult, but VFT, which the analyst uses to guide discussion with those involved in the decision-making process and which offers techniques that promote creativity, makes it possible for objectives to be identified. Various techniques that stimulate identifying objectives are set out by KEENEY (1996), and include the questions below:

1. A wish list. What do you want? What do you value? What should you want?
2. Alternatives. What is a perfect alternative, a terrible alternative, a reasonable alternative? What is good or bad about each?
3. Problems and shortcomings, what is wrong or right with your organization? What needs fixing?
4. Consequences. What has occurred that was good or bad? What might occur that you care about?
5. Goals, constraints, and guidelines. What are your aspirations? What limitations are placed upon you?
6. Different perspectives. What would your competitor or your constituency be concerned about? At some time in the future, what would concern you?
7. Strategic objectives. What are your ultimate objectives? What are your values that are absolutely fundamental?
8. Generic objectives. What objectives do you have for your customers, your employees, your shareholders, yourself? What environmental, social, economic, or health and safety objectives are important?
9. Structuring objectives. They follow means-ends relationships: why is that objective important, how can you achieve it? They specify why they are used: what do you mean by this objective?
10. Quantifying objectives. How would you measure achievement of this objective? Why is objective A three times as important as objective B?

The list of initial objectives will have many items that are not really goals but alternatives, rules and criteria for evaluating alternatives. But, each item on the list can be converted into an objective and defined as a fundamental objective or means objective, where the former set is an essential reason for the interest in the problem and the latter serves as a means to achieve the fundamental objectives.

The structuring process helps DMs to identify the objectives that are not present in the hierarchy or network of objectives, and avoids redundancy in determining them. Also, if there are voids in the structure, it is possible to define the types of objectives needed to fill them.

From this statement, it is possible to organize the fundamental objectives in a hierarchical manner, where the highest levels assist in specifying more general objectives and the lower ones indicate the degree of achievement of the objectives of the highest level (means objectives). It is also possible to organize networks between objectives where these are connected to several other objectives, which will indicate relationships of influence. Structuring fundamental objectives in a hierarchical way is then of utmost importance in order to develop decision models with multiple objectives. At this point it is possible to check to what extent the alternatives satisfy the problem, by comparing them one by one with the revealed objectives.

It is helpful to focus on one objective at a time and consider alternatives that will satisfy it alone. However, this must be done with all the specified objectives and then the process must be repeated by comparing two objectives at a time, then three and so on until all objectives are compared together so that the alternative chosen satisfies them all.

2.2 Multicriteria Decision-making

In classical optimization problems, there is an objective function to be maximized or minimized in order to choose an alternative from a set of possible alternatives. However, in real problems, usually there is more than one objective to be dealt with simultaneously, in which several situations conflict with each other, i.e., the problem needs to satisfy multicriteria. Multicriteria Decision Making (MCDM) considers a DM´s preference structure and his/her value judgment. The DM’s preferences are incorporated into the decision model in order to support the choice of an alternative and, by doing so, multiple criteria will be analyzed simultaneously. DM's preferences consist of the subjective evaluation of criteria by a DM. This subjectivity is an inherent part of the problem and cannot be avoided (DE ALMEIDA et al., 2015).

As one of the most effective and influential sub-areas of Operation Research, MCDM includes various valuable techniques to guide DMs in identifying and structuring decision problems, and in explicitly aggregating and evaluating multiple alternatives in decision processes (KUANG et al., 2015; STEWART, 1992). To that end, MCDM methods have been proposed in recent years as a means for helping DMs to select the best compromise among alternatives, thus providing them with a powerful tool that can be applied to forming an efficient water management strategy, as well as to gaining the widest possible social acceptance. Throughout more than four decades, the development of MCDM has been rapid, numerous theoretical and practical advances have been achieved, and significant reviews have been presented by several researchers (BELTON; STEWART, 2002; FIGUEIRA et al., 2005; KEENEY; RAIFFA, 1976; STEWART, 1992; VINCKE, 1992).

The choice of an MCDM method depends on several factors, such as (DE ALMEIDA et al., 2015; GUITOUNI; MARTEL, 1998; OZERNOY, 1992): i) the problem and context analyzed; ii) the available information and its degree of accuracy; DM's rationality and their preference structure; and iii) the problematic chosen (problem of choice, classification, ordering, portfolio).

There are many ways of classifying MCDM/A methods. MCDM methods may be classified according to the action space, which can be either discrete or continuous. A common classification given in the literature (BELTON; STEWART, 2002; PARDALOS et al., 1995; ROY, 1996; VINCKE, 1992) separate MCDM/A methods in three groups: unique criterion of synthesis methods; outranking methods; and interactive methods.

In the first group, the unique criterion of synthesis methods is based on a process of an analytical combination of all criteria in order to produce a global evaluation or score for all alternatives, thus producing a complete pre-order. The additive model is a common example of this kind of method and is the basis for many deterministic additive methods, such as AHP (SAATY, 1986), SMARTS (EDWARDS; BARRON, 1994), MACBETH (BANA E COSTA et al., 2005). These are methods for a deterministic set of consequences and these may be referred to as Multi-Attribute Value Theory (MAVT). Multi-Attribute Utility Theory (MAUT) (KEENEY; RAIFFA, 1976) is also included in this group.

Regarding the second group, unlike the first group, many outranking methods provide the final recommendation of alternatives by pairwise comparison, by considering the incomparability relation. These methods produce a partial pre-order of alternatives. The main methods in this group are the ELECTRE and PROMETHEE family methods (BELTON; STEWART, 2002; ROY, 1996; VINCKE, 1992).

In the third group, there are the interactive methods, which can be associated with discrete or continuous problems; although, in the majority of cases, this group of methods includes Multi-objective Linear Problems (MOLP) (COELLO COELLO et al., 2007; EHRGOTT, 2006; KORHONEN, 2005, 2009).

Furthermore, the fourth group includes the disaggregation methods, which consist of collecting information from the DM on a global evaluation of a few alternatives, for later inference on the parameters of an aggregation model (DOUMPOS et al.,, 2001; JACQUET-LAGRÈZE; SISKOS, 2001).

MCDM methods may also be classified according to their form of compensation for aggregating the criteria, and take the DM's rationality into account. Therefore, two types of rationalities may be considered: compensatory and non-compensatory methods (FIGUEIRA et al., 2005; ROY, 1996; VINCKE, 1992). As remarked by BOUYSSOU (1986), a preference relation is compensatory if there are tradeoffs amongst criteria and it is non-compensatory otherwise.

As previously mentioned, the mathematical model most used for aggregating criteria is the additive aggregation model, as presented by Equation 2.1:

$$\mathbf{v(a_i) = \sum_{j=1}^{n} k_j V_j(x_{ij})} \qquad 2.1$$

where $v(a_i)$ is the global value of alternative a_i; k_j is the parameter related to the inter-criteria evaluation of criterion j, named the constant scale of criterion j (weight), and usually normalized as $\sum_{j=1}^{n} k_j = 1$; $V_j(x_{ij})$ is the consequence value for criterion j; and x_{ij} is the consequence or outcome of alternative i for criterion j.

The additive model has some properties that should be checked before being applied (DE ALMEIDA et al., 2015). This model follows the preference structure (P, I), in which it is possible to obtain a complete pre-order or a complete order; thus, one of the assumptions of this model is that the DM is able to compare all consequences and order them. Let x_z and x_y be two consequences, the following conditions hold: a) $x_y P x_z \rightarrow v(x_y) > v(x_z)$; b) $x_y I x_z \rightarrow v(x_y) = v(x_z)$. Also, the transitivity property holds for the preference P or I, so that for three consequences x_w, x_y and x_z, if $x_w(P, I)x_y$ and $x_y(P, I)x_z \Rightarrow x_w(P, I)x_z$.

Another property of this model is the mutual preference independence condition amongst criteria (KEENEY; RAIFFA, 1976). Let X and Y be two criteria, the preference independence between X and Y occurs if and only if the conditional preference in Y space (an intra-criteria evaluation given different levels of y, such as y' and y''), given a certain level of $x = x'$, does not depend on the level of x. That is, $(y', x')P(y'', x') \Leftrightarrow (y', x)P(y'', x)$, for all x, y' and y''.

Scale constants are substitution rates between criteria (BELTON; STEWART, 2002; KEENEY; RAIFFA, 1976; VINCKE, 1992). KEENEY and RAIFFA (1976) point out that it might happen that a criterion may have a scale constant larger than any other and yet it has less importance. The literature contains many scale constant elicitation procedures (WEBER; BORCHERDING, 1993). Amongst these, there are the Tradeoff and Swing procedures. The Tradeoff procedure is presented in detail by KEENEY and RAIFFA (1976). It is based on a sequence of structured questions put to the DM in order to obtain preference information, based on choices between two consequences. The swing procedure is included in the SMARTS method (EDWARDS; BARRON, 1994). The determination of scale constants is based on direct information given by the DM, takes the range of the consequences into consideration, and is also based on a sequence of structured questions. However, some inconsistencies can arise when the Tradeoff method is applied directly. This is related to the difficulty, in cognitive terms, that the DM has (WEBER; BORCHERDING, 1993). To help solve these inconsistencies, a flexible elicitation procedure for scale constants in the additive model (FITradeoff) is proposed by DE ALMEIDA et al. (2016), which uses partial information to perform dominance tests based on a linear programming problem.

2.2.1 Multiattribute Group Decision-Making

In group decision-making problems, different DMs are involved, each with different interests and value systems. When decisions are made by a group of people, the focus of the decision-making process ceases to be on a single DM within the group of DMs involved. This introduces a new question of how to best aggregate DMs' preference structures.

Two major groups separate the types of procedure for group-decision aggregation: i) aggregation from the DM's initial preferences, and ii) aggregation from the DM's outcomes and final choices. In the first type of procedure, DMs act together; the parties are willing to be more flexible about their own preferences for achieving the group's overall objective. In the second kind of procedure, each DM acts according to his or her preference system and the aggregation process focuses on the individual priorities of each DM (DE ALMEIDA et al., 2012). This kind of aggregation is often performed by using voting procedures which are presented in Section 2.3.

The "aggregation from DM's outcomes and final choices" includes, for example, the additive model. DMs agree on the intra-criteria evaluation, which means that the group has reached a consensus on the performance of alternatives according to each criterion. Each DM has their own value function, which means that each DM identifies the weight (constant scales) of the criteria individually. Later a group function aggregates the individual functions.

The group function is defined by Equation 2.2:

$$\mathbf{V(a) = \sum_{i=1}^{m} w_i v_i(a)} \qquad 2.2$$

where w_i is the weight of the evaluation of each DM for the group evaluation, and $\sum_{i=1}^{m} w_i = 1$.

The elicitation of constant scales is different for the individual and group functions (k_j and w_i, from Equations 2.1 and 2.2, respectively). For the individual function, the constant scale represents the trade-offs rates among attributes, which gives the idea of how to compensate for the loss of an alternative in one of the attributes with a gain in another.

The aggregation of these functions into a group function takes into account two different factors that represent the weights of the evaluation by each DM for the group value-function (KEENEY, 2013a):

- **The DMs' relative importance.** Each DM can have the same relative importance for the decision problem or a different relative importance. For example, if a WSC is formed by more representatives from the government than other sectors of society, this could be taken into account in the decision process. If the group has a parity decision task, all DMs have the same relative importance.
- **The interpersonal comparison of the value function.** In this case, the group will make evaluations such as, what is the significance to DM1 of going from value $v_1 = 0$ to $v_1 = 1$ (where 0 is the worst consequence for DM1 and 1 is the best) compared to DM2 going from $v_2 = 0$ to $v_2 = 1$. For example, suppose that for DM1 it is 3 times more significant than for DM2. In this case, the ratio $w_1 : w_2$ is $3 : 1$. The group value function provides a rating for all alternatives. The one with the highest rating is the solution recommended to the group.

Other group decision-making methodologies, using different multicriteria methods for aggregating DMs' preferences, include those put forward by SILVA et al. (2010a) and ALENCAR et al. (2010). SILVA et al. (2010a) propose a model for group decision-making where, in a first step, the PROMETHEE II method is used to obtain the individual rankings of alternatives for each DM. Later, the ELECTRE IV method is used to obtain a global ranking. ALENCAR et al. (2010) propose a three-stage model as follows: i) in a first phase, DMs use the ELECTRE II method to individually evaluate alternatives, and thus obtain their individual rankings of alternatives; ii) the output of the first phase is used to generate a global matrix of alternatives versus DMs; iii) in a third phase, DMs obtain the group preference by applying the ELECTRE IV method to aggregate their individual preferences. Other methods use the DMs' final rankings as input for a voting system (MORAIS; DE ALMEIDA, 2012). Voting systems have been used in the literature for purposes other than elections. This is actually a very useful approach for group decision making, especially for heterogeneous groups. This happens because when a DM votes they are choosing an alternative or ordering alternatives according to their own value system. Thus, each DM can evaluate the alternatives the way they wish because the information that is going to be used for the group aggregation, which is simply the rules of the voting system, will be the final individual (global) evaluation of alternatives. The DMs can use different methods for the individual evaluation, be they compensatory or non-compensatory, as long as the method provides a ranking that can be used as input in the voting system. Then, the voting system recommends an alternative to the group, based on their individual rankings (or provides a ranking of alternatives for the group).

2.3 Voting procedures

Some of the most popular voting procedures in the literature are the Borda procedure (BORDA, 1781; NURMI, 2010), the Condorcet procedure (CONDORCET, 1785) and Approval voting (BRAMS; FISHBURN, 1978).

The Borda procedure consists of (BORDA, 1781; NURMI, 2010): i) ordering all alternatives for each DM considered; ii) assigning a score for each alternative according to its position in the ranking; iii) the scores of each alternative provided by each DM are summed and this results in a final score; iv) the alternative with the best score is selected. There are other variations of the Borda procedure, for example, it is considered that the evaluation of each DM has a weight; the scores are then aggregated by using a weighted sum.

The Condorcet procedure (CONDORCET, 1785) consists of a pairwise comparison between all alternatives for all DMs. For example, when alternative *a1* and *a2* are compared, if the majority of DMs find that alternative *a1* is better than *a2*, the procedure considers that *a1* is more preferred than *a2*. After all pairwise comparisons are made, the procedure provides an order of alternatives. An alternative that wins in every head-to-head comparison is called the Condorcet winner. One of the limitations that might occur in this procedure is that preferences can be cyclic. Consider for example the game rock-paper-scissors with three players. If each player chooses a different hand shape, each player will win against one of the other players and lose to another player, thus forming a cycle; therefore, the procedure will fail to rank the alternatives. This is called the Condorcet paradox.

The Approval voting procedure (BRAMS; FISHBURN, 1978) allows the DMs to approve or not to approve the alternatives. Thus, they face a dichotomy when evaluating each alternative. This can be represented by assigning a score of 0 to each alternative that is not approved and a score of 1 to each alternative that is approved. The DMs can approve more than one alternative. The alternatives with most approval votes is selected.

Other methods such as Fallback Bargaining suggested by BRAMS and KILGOUR (2001), Condorcet's practical method presented by NURMI (1999) and the Weighted Voting System by Quartile (WVSQ) by MORAIS and DE ALMEIDA (2012), are positional voting methods. In these methods, voters rank-order the alternatives from best to worst and a set of winners is selected using the positions of the alternatives in the voters' preference orders (LLAMAZARES; PEÑA, 2015).

The WVSQ focuses on two groups of alternatives: those that are positioned in the upper quartile of the ranking and those that are placed in the lower quartile. Figure 2.1 presents the structure and steps of the method which are carefully discussed in MORAIS and DE ALMEIDA (2012). The alternatives at the top of the ranking are the preferable ones, and the ones at the bottom are the alternatives the DMs wish to avoid. If an alternative is placed at the top of the ranking for one DM, but is placed at the bottom for a different one, this alternative will be penalized in the veto phase. This enables a more balanced choice of alternatives for the group.

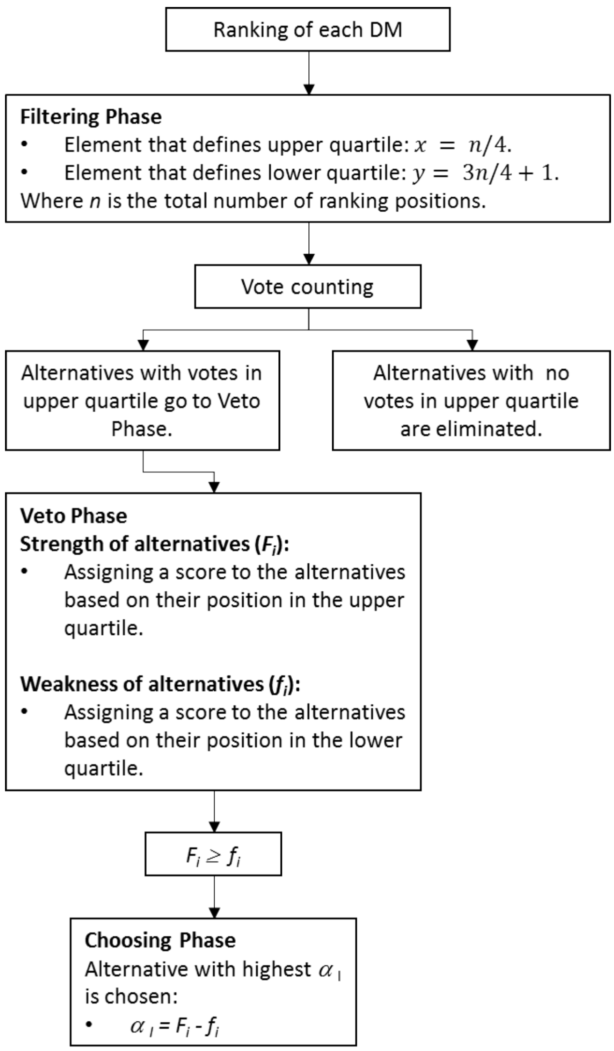

Figure 2.1 Framework of the weighted voting system
Source: URTIGA et al., 2017.

2.4 **Water Resources in Brazil**

Water is a substantial asset for basic human needs, as well as being essential for the development of society, which also depends on water for economic activities, such as human consumption, agriculture, fishing, industry, navigation and power generation. Given its importance for the survival of human life, problems associated with water scarcity have led to major discussions around the world about the need for consumption patterns to change. Globally, rainfall is poorly distributed both geographically and periodically. There are regions where rainfall is abundant as well as arid regions where precipitation is rare. The volume of precipitation that meteorologists expect to occur over a period of months, may occur within a few days. This instability, coupled with the degradation of water and its increasing demand by the world population, increases the problem of water scarcity in many countries (UN-CSD, 1994).

High levels of pollution, the inadequate use and lack of conservation of water resources lead to the quality of water suitable for human consumption being degraded. Therefore, the use of water for multiple purposes is restricted or unfeasible, which aggravates the problem of scarcity and contributes to the generation of conflicts (ASSUNÇÃO; BURSZTYN, 2002). In the semi-arid regions of Brazil, as in the case of the northeastern 'sertão', the natural limitation of water, due to natural characteristics of the region, further aggravated by long periods of drought, makes disputes over water more severe. Several types of conflicts can be considered, which include (CUNHA et al., 2012):

- Consumption use vs. Irrigation: this happens mainly in periods of great water shortage in which the local authorities limit the exploitation of the resource by irrigators;
- Public Supply vs. Urban Expansion: this happens when urban areas increase and encroach on the water source, and discharge urban sewage into it, thus polluting it;
- Industry vs. Fishing: this occurs when water pollution is caused by chemical or biological waste, causing the fish to die and, consequently, harming the livelihood of the fishermen;
- Public vs. Industry: this occurs when industry is prevented from dumping industrial waste into a body of water which is used to supply the population.

The Semi-arid region of northeast Brazil is poor in surface drainage. The result is the existence of a dense network of temporary rivers, such as the Pajeú River, located in the state of Pernambuco. The main exception to temporary rivers is the São Francisco River. The policy of water accumulation in dams, typical of the region, was developed by constructing reservoirs to perennial temporary rivers (CIRILO, 2008). Today, in 2017, northeast Brazil faces the worst drought of the last 50 years. Data from the National Water Agency (ANA 2016) shows, for example, that the last time the reservoir of Serrinha II, located in the backlands of Pernambuco, was completely filled during the rainy season was 10 years ago. Most reservoirs of the state of Pernambuco are dry. Allocations that were made based only on estimates of stored water, inefficient irrigation practices, pollution, and for other reasons, coupled with severe droughts and evaporation, helped to deplete the water in the reservoirs. The negative effects caused by the shortage of water have affected the economy, health, and well-being of local people.

Since decisions regarding water affect all economic activities, the environment and life in communities, it is important that society takes an active part in opportunities to discuss and collectively decide on water issues and when this is done, multiple perspectives are taken into consideration such that the sustainability of water management and planning is more likely to be maintained. Therefore, Brazil took an important step in improving its water resources management when it replaced a sectorially-based water management system with an integrated and decentralized one. The decisions moved from the federal, state and municipal levels to the river basin level by creating WSCs (PORTO; KELMAN, 2000). The WSCs are the entities which are the closest to being bodies which offer a forum in which water conflicts faced by local communities can be discussed. They are formed by government representatives (municipal and state level), water users (industry, agriculture, etc.) and civil society (universities, community associations, NGOs), in order to bring together different sectors of expertise, economic power and interests (SILVA et al., 2010, URTIGA; MORAIS, 2016).

WSCs are permanent advisory and deliberative bodies. The WSC members who are representatives of civil society and water users are elected by the population. From time to time the members submit themselves to re-election and/or new members are elected so as to encourage participation and make room for other ideas and perspectives from new members (INEMA, 2016). The creation of WSCs shows that it is possible to have democratic and plural public organizations of social participation, in which conflicts become visible and differences are confronted. This enriches the process of decision-making as questions and collective demands are presented in the search for sustainable water use. Thus, the participation of various sectors of society generates a qualitative change in public management, since other representatives levels of leadership, beyond the state, are incorporated as DMs (JACOBI; BARBI, 2007).

2.5 Final Comments

Chapter 2 presented an overview of the methods used in the development of this thesis including: i) Problem Structuring Methods; ii) Multicriteria Decision-Making Methods; iii) Multicriteria Group Decision Methods; and iv) Voting Systems. Following Chapter 2, Chapters 3, 4 and 5 present the results of the thesis. In Chapter 3, a pre-negotiation model by problem structuring is presented. Chapter 4 displays a participatory model for a group choice of alternatives. Chapter 5 closes the results of this thesis by presenting a group decision model for selecting combinations of alternatives.

3 PRE-NEGOTIATION FRAMEWORK TO PROMOTE COOPERATIION THROUGH A VALUE CREATION APPROACH

A framework is proposed for pre-negotiation by value creation in water resource conflicts using a Valued-Focused Thinking (VFT) approach. When values are created this means that the parties in conflict want a way to enhance the number of issues that will be shared between them so there can be improvements for all parties. Very often in a problem-solving conflict, the lack of information leads to a distributive negotiation. A distributive negotiation can turn into an integrative negotiation when values are created. The results in this Chapter are based on the findings of URTIGA and MORAIS (2015b) and MEDEIROS, URTIGA and MORAIS (2017).

3.1 Introduction

The fair allocation of water is a key issue in managing water resources and is regarded as one of the main reasons for conflicts related to watersheds around the world (WANG, 2003). When different water users compete for the same limited water supply, conflicts arise. Competition between different sectors for the use of water is a reality of most places. As exemplified in Section 2.4, it is common to see conflicts over using water for agriculture and urban life and conflicts over ensuring environmental sustainability. All these problems raise concern about how decision making with regard to water resource should be tackled.

Negotiation has always been an important tool for resolving conflicts among people, countries and organizations. According to WATKINS (1999), people cannot achieve all objectives by imposing their decisions on others; they must negotiate and interact with each other as they depend on others to undertake their activities.

Negotiation regarding water resource conflicts usually involves multiple players and their bargaining with each other. Negotiation models can help obtain important items of information especially when these identify strategies that might enable cooperation among players and also when they identify other aspects about asymmetric information, externalities, lateral payment, etc.

There have been many contributions to the literature of negotiation techniques that include dialogue, mediation and facilitation. This approach encourages the development of negotiation support tools which can facilitate communication, improve problem structuring and assist complex negotiations such as NEGO (KERSTEN, 1985), MEDIATOR (JARKE et al., 1987), PERSUADER (SYCARA, 1993) and INSPIRE (KERSTEN; NORONHA, 1999).

The Decision Support System Graph Model for Conflict Resolution (GMCR) (HIPEL et al., 1999) is was designed to not only to assist the choice of a course of action, but also to assist the preparation phase of the negotiation process. MA et al. (2013) use the Graph Model for Conflict Resolution to model a transboundary conflict between Canada and the United States due to sediment contamination in Lake Roosevelt and identify several potential solutions to this conflict. In a different context, HIPEL et al. (2014) examine the main conflicts that have occurred in the past along the Euphrates River involving Turkey, Syria and Iraq and model these conflicts using the Graph Model for Conflict Resolution. The analysis can be used to help manage similar situations in the future.

Another negotiation support system is ICANS developed by THIESSEN and LOUCKS (1992), which an example of a negotiation support system (NSS) applied to conflicts involving water resources. The tool helps each party to identify admissible alternatives that should be preferred by all parties when compared to a scenario in which there is no agreement. The tool also assists the parties to conduct counter-offers, i.e., allows various interactions between negotiators so that they may reach an agreement.

KRONAVETER and SHAMIR (2009) proposed an NSS to assist both parties to negotiate how to allocate the water resource they share. This tool allows them to identify and alter their functions and use the Analytic Hierarchy Process (AHP) to structure and give weights to objectives (criteria). It assists the negotiators to move towards Pareto efficient solutions, to identify the Nash equilibrium and then to try to move this point to a temporary border thereby creating values for both parties.

To improve and create new negotiation models with regard to water resources, it is fundamental to analyze the relevant factors, emphasizing the aspects that can contribute to designing tools based on the interests of all parties so that these facilitate understanding, communication and learning. As discussed in Section 2, Problem Structuring Methods (PSM) (such as SSM, SODA, VFT and SCA) can help in the identification of the relevant factors while modeling the problem prior to the decision-making process itself. Identifying appropriate decisions-makers (DMs) and the objectives, criteria and constraints of the problem should be done prior to the negotiation process. PSMs can also be of great help when drafting Negotiation Support Systems (NSS) as a negotiation is a process of interaction and communication involving many variables. NSS tend to facilitate the negotiation process and make it more efficient; problem structuring helps the negotiator think outside the box and creatively define the problem, find new alternatives, objectives, and, in some cases, even decision opportunities.

Even in pure conflict scenarios, which often occur when allocating water resources, there could be coordination between the parties if information were shared and the interests of all parties taken into account. PSMs can assist during this phase. Having as an example the well-known case of two sisters arguing over an orange, where one sister wants the whole orange to make juice and the other wants the peel to make marmalade. If they both have this information, each can have the entire part that interests them. Otherwise, they will compete for the largest piece of orange possible (KERSTEN, 2001). The same situation could happen in a water allocation problem. For example, in a dispute between the agricultural sector and a local community for the allocation of the same limited water supply, the community will try to get as much water as possible from the agreement, and so will the agricultural sector. Now, imagine that, in reality, what the population wants is less polluted water. Adding this new issue to the negotiation problem "level of pollution" can change the scenario of the dispute. The agricultural sector might agree to invest in water pollution prevention if it can use a larger volume of water, while the population might agree to have access to less water if the smaller amount is of better quality. The DMs in this situation have turned a distributive negotiation into an integrative negotiation, identifying a different issue that allows them to make tradeoff relations and understand that they can achieve a better result by giving up in terms of one issue in order to gain a specified amount on another issue.

Creation of value, exchange of relevant information, and problem structuring are key elements for integrative negotiation (RAIFFA, 1996). Thus, by engaging on these activities, awareness is raised regarding the importance of structuring problems involving water resources, before the negotiation process itself starts. Water cannot continue as a source of tension between people living in the same geographical area. In fact, their common need should serve as a catalyst for cooperation, not conflict (ATWI; CHÓLIZ, 2011). A framework is proposed to assist DMs in finding issues that are of interest of all of them, especially issues that could not be identified without the help of a tool that promotes creativity when thinking about values. The techniques from VFT were chosen among other problem structuring methods to help in the identification of issues. Because of the way VFT was designed, it helps DMs think about their objectives in a structured way, enabling the identification of a hierarchy relationship among objectives.

This framework makes a difference by providing a structured way in finding issues that are of common interest for all DMs, especially issues that could not be identified before, without the help of a tool that promotes creativity when thinking about values. The framework presented not only uses VFT techniques to identify the objectives and elaborate the objectives tree, but also: i) represents the objectives of all DMs in a single joint tree, putting together the objectives that have the same meaning for the DMs, ii) preserves the hierarchy of objectives of each DM and, more importantly, iii) identifies the relationships of these objectives among DMs. These relationships are very important for the identification of common issues to be negotiated during de negotiation process. This study also shows that a facilitator can still find the same issue to represent different objectives and by this, find a point of interest for the DMs to negotiate.

The framework presented serves as a preliminary phase of a negotiation process as a tool to help DMs identify issues that are of common interest to be negotiated and by doing so, evaluate trade-off relationships in order to provide a way for them to think in cooperation and visualize that they can achieve a higher payoff when they consider different issues. Thus, a DM could receive more in an issue that is of higher interest for him/her while giving out in a different issue that is less valuable to him/her and more valuable to the other DM.

3.2 Proposed Framework

The objective of the proposed approach is to assist negotiators to achieve a more cooperative environment by creating negotiation issues. The creation of values is possible by using problem structuring. The presence of a facilitator is needed to guide the whole process.

The first step of VFT will help DMs individually to think creatively about values. After creating a list of objectives, the VFT structuring step will separate them into means objectives and fundamental objectives. Each negotiator will then have a hierarchy of objectives that he/she has an interest in negotiating. The facilitator will aggregate the parties' hierarchy trees into a single tree. After that, issues (attributes) to be negotiated that concern these objectives will be considered by the facilitator and in a meeting with the DMs they will agree on a single list that will contain all items on which they are willing to negotiate. This meeting takes the form of a workshop, a step also used by SODA to aggregate cognitive maps. The structure of the approach is summarized in Figure 3.1.

When a single list is defined for all sides, the negotiators will have a set of possible issues that might be considered during the negotiation. The negotiation process starts from there. Note that VFT is not being used in its full form. The main goal is to identify the different values of the interests of each individual negotiator such that this will enable them to think in cooperation with each other so as to achieve a joint gain by combining these values into alternatives while they are negotiating.

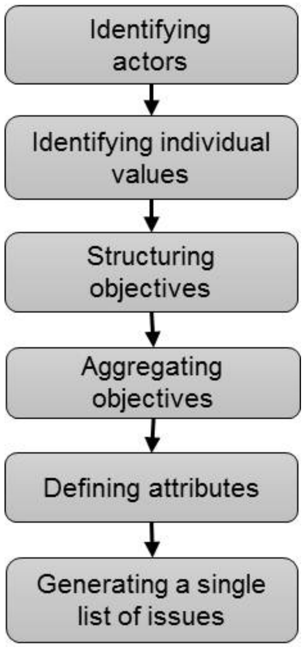

Figure 3.1 Structure of the framework proposed

3.3 Creating Negotiation Issues by Using VFT

The presentation of the framework will follow the structure presented in Figure 3.1. To illustrate each step of the approach a virtual case study is presented. Information from professionals who oversee participatory decision-making in WSCs regarding water management and from the literature was used to build hierarchies of the objectives. The virtual case study reflects a dispute between a community and the industry sector on the use of a body of water. Because of the concentration of pollutants in the water which becomes more evident in periods of drought, the local community pressures the local authority to prevent the industry sector from using that body of water. However, this sector employs so many of the local population, and therefore adverse effects on production and profit would also cause negative consequences for the population and the local authority.

The proposed approach is used to help turn this dispute over water allocation into a dispute that includes other values and issues and, by doing so, this enables a distributive negotiation to be visualized as an integrative negotiation. Therefore, all parties can have gains that will attenuate the possible indirect effects that they could suffer from as a result of an agreement that was bad for one of the parties.

3.3.1 Identifying Actors

This stage is used to identify all the actors involved in the negotiation process. The DMs are those whose objectives and preferences are elicited. They often have divergences regarding their value systems (ROY, 1996). The DMs have to make clear if they themselves will participate in the process or if they will contribute indirectly by having someone else represent them during the process (a client). According to RAIFFA (1982), other actors may intervene in the negotiation. They usually are a facilitator, mediator or arbitrator.

The use of this approach is feasible if the presence of the facilitator is possible. Also, the approach can be used if the DMs or their representatives have the availability to interact with the facilitator. In this example, the parties involved are a representative from the local authority, a representative from the local community and a representative from the local industry. The facilitator guides the whole process.

3.3.2 Identifying the Objectives of Individual DMs

In the first step VTF is used to identify objectives and to structure these objectives. The most obvious way to create value is to think in terms of the interests of the disputing parties - What do you want to achieve in this situation (KEENEY, 1996)?

Various techniques that stimulate the identification of objectives are shown in KEENEY (1996). VFT questioning techniques is used to elicit the objectives of the representatives. Some of the questions developed for the representatives and their respective answers are shown in Table 3.1, Table 3.2 and Table 3.3. By using this approach, the relationship between the fundamental and mean objectives becomes more evident to the facilitator. This relationship is presented in Section 3.4.

Table 3.1 VFT questions to and answers from the representative of the local community

Questions	Responses
What is wrong with the watershed?	The water is polluted and unsuitable for drinking and other purposes.
What causes water pollution?	The discharge of harmful chemicals and compounds into the water.
How do you notice that the water is polluted?	Because the concentration of toxins is higher than the level permitted by the regulatory body.
What could be done to mitigate the pollution?	Industry should stop using the basin. If not possible, more severe policies to regulate industrial effluents are needed. Discharges of industrial wastewater into municipal sewer systems must be pre-treated.
What, do you believe, interests industry with regard to the river basin?	They are interested in the amount of water allocated for production purposes.

What do you want?	The water to be preserved so it can be suited for human and aquatic life.
Why?	Because only water bodies provide us with fresh water, and so, keeping them clean is an issue of survival not only for humans but for all other forms of life.

Source: URTIGA and MORAIS (2015).

Table 3.2 VFT questions to and answers from the local authority

Questions	Responses
What is right with the watershed?	The watershed is a source of natural water used to supply the population's basic needs and it's also used by industry for production ends.
What is wrong and what needs fixing?	The population claims that the water is polluted and unsuitable for human and aquatic life. Industry discharges too many pollutants into the river. Actions of the population also aggravate the pollution problem.
What should be done?	The private sector should invest more in treatment facilities. The population should be more educated about water preservation and waste.
What is your responsibility in this matter?	To implement effective policies to prevent pollution and help to raise awareness about how critical it is to preserve natural resources.
What do you want?	To guarantee suitable water for the population's basic needs and also to guarantee that industry has access to water for productive ends.
Why?	Because the government wants to be able to meet the interests of both sectors and thus be recognized as a good government.

Source: URTIGA and MORAIS (2015).

Table 3.3 VFT questions to and answers from industry

Questions	Responses
What is wrong with the watershed?	The water is polluted and the population is pressuring the local authority to prevent industry from using this body of water.
What do you think could be a good alternative?	To have this body of water designated only for industrial production as we are responsible for a big share of the local economy.
What do you think the local population wants?	To have access to water with good quality.
How could you help the community achieve what they want?	We could invest in waste treatment, however this would cost me money and increase production costs. We would have to be compensated somehow. We also cannot afford paying for an alternative source of water.
Why?	Because we want to increase profit and produce at a competitive price. Having more costs would negatively affect that.
How do you think you could be compensated?	For example, if the government gave some tax reduction for environmental friendly companies we could feel motivated to invest more in water treatment facilities. Also would be good for business to have a secured amount of water designated to productive ends. .

Source: URTIGA and MORAIS (2015).

A facilitator helps each party into creating an individual hierarchy of values to be included in the negotiation process, guided by the type of questions shown in the tables above.

3.4 Structuring Objectives

The first questioning with the DMs will raise many items such as alternatives, constraints and criteria that are not objectives. The facilitator will guide the DMs as to how to transform these items into objectives and to classify them into means objectives and fundamental objectives (KEENEY, 1996).

Fundamental objectives concern the ends that DMs value in a specific decision context while means objectives are how they can achieve these ends. Notice that ends and means are context dependent.

This approach not only helps to identify all of the relevant objectives, including previously unrecognized objectives, but it also provides a logical and consistent way of identifying the relationships between objectives (MORAIS et al., 2013).

Figure 3.2 shows the structured objectives for the industry sector is presented. The overall fundamental objective is to "increase profit". More detailed fundamental objectives include to "increase productivity" and to "increase demand". As for the means objectives, the ones related to "minimize production costs" are to "increase efficiency" which means the efficient use of available resources (financial, labor, water, capacity) and also relates to the means objective to "lower input expenses". What would lower input expenses is to have access to fresh water for production ends and to minimize the cost of water treatment. The means objectives related to "to increase demand" are "to have a competitive price" and to create a "good image for the customers". To be able to offer a competitive price, production costs have to be minimized while to achieve a good image among its customers, industry needs to demonstrate that it is environmentally and socially responsible.

Figure 3.3 illustrates the objectives' hierarchy for the representative of the local population. The representative of the local community has two major objectives which are to "maximize income" in the community and to ensure "good health and well-being". These had better specify the objective "to maximize the quality of life". The DM wishes to ensure that sufficient water is available for multiple economic uses so as to maintain production and services at least at their current levels in different economic sectors and thereby to increase the employment rate and maximize the income of the local community. The DM also wishes to have "good water for sports and leisure", "to have sufficient water to meet people's basic needs" and "to have a healthy environment" so as to achieve the good health and well-being of the community. In addition to these means objectives, Figure 3.3 also lists other means objectives.

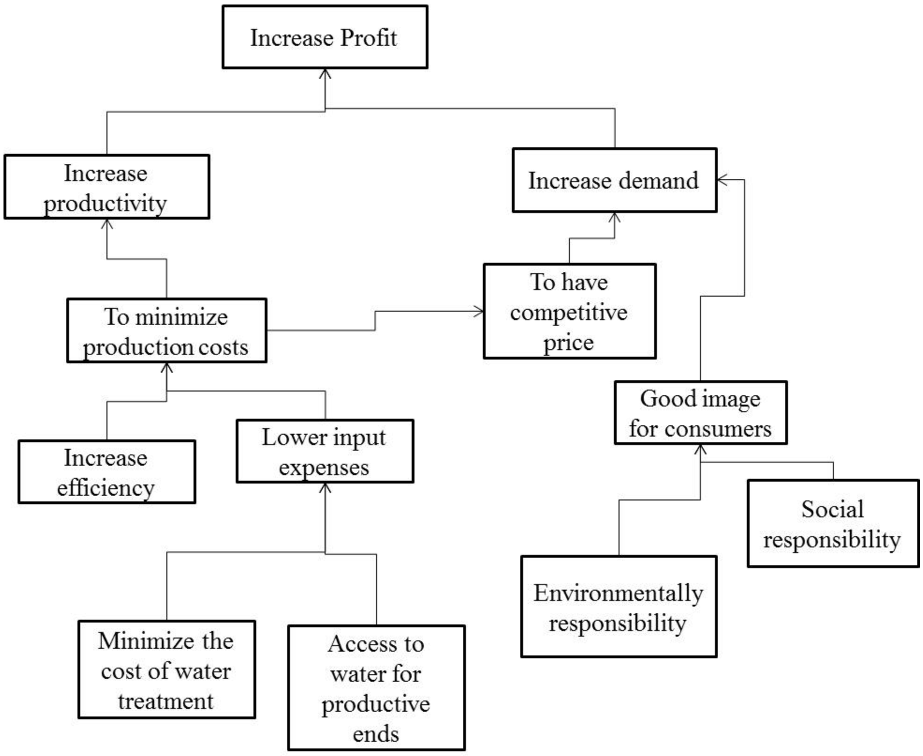

Figure 3.2 Relationship between objectives for Industry
Source: URTIGA and MORAIS (2015).

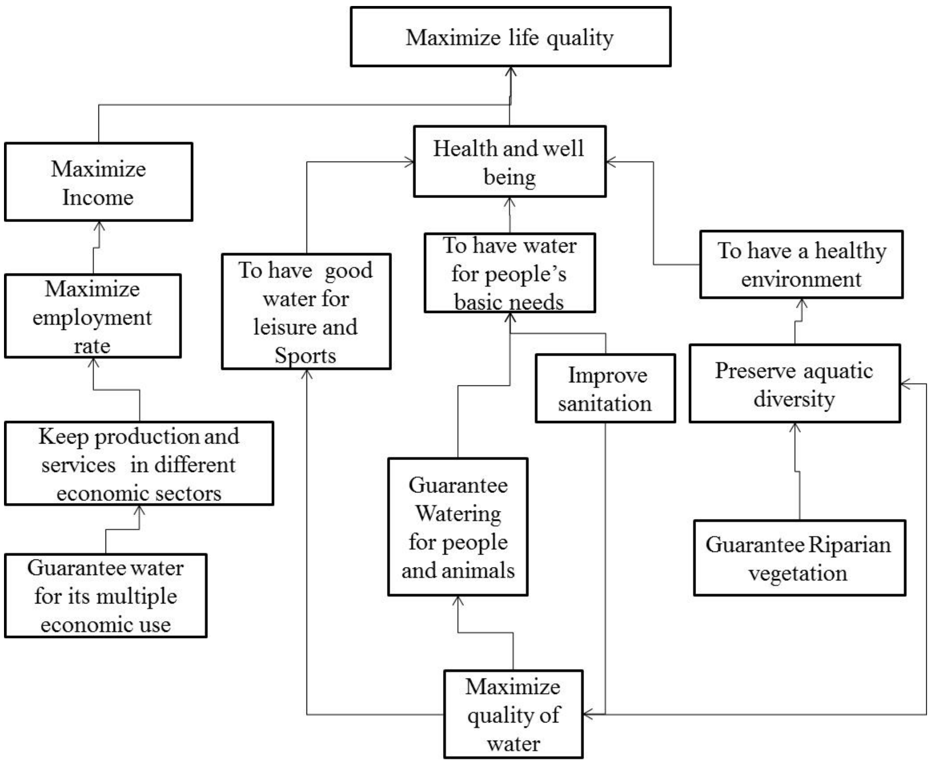

***Figure 3.3** Relationship between objectives for the representative of the local population*
Source: URTIGA and MORAIS (2015).

As to the hierarchy of the local authority's objectives, the fundamental objectives are to "have the government approved by society", "to meet the needs of industry", "to have efficiency in office administration" and "to meet the community's needs" as shown in Figure 3.4. The means objectives are presented after the fundamental objectives, following the logic presented in Figure 3.2 and Figure 3.3.

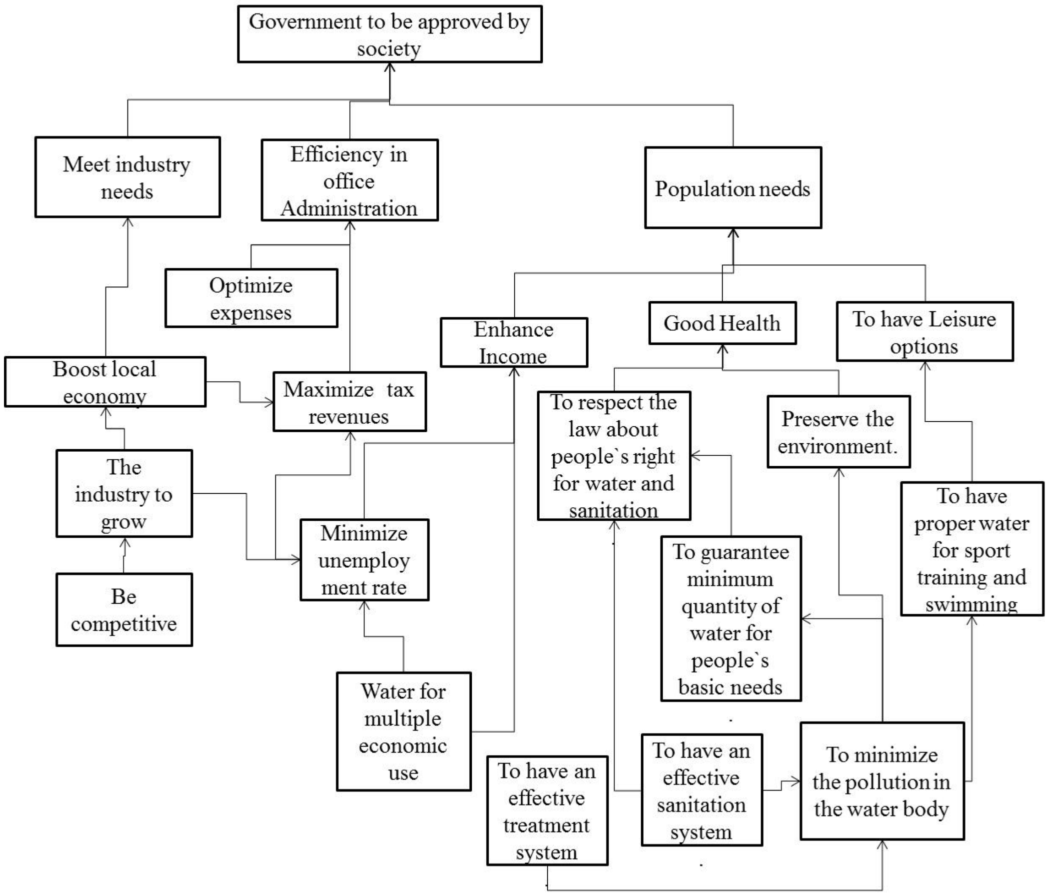

Figure 3.4 Relationship between objectives for the representative of the local authority
Source: URTIGA and MORAIS (2015).

3.5 Aggregating Objectives

After obtaining the hierarchies of objectives of each negotiator, the facilitator will put together the common values, thereby identifying clusters and what relationships there are between the objectives of different DMs. This step, which is a very important step of the procedure, is taken in a form of a workshop. Not only will it be useful to define the issues to be negotiated, but it can also generate a friendly environment for the parties, as they will work together as a team with the same purpose: that of enhancing the quality of the results of the negotiation.

In the workshop, the facilitator will discuss definitions with the negotiators, identify redundant objectives for the parties, and with the synergy created by the discussion, may even include new objectives. They will exchange information and concepts, and agree and disagree on what values they are willing to negotiate. Thus, after discussing the individual objectives, a tree containing the values of all DMs is created which is represented in Figure 3.5.

In order to draw up the objective tree that represents the objectives of the group, the facilitator has to make comparisons between the objectives of each DM in order to identify the objectives that have the same meaning. He/she will merge these so that each objective appears only once in the objective tree and thus double representation will be avoided. The facilitator also identifies how the objectives are linked to each other (networks). The network is important when evaluating the issues that will be considered in the negotiation phase and also when evaluating alternatives. This representation is presented in Figure 3.5. There is an objective network within the objectives of individual DMs and network that links the objectives of different DMs. For example, for the DM who is the representative of the community, “to have good water for leisure and sports” is related to “guarantee water for its multiple economic uses”. There are also links between the objectives of the DM. For example, the objective “industry growth” of the representative of the local authority has an impact on the objective “to minimize the unemployment rate” of the representative of the local community. Also the objective “to boost the local economy” of the representative of the local authority is related to the objective “to increase demand” of the representative of industry. In Figure 3.5 selected relationships are shown to avoid cluttering. The hierarchy between objectives is shown by the continuous line and the network by the dotted line.

In the workshop meeting the DMs clarify the meaning of their objectives and therefore the facilitator is able to identify what objectives are the same in order to merge them and thus to avoid the representing redundant objectives in the objective tree. The objective “to minimize the pollution in the water body”, for example, means the same as “to maximize water quality” based on the description given by the DM in the interaction with the facilitator. Thus, in the group’s objective tree they appear as the same with a representation of “to minimize water pollution”. Note that the hierarchy of objectives for the different DMs is preserved. The objectives “to have an effective sanitation system” and to “improve the sanitation system” were also considered the same in the group tree. The same goes for “to guarantee minimum water for people’s basic needs” and “to have water for people’s basic needs”.

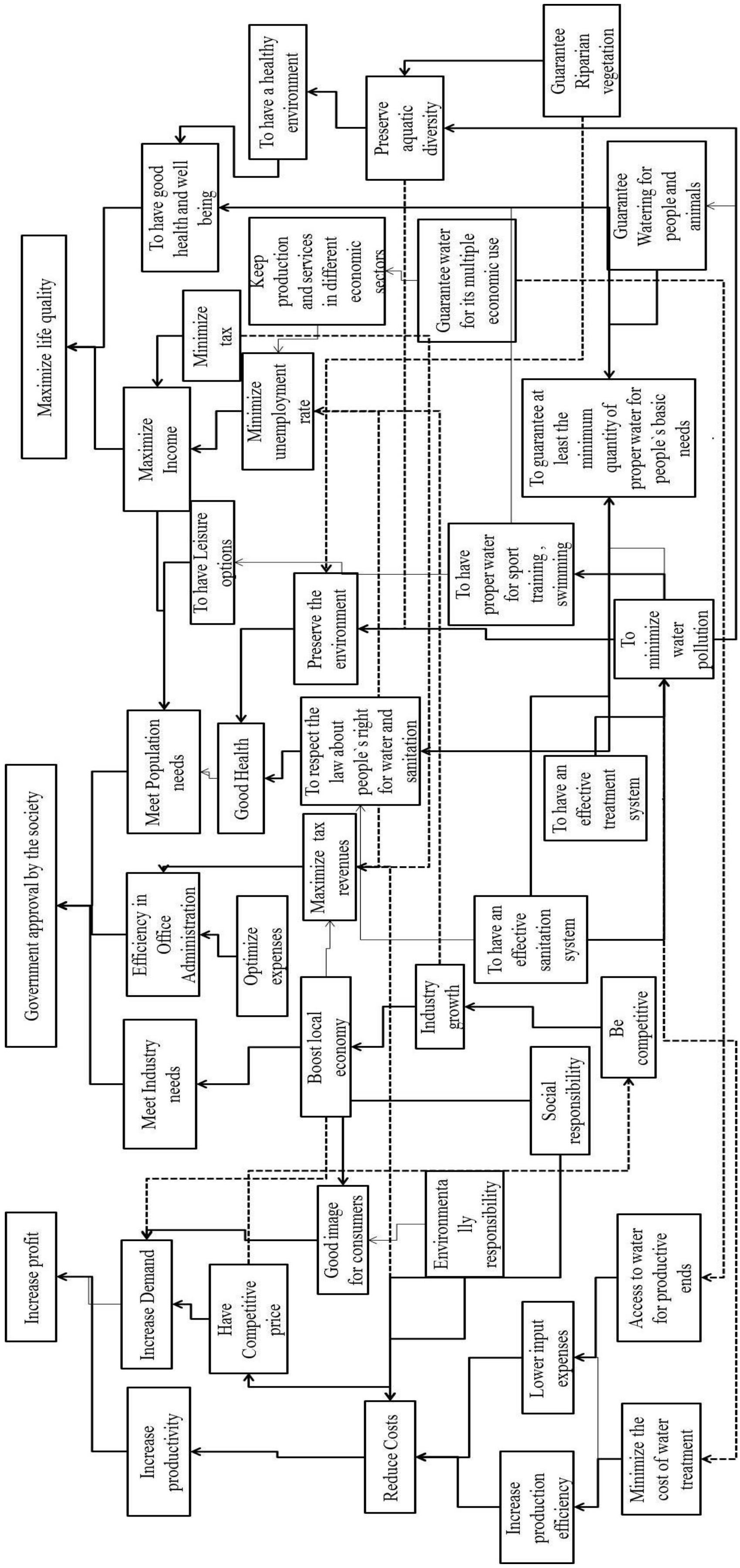

Figure 3.5 Joint objectives tree

Source: URTIGA and MORAIS (2015).

The facilitator can also identify the relationship of the objectives of one DM with the objectives of the others. By doing so, DMs can better understand the effect of an alternative on the various objectives for each DM. If the construction of a sanitation station is a chosen alternative, then it will affect the objectives which are lowest in the hierarchy i.e. “to maximize the quality of water” and “to improve sanitation for the population”. However, for example, this will also affect the cost of treating water which will be used by industry for production purposes. Now on considering the objective “to have a competitive price” for the representative of industry and “be competitive” for the representative of local authority, the objectives might look the same. However, they are not considered the same based on how the DMs describe them. The objective “to have competitive prices” is related to having a better price compared to outside companies, while “to be competitive” is related to having a good cost benefit relation and to having a good relationship with customers. These objectives on the other hand, are related and this relationship is represented by the dotted line in the picture. To build the relations among the objectives the help of a specialist can be used.

3.6 Defining Attributes

When the facilitator has the joint objective tree, he/she can examine the DMs’ objectives and assign issues (attributes) to represent these objectives. When they have the attributes, the negotiators can evaluate how an offer could satisfy their objectives. The DMs might have different objectives that can be represented by the same attributes. So, even with different objectives they can rely on a common issue in the negotiation process to find a better solution. In this process of assigning attributes, the help of a specialist can also be used.

For this problem, a facilitator has considered six different attributes: tax rate, expenditure on water treatment, concentration of toxins/m3, number of new job vacancies, volume of water allocated, and hectares of planted riparian vegetation. The tax rate attribute represents the objectives “to lower input expenses” for the DM from industry, “to maximize tax revenues” for the local authority DM and “to minimize tax” for the local community DM. Expenditure on water treatment can represent “environmental responsibility” and “expenditure in water treatment” for the industry DM, “to have an effective water treatment system” and “minimize water pollution” for the local authority DM and for the local community DM. Concentration of toxins concentration of toxins/m^3 can directly represent “to minimize water pollution”, “to minimize the costs of treating water” and “environmental responsibility”. The number of new job vacancies can represent “to minimize the unemployment rate”, “social responsibility”, “to lower input expenses", "to maximize tax revenue". The volume of water allocated can represent "to access water for production ends", "to guarantee at least the minimum quantity of water for people`s basic needs", "to guarantee water for its multiple economic use". Hectares of planted vegetation can represent "environmental responsibility", "to preserve the environment" and "to guarantee riparian vegetation".

Having identified the common issues by engaging on a problem structuring phase prior to the negotiation process, the negotiator can compensate for the offers and counteroffers from other negotiators based on the several issues that represent different objectives. As a result, the negotiators leave behind being part of a scenario of distributive negotiation and enter a scenario of probable integrative negotiation. If the local community representative wants the quality of water to be better, the industry sector representative might agree to spend more on water treatment if industry can have more access to water and if the local authority reduces its tax rates. Similarly, the local authority might agree to reducing tax rates, if industry sector agrees to hiring more local employees and so on.

Understanding and identifying common objectives help the negotiators to engage in a cooperative negotiation as they try to work together to find solutions that can generate a better payoff for everyone involved, instead of behaving as true opponents. At the end of this step the negotiators have a set of issues that could be used during the negotiation process that would contribute to integrative negotiation. That does not mean that the parties would have to make use of all objectives to reach an agreement; they could find a compromise with just a few. If they find that is necessary or that they could achieve a higher joint gain by adding another issue to the negotiation that issue can be found on the list. In this case, preferences should be elicited again considering all objectives.

3.7 Discussion

The pre-negotiation framework helps the representatives to identify many relevant aspects that were not evident to the WSC hitherto, such as structured objectives, attributes, and the different interests the representatives hold in common, which will serve as input for the negotiation process. A tree of objectives (aggregated tree) is used to represent the perceptions of all representatives. The pre-negotiation framework is important so as to create a friendlier atmosphere in the WSC, since the representatives will work together in an attempt to achieve mutual gains. The representatives will exchange information and try to identify what each of them could give and receive from the others, in order to reach a better compromise solution. To

RIST et al. (2007), sharing experiences, interests and perspectives often helps create both mutual understanding and a shared point of view on rules and responsibilities, when managing natural resources. In a paper presented by DUCROT et al. (2014), many participants mentioned that in a participatory approach they were able to learn more about other people's points of view. Engaging in a participatory process has improved the participants' knowledge about the complexity of environmental issues. According to these authors, participation also made people change their positions, beliefs and norms. The interaction was also important to establish trust.

This Chapter focuses on a pre-negotiation framework for multi-attribute negotiations, rather than on the negotiation process itself. A multi-attribute negotiation can be challenging, as modeling DMs' preferences over multiple issues is usually a complex process; also to find an efficient solution, which is when the DMs reach a Pareto-optimal solution, is not trivial. A Pareto-optimal solution is when the payoffs of a DM cannot be further be improved, without leading other DMs to worse payoffs (LAI et al., 2004). However, in the literature there are studies that can assist DMs to overcome these difficulties in multi-attribute negotiations. These include those put forward by FATIMA et al. (2004) and SYCARA (1990, 1993).

According to some authors, having to establish tradeoff relationships among issues might demand a high cognitive effort from DMs (DE ALMEIDA-FILHO et al., 2017; MUSTAJOKI et al., 2005). This is because they have to precisely state what the values of an agreement are that will provide a payoff that they find indifferent in comparison to the payoff of another agreement. These procedures usually require the analyst (who in this Chapter is also the facilitator) to ask the DMs several questions until all the weights are elicited. Taking these difficulties into account, these authors have proposed flexible methods to elicit weights for additive functions by using approximate weights, where the DM only has to concentrate on providing preference relation information (DE ALMEIDA-FILHO et al., 2017; MUSTAJOKI et al, 2005; NELYUBIN; PODINOVSKI, 2011). These elicitation procedures can be incorporated into a multiattribute negotiation model for the negotiation phase, with appropriate adaptations, in lieu of the tradeoff method.

3.8 Final comments

This framework helps the negotiators to visualize which issues each party is able to negotiate. Therefore, it will be easier to make offers and counteroffers that really matter to the bargaining process. This possibility might be a factor that will help stimulate the DMs to share their true expectations so as to improve the quality of the cooperative negotiation.

When value is created, this means that the parties in conflict have found a way to enhance the number of issues that will be shared among them. Thus, there are improvements for all sides. The creation of values improves the chance of the parties getting what they want out of the negotiation in a more cooperative environment.

This is especially important in the context of water resource conflicts as water has a vital role in the life and development of the population, which makes such disputes in general even more fraught and severe. The framework presented creates values to turn distributive negotiation into integrative negotiation by using VFT to help structure the process so that the parties can rely on integrative negotiation to reach an agreement. The creation of values using problem structuring demands more flexible management of issues and options, so that new issues might be added to the negotiation process, should all parties agree to this. This would be possible by using an NSS that allows the inclusion of issues during the negotiation process in the existing model and considers the constraints and objectives already in the model and also the negotiators' preferences.

4 A VALUE-BASED PARTICIPATORY DECISION MODEL TO ASSIST PARTICIPATORY WATER MANAGEMENT

A model is presented for participatory decision-making, designed to tackle problems faced by WSCs when making decisions on the management and planning of water resources. Based on the group's values, which are, identified by using the framework presented in Chapter 3, with some adaptation for a group decision-making approach, alternatives are created and attributes identified to evaluate these alternatives. The process stimulates interaction and communication and enables the problem to be modeled based on the perspectives of the group rather than on those of single individuals. A multiple-attribute value function aggregates the group's preferences. An application illustrates the applicability of the framework.

4.1 Introduction

Decision analysis methodologies provide the DM with insights into how to select an alternative that will satisfy his/her objectives. In group decision-making, two or more DMs must together choose an alternative from a set of two or more alternatives that will represent the group's objectives. This is the problematic that is approached in this Chapter, where a WSC has to decide on which alternative to select in order to address a certain problem.

A methodology is proposed to promote communication, interaction and to structure the problem as part of the group decision process. The methodology consists of 3 phases: i) in the first one the problem and the DM's objectives are structured; ii) in the second, the DMs evaluate the alternatives individually based on a value function, iii) and in the third phase, the alternatives are evaluated based on a group value-function. This Chapter uses a similar framework to the one proposed in Chapter 3. The main differences are that in Chapter 3, the framework was used to structure the problem, which would later serve as an input for a negotiation process; in this Chapter, the decision problem is structured focusing on the problematic of having a group collectively rate alternatives. In Chapter 3, the framework was used, in general terms, to structure objectives, identify common objectives and identify issues of mutual interest that could be negotiated among DMs. In this Chapter, the group of DMs structures their objectives, find out which objectives they hold in common, and they use the objectives to identify alternatives which are later evaluated by the group. The DMs also choose the attributes in a way that the objectives of all DMs are represented when evaluating alternatives.

The reason why new methodologies are important to assist decision-making in WSCs is that the DMs tend to use a simple voting system to aggregate DMs' preferences in order to select or rank alternatives (URTIGA; MORAIS, 2015a). As explained before, when a DM votes, he/she has already analyzed the alternatives according to his/her own criteria and value system, but not necessarily in a structured way. This means that the DMs could potentially miss important aspects of the decision problem especially when many alternatives and criteria are involved. Thus, structured methodologies to help these DMs in analyzing alternatives are important. What is also important is to have an adequate method, according to the decision situation, in which the DMs' preferences are taken into account, so as to make a decision which represents the whole group.

Therefore, many studies in the literature have been carried out to try to find ways to best represent the group's preferences when a decision analysis is being undertaken. Such studies include those by BORAN et al. (2009b), CAI et al. (2004a), KEENEY (2013a), LEYVA-LÓPEZ ; FERNÁNDEZ-GONZÁLEZ (2003a), MORAIS; DE ALMEIDA (2012), SILVA et al. (2010a) and GHANBARPOUR et al. (2005).

KEENEY (2013b) proposes a multiple attribute decision analysis model for group decision-making. The approach allows for each group member having different frames of their joint decision, including different events and consequences. BORAN et al. (2009b) propose a method based on TOPSIS, combined with an intuitionistic fuzzy set, so as to make a group choice for a supplier. An intuitionistic fuzzy weighted averaging (IFWA) operator is used to aggregate DMs' individual opinions for rating the importance of criteria and alternatives. LEYVA-LÓPEZ and FERNÁNDEZ-GONZÁLEZ (2003b) propose an ELECTRE GD method for group decision analysis. A genetic algorithm explores the outranking relation of alternatives, based on the ideas of concordance, discordance, veto and incomparability, present in the ELECTRE method. First, the outranking relation is built by using the ELECTRE III method, and a genetic algorithm is used to explore this relation. A final ranking of the alternatives is obtained for each DM which is later explored by a supra DM. This results in a final ranking of the alternatives.

More specifically, in the context of water resources management, GHANBARPOUR, HIPEL and ABBASPOUR (2005) use two different group-decision making approaches to analyze the interaction and assess the preferences for alternatives of different stakeholders, such as: i) community leaders; ii) experts and iii) government, with regard to alternatives. The problem comprises watershed issues, focusing on a long-term watershed planning and management process. SILVA et al. (2010b) propose a model for group decision-making in water resources management, where the PROMETHEE II method is used to obtain the individual rankings of alternatives for each DM, and then, the ELECTRE IV method is used to aggregate the DMs' individual rankings so as to obtain a ranking for the group. CAI et al. (2004b) develop a method and a Group Decision Support System to solve a group decision problem in water resources planning by combining modeling techniques of: i) multiple objective analyses; ii) multiple criteria methods, and iii) multiple-participant decision methods.

Most decision methodologies, such as the ones presented above, have one thing in common, namely, they assume that the DMs are already thoroughly familiar with all important aspects of the decision problem, the possible alternatives and their objectives. They assume that the alternatives are given and that the objectives have been clearly identified. By using the model presented in this Chapter, DMs' objectives can be considered before identifying alternatives, in order to collect a set of decision alternatives that better represents the group's objectives. One can argue that the group can evaluate any alternative; if an alternative is not of interest to some members of the group, they can simply evaluate this alternative as poor. This is true. However, if it is in the interests of the group to have alternatives that represent the DM's objectives, then their objectives should be carefully considered when identifying them. Taking into account the objectives of all DMs before identifying alternatives prevents good alternatives from being considered in the evaluation step because the DMs did not think of their objectives when identifying alternatives.

The model proposed in this Chapter differs from the studies by KEENEY (1992, 2012) in the following ways:

a) The original VFT method was designed for a single DM, however this study contributes to understanding how VFT can be used in a participatory decision process, as better explained in b);
b) KEENEY (2012) proposes a Value-focused brainstorming method for identifying alternatives. However, the one proposed in this Chapter takes into account the dynamics of WSCs; in other words, how the actors within a WSC interact with one another, so as to structure objectives and identify alternatives and attributes. First, the representative of a WSC structures his or her objectives individually, without interference by other representative. The representative shall have meetings with the group it represents to discuss, for example, what their concerns and expectations are. However, it is the objectives of the representative that are structured in the decision-making process. It is only after each representative's objectives have been structured that the groups' objectives are considered in a single objective tree, with

the assistance of a facilitator. This is helpful because it prevents a DM from being heavily influenced by other actors and his or her objectives not being well represented in the decision process. To identify alternatives, each representative starts by performing this step individually, considering his or her objectives and the objectives of the group. Thereafter, the opinions of other actors are considered. The same goes for identifying the attributes to represent the objectives for evaluating alternatives. Group sessions with the groups that the representative represents and with other representatives, can take place in order to bring new perspectives to the problem structuring process. The study presented in this Chapter also makes the contribution of using VFT to assist a participatory decision-making process in a new context, which is that of WSCs.

For evaluating alternatives, the additive model is used. Each representative evaluates the alternatives by using an individual value-function. Later, the individual functions are aggregated by a group-value function. Thus, by using this model, the DMs are able to make decisions considering the group's perspective of the problem, but without losing sight of the individuality of each DM in the group, since the evaluation is made by each DM individually and subsequently aggregated for the group evaluation.

One of the problems preventing the community from taking an active part in participatory decision processes is that they often feel that their preferences are not being considered when their representatives make decisions. This discourages, for example, the community to attend WSC meetings. In this model, the sectors of society represented within a WSC are included in the decision-making process by helping their representatives to structure the problem (identifying objectives, alternatives, criteria) by considering the perspectives of these sectors. Although it is the representatives who make the final decision, and who might be held accountable for the decision (in the sense that they can be prosecuted by public prosecutors), the consequences affect everyone. Thus, being part of the decision problem helps the different sectors of society to keep up-to-date with the choices made by their representatives, and externalize their desires. It is also expected that, when the community is more often present in the decision-making process, they can prevent any external pressure that seeks to favor specific groups from (unduly) influencing decisions within the WSC. By doing so, a more sustainable management of water resources is possible.

In sum, based on VTF fundamentals, this Chapter puts forward a model for participatory decision-making to help a group of DMs choose an alternative that represents the value-systems of all DMs involved. The decision process is guided from the moment it begins until a recommendation is put forward. It starts by identifying and structuring objectives, moves on to defining alternatives and attributes and, finally, alternatives are evaluated and ranked. The applicability of the model is demonstrated by presenting a virtual case study regarding how a WSC might best evaluate alternatives for revitalizing a watershed.

4.2 Proposed Model

Usually, decision-making methods tackle a decision problem by considering that a set of alternatives is given, following which the objectives and criteria are considered. However, this can be seen as a reactive way to approach a decision problem. The DMs could consider the values of the group prior to identifying the alternatives, in order to choose the solution that best represents the group's objectives. The model presented below assists the DMs from the beginning of identifying the problem and structuring objectives for the group members. It does so by identifying common attributes to measure the objectives and by identifying relevant alternatives for the group. These steps are performed using an adapted version of Value-Focused Thinking that aims to adapt a model for a single DM problem to one that takes a group approach. The process is guided by a facilitator, who is responsible for the interactions with the DMs, for collecting the necessary information and for structuring them so as to assist the DMs.

The process begins with the DMs thinking about their values individually. The techniques from VFT help with the creative thinking. The values are then structured into means and fundamental objectives, the means being a way to achieve the fundamental objectives in a hierarchical structure. The facilitator then aggregates the individual hierarchies into a single one after he/she has identified similar and different objectives and the relationship between them. Having obtained the group hierarchy and taken advantage of the interactions between the facilitator and the group, attributes can be assigned to the objectives in the hierarchy.

When trying to identify alternatives, one evident way is to think about objectives. The group should consider all objectives in the hierarchy. One objective can be taken at a time, then two at a time and so on so as to find all possible alternatives that are relevant for each DM. Only alternatives that are relevant to at least one DM should be considered. After identifying the alternatives, they can be evaluated, while taking the DMs' multiple attributes into consideration. A value function is elicited for each DM and each function is then aggregated into to a single function that will represent the group's preferences for the alternatives over the attributes. The alternative with the highest global value is selected. The facilitator is present to assist the DMs in each step of the model.

To illustrate the applicability of the model, the data regarding the structuring of objectives in Chapter 3 will be used. In Chapter 3, VFT was used as a preliminary step of a negotiation procedure. Even though the purpose is different, the structure and hierarchy of objectives can also be used as a group perspective. The details for the development of each step are discussed in Section 4.3. Figure 4.1 presents the structure of the model.

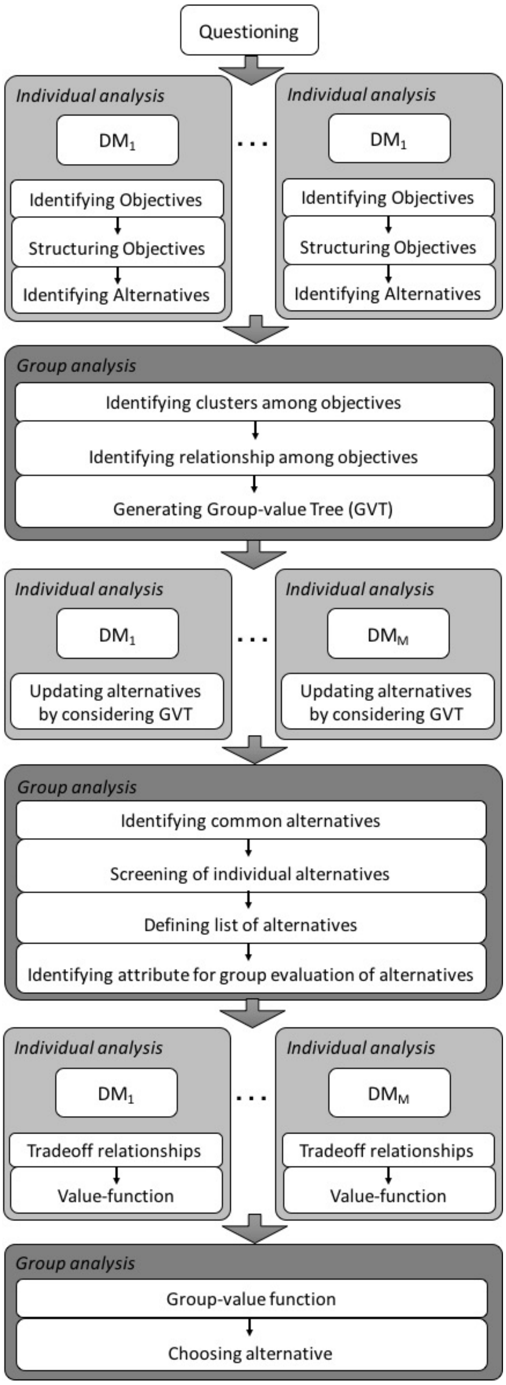

Figure 4.1 Group Decision Model

4.3 Illustration and detailing of each step of the Proposed Model with an example in the context of Water Management

For each step of the model, a virtual case study is used to illustrate its applicability. The virtual case study is based on a realistic decision problem of a WSC which is engaged on a revitalization project and needs to address how best to evaluate alternatives in order to tackle water pollution and degradation problems in the watershed they represent. Revitalizing a watershed comprises stopping erosion processes, improving sewage systems, reviewing solid waste management, etc. The representatives identify alternatives for this matter based on their objectives and evaluate the alternatives from a multicriteria perspective. The information available in the case study of Chapter 3 is used and, thus, the objective trees used in Chapter 4 are those presented in Chapter 3. The information used in this virtual case study was also gathered by having the author attend Advisory Consul and WSC meetings, by evaluating meetings' minutes, interviewing representatives and conducting searches in the literature. This led to reaching a better understanding of the interests of each party present in the virtual case study. The author was invited by the Agência de Água de Clima de Pernambuco – APAC (Agency of water and Climate of Pernambuco) to attend some meetings which were held in Ibimirim, Serra Talhada and Recife, in Pernambuco (Figure 4.2, Figure *4.3*, Figure *4.4*, and Figure 4.5). The Agency also made available the Minutes of several meeting which were used to inform this study.

Figure 4.2 Local community at the meeting in Serrinha Reservoir – Serra Talhada

Figure 4.3 Meeting in Serra Talhada for Serrinha II Reservoir

Figure 4.4 Meeting in Ibimirim for Poço da Cruz Reservoir

There are different types of actors taking part in this decision problem:

1. The DMs, who are the members of the WSC, who are called representatives. As explained in Section 2.4, they are elected by the population (except for the representative of government). Three representatives are considered, a representative of the government (RG), a representative of Industry (RI), and a representative of the local community (RC).
2. A facilitator, who is responsible for guiding the structuring and decision-making process.

3. The interest groups, who are present at meetings to share their concerns and points of view, which can be taken into consideration by the representatives when making the decision.

Figure 4.5 Meeting at APAC- Recife

The facilitator starts the process by explaining the methodology to be used. The facilitator's role is also to bring every representative and the interest group into the discussions, to observe their degree of commitment and to mediate conflicts. After explaining the methodology, the WSC defines the problem to be analyzed. In this case it was that of "improving of water quality and the environment around the river". The facilitator is now ready to initiate the private interviews.

The problem is investigated in accordance with each representative's perception. The mediator conducts individual interviews using questioning techniques to assist each representative to individually identify and structure his/her objectives. This step is performed individually, thereby generating a hierarchy of objectives like the one presented in Figure 3.2 , which is called a value-tree. This interactive process encourages the representatives to state their legitimate interests. The value-trees represent the representatives' interests. However, meetings with the groups they represent are held so as to allow the representative to take into account different perspectives. This also helps promote the participation of the community.

Thus, the facilitator starts the structuring process by questioning the representatives separately about topics such as: what they want to achieve, what their objectives are, what they do not want to happen, what the cause of the problem faced is and what the solutions could be. This type of questioning makes the representatives think about their problems and values creatively, thereby bringing up issues and views that would not have been thought of without the help of a structured methodology to guide creative thinking. KEENEY (1996) develops different questioning techniques that stimulate the DMs to identify objectives. After identifying the objectives, a more important step is that of structuring them into fundamental and means objectives. The ends that representatives value in a specific decision context are the fundamental objectives and how they can achieve these ends are the means objectives. The ends and means are context dependent.

The individual value-trees can be built during the interviews or shortly thereafter. However, the facilitator should always obtain feedback from the representative to check if the tree sufficiently represents his or her interests. Table 4.1, Table 4.2 and Table 4.3 show the hierarchy of objectives for each representative. In Table 4.1 for instance, the strategic objective for Industry is to increase profit. The fundamental objectives are "to increase productivity" and "to increase demand". The other objectives are means objectives. The industry sector wants to be seen to be socially and environmentally responsible because this will enhance its image among its customers. It not only wishes to do this but also to offer a competitive price so as to be able to increase the demand for its products/services. The Industry sector also wants to access fresh water for production ends and to minimize the cost of water treatment, because having these will help to lower input expenses. To lower input expenses and to increase efficiency will help to increase productivity. Finally, to increase productivity and increase demand will help the sector increase its profits. The same reasoning can be used to interpret Table 4.2 and Table 4.3. Table 4.2 presents the relationship between the objectives of the local community. Table 4.3 presents the relationship between the objectives of the representative of the local government.

Having obtained the individual hierarchy of objectives, the facilitator can start the process of identifying clusters and the relationships that exist between the objectives if the representative is different. Thus, the group value-tree is initially constructed from the individual value-trees, with the facilitator taking great care over considering the interests of all representatives. A preliminary group value-tree is presented to the representatives in a workshop during which they can discuss if anything should be modified, if some aspect should be included, if everyone has the same understanding on the meaning of each objective, etc. They obtain a broader view of each representative's interest. This is an opportunity for the representatives to connect with each other, to express their concerns, to make suggestions, to present the individual points of view and to improve their understanding of the needs of the other representatives.

Table 4.1 Hierarchy of Objectives for the representative of Industry

To increase profit	
1.	To increase productivity
1.1	To increase efficiency
1.2	To lower input expenses
1.2.1	To minimize the cost of water treatment
1.2.2	To access fresh water for production ends
2.	To increase demand
2.1	To have a competitive price
2.2	To enhance its image among its customers
2.2.1	To be seen to be environmentally responsible
2.2.2	To be seen to be socially responsible

Table 4.2 Hierarchy of Objectives for the local community

To maximize the quality of life	
1.	To maximize income
1.1	To maximize the employment rate
1.1.1	To keep production and services in different economic sectors
1.1.1.1	To guarantee water for the community’s multiple economic uses
2.	To ensure good health and well-being
2.1	To have good water for leisure and sports
2.2	To have water in an amount that meets people's basic needs
2.2.1	To improve sanitation
2.2.2	To guarantee clean water for people and animals
2.2.2.1	To maximize the quality of water

Creating a group-value tree is important because when similar objectives are identified this means that there is a common point between the representatives and it is possible to identify alternatives that will help the representatives achieve that common objective. It is also possible to identify a common attribute to evaluate alternatives regarding that objective. Additionally, when relationships between the objectives are identified, even if the representatives do not share the same objectives, the same attribute can be used to evaluate different objectives. For the task of assigning attributes, the help of a specialist can be used. For the illustration of a joint value-tree of objectives, please see Figure 4.6.

In the example used here, the facilitator finds that the objective “to minimize the pollution in the water body” means the same as “to maximize water quality” based on the description given by the representative when interacting with the facilitator. By having this information, the facilitator could unify the objectives in the value-tree, thereby avoiding redundancy, but maintaining the hierarchy. The representatives also considered that other objectives were the same, such as “to have an effective sanitation system” and to “improve the sanitation system”; “to guarantee minimum water for people’s basic needs” and “to have water for people’s basic needs”.

Table 4.3 Hierarchy of Objectives for the government representative

For society to approve of Government actions	
1.	To meet the needs of Industry
1.1	To boost the local economy
1.1.1	Industry is seen to be growing
1.1.1.1	To be competitive
2.	To have efficient office administration
2.1	To optimize expenses
2.2	To maximize tax revenues
2.2.1	To minimize the unemployment rate
2.2.1.1	To have water for multiple economic uses
3.	To meet the needs of the population
3.1	To enhance income
3.1.1	To have water for multiple economic uses
3.1.2	To minimize the unemployment rate
3.2	To guarantee good health
3.2.1	To respect the law about people's right to water and sanitation
3.2.1.1	To have an effective sanitation system
3.2.1.2	To guarantee the minimum quality of water for people's basic needs
3.2.1.2.1	To minimize the pollution in the water body
3.2.3	To preserve the environment
3.2.3.1	To have an effective sanitation system
3.3	To have leisure options
3.3.1	To have clean and sufficient water for swimming and other water sports
3.3.1.1	To minimize the pollution in the water body

The facilitator also found that the objective of the representative of the local authority, “to boost the local economy”, is related to the objective of the representative of industry, “to increase demand”. Another relation observed was that of “industry growth” of the representative of the local authority and “to minimize the unemployment rate” of the representative of the local community. This happens because if the economy grows, the industry will produce more, and thus will hire more. This will have a positive impact on the objective “to minimize unemployment rate”. The facilitator presents a preview of the group’s objective tree for discussion at a meeting with the representatives at which adjustments can be made.

The value-tree is also used to assist the representatives in the process of identifying alternatives. To identify alternatives collectively, this study proposes the following steps:

1) Each representative thinks individually about their objectives to identify alternatives. Each representative can have discussions with the group he/she represents.

2) The process considers first the individual value-trees. First, each fundamental objective is considered one at a time. By thinking about these objectives the representatives try to identify alternatives that could assist them in achieving their objectives. For example, in Figure 4.6 “to increase productivity” is a fundamental objective for the representative of industry. The representative considers this fundamental objective and the means objectives related to it in order to think about alternatives. Based on his value-tree, the alternatives “implementation of a sewage system” and “implementation of a treatment center” are related the objectives at the bottom of the hierarchy, which are “to have access to water for productive ends (clean water)”, “to minimize costs for water treatment”, “to be perceived as environmentally and socially responsible by its consumers”.
3) All objectives, fundamental or means, should be considered in this process. The representatives first consider a fundamental objective, then the means objectives until they reach the objectives that are lowest on the tree. They can go back up the tree to see if other alternatives can be considered.
4) The representatives will also consider the value-tree of the other representatives to see if more alternatives are identified. Figure 4.6 shows examples of identified alternatives.
5) The representatives perform an initial evaluation of alternatives to see if they meet their fundamental objectives. Thus, for example, for the representative of Industry the alternatives “implementation of a sewage system and “implementation of a treatment center” which are related to the objectives at the bottom of the hierarchy, which are “to have access to water for productive ends (clean water)”, “to minimize costs for water treatment”, “to be perceived as environmentally and socially responsible by its consumers”, assist the representative of Industry to achieve these objectives. Since these alternatives assist the representative in achieving his objectives at the bottom of the tree, consequently, they also assist the representative to achieve the fundamental objective “to increase productivity”. The representatives consider the alternatives for each fundamental objective at a time, then two at a time, three at a time and so on. Thus, the representative can check if a given alternative would assist the representative in achieving the other fundamental objectives as well.

6) After each representative has performed this step, the information is shared with the other representatives (of the WSC). The interest groups are also consulted so as to update the group of alternatives identified.
7) The common alternatives among the DMs will potentially satisfy fundamental objectives of the whole group.
8) For the other alternatives, an initial evaluation can be performed with a process similar to the individual one. Thus, the representatives consider each fundamental objective of the group's value-tree to see if the alternatives would satisfy the group's fundamental objectives.
9) The representatives must agree on a set of alternatives to be evaluated. They should only concern themselves with that are relevant to at least one representative (Keeney, 2013). It would be potentially helpful if the representatives formally evaluated alternatives that are of interest of the whole group. The representatives can screen the alternatives to decide which ones will be evaluated. If an alternative seems very important to at least one of the representatives, it shall be considered in the group evaluation. The other representatives, who do not think the alternative is important, can evaluate it as poor.

The set of alternatives considered in this problem are described in Table 4.4.:

Table 4.4 Alternatives considered by the group

Alternative	Description
A1	Implementation of a sewage system
A2	Treatment Station
A3	Construction of a landfill site
A4	Educational campaign to reduce pollution
A5	Protection of the dam
A6	Improve collection of waste material

All alternatives are beneficial to the representatives as they will reduce water pollution, and consequently increase the amount of fresh water available, which means that the water could be suitable for different uses. Also implementing the alternatives, together with the benefits that will result from this, will have a positive impact on the employment rate, which means more income, more consumption and more.

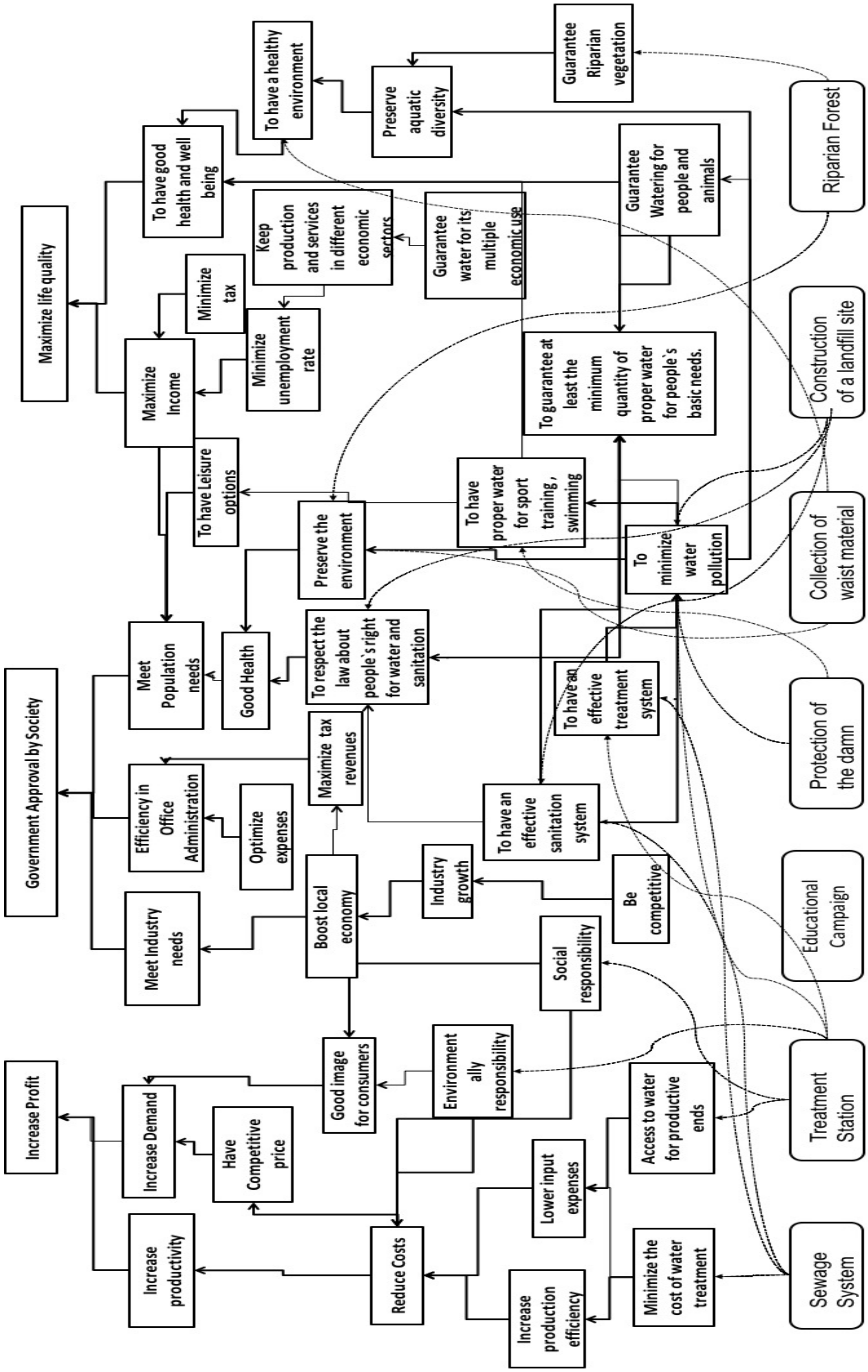

Figure 4.6 Group-Objective Tree with alternatives
Source: Adapted from Urtiga and Morais, 2015.

After identifying the alternatives, with the assistance of the facilitator, the representatives can think about identifying attributes. The group value-tree is used to identify the attributes so as to evaluate the alternatives, and it is also important in helping to identify which attributes are of common interest to all representatives; in a process similar to that presented in Chapter 3. All fundamental objectives must be represented in the evaluation process with attributes. In this virtual case study, different common attributes can be identified: the tax rate percentage, the concentration of coliforms/100 milliliters; the number of new job vacancies; the number of hectares of planted riparian vegetation and the response time. The tax rate percentage attribute can represent the proportion of the cost of the alternatives relative to the tax rate. This could affect the objectives "to minimize tax rate" for both the representative from Industry and the representative of the community, and "to optimize expenses" for the representative of the local authority. The concentration of coliforms/100 milliliters can directly represent "to minimize water pollution", "to minimize the costs of treating water" and "environmental responsibility". The number of new job vacancies can represent "to minimize the unemployment rate", "social responsibility", "to increase demand", "to maximize tax revenue". Hectares of planted vegetation can represent "environmental responsibility", "to preserve the environment" and "to guarantee riparian vegetation".

For this problem, three different criteria/attributes were chosen to evaluate the alternatives,: i) quality of water which is related to the fundamental objectives "to increase productivity" and "to have good health and well-being"; ii) the number of jobs created due to implementing the alternative, which is related to the objectives "to increase demand" and to "maximize income"; iii) response time, which is the minimum estimated period (days) to achieve the benefits from the implemented alternative, the attribute is related to the fundamental objective "to have efficient office administration".

The attributes are described in *Table 4.5*, two of which cover the social/economic aspects and the other the environmental aspect.

Table 4.5 Description of the considered criteria

Criterion	Description
Quality of water	This criterion is measured by the reduction rate of coliforms/100millilitres. The higher the concentration, the more polluted the water is. Having a higher reduction rate is preferable to having a lower rate.
Number of jobs created	Number of jobs created due to implementing the action. A higher number is preferable to a lower number.
Response time	Units are given in days. This is the minimum time to achieve the benefits from the alternatives. The fewer the number of days, the more the performance of the alternative is preferred.

After the group has defined alternatives and attributes, the representatives evaluate the alternatives in order to rank them according to the group's preferences. This step is performed in Section 4.4.

4.4 Evaluating Alternatives (Aggregation of Preferences)

The facilitator explains to each representative what should be done for individual and group assessments. Each representative must evaluate the alternatives based on an individual additive value-function. The individual values are aggregated in a group value function. For each representative, there is a value-function to evaluate the alternatives, such as shown in Equation 4.1.

$$v_i(a) = \sum_{j=1}^{n} k_j v_j(a) \qquad (4.1)$$

where k_j are the constant scales that reflect the trade-offs between the attributes, $\sum_{j=1}^{n} k_j = 1$, and v_j the value given to the performance of each alternative in each criterion j.

The group function will be determined by Equation 4.2.

$$V(a) = \sum_{i=1}^{m} w_i v_i(a) \qquad (4.2)$$

where w_i is the relative weight of the evaluation of each representative.

In the individual value-function, trade-offs are defined by using the indifference relations of the consequences for each representative (KEENEY; RAIFFA, 1976). For example, the facilitator asks the representative of the community the following question: from the worst consequence, if you had to choose to raise the performance of one criterion to the best level, which one would you choose as first, second and third? These answers determine an order of importance for the criteria. The facilitator then questions if the representative prefers some consequences to others. Therefore, for a specific criterion, the facilitator can vary the performance value until the representative finds an indifference relation between different consequences.

For the virtual case-study, the attributes were ordered based on the information gathered in interviews, meetings with WSC and the Minutes of meetings. It was possible to order the attributes based on the representative's interests. Since it was not possible to elicit tradeoff relations, for assigning weights, surrogate weights (ROC) (DE ALMEIDA FILHO et al., 2018; EDWARDS and BARRON, 1994) were used to represent the representative's preferences. The weights of each criterion for each representative are presented in Table 4.6.

Table 4.6 Constant scale for each DM

DMs	C1	C2	C3
Government representative	0.2778	0.1111	0.6111
Industry representative	0.6111	0.1111	0.2778
Community representative	0.61111	0.2778	0.111

After evaluating the performance of the alternatives according to the attribute for each representative, the facilitator assists the representatives in determining the group value-function. For the evaluation procedure, each representative has his/her own value-function. The aggregation of these functions into a function for the group takes into account two different factors (KEENEY, 2013a).

Consider that the representative of the community and the representative of the government represent 30% and 70% of the WSC, respectively. In this case, their relative weights would be 3×0.3 for the representative of the community and 1×0.7 for the representative of the local government. Now, as to the scaling factors (sum of weights equals 1), the weights are $w_1 = 0.562$ and $w_2 = 0.437$. Thus, by having identified these weights the representatives' value-functions can be aggregated into a single value-function where the contribution of each individual evaluation will be determined by these weights. For more information on how the groups determine the weights, see KEENEY (2013b), KEENEYand RAIFFA (1976) and BAUCELLS and SARIN (2003).

In this evaluation, it was considered that for the representative of the community (RC) it would be more significant to go from value $v_1 = 0$ to $v_1 = 1$ than to the representative of Industry (RI) and to the representative of local government (RG). For the RI and RG, the same weights are considered, resulting in Equation 4:

$$V(a) = 0.3 \times v_1(a) + 0.3 \times v_2(a) + 0.4 \times v_3(a) \tag{4.3}$$

The ranking of the alternatives by the group is presented in Table 4.7. Having obtained the group's evaluation of alternatives, the best placed alternative in the ranking is A1 (Implementation of a sewage system), which is the best alternative for the representative of the community and the representative of industry. The second best alternative for the group would be A3 (construction of a landfill site). The evaluation results in a ranking of alternatives which assist the WSC in prioritizing the actions that will be implemented in the watershed they represent since, usually, not all alternatives can be implemented at once.

Having concluded evaluation process, the main responsibilities and actions that the representatives must meet and fulfill are set out in a written agreement. They decide on the deadline for implementing the actions. The WSC monitors implementation by making periodic examinations with a view to detecting improvements in water quality.

Table 4.7 Ranking of Alternatives

Alternatives	RG	RI	RC	Group Rates	Group Ranks
A1	0.512	0.727	0.693	0.649	1
A2	0.040	0.077	0.090	0.071	6
A3	0.605	0.444	0.492	0.512	2
A4	0.304	0.354	0.305	0.319	5
A5	0.637	0.303	0.175	0.352	4
A6	0.677	0.405	0.351	0.465	3

4.5 Discussion

To illustrate the applicability of the model, a virtual case study involving three representatives is described. The model, however, is suitable for larger groups. If for example, there were five representatives with different and conflicting interests, it would be viable, yet more complex, to design and aggregate 5 different value-trees. However, the general idea is to simplify the representation of the interests by creating subgroups where the representatives within each subgroup are more homogeneous. When the number of representatives increases, it is likely that some of them will share similar interests regarding the problem they are analyzing. The facilitator can group them to represent their interests in the same value-tree. But, how is the facilitator going to identify these subgroups? First, the facilitator can already obtain some insights about some of their general objectives by looking at the activities they perform. The facilitator should also meet with all representatives, prior to designing the value-trees, to obtain more information so he/she can compile the subgroups. When building a value-tree for the group, some inconsistencies may arise due to the facilitator's influence on the resulting tree.

The aggregation procedure depends highly on the facilitator who uses common sense to consider the existing hierarchies between ideas. Thus, it is important that the facilitator is impartial and always gets feedback from the representatives. Also, the facilitator must be careful not to influence the answers of the representatives during interviews as much as possible.

In the evaluation phase, agreeing on weights for the representatives it might not be a straightforward task for the group to reach agreement on weighting the representatives. This is because the higher weight a representative has assigned to him/her, the lower those of the other representatives will be, and this can cause a conflict within the group. KEENEY (2013a) points out two procedures, one of which is to have each representative design his/her own set of scaling factors and perform analysis with each of these factors to gain insights on how to reach an agreed decision. The second one is based on setting limits on the relative importance and interpersonal comparisons, or in a more direct way, on the relative scaling factors, Thus, for example, the representatives can establish that the difference in value of a representative going from the worst consequence to the best consequence cannot be more than twice the worst value.

Even when, at first, the representatives agree on a weight, further analysis must be performed throughout the decision process. If, for example, the group ranking is over-sensitive to small changes in the weight or, in other words, if a slight change in the weights cause changes in the group's ranking of the alternative, then the weights should be evaluated more carefully because this directly influences the group's result. Thus, it is important that the representatives have this information before choosing the alternative. If necessary, they can reconsider the weights and re-evaluate the alternatives.

In general terms, the model presented in this Chapter shows how a participatory decision-making problem can be addressed to represent the WSC's preferences. The representatives use the VFT structure adapted to a group approach to identify the attributes of objectives, and alternatives based on the group's objectives. This means that the representatives are able to define a group of alternatives that is of interest to them all. It is most likely that all members will agree on the alternatives since they reflect their objectives. The model also helps promote the engagement of the community in the decision process as the public can participate in all the process to share their point of views. The model also guides the representatives from the beginning stages of structuring the group problem to choosing an alternative.

4.6 Final Comments

Most group decision methodologies assume that the DMs know their objectives and criteria regarding a decision problem. They also assume that the DMs know and agree on a set of alternatives. However, knowing these aspects of the decision problem is not as simple as it seems. If they do not use a structured methodology, DMs can leave out information that is important for the decision problem. Value-Focused Thinking is a method that assists a DM to think creatively about his/her objectives and from the objectives to create alternatives and attributes to evaluate these alternatives. This is especially important in group decision-making when the members of the group have the task of choosing an alternative that best represents the group's values.

A model is presented for group-decision based on VFT to help representatives of WSCs to structure their problem; to think about objectives and the objectives that they share in common and from the objectives to identify alternatives to the problem faced. Besides identifying common objectives between the representatives, attributes to evaluate the alternatives are also identified. To evaluate the alternatives based on the individual and group value systems, an additive model is used to aggregate the individual additive value functions of each representative into a group value function. Having obtained the group function, each alternative considered can be evaluated and ranked, thus providing a prioritization of alternatives to the group. The best solution is the one with the highest rating/ or the one that is placed highest in the ranking compared to the other alternatives.

A way to establish the weights for the group function is discussed and a simulation of a virtual case study is examined in order to illustrate each step of the model. The decision problem faced by the group is supported from the beginning of structuring the problem and defining the group of relevant alternatives, until an alternative is chosen.

Chapter 6 presents the most important contributions and limitations of the model.

5 GROUP DECISION APPROACH TO SUPPORT WATERSHED COMMITTEES IN CHOOSING AMONG COMBINATIONS OF ALTERNATIVES

A group decision-making approach is proposed that permits each member of a group to state his or her preferences with respect to combinations of alternative solutions to a problem during a collective process to arrive at a compromise via a special voting procedure. The results in this chapter are based on the findings of URTIGA et al. (2016).

5.1 Research Problem

In Chapter 4, a group decision approach was presented for assisting members of a group on choosing among single alternatives, based on their value systems. It was considered that a single alternative was being chosen at a time. In this chapter, a group has to collectively decide over combinations of alternatives. In this case, complexities of the decision problem can grow, as other aspects have to be taken into consideration such as how to address the possible combinations of alternatives and how the combinations, rather than the original alternatives, meet the DMs' objectives.

In Brazil, for example, it is very common that the funding agencies of the federal or state governments publish a request for proposals to invest in the management of water resources. Based on consultants' reports, the WSC chooses the alternatives that will be funded and subsequently implemented to address specific problems.

The need to discover how to assist the WSC in evaluating combinations of alternatives motivated this study, which takes into account the aforementioned aspects in this type of decision problem. One may suppose that by using a ranking of the original alternatives according to preference, the alternative placed first in the ranking would be chosen first, and the alternative placed second would be selected second and so on. However, this approach may not be sufficient when combinations among the alternatives are considered. For example, suppose that the alternatives a, b, c and d are ranked in this respective order, from best to worst. One could say that if a is chosen the next best alternative to be selected would be b. However, given that a is already chosen, alternative c could be better than alternative b to achieve the DM's objectives together with alternative a.

In this Chapter, a flexible approach is presented for ranking combinations of alternatives separately for each DM. These rankings are used as input to a voting procedure for choosing the most appropriate combination of alternatives. Over the years many researchers have put forward useful and interesting methodologies to rank and choose alternatives in a group decision-making situation, but utilizing approaches which differ from the new overall procedure given in this Chapter. For instance, ZNOTINAS and HIPEL (1979) recommend that each key interest group separately evaluates alternative solutions according to a range of factors or criteria for addressing a water management problem, such as the proposed large-scale Garrison Diversion Unit irrigation project in North America, followed by amalgamating viewpoints for employment in a group decision by using a fuzzy set approach. RAJABI et al. (1998) point out that the final solution to a problem may consist of a combination of separate alternatives and design a procedure for accounting for interdependence among separate alternatives. These authors apply their approach to a water policy subset selection problem concerned with planning the water supply in the Regional Municipality of Waterloo located in Southern Ontario, Canada (RAJABI et al., 1999).

LUCCHETTI et al. (2015) also propose methods for ranking combinations of alternatives, which they call a collection of objects, by taking into consideration that alternatives grouped together can result in multiple interactions. To evaluate the combinations, LUCCHETTI et al. (2015) make use of utility and probabilistic values. MORETTI and TSOUKIÀS (2012) introduce a class of Shapley extensions for ranking combinations of objects. The family of extensions takes into account the possible interaction effects among the objects when representing preferences. YIN et al. (1999) employ fuzzy relational analysis for comparing alternatives and combinations of alternatives for tackling the problem of fluctuating water levels within the Great Lakes straddling the Canadian/US border, in the face of high uncertainty. CHEN KILGOUR and HIPEL (2012) propose a group decision approach that aggregates case-based linguistic decision rules using a combination of the dominance-based rough set approach and Dempster-Shafer Theory. To take uncertainty into account in multiple criteria decision making, KUANG et al. (2015) integrate continuous grey numbers with linguistic expressions to permit each DM's preference according to multiple criteria to be expressed. The grey preferences across DMs are amalgamated using an algorithm prior to employing PROMETHEE II to generate a ranking of alternatives. A rich range of papers on contributing to multiple objective decision-making in water resources appears in a monograph edition published by the American Water Resources Association (HIPEL, 1992). CAI et al. (2004a) develop a method and a group decision support system to solve a group decision problem in water resources planning by combining modeling techniques of multiple objective analyses and multiple criteria and multiple participant decision methods. MADANI et al. (2014) put together voting methods with a Monte-Carlo simulation to model social choice decision making under uncertainty in water resources policy analysis.

The proposed approach makes a number of concrete advances. For instance, possible combinations of alternatives for addressing a water management problem are systematically generated using what is called an Option Form approach (HOWARD, 1971). Additionally, each interest group is permitted to rank the combinations of alternatives according to its preferences or value system. In particular, the model elicits the DM's preferences through a generalization of the option prioritizing approach, extensively used in the literature within a conflict analysis context (HIPEL, 2009; KILGOUR; HIPEL, 2010). Although it is widely employed for conveniently obtaining preferences for a DM within the Graph Model for Conflict Resolution (GMCR) (FANG et al., 2003a, 2003b; HIPEL et al., 1997), the option prioritizing approach has not been previously utilized within a Multiple-criteria Decision Analysis context. With appropriate adjustments, the authors show that the procedure can be of great assistance when ranking combinations of alternatives. More specifically, the DM provides ordinal preference information in an interactive way through what are called preference statements, which reduces the cognitive burden of having to make many comparisons or to define tradeoff relations. What is also particularly useful about this procedure is that it is possible to consider logical statements regarding the combination of alternatives. Overall, the approach is used to assist each DM to obtain a ranking of the combinations of alternatives. To preserve the way WSCs usually decide, after individual preferences are elicited, these rankings are used as input to a voting procedure for choosing the most appropriate combination of alternatives. The ranking information is aggregated using the Weighted Voting System based on Classification by Quartile (WVSQ) (MORAIS; DE ALMEIDA, 2012) to provide the final recommendation to the group. Therefore, the preferences of individual interest groups are openly recognized and taken into account when obtaining an overall "fair" ranking of combinations of alternative solutions.

Voting systems are mostly simple and transparent, both for the voters and those who calculate the winning alternative, and are therefore an appropriate tool for employment within this context of group decision making. The weighted voting quartile method has a phase in which the best alternatives are filtered. In addition, there is the veto phase that avoids alternatives being chosen that have received very low rankings from some interest groups while other DMs placed them in high-ranking positions. Thus, this procedure enables the group to make a more balanced choice of alternatives.

5.2 Proposed Model

The evaluation process in this approach begins when the DMs and alternatives are known and all DMs agree to evaluate them. There are different methods that can help DMs find alternatives and that could be easily incorporated into this approach. These methods assist the DMs in identifying alternatives that reflect the group's interest. Some examples include Soft Systems Methodology - SSM (CHECKLAND, 1981; CHECKLAND; HOLWELL, 1997), Strategic Options Development and Analysis - SODA (EDEN; ACKERMANN, 2001), Value-Focused Thinking- VFT (KEENEY, 1992) and Strategic Choice Approach (SCA) (FRIEND; HICKLING, 2005).

When alternatives are defined, the process of generating the possible combinations of alternatives starts by using what is called the Option Form Approach; this step is explained in more detail in Section 5.3.1. After the possible combinations of alternatives are known, the filtering step begins. Restrictions that are imposed by the problem are used to remove infeasible combinations. For example, the group can only choose a limited number of alternatives at a time because there is a limited number of projects that can proceed simultaneously. The amount of financial resources available are also a constraint, and it is a very common one when selecting alternatives. Another constraint is the limited time to implement the combination selected. The combinations of alternatives that do not respect the constraints are excluded as infeasible sets. This step can be performed with the help of the software GMCR+ (KINSARA et al., 2015) or GMCR II (FANG et al., 2003a, 2003b; HIPEL et al., 1997).

With the feasible combinations defined, each DM evaluates them individually according to his or her preferences. The evaluation method is presented in Section 5.3.1. The evaluation leads to a ranking of the combinations of alternatives, which constitute the input for the voting procedure (WVSQ) (MORAIS; DE ALMEIDA, 2012), where the individual preferences are aggregated in a group perspective. The voting procedure is presented in Section 5.4. The graph in Figure 5.1 illustrates each step of the proposed approach.

5.3 Alternative Prioritizing

Option prioritization is one of the approaches that can be used to rank states according to preference for a DM involved in a conflict when using the Graph Model for Conflict Resolution (KILGOUR; HIPEL, 2010). When utilizing this method, preference statements written in terms of options are listed from most to least preferred. The option prioritizing approach is based on mathematical logic and is simple to use. It has been successfully employed to model preferences for each DM in different kinds of conflict situations (HE et al., 2014a). In addition, as mentioned above, there are two decision support systems for obtaining preferences for every DM using options prioritization when formally studying a specific conflict. In Section 5.3, a generalization of option prioritizing for analyzing combinations of alternatives is presented.

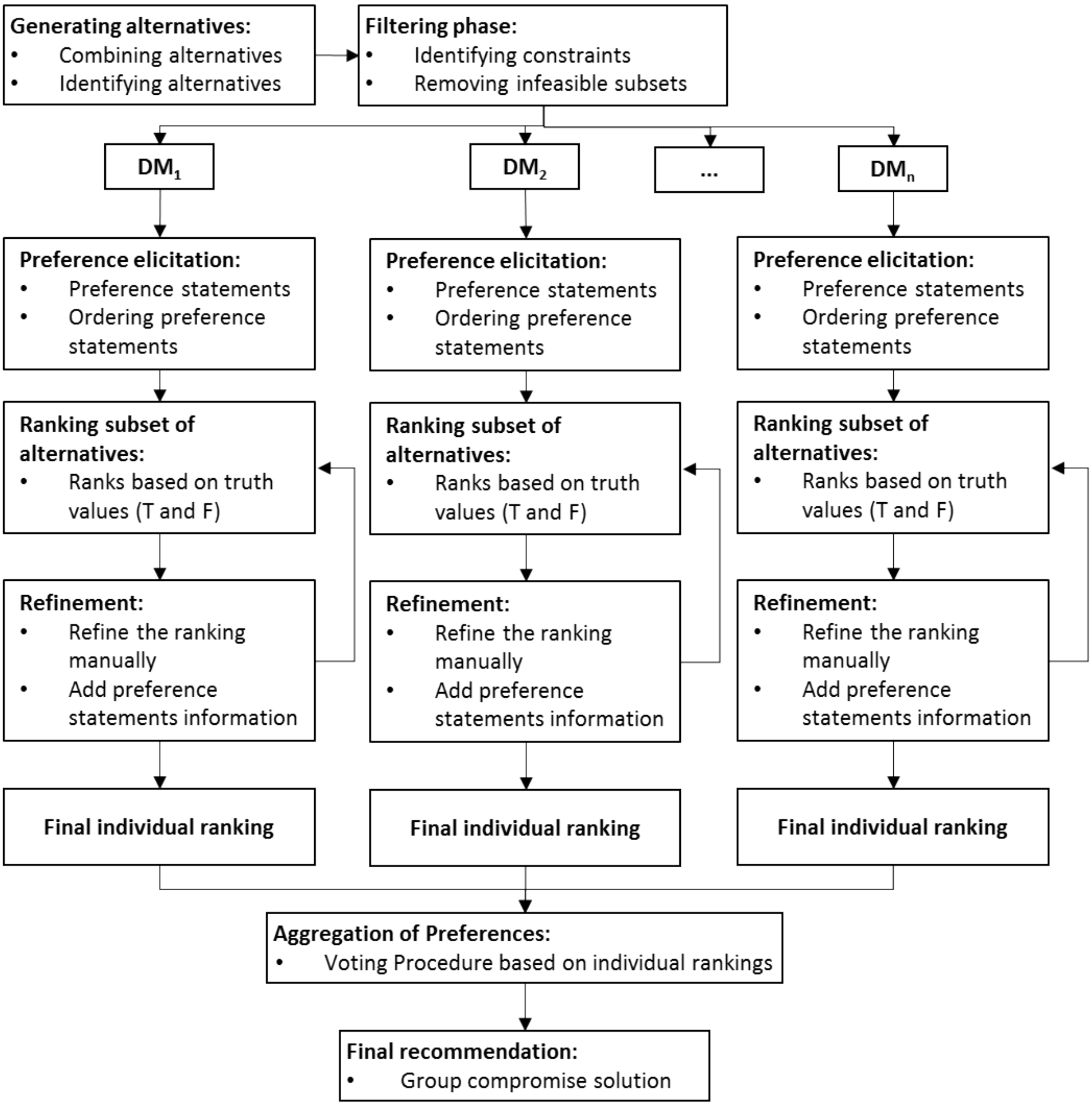

Figure 5.1 Structure of the group-decision model
Source: URTIGA et al., 2016.

5.3.1 Preference Statements for Combination of Alternatives

The participants of the group decision are called the DMs. The set of DMs is given by $N = \{1, 2, \dots, n\}$, where $n \geq 2$. The subset of alternatives considered in the problem by the group is $A = \{a_1, a_2, \dots, a_m\}$, where $m \geq 2$.

Because a final solution to a given problem is often a combination of separate alternatives, one may wish to consider the set of all combinations of alternatives which is the Power Set of A, denoted as 2A. One can equivalently define the combinations of alternatives as a mapping where:

$$s: A \rightarrow \{0, 1\}$$
$$a_j \rightarrow s(a_j) = \begin{cases} 1, & if\ a_j \text{ is included in the set} \\ 0, & otherwise \end{cases} \quad 5.1$$

This approach for generating all possible sets of combinations of alternatives reflects the Option Form of a conflict, first put forward by HOWARD (1971) for generating the possible set of states in a conflict, and further refined for employment within the Graph Model for Conflict Resolution (KILGOUR et al., 1987) and the associated decision support systems GMCR+ (KINSARA et al., 2015) and GMCR II (FANG et al., 2003b). The employment of Option Form for generating all possible combinations of alternatives for use in group decision constitutes a contribution of this current research. Because some combinations of alternatives may be infeasible, for example, due to cost or physical systems constraints or some type of logical infeasibility, one should remove these combinations from the set of all possible combinations of alternatives and only deal with the remaining feasible ones. Let this feasible set of combinations of alternatives be denoted by $S = \{s_1, s_2, \dots, s_j\}$ for which each s_i contains one possible feasible combination of alternatives.

When applying the Graph Model for Conflict Resolution to a given dispute, one can employ GMCRII (FANG et al., 2003a, 2003b) or GMCR+ (KINSARA et al., 2015) to generate the set of mathematically feasible states from which the infeasible states are removed. When an option is replaced by a specific alternative, the same procedures can be employed to determine the feasible set of combinations of alternatives for use in group decision-making as explained herein.

With the combinations of alternatives defined, the DMs can evaluate them based on their individual preferences. The basis for elicitation of preferences is the preference statements provided by DMs. The DMs order the preference statements so the statement that is considered of highest priority in determining the preferences makes the first change in the ranking of the combinations of alternatives; thus, it must appear first in the set of preference statements. Each preference statement μ takes a value either True (T) or False (F) at a particular combination of alternatives.

The preferences over the combinations can be determined in the following way. Let $\{\mu_1, \mu_2, \ldots, \mu_k\}$ be the set of preference statements. A combination of alternatives s1 is preferred to s2 if and only if there is i, $0 < I < k$, such that

$$\begin{array}{lcl} \mu 1(s1) & = & \mu 1(s2) \\ \mu 2(s1) & = & \mu 2(s2) \\ \ldots & \ldots & \ldots \\ \mu i\text{-}1(s1) & = & \mu i\text{-}1(s2) \\ \mu_i(s_1) = T & \text{and} & \mu_i(s_2) = F \end{array}$$

where T and F mean true and false, respectively.

There are different types of preference statements (HIPEL et al., 1997): i) non-conditional; ii) conditional; iii) biconditional. The non-conditional statement expresses the preferences over single alternatives. The other two types express preferences over the interaction of more than one alternative. Table 5.1 shows the types of preference statements and their connectors.

Table 5.1 Logical connectives and examples of their use in the Graph Model for Conflict Resolution

Logical connective names	Examples of expression in GMCR II/GMCR+
Non-conditional:	
Negation ("NOT" or -)	*-a*
Conjunction ("AND" or &)	*a&b*
Disjunction ("OR" or │)	*a│b*
Conditional:	
If (IF)	*a IF b*
Biconditional:	
If and only if (IFF)	*a IFF b*

Source: URTIGA et al. (2016).

What is particularly interesting about the “alternative prioritizing” approach is that the DMs are able not only to evaluate individual alternatives, but to evaluate the interaction among them, which makes it very suitable when the DMs have to choose a combination of alternatives rather than single alternatives. Thus, this approach can cope with a DM expressing their ordinal preferences when combining one alternative with another one. The DM can express in a simple way that, for example, they prefer not to place one alternative in the same set with others, or that they do not wish that two or three alternatives be placed together in the same set.

Table 5.2 shows how to represent the interaction among alternatives in the “alternative prioritizing” approach and the interpretation of each preference statement. The preference statements are presented in order of importance; thus, if for a DM the most important preference statement is that alternative “a” is present in the combination, regardless of the other alternatives, this will be the first preference information to change the ranking of the combinations of alternatives. Before the preference statements are considered, all combinations of alternatives have no ranking. Each preference statement given by the DMs will introduce ranking. Thus, if the most important preference statement for a DM is to have alternative “a”, regardless of the other alternatives, then all combination for which “a” is true will be placed in front of the combinations having “a” as false.

Now, suppose that the second most important preference statement is to have alternative “b” only in the case that alternative “c” is selected. Suppose that these alternatives are complementary; thus, a DM would prefer to have “b” and “c” together in the same combination (b IFF c). The combinations for which this preference statement is true are placed in front of those for which the statement is false. Thus, the combinations for which “a” is true and “b IFF c” is true are ranked before the combinations for which these preference statements are false. The procedure will most likely give a pre-order of the combinations of alternatives. The DM can refine the ranking information by changing the ranks manually or entering new preference information, always taking into consideration the importance of the preference statements (FANG et al., 2003a, 2003b; HIPEL et al., 1997).

With the structure presented in Table 13, the DMs can express their preferences. The help of an analyst can be of use to assist a DM in translating their preferences into preference statements.

5.4 Voting Procedure

The WVSQ procedure is used here to recommend a combination of alternatives, which represents a group of DMs, as a solution to a given problem. Since the problem considers combinations of alternatives, many combinations are generated from the original alternatives. With a large number of combinations of alternatives to take into account, the DMs can focus on the most relevant ones, which are the one at the top of the ranking (preferable combinations), and the ones that are lowest on the ranking (combinations the group would like to avoid). In Section 2.3 the WVSQ is presented in more detailed showing how the final ranks are calculated. The output generated by the “alternative prioritizing” procedure, which are ranks, can be used in any voting procedure. This is also important in this particular problem since the objective of having a WSC is to have solutions that can address the interests of different sectors of society. The characteristics of the group and problem will influence the choice of method.

Table 5.2 Preference Statements (PSs) for evaluating combinations of alternatives

PS	Situation	Interpretation
a	A combination with alternative a is more preferred than a combination without a.	Alternative a, alone, is important to the DM.
$-a$	A combination without alternative a is more preferred than a combination with a.	The DM does not wish this alternative to be selected.
a & b	A combination with alternatives *a* and *b* (same time) is more preferred than a combination without both alternatives.	The DM wants to select a combination with both alternatives.
$a\ OR\ b$	A combination with alternatives *a* or *b* (*a*; *b*; or *a* and *b*) is more preferred than a combination without both alternatives.	The DM considers both alternatives important to the decision problem.
$a\ IF\ b$	A combination with alternative a will be preferred if it contains alternative *b*, but it can also be preferred in different situations.	If b is placed in the combination, the DM would prefer *a* to be in it too if, for example, *a* can improve the performance of alternative *b*.
$a\ IFF\ b$	A combination with alternative a will only be preferred if it also contains alternative a.	A will only be important to the problem if and only if alternative *B* is also selected. For example, in the case of complementary alternatives *a* can only be helpful together with *b*. Both alternatives together would be helpful for the decision problem from the DM's perspective.
$a\ IF$ $-\ b$ & $-\ c$	A combination with alternative a will be preferred if it does not contain *b* and *c*, but it can also be preferred in different circumstances.	If alternatives b and c are not in the set, then the DM would prefer to have alternative a in this combination. For example, if *b* and *c* complement each other, but together they are a substitute to alternative a, then it would not be of interest to the DM to select all these alternatives at the same time.

Source: URTIGA et al. (2016).

5.5 Application and Discussion

As mentioned in Section 5.1, WSCs face group decisions where they have to choose a combination of alternatives to solve a problem instead of a single alternative. This raises the questions of how to evaluate these alternatives and the benefits of each to the decision problem without making the preference elicitation procedure overly demanding for the DMs. How can the interaction among these alternatives be addressed? For instance, consider that for a certain DM the most important action is to choose an alternative that will clean a certain body of water. If there is more than one alternative available to address this problem, which one would the DM choose? If they could choose more than one, would the DM choose two alternatives to address the same aspect or would they, for example, prefer to combine one of these alternatives with another one that would help prevent the pollution from happening?

With the alternative prioritizing approach, these aspects of preference can be taken into account in the form of preference statements. Each DM separately can evaluate the available combinations alternatives and rank them according to their individual preferences. The WSCs usually rely on simple voting systems to make a group decision. For this scenario, a suitable voting procedure would be the WVSQ as explained before.

In this Section, a virtual case study is presented using realistic information to illustrate the applicability of the proposed approach. The information was obtained by interviewing professionals involved with water management and in the literature from the works of SILVA and MORAIS (2014), URTIGA and MORAIS (2015a, 2015b).The problem selected is regarding the conservation of a Brazilian watershed. This particular problem was chosen because in Brazil it is very common that the funding agencies of the federal or state governments publish a request for proposals to invest in the management of water resources. Based on consultants' reports, the WSC chooses the alternatives that will be funded and subsequently implemented to address specific problems. The case study is important to illustrate real world situations faced by WSCs and how the proposed approach can help WSCs in making informed decisions such as this.

5.5.1 Choosing Alternatives to Prevent Watershed Degradation

In this case study, the WSC has to choose a combination of alternatives from several other combinations to address the problem of conservation of the watershed they represent. The WSC comprises representatives of different sectors of society to ensure a participatory approach in the management of water resources, as required by law. Five DMs are considered: i) a representative of industry, ii) a representative of the agricultural sector, iii) a representative of the water treatment and supply company, iv) a representative of the local government, and v) a representative of the local population.

The alternatives considered in this decision problem are presented in Table 5.3. We assume that they were already decided on and the group agrees on evaluating them. The methodologies presented in Sections 2 and 4.3 can help the DMs define these alternatives. Seven alternatives are considered, from which the possible combinations of alternatives are generated.

Table 5.3 Alternatives considered by the DMs in the decision problem

Label	Alternatives	Description
a_1	Sewage treatment facility	To implement a secondary sewage facility.
a_2	Educational campaign to the population	To promote an educational campaign to the population raising awareness about how to preserve water and the environment (recycling, etc.).
a_3	Monitor agricultural practices	To monitor agricultural practices, offering tax subsidies for those that demonstrate environmentally friendly practices and penalizing those that do not.
a_4	To plant riparian vegetation	Recovery of riparian vegetation along the riverbanks.
a_5	To improve the collection of waste material	To improve the collection of waste material along the river, such as providing periodic trash removal.
a_6	Dredging	Excavation activity in the river to collect sediments from the river bottom and dispose of them at a different location.
a_7	Macro drainage	Artificial canals, storm drains, dikes and other constructed structures to improve discharge of the surface runoff.

Source: URTIGA et al. (2016).

5.5.2 Generating and Filtering Combinations of Alternatives

The combinations of alternatives are generated by using the Option Form Approach as presented in Section 5.3.1. From the seven original alternatives considered by the WSC, 128 combinations of alternatives are generated. The GMCR+ and GMCR II software can handle large problems, so there are no computational issues.

For the filtering phase, certain constraints were considered to demonstrate that infeasible combinations can be removed from the original set of possible combinations of alternatives. However, different constraints can be used such as financial resources, time, if the selection of any alternative is mandatory, number of projects managed at the same time, and labor costs. Using the appropriate information, different constraints can be considered, which will remove many infeasible combinations of alternatives from the problem.

For the purposes of illustration, some simple constraints were considered in this problem, as follows: i) at least two alternatives have to be selected, so the number of alternatives in the combination must be at least two; ii) the WSC cannot handle managing more than five projects at the same time, so that each combination can only consist of at most five alternatives.

From the definition in Section 5.3.1, the set of feasible combinations of alternatives is denoted by $S = \{s_1, s_2, \ldots, s_j\}$, thus according to the problem constraints, $s \in S$ if and only if

$$2 \leq \sum_{j=1}^{m} s(a_j) \leq 5 \qquad 5.2$$

With the given constraints, from the 128 combinations of alternatives, 12 were eliminated, leaving 112 combinations to be analyzed by the WSC. The feasible combinations of alternatives are presented in Table 5.4. Table 5.4 shows the alternatives that are present in each feasible combination of alternatives. Each alternative receives a value of 1 or 0, which, in this table, is presented by letters Y and N: i) "Y" is for yes, which means that the alternative is present in the combination of alternatives; ii) "N" is for no, which means that the alternative is not part of the combination of alternatives. For example, the "combination of alternatives 1" comprises alternatives a_1 and a_2. Thus, these alternatives received the corresponding letter Y in Table 5.4. On the other hand, alternatives a_3 to a_7 are not part of the "combination of alternatives 1", thus they received the corresponding letter N.

Table 5.4 Combinations of Alternatives

Source: URTIGA et al. (2016).

	Combinations of Alternatives																											
	1	**3**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
a_1	Y	Y	N	Y	Y	N	Y	N	Y	N	Y	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	Y	N
a_2	Y	N	Y	Y	N	Y	Y	N	N	Y	Y	N	Y	Y	N	N	Y	Y	N	N	Y	Y	N	N	Y	Y	N	Y
a_3	N	Y	Y	Y	N	N	N	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y	N	N	N	N	Y	Y	Y	Y	N	N
a_4	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	N	N
a_5	N	N	N	N	N	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N
a_6	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	Y
a_7	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	29	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**	**56**
a_1	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
a_2	Y	N	N	Y	Y	N	N	Y	Y	N	N	Y	Y	N	N	Y	Y	N	N	Y	Y	N	N	Y	Y	N	N	Y
a_3	N	Y	Y	Y	Y	N	N	N	N	Y	Y	Y	Y	N	N	N	N	Y	Y	Y	Y	N	N	N	N	Y	Y	Y
a_4	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y
a_5	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
a_6	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
a_7	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	57	**58**	**59**	**60**	**61**	**62**	**63**	**64**	**65**	**66**	**67**	**68**	**69**	**70**	**71**	**72**	**73**	**74**	**75**	**76**	**77**	**78**	**79**	**80**	**81**	**82**	**83**	**84**
a_1	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
a_2	N	Y	Y	N	N	Y	Y	N	N	Y	Y	N	N	Y	Y	N	N	Y	Y	N	N	Y	Y	N	N	Y	Y	N
a_3	N	N	N	Y	Y	Y	Y	N	N	N	N	Y	Y	Y	Y	N	N	N	N	Y	Y	Y	Y	N	N	N	N	Y
a_4	N	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N	N	N	Y	Y	Y	Y	Y
a_5	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
a_6	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
a_7	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	85	**86**	**87**	**88**	**89**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**100**	**101**	**102**	**103**	**104**	**105**	**106**	**107**	**108**	**109**	**110**	**111**	**112**
a_1	Y	N	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	N	Y	N	Y	N	Y	N	N	Y	N	N
a_2	N	Y	N	N	Y	Y	N	N	Y	Y	N	N	Y	Y	N	N	Y	N	N	Y	Y	N	N	Y	N	N	Y	N
a_3	Y	Y	N	N	N	N	Y	Y	Y	Y	N	N	N	N	Y	Y	Y	N	N	N	N	Y	Y	Y	N	N	N	Y
a_4	Y	Y	N	N	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N	N	Y	Y	Y	Y
a_5	Y	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
a_6	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
a_7	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

5.5.3 Preference Elicitation and Ranking

The representatives of the WSC considered in this decision problem are presented in Table 5.5. Each DM evaluates separately the combinations of alternatives, based on their preferences. This does not mean that the DMs cannot take into account the perspectives of other DMs or stakeholders. If a DM wants to take into consideration others' interests, he or she can express this while evaluating the alternatives individually.

Table 5.5 DMs

DMs		Individual interests
DM_1	Representative of Industry	To increase profit: to have water for production ends, reduce costs, increase demand and increase efficiency.
DM_2	Representative of Agricultural Sector	To increase profit: to have water for irrigation, reduce costs and increase efficiency.
DM_3	Representative of Water Treatment and Supply Company	To serve the community; to profit (increase demand, reduce costs).
DM_4	Representative of Local Government	To have the government be seen as effective: efficiency in office administration, meet population needs, meet industry needs, meet agricultural sector needs.
DM_5	Representative of Civil Society	To have a good quality of life: to have a healthy environment, to maximize income, health and well-being.

Source: URTIGA et al. (2016).

For the representative of industry, it is very important to implement alternatives to clean the water. Not only will this affect its production expenses, because it may allow more access to clean water for production ends, but this will also create a positive public image. If the water is being treated, this will mitigate the damage to public relations from pollution caused by industrial production. Thus, for the representative of industry the most important measure is to implement a sewage system and improve the collection of waste material. In terms of preference statements, the first one is a_1 & a_5. This first preference statement will cause the combinations of alternatives in which its statement is true to be placed in front of the others. The second most important one is that even without the improvement of waste collection, the sewage treatment is still implemented, regardless of the other alternatives; thus, the representation of the preference statement is simply a_5.

The representative of the agriculture sector considers that any measure to prevent the pollution of water without having an effect on the agricultural production is important. For them, having a new sewage system or improving the collection of waste material would be the most important alternatives. The second most important preference statement is that the alternative to monitor agricultural practices is not selected. This is represented by $-a_3$. The next most important preference statement is that the group implement dredging and the revegetation of the riparian forest. Dredging will remove the sediments in the river, thus enhancing the amount of water available in that region, and the revegetation will prevent sediments from entering the water. However, the DM prefers this combination if the macro drainage alternative is not selected because, for them, choosing dredging or macro drainage would mainly serve the same purpose. Thus, for this DM the second preference statement would be a_4 & a_6 IF $-$ a_7. The third would be macro drainage and revegetation of the riparian forest if not drainage. The preference statements for the DMs are presented in Table 5.6.

For the representative of the water treatment and supply company, it would be more important to take actions against pollution before building another treatment facility. What is most important for them is to implement an educational campaign and monitor agricultural practices (a_2 & a_3) that are direct sources of water pollution, to improve the collection of waste material (a_5), to plan riparian vegetation (a_4) and to install a secondary sewage treatment facility (a_1).

For the government, the most important thing is to monitor agricultural practices, because they are one of the main sources of water pollution and consumption, and implement an educational campaign. To implement a secondary sewage treatment facility if and only if the collection of waste material is improved is the second preference statement. To remove sediments from the river by implementing a macrodrainage to ease water flow and to plant riparian vegetation is the third preference statement. For the representative of civil society (general public), what matters most is to implement a secondary sewage treatment, to improve the collection of waste and to plant riparian vegetation. Secondly, it is to monitor agricultural practices and finally to educate the population.

Table 5.6 Preference statements for each DM

DM_1	**DM_2**	**DM_3**	**DM_4**	**DM_5**
a_1 & a_5	a_1 OR a_5	a_2 & a_3	a_2 & a_3	a_4 & a_1 & a_5
a_5	$-a_3$	a_5	a_1 IFF a_5	a_3
a_3	a_4 & a_6 IF $-a_7$	a_4	a_6 IF $-a_7$	a_2
a_2	a_4 and a_7 IF $-a_6$	a_1	a_7 IF $-a_6$	

Source: URTIGA et al. (2016).

In some cases, DMs might need to perform some refinements in the preference information by changing the ranks manually or entering new preference information. DMs can, for example, change the order of preference statements and see how this affects their ranking and can make sure that the order they are giving reflects their wishes. A DM can also enter new preference information or directly order the combinations of alternatives that are indifferent to each other because the amount of information that he or she gave originally was not enough to refine the ranking and does not necessarily mean the alternatives are truly indifferent. Consider the combinations of alternatives given by $s_{22}, s_{26}, s_{49}, s_{79}$. The first preference statement stated by DM2 "a_1 OR a_5" is true for all these combinations. Thus, no changes in ranking are observed. By the second preference information "–a_3", the combinations s_{22} and s_{53} become preferred to the other combinations. However, they are still indifferent to each other. The next preference statement is "a_4 & a_6 IF – a_7". This means that, for every combination where alternative a_7 is selected the statement is true. For the ones where a_7 is not chosen, they will only be true when a_4 and a_6 are both selected. In this case, the statement is true only to s_{53}. This means that s_{53} is preferred to s_{22}, which is preferred for s49, which in turn is indifferent to s_{26} and s_{79}. The next preference statement is "a_4 & a_7 IF – a_6". This statement is true for s_{53} and s_{49}. Thus, the new order of preference is: s_{53} is the most preferred, then s_{22}, then s_{49}; the DM is indifferent between s_{49} and s_{26}, which is preferred to s_{79}. Table 5.7 and Table 5.8 list the ordering of combinations of alternatives for each of the five DMs from most to least preferred for which combinations appearing at the same rank are equally preferred.

Table 5.7 Ranking for each DM

Position	**DM_1**	**DM_2**	**DM_3**	**DM_4**	**DM_5**
1	26	53	26	56	26
2	49	83	56	49	55
3	79	22	86	48	85
4	18	105	25	41	24
5	55	45	49	40	53
6	85	75	79	33	83
7	24	14	18	32	22
8	107	49	48	26	51
9	47	26; 79	78	86	81
10	77	18	17; 108	25	20; 110
11	16	98	41	79	41
12	53	37	71	18	49
13	83	110	11	78	33
14	22	96	40	17; 108	56
15	105	35; 51	70	71	40
16	45	111	10; 101	11	48
17	75	97	33	70	32
18	14	36; 52	63	10; 101	71
19	110	95; 109	4; 94	63	79
20	51	34; 50	32	4; 94	63
21	81	67	62	62	86
22	20	7	3; 93	3; 93	70
23	103	81	55	55	78
24	43	65	85	54	62
25	73	20	24	47	11
26	12	5	53	46	18
27	41	66; 82	51	39	4; 94
28	71	21	83	38	25
29	11	6	81	31	10; 101
30	94	64; 80	22	30	17; 108
31	33	19	20; 110	85	3; 93
32	63	90	54	24	39
33	4	29	84	84	47
34	100	88; 103	23; 112	23; 112	31
35	39	27; 43	52	77	54
36	69	89; 104	50	16; 107	38
37	9	28; 44	82	76	46
38	92	87; 102	80	15; 106	30
39	31	42	21; 111	69	69
40	61	59	19; 109	9; 100	77
41	2	1	47	68	61
42	98	57; 73	77	8;99	84
43	37	12	16; 107	61	68
44	67	74	45	2; 92	76
45	7	58	43	60	60
46	90	72	75	91	9; 100
47	29	41	73	53	16; 107

Table 5.8 Ranking for each DM (continued)
Source: Urtiga et al. (2016).

Position	DM_1	DM_2	DM_3	DM_4	DM_5
48	59	100	14; 105	52	2; 92
49	1	39; 55	12; 103	45	23; 112
50	96	101	46	44	9; 99
51	35	40; 56	76	37	15; 106
52	65	99; 112	15; 106	36	91
53	5	38; 54	44	29	37
54	88	71	42	28	45
55	27	11	74	83	29
56	57	85	72	22	52
57	101	69	13; 104	82	36
58	56	24	102	21; 111	44
59	40	9	39	75	28
60	86	86	69	14; 105	67
61	70	70	9; 100	74	75
62	25	25	37	13; 104	59
63	10	10	35	67	82
64	108	68; 84	67	7; 98	66
65	93	23	65	66	74
66	32; 48	8	7; 98	6; 97	58
67	62; 78	94	5; 96	59	7; 98
68	3; 17	33	38	1; 90	14; 105
69	99; 112	92	68	58	1; 90
70	38; 54	107	8; 99	89	21; 111
71	68; 84	31	36	51	6; 97
72	8; 23	47	34	50	13; 104
73	106	108	66	43	89
74	91	93	64	42	35
75	30; 46	32; 48	6; 97	35	43
76	60; 76	106	95	34	27
77	15	91	31	27	50
78	97; 111	46	61	81	34
79	36; 52	30	2; 92	20;110	42
80	66; 82	63	29	80	65
81	6; 21	4	27	19; 109	73
82	89; 104	77	59	73	57
83	28; 44	61	57	12; 103	80
84	58; 74	16	1; 90	72	64
85	13	2	88	102	72
86	95; 109	78	30	65	5; 96
87	34; 50	62	60	5; 96	12; 103
88	64; 80	3	91	64	88
89	19	17	28	95	19; 109
90	87; 102	60	58	57	95
91	42	76	89	88	102
92	72	15	87	87	87

5.5.4 Preference Aggregation

The evaluation of the combination of alternatives by each DM results in individual rankings over the set of feasible combinations of alternatives. The individual ranking information is used as input in the WVSQ so as to assist the WSC in choosing a combination of alternatives that represents all DMs. The WVSQ calculates which combination of alternatives should be recommended to the WSC based on positional counting.

After obtaining the ranking information of each DM, the evaluation continues based on the formulas and steps presented in Figure 2.1. First, the upper and lower quartiles are identified as a previous step to calculating the strength and weakness of the combinations of alternatives. Table 5.9 presents the lower and upper quartiles for each DM.

The positional counting of the combinations of alternatives starts based on their ranking positions, such as follows. For each combination of alternatives, a score for strength or weakness is designated taking as a reference the positions of the upper and lower quartiles, respectively. For the strength score, for each time that a combination of alternatives appears in the position $\frac{\mathrm{n}}{4}$ it will receive a score of 1; for each time they appear in position $\frac{\mathrm{n}}{4}-1$, a score of 2; if they are placed in the first position of the upper quartile, in this case $\frac{\mathrm{n}}{4}-22$, they will receive a score of 23. Note that the scores only represent an order. Having a score of 22 does not mean that the DM prefers twice as much a combination of alternatives compared to one with a score of 11. It only indicates that the first is preferred to the latter. Taking as an example the combination s48 that is present in the upper quartile of three DMs, it receives a score of 0 for not being placed in the upper quartile of DM1, also a score of 0 for not having a position in the upper quartile of DM2, a score of 16 for being placed 8th in DM3's upper quartile, a score of 21 for being placed 3rd in the upper quartile of DM4 and a score of 8 for being placed 16th on DM5's upper quartile, thereby giving a total score of 45 to represent the strength (F) of this combination of alternatives. For the weakness score, the combinations of alternatives placed in the first position of the lower quartile will receive a score of 1, in the second position a score of 2, thereby making the alternatives that are placed lower in the ranking of the DMs to have a higher weakness score. In this case, for each time a combination of alternatives is placed last in the lower quartile it will receive a score 23. Taking for example s_{48}, it will receive a weakness score of 6 because it is placed in 6th DM2's lower quartile. Since this combination of alternatives is not present in the other DMs' upper quartile, the final weakness score (f) is 6.

The α value of s_{48} is $45 - 6 = 39$. Table 5.10 shows an example of this evaluation procedure for 11 of the best combinations for the group of DMs.

Table 5.9 Weighted Voting System: Upper and lower quartiles of each DM

DM_1		**DM_2**		**DM_3**		**DM_4**		**DM_5**	
Upper	**Lower**	**Upper**	**Lower**	**Upper**	**Lower**	**Upper**	**Lower**	**Upper**	**Lower**
26	38; 54	53	107	26	8; 99	56	89	26	21; 111
49	68; 84	83	31	56	36	49	51	55	6; 97
79	8; 23	22	47	86	34	48	50	85	13; 104
18	106	105	108	25	66	41	43	24	89
55	91	45	93	49	64	40	42	53	35
85	30; 46	75	32; 48	79	6; 97	33	35	83	43
24	60; 76	14	106	18	95	32	34	22	27
107	15	26	91	48	31	26	27	51	50
47	97; 111	49	46	78	61	86	81	81	34
77	36; 52	79	30	17; 108	2; 92	25	20;110	20; 110	42
16	66; 82	18	63	41	29	79	80	41	65
53	6; 21	98	4	71	27	18	19; 109	49	73
83	89; 104	37	77	11	59	78	73	33	57
22	28; 44	96; 110	61	40	57	17; 108	12; 103	56	80
105	58; 74	35; 51	16	70	1; 90	71	72	40	64
45	13	111	2	10; 101	88	11	102	48	72
75	95; 109	97	78	33	30	70	65	32	5; 96
14	34; 50	36; 52	62	63	60	10; 101	5; 96	71	12; 103
110	64; 80	95; 109	3	4; 94	91	63	64	79	88
51	19	34; 50	17	32	28	4; 94	95	63	19; 109
81	87; 102	67	60	62	58	62	57	86	95
20	42	7	76	3; 93	89	3; 93	88	70	102
103	72	81	15	55	87	55	87	78	87

Source: Urtiga et al. (2016).

Table 5.10 Positional Counting for the first Placed Combinations

Position for the WSC	s	F	f	α	Frequency in upper quartile
1	26	101	0	101	5
2	49	90	0	90	5
3	79	71	0	71	5
4	18	62	0	62	4
5	56	55	0	55	3
6	53	54	0	54	3
7	83	51	0	51	3
8	22	48	0	48	3
9	41	46	0	46	3
10	55	43	0	43	4
11	48	45	6	39	3

F: strength of combination; f: weakness of combination; α: F - f

Source: Urtiga et al. (2016).

Based on this voting procedure, the combination of alternatives s_{26} is the chosen one. This combination is placed in the first position in the ranking of three DMs and is in the upper quartile for all DMs, which means that the combination is not penalized. The combination s_{26} consists of alternatives a_1, a_2, a_3, a_4, a_5. Thus, from seven alternatives available, a group of five alternatives was chosen, respecting the constraints and preferences of the DMs.

5.6 Final Comments

The members of a WSC frequently face decisions in which they have to choose which combination of alternatives should be implemented in the watershed they represent. In fact, in many decision problems the final solution recommended is a combination of alternatives that complement each other rather than one single best alternative (RAJABI; KILGOUR; HIPEL, 1998; YIN; HUANG; HIPEL, 1999). These types of decisions are not trivial especially because of the large amount of information to be considered.

An approach is proposed that is able to assist a DM in evaluating combinations of alternatives using a simple and yet solid method. The combinations are generated by what is called the Option Form Approach. The DMs rank the combinations of alternatives by providing preference statements in an interactive way. Depending on the number of original alternatives, this can result in a large number of combinations of alternatives. Because of this, eliciting preference information by, for example, using pairwise comparison might be impractical for a DM. With the alternative prioritizing approach, the DMs are able to rank the combinations of alternatives by providing logical preference statements, which need less information from a DM. This was possible by generalizing the option prioritizing approach which has been successfully used in conflict investigations.

There are also two different decision support systems (GMCRII and GMCR+) that are able both to support the DMs in generating the feasible combinations of alternatives and to support them in stating preferences, which make the analyses even more straightforward and viable, even when many original alternatives are involved. Although this approach was specifically developed to assist decision-making in WSCs, this approach can be used for other decision problems with similar characteristics. Since the output ranks combinations of alternatives for each DM, the group has the flexibility of choosing the voting rule or other suitable aggregation procedure that will better represent the interests of the DMs involved.

The aggregation procedure chosen was the Weighted Voting System based on Classification by Quartile. This procedure allows the DMs to focus on the relevant combinations of alternatives. Additionally, the procedure favors the combinations of alternatives that the DMs place higher in their ranking and penalizes the combinations that they place lower, while disallowing a high position in one of the DM's rankings to compensate for the low position in another DM's ranking. For this voting procedure, a voting support system was also presented which makes the application of the method easier and more intuitive to the DMs as they can better visualize how changes in the information they input in the system change the final recommendation.

6 FINAL REMARKS AND FUTURE STUDIES

This Section presents an overview of the most important results achieved in this thesis. The results show a satisfactory response to the objectives outlined in the Introduction. In general, the thesis succeeded in designing methods that increase participatory decision-making in water resources management.

6.1 Contributions

In Chapter 3, the thesis proposes a framework to structure the DMs' objectives as a pre-negotiation phase. This framework makes a difference by providing a structured way to find issues that are of common interest of all DMs, especially issues that could not be identified hitherto, without the help of a tool that promotes creativity when thinking about values. The framework presented not only uses VFT techniques to identify the objectives and draw up the objectives tree, but also represents the objectives of all DMs in a single joint tree, thus putting together the objectives that have the same meaning for the DMs. It preserves the hierarchy of objectives of each DM and, more importantly, identifies the relationships of these objectives among DMs.

Chapter 4 puts forward a model to assist WSCs in choosing alternatives, taking into account the different perspectives and objectives of the DMs involved, who are representatives of different groups: civil society, water users and the local authority. The decision process is guided from the moment it begins until it ends by merging VFT with the additive model, for group decision making. It starts by identifying and structuring objectives, and moves on to defining alternatives and attributes. Finally, all DMs individually evaluate the alternatives and a choice is made considering the group evaluation. By using this methodology, the DMs are able to make decisions considering the group's perspective on the problem, but without losing sight of the individuality of each member of the group.

Chapter 5 approaches the problematic where a WSC faces the problem of choosing a combination of alternatives rather than a single alternative. The possible combinations of alternatives are systematically generated using an option form approach. DMs individually rank combinations based on their preferences by providing ordinal information in an interactive way. In this approach, each DM expresses his or her preferences using logical preference statements regarding combinations of alternatives. A group recommendation is obtained after aggregating the final individual ranks using a voting system based on classification by quartiles.

6.1.1 Managerial Implications

The framework presented in Chapter 3, assists in structuring the DMs' objectives in order to find issues in common, solutions to which they will negotiate with each other. The framework also assists the DMs to understand the problem they are facing, also to become familiar with the perception and needs of other DMs. It also assists the DMs to have a deeper understanding of their own objectives by having the DMs think of them in a creative manner for which a questioning procedure is used. The framework contributes to their understanding what their main goal is and how it can be achieved by having their objectives structured; which is a key element if the results of the negotiation itself are to be successful. It promotes cooperation and reduces conflicts by having the DMs interact for the same purpose, which is to increase the results of the negotiation. Finally, it assists the DMs to visualize an integrative negotiation in which different issues of their interest will be negotiated, thus allowing them to think about tradeoff relations in order to compensate a loss in one issue by a gain in another. Thus, it easier for the DMs to make offers and counteroffers that really matter during the bargaining process.

The model presented in Chapter 4 helps DMs identify and structure their objectives, understand what interests they have in common and on what issues they diverge, thereby improving their understanding about the problem and about the interests of the whole group. The model also assists the DMs to identify alternatives based on their objectives rather than only by considering pre-defined alternatives. This means that the alternatives generated are more focused on what the DMs want to achieve. On using a hierarchical tree of objectives, the DMs can also identify more clearly which attributes could be chosen to represent their objectives in the evaluation process, thus facilitating the choice of attributes. Therefore, in general terms, the DMs are able to think and identify relevant aspects of the decision problem and so reduce the chance of missing aspects that could be left out if no method was used. The DMs are able to express their individual preferences and evaluate the alternatives accordingly. A group value-function aggregates the individual value-functions, which means that the preferences of all DMs are clearly represented in the decision-making process. With this model, the DMs are able to actively take part in the decision-making process, from starting to understand the problem, then identifying objectives, and creating alternatives, until the process of choosing attributes and selecting the alternatives. This being said, the model promotes the engagement of the DMs throughout the entire decision-making process. The information gathered during the VFT phase is useful for taking other decisions that may arrive, after making the appropriate adjustments to the specific problem. This is an advantage since the DMs will face many other decision situations and the effort needed in future interactions can be reduced.

The approach presented in Chapter 5 provides an approach for evaluating combinations of alternatives using a simple and solid method. Depending on the number of original alternatives considered in this problematic, this could result in a large number of combinations of alternatives. Thus, eliciting preference information by, for example, using pairwise comparison might be impractical for a DM. In this approach, the DMs individually rank combinations based on their preferences by providing ordinal information in an interactive way, which needs less information from a DM. This reduces the cognitive burden of making many comparisons or defining tradeoff relations. The DMs' preferences are aggregated by using a voting procedure. The voting procedure is simple and transparent for voters and does not present severe computational difficulty, thereby making this approach an appropriate tool to use in the context of group-decision making. It also maintains the traditional way of making decisions within the WSC, which is by taking a vote. This might make the proposed approach more readily acceptable within a WSC.

6.2 Limitations

The limitations regarding the framework in Chapter 3 include having, perhaps, many issues identified that could be negotiated. However, it does not assist the DMs on how to choose which ones will make it into the bargaining process. The DMs could reach an agreement considering only a few issues, which would simplify the problem mathematically. However, how are they going to decide among the issues that were identified, which ones to consider?

The limitation in Chapter 4 regards the fact that depending on the problem the DMs are facing, they might diverge too much. This can negatively affect reaching consensus as to the weights in the group function. However, if this happens, other aggregation methods can be used by considering the individual evaluation of each DM as input, such as a voting procedure.

In Chapter 5, unlike in Chapter 4, the method used provides a ranking of combinations of alternatives, instead of a rating. Which means that the information collected is the ordering of combinations of alternatives (if a DM prefers a combination of alternative to another); information on by how much more a DM prefers a combination of alternative to another is not collected. The problem with using rankings instead of ratings is that the evaluation method can lead to intransitivity.

6.3 Future Work

In addition to addressing the limitations presented in the previous Section 6.2, a general recommendation for future studies is to apply these approaches in different contexts of decision-making problems. More specifically, for the framework in Chapter 3, it would be a significant addition if rules were defined so as to guide the DMs in selecting what issues that have been identified can be negotiated. Additionally, since there are multiple issues to be considered, which might require the DMs to make a greater cognitive effort in order to express individual preferences, it would be important to develop a Negotiation Support System (NSS) with a flexible model to assist the DM during the process of eliciting preferences and also when evaluating offers and counter-offers. For the model presented in Chapter 4, a suggestion is to use different evaluation and aggregation methods that might require less time and cognitive effort from the DMs, without losing the quality of the recommendation and how the DMs feel about their preferences being represented in a decision process. Finally, for Chapter 5, it would be interesting to develop a Decision Support System specially to allow the DM to insert information about the restrictions of the problem, since this is not possible when using GMCR+ software. It would also be helpful if other voting procedures were available in the system, as the DMs would have more flexibility in using the voting procedure of their choice.

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