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**DEVELOPMENT OF AN INTELLIGENT DECISION SUPPORT SYSTEM  
FOR THE MANAGEMENT OF WATER RESOURCES  
IN A LOW FLOW RIVER BASIN**

**FINAL MASTER'S PROJECT**

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# Abbreviations

<b>CC</b>	Climate Change
<b>GC</b>	Global Change
<b>PS</b>	Primary Sources
<b>AR</b>	Alternative Resources
<b>RW</b>	Reclaimed Water
<b>DS</b>	Desalination
<b>WD</b>	Water Demand
<b>WS</b>	Water Supply
<b>Ind</b>	Industrial
<b>Dom</b>	Domestic
<b>Agr</b>	Agriculture
<b>EcoStress</b>	Ecological Stress
<b>WaSSIR</b>	Water Supply Stress Index Ratio
<b>WE</b>	Water Extracted from a river
<b>WF</b>	Water Flow in a river
<b>PC</b>	Primary Source's Cost
<b>AC</b>	Alternative Resource's Cost

# Chapter 1

## Introduction

Humans must deal with complex decision making problems in a large variety of fields, some of those problems may involve large amounts of resources, including money. That is the reason why Multi-Criteria Decision Aid (MCDA) methods are gaining importance. These methods consist of the following steps: analysis and weight of criteria, evaluation of the alternatives and finally identification of preference relations among the alternatives that allow the decision maker to find a solution to each problem taking into consideration those conflicting criteria.

This master thesis is framed into a research project funded by the Spanish government (code TIN2012-34369) of the ITAKA research group, at the Department of Computer Science and Mathematics, URV. The web page of the project is the following: <http://deim.urv.cat/~itaka/SHADE/>.

The main aim of the SHADE project is the development of new techniques to solve some of the current limitations of decision support systems, focusing on these three tasks:

1. Management of multi-valued semantic variables, with the assistance of domain ontologies.
2. Management of hierarchically structured criteria in multi-criteria decision support systems based on outranking relations.
3. Automatic dynamic adaptation of the users' preferences based on the analysis of their interaction with the system.

The developed techniques will be tested and refined in three different domains, with the collaboration of several partners from different institutions:

- Recommendation of tourism activities (data and ontologies from the DAMASK, SigTur and EnoSigtur projects, experience of the Scientific and Technological Park of Tourism and Leisure and the Tourism Studies Foundation-Costa Dorada).
- Analysis of the treatment of the brand in Web sites of tourist destinations (data from the CODETUR project, experience from the research groups on Communication involved on that project).
- Analysis and selection of methods for managing river water (data from the SCARCE project, experience of the innovation and technology transfer center TecnATox and the AGA research group from URV).

This thesis will focus on the third application field, and has had the collaboration of the members of the AGA team. In relation to the necessities detected in this particular case study, the master thesis has contributed to task number 2 (multi-criteria decision support systems with hierarchical criteria) by improving the existing model and software, previously developed at the ITAKA research group.

In particular this document will study the problem of evaluating several sectorial water allocation policies in Tarragona, an industrial and agricultural town of Catalonia. Changes in water supply conditions for economic activities and environmental uses are likely to be affected by global change, including altered frequency of extreme events, such as droughts [13] due to climate change, but also changes in the demand for technological or demographic reasons. Lack of additional water resources to fulfill increasing water demand coupled with increased awareness on environmental issues and adverse effects of climate change are making decisions on water allocation rather complex. Meeting the new challenges on water resources management implies the quantification of the global change impact on basin-scale hydrology [23].

Water allocation describes a process whereby an available water resource is distributed to legitimate claimants and the resulting water rights are granted, transferred, reviewed, and adapted. The allocation of water resources in river basins is one of the critical issues. A holistic approach to water supply management at the watershed-scale considering different criteria would be valuable, where individual water related sectors, such as agriculture, domestic, and industrial water supply are considered together to draft possible management strategies. The main goal of this study is to rank the different water supply strategies for possible demand scenarios. Due to the shortfall in supply from primary water resources, this study is focused on the use of alternative water supply scenarios for the demand of water of three major sectors: domestic, industrial and agricultural. Different future scenarios will be considered. For each of them the goal is to

obtain a ranking of a set of possible actions with regards to different types of indicators, such as costs, environmental impact or water stress.

## 1.1 A brief overview of MCDA

MCDA is a scientific research field that develops methodologies for decision support that intends to improve the quality of decisions by helping decision makers to take rational decisions according to their preferences. These preferences differ from decision maker to decision maker, so the outcome depends on who is making the decision and what their goals and preferences are. MCDA aims to obtain a coherent structure that should guide the decision aiding process and facilitate communication about the decisions. Decision problems are classified into three types, according to [7]:

- *Choice*. The selection of a small number of “good” alternatives is performed such that a single alternative may finally be chosen among the subset. The selection procedure is based on the comparison between alternatives in order to eliminate the greatest number of them. The remaining subset contains all the most satisfying alternatives, which are non-comparable between one another.
- *Sorting*. It consists of an assignment of each alternative to one category (judged as the most appropriate) among a family of predefined categories, which must be ordered according to some preference consideration.
- *Ranking*. In this type of problems, a complete or partial preorder of all the alternatives is calculated which can be regarded as an appropriate instrument for comparing actions between one another.

This master thesis focuses on ranking problems, for which two main approaches can be distinguished: Multi-Attribute Utility Theory (MAUT) that was designed to handle tradeoffs among multiple objectives and Outranking methods.

## 1.2 Outranking methods

The main aim of these methods is to build a binary outranking relation  $S$  on the set  $A$  of alternatives.

Given two alternatives  $a$  and  $b$  in the set  $A$ , the outranking relation between  $a$  and  $b$  can be defined as “alternative  $a$  outranks alternative  $b$  if, given the decision maker’s preference, the quality of the evaluation of the alternatives and the context of the problem,

there are enough arguments to decide that alternative  $a$  is at least as good as alternative  $b$ , while there is no overwhelming reason to refute that statement". In other words, one alternative outranks another if it outperforms the other on enough criteria of sufficient importance and it is not outperformed by the other option by having a significantly inferior performance on any single criterion. Each alternative in the set of alternatives is compared to all the other members of the set in a pairwise manner to determine their degree of outranking or outranked. A pairwise comparison of the alternatives based on each criterion in the family of criteria is obtained.

One of the most well-known outranking methods is ELECTRE, which acronym stands for Elimination Et Choix Traduisant la RÉalité (Elimination and Choice Translating Reality)[16].

ELECTRE methods comprise two steps:

1. Building the outranking relation.
2. Exploiting the relationship with special focus on the type of the problem: choice, sorting or ranking.

The ELECTRE family consists of many methods, each of them with different purposes:

- *ELECTRE-I and ELECTRE-IS*: These two methods were designed for choice problems.
- *ELECTRE-II*: The aim is to rank the alternatives.
- *ELECTRE-III*: Target ranking problems involving pseudo-criteria, based upon a valued outranking relation.
- *ELECTRE-IV*: It is used for ranking actions without introducing any weighting of criteria.
- *ELECTRE-TRI*: Used for sorting problems.

The present work is focused on ELECTRE-III since the goal of our study is to build a ranking of different alternatives.

The ELECTRE Methods have been widely used in many MCDA decision problems, such as agriculture and forest management, energy sector, environmental and water management, finance, military, project selection, personnel recruiting and transportation [2], [4], [12], [14].

### 1.3 Goals of the Master Thesis

The objective of this work is to develop a Decision Support System (DSS) for helping the decision-makers to control and manage water resources efficiently by studying different future scenarios of global change.

The following specific goals have been addressed:

1. Study the outranking methods and their extension to hierarchical structures of criteria.
2. Formalize the problem of water resources management using the MCDA model: build the criteria, their hierarchical relations, define the set of alternatives and their corresponding evaluations. This step may require defining some pre-processing algorithms to the input data provided by the experts.
3. Establish the appropriate parameters for this problem according to the ELECTRE outranking method: weights, indifference thresholds, preference thresholds, veto thresholds, etc.
4. Revise the method ELECTRE-H that is being developed in the ITAKA group to analyse if it covers all the particularities of this specific problem. Extend the method and software according to the new necessities identified.
5. Apply the ELECTRE-H method to the dataset considering different water management strategies and different scenarios.
6. Analyse the results in collaboration with the AGA experts.

### 1.4 Structure of the Thesis

The work is divided into seven chapters. Chapter 1 of this work provides a description of the project and presents the fundamental notions of decision making and the relevance of MCDA for solving complex decision problems.

Chapter 2 provides a brief background and explanation of the method used in this work. In the first place, the main elements involved in a decision problem are described. Following that, the classic ELECTRE-III method was explained. This chapter concludes with the adaptation of the ELECTRE-III method to a hierarchical structure.

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In chapter 3, the functionalities of the existing ELECTRE-III-H software is described using some screenshots together with explanation text, making focus mainly on those used in this thesis.

The environmental decision problem targeted in the present work is described in chapter 4. Firstly, the geographical context along with the time context are stated. Secondly, the reason why this study is significant due to future changes is explained. following that, the model proposed for the object of study is presented.

Chapter 5 covers the implementation carried out to solve the decision problem described in the previous chapter. Also, the integration of the new components with the existing ones is explained.

In chapter 6, the evaluations of the different water strategies with several configurations are presented. The obtained results are analyzed and a comparison among the results produced by varying the configurations is shown, which lead to the general conclusions to the problem presented in this work.

Chapter 7 presents the conclusion of this work and suggests ideas for future work.

## Chapter 2

# Basic Concepts

This chapter presents the preliminar information needed to develop this master thesis. First, an introduction to the ELECTRE method is done, with focus on the ranking procedure. Next, the hierarchical version used as input of this master thesis is also explained.

### 2.1 Main elements of the decision problem

The input data needed for the ELECTRE Method involve:

- A finite set of  $n$  *alternatives* (or actions) available to the decision maker.  $A = \{a, b, c, \dots\}$
- A finite set of *criteria*  $G = \{g_1, g_2, \dots, g_j, \dots, g_m\}$  with  $m \geq 3$ . A criterion is a tool constructed for evaluating and comparing potential alternatives according to a well-defined point of view [17]. Alternatives are evaluated according to a criterion, which results in performance levels that can be represented as an evaluation matrix for decision making analysis. For each criterion it is necessary to define the set of all possible evaluations each criterion can lead to in order to allow the comparison of the alternatives. For this purpose, the performance of alternative  $a_i$  on criterion  $g_j$ , denoted  $g_j(a_i)$ , must be evaluated. For the sake of simplicity, the maximization of  $g_j$  is assumed.
- A *weight*  $W$  assigned to each criterion represents its relative importance. The higher the criterion's importance, the more weight it should be assigned.
- A *preference system* which assigns one of the following types of relations: Indifference, Preference or Incomparability.

### 2.1.1 The preference system

Preferences in ELECTRE methods are modeled by a binary outranking relation  $S$ ,  $aSb$  can be traduced as “ $a$  is at least as good as  $b$ ”. Considering two alternatives  $a$  and  $b$  from set  $A$ , the following four preferences situations may be possible:

- $P$  (*Strict Preference*): it corresponds to a situation where there are clear and positive reasons in favor of one of the two alternatives. If  $aSb$  and not  $bSa$  then  $aPb$  ( $a$  is strictly preferred to  $b$ ).
- $I$  (*Indifference*): it corresponds to a situation where there are clear and positive reasons that justify an equivalence between the two alternatives. If  $aSb$  and  $bSa$  then  $aIb$  ( $a$  is indifferent to  $b$ ).
- $P^-$  (*Inverse Preference*): it corresponds to a situation where there are clear and positive reasons that invalidate strict preference in favor of one of the two alternatives, but they are insufficient to deduce either the strict preference in favor of the other action or indifference between both actions, thereby not allowing either of the two preceding situations to be distinguished as appropriate. If  $bSa$  and not  $aSb$  then  $aP^-b$  ( $a$  is inversely preferred to  $b$ ).
- $R$  (*Incomparability*): it corresponds to an absence of clear and positive reasons that would justify any of the three preceding relations. If not  $aSb$  and not  $bSa$  then  $aRb$  ( $a$  is incomparable to  $b$ ).

### 2.1.2 Pseudo criterion

According to [8] a pseudo-criterion is a function  $g_i$ , associated with two threshold functions  $q_j(\cdot)$  and  $p_j(\cdot)$  satisfying the following condition: for all entered pairs of actions  $(a, b) \in A \times A$ , such that  $g_j(a) \geq g_j(b)$ ,  $g_j(a) + p_j[g_j(b)]$  and  $g_j(a) + q_j[g_j(b)]$  are non-decreasing monotone functions of  $g_j(b)$ , such that  $p_j[g_j(b)] \geq q_j[g_j(b)] \geq 0$  for all  $a \in A$ .

Therefore, the degree of significance of each criterion  $g_j$  is reflected by means of two direct thresholds  $q_j$  and  $p_j$ , according to [18].

- Indifference threshold  $q_j[g_j(a)]$  is the value beneath which the decision maker does not perceive any difference between two alternatives.
- Preference threshold  $p_j[g_j(a)]$  is the value above which the decision maker shows a clear strict preference of one alternative option over the other.

Indifference and preference thresholds specify the discriminating power of a criterion when measuring the outranking relation between a pair of alternatives.

## 2.2 Classic ELECTRE-III

In ELECTRE-III the outranking relation can be interpreted as a fuzzy relation. To construct this relation, the definition of a *credibility index*, which characterizes the credibility of the assertion "a outranks b" is required, as explained in [10]. This index is defined by using both the concordance index and a discordance index for each criterion  $g_j$  in  $G$ .

### 2.2.1 Concordance

According to the definition of indifference threshold  $q_j$ , the  $j$ th criterion is in concordance with the assertion  $aSb$  iff  $g_j(a) \geq g_j(b) - q_j$ . The subset of all criteria of  $G$  which are in concordance with the assertion  $aSb$  is called the concordance coalition.

The concordance index  $c(a,b)$  characterizes the strength of the positive arguments able to validate the assertion  $aSb$ . The concordance index can be defined as follows:

$$c(a,b) = \frac{1}{W} \sum_{j=1}^m w_j c_j(a,b)$$

$$W = \sum_{j=1}^m w_j$$

and

$$c_j(a,b) = \begin{cases} 1 & \text{if } g_j(a) \geq g_j(b) - q_j(b) \\ 0 & \text{if } g_j(a) \leq g_j(b) - p_j(b) \\ \frac{g_j(a) - g_j(b) + p_j(b)}{p_j(b) - q_j(b)} & \text{otherwise} \end{cases}$$

### 2.2.2 Discordance

There may be cases in which a criterion is discordant in respect of the assertion  $aSb$  but the strength of this opposition can be more or less compatible with the assertion's acceptance. For that, the veto threshold  $v_j[g_j(a)]$  was defined. It refers to the value

where the discordant difference in favor of one alternative greater than this value will require the decision maker to negate any possible outranking relationship indicated by the other criteria. The partial discordance  $d_j(a, b)$  index of criterion  $g_j$  can be defined as follows:

$$d_j(a, b) = \begin{cases} 1 & \text{if } g_j(a) - g_j(b) < -v_j(a) \\ \frac{g_j(a) - g_j(b) + p_j(a)}{p_j(a) - v_j(a)} & \text{otherwise} \\ 0 & \text{if } g_j(a) - g_j(b) \geq -p_j(a) \end{cases}$$

### 2.2.3 Credibility index for the outranking relation

In ELECTRE III, the aggregation procedure associates for each ordered pair of alternatives  $(a, b) \in A \times A$  a credibility index of the assertion  $aSb$ . The credibility index is a fuzzy measure denoted by  $\sigma(a, b) \in [0, 1]$  and combines  $c(a, b)$  and  $d_j(a, b)$  in the following equation:

$$\sigma(a, b) = c(a, b) \prod_{j \in J(a, b)} \frac{1 - d_j(a, b)}{1 - c(a, b)}$$

Where  $j \in J(a, b)$  if and only if  $d_j(a, b) \geq c(a, b)$ .

### 2.2.4 Exploitation by distillation

Once the credibility matrix is calculated, the next step in the ELECTRE-III method is the exploitation. Its goal is to obtain adequate results from which recommendations can be derived. The above mentioned credibility matrix is used to build a partial preorder of the alternatives in  $A$ . This procedure is known as distillation. This refinement can be done in two ways, from  $S_1$  to  $S_r$  ( $r$  is the number of credibility levels) or viceversa. ELECTRE-III considers both possibilities and ranks the alternatives in two complete preorders which are constructed in two different ways. The first complete preorder is obtained in a descending manner (descending distillation), selecting the best rated alternatives initially, and finishing with the worst. The second complete preorder is obtained in an ascending manner (ascending distillation), selecting the worst rated alternatives initially, and finishing with the best. Both distillations make an iterated choice based on a qualification index measured from  $S_i$ . An illustrative example is shown in the Figure 2.1 for  $A = \{a, b, c, d, e, f, g, h, I, j, k, l\}$

The intersection of these two complete preorders generates a partial preorder. as it is shown in Figure 2.2, where the arrows indicate a transitive preference relation. The partial preorder should be understood in the following way:

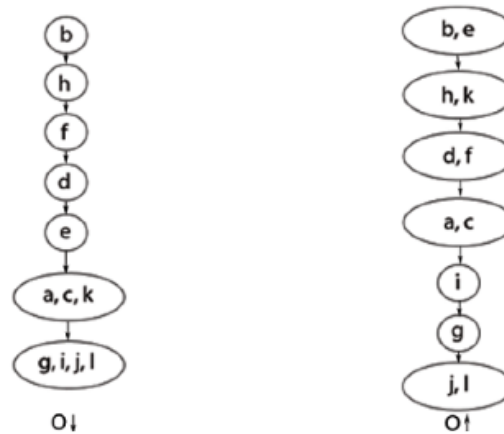


FIGURE 2.1: Descending and ascending complete preorders generated from distillation

- $b$  is preferred over  $e$  and  $h$  since there is an arrow going from  $b$  to  $h$ . The same reasoning leads to state that  $e$  is preferred over  $k$  and  $h$  is also preferred over  $k$ ,  $h$  is preferred over  $f$  while  $f$  is preferred over  $d$ . Both  $k$  and  $d$  are preferred over  $a$  and  $c$ , and so on. Moreover,  $b$  is preferred to the rest by transitivity.
- $e$  and  $h$  are incomparable. The same relation applies to  $k$  and  $f$  and  $k$  and  $d$ .
- $a$  and  $c$  as well as  $j$  and  $l$  are indifferent between them, this can be easily noticed since they are in the same circle.

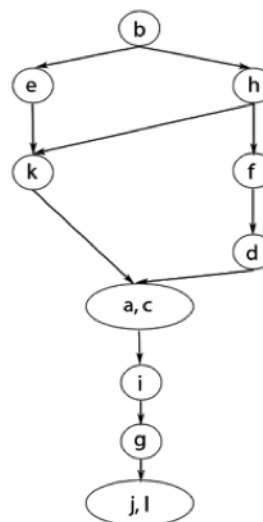


FIGURE 2.2: Partial preorder generated from the intersection of the descending and ascending complete preorders

It is worth to note that the incomparability relation maybe of great interest for the decision maker, because it indicates that the two incomparable alternatives have different strengths and weaknesses that make impossible to decide which one is better. Additional criteria should be included to break the incomparability. On the other hand,

and indifference relation indicates that two alternatives are equivalent, having the same good and bad points, so that any of them gives the same reward.

In methods that only provide a total ranking, this distinction cannot be done, and in both cases the alternatives get the same final rank position. This highlights the interest of constructing partial preorders instead of total rankings.

### 2.3 Hierarchical version of ELECTRE

In the SHADE project developed at the ITAKA research group, the ELECTRE-III model has been adapted to solve the ranking problematic using a hierarchical structure of criteria, as defined in [6], where three types of criteria can be distinguished depending on the level of generality:

- Root criterion: Unique element that is the most general criterion. It is placed at the top of the tree and it does not have any parent. It represents the main goal of the decision maker.
- Elementary criteria: They are placed at the lowest level of the hierarchical tree. Each criterion has a unique parent.
- Intermediate criteria or subcriteria: They correspond to a group of subcriteria or elementary criteria and are placed in an intermediate level of the tree, between the root and elementary criteria. Each intermediate criterion has also a unique parent.

Both the Root Criterion and the Intermediate Criterion may have multiple direct descendants.

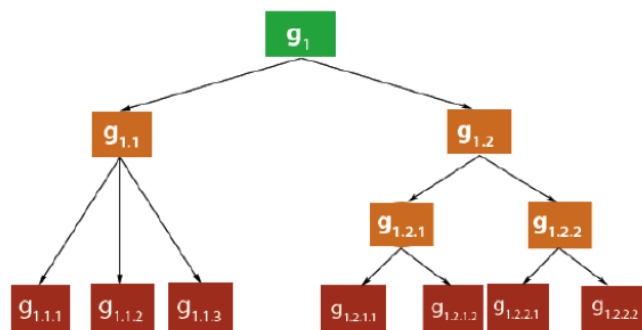


FIGURE 2.3: Hierarchical structure of criteria

The notation is as follows: Root criterion  $\mathcal{R}$ :  $\{g_1\}$

Elementary criteria  $\mathcal{E}$ :  $\{g_{1.1.1}, g_{1.1.2}, g_{1.1.3}, g_{1.2.1.1}, g_{1.2.1.2}, g_{1.2.2.1}, g_{1.2.2.2}\}$

Intermediate criteria or subcriteria  $\mathcal{I}$ :  $\{g_{1.1}, g_{1.2}, g_{1.2.1}, g_{1.2.2}\}$

All criteria in set  $G$  can be considered as pseudo-criteria, associated with indifference, preference and veto thresholds, except for the root criterion. The indifference  $q_j(a)$ , preference  $p_j(a)$ , and veto  $v_j(a)$  thresholds referring to elementary criteria from set  $\mathcal{E}$  are defined in the same way as in ELECTRE-III method, based on the performance of the alternatives, depending on the scale of measurement of each criterion  $g_j$ . On the other hand, the indifference  $q_j(a)$ , preference  $p_j(a)$ , and veto  $v_j(a)$  thresholds referring to criteria from the intermediate criteria, are functions of the difference of rank order positions of the compared alternatives in a partial preorder. Having that  $|A| = n$ , then  $q_j(a) \leq p_j(a) \leq v_j(a) \leq n - 1$ .

What weights assigned to the criteria are concerned, intermediate criteria may have a weight  $w_j$  that indicates its relative importance with respect to the other descendants of their parents (i.e. adjacent nodes). An example of the weights is shown in the Figure 2.4.

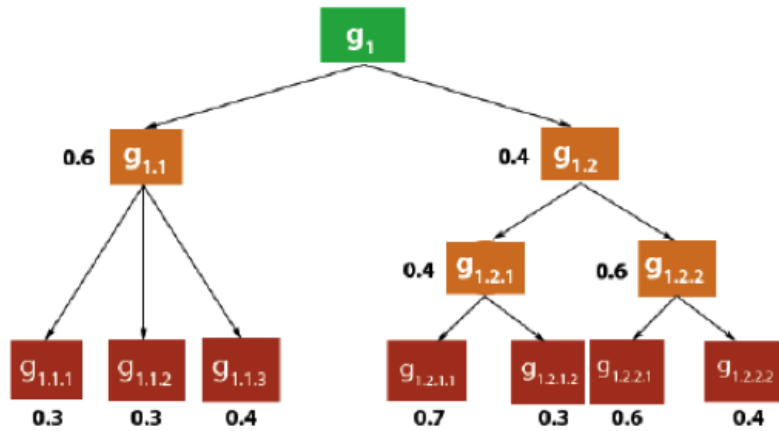


FIGURE 2.4: Weights in the hierarchical structure of criteria

### 2.3.1 The algorithm of ELECTRE-III-H

First of all, the classic ELECTRE-III is calculated for the intermediate criteria where the children are only elementary criteria. For example, based on the Figure 2.4, classic ELECTRE-III method is processed for intermediate criteria  $g_{1.1}$ ,  $g_{1.2.1}$  and  $g_{1.2.2}$ . This generates a partial preorder in each node as the result of the aggregation of the corresponding subcriteria. This result is propagated upwards based on the difference in the

rank order values of the compared alternatives in a partial preorder, new partial concordance and discordance indexes have been defined. Those measures take into account the indifference, preference and veto thresholds with respect to the rank order values in the partial preorder. Afterwards, the credibility matrix is calculated as in the classic ELECTRE-III, by merging the partial concordance indexes obtained for each different type of criterion. This credibility matrix is then exploited with the distillation algorithm. Two complete preorders are generated from the ascending and descending distillation chain which are intersected to generate a partial preorder  $O_j$  for criterion  $g_j$ .

Following the example shown in Figure 2.4, a final result ( $g_1$ ) is obtained by the aggregation of partial preorders  $O_{1.1}$  and  $O_{1.2}$ .

It is important to remark that in case that an intermediate criterion has as children intermediate criteria and other elementary criteria, the partial concordance and discordance indexes are calculated as in ELECTRE-III for elementary criteria, but new indexes have been defined to manage the partial preorders obtained at the intermediate criteria of lower levels. These new measures are explained below.

### 2.3.2 Concordance and discordance in intermediate nodes

The new indexes take as input the partial preorders calculated at the descendent nodes in the hierarchy. Each of them is analyzed independently.

The *Rank Order Value* of an alternative  $a \in A$  in a partial preorder  $O_j$ , denoted by  $\Gamma_j(\cdot)$ , is the number of alternatives that are preferred to  $a$  in this partial preorder.

Depending on the type of relation between the alternatives  $a$  and  $b$  in the partial preorder, the following cases are given.

#### 2.3.2.1 Preference and indifference relations, $P$ and $I$

Since both preference  $aP_jb$  and indifference  $aI_jb$  relations in  $O_j$  give evidence that  $O_j$  clearly supports the  $aSb$ , the value of partial concordance index is set to 1:

$$c_j(aPb) = 1$$

$$c_j(aIb) = 1$$

Hence, the partial discordance index in both cases are set to 0:

$$d_j(aPb) = 0$$

$$d_j(aIb) = 0$$

### 2.3.2.2 Inverse preference relation, $P^-$

When  $b$  is preferred over  $a$  in the partial preorder  $O_j$ , the strength of the difference between  $b$  and  $a$  should be considered to calculate the degree of concordance and discordance with respect to the outranking relation  $aSb$ . Four cases can be distinguished:

- **Case 1.**

$$\text{if } \Gamma_j(a) - \Gamma_j(b) \leq q_j(a), \text{ then } \begin{cases} c_j(aP^-b) = 1 \\ d_j(aP^-b) = 0 \end{cases}$$

- **Case 2.**

$$\text{if } \Gamma_j(a) - \Gamma_j(b) < q_j(a) \text{ AND } \Gamma_j(a) - \Gamma_j(b) \leq p_j(a), \text{ then } \begin{cases} c_j(aP^-b) = \frac{p_j(a) - (\Gamma_j(a) - \Gamma_j(b))}{p_j(a) - q_j(a)} \\ d_j(aP^-b) = 0 \end{cases}$$

- **Case 3.**

$$\text{if } \Gamma_j(a) - \Gamma_j(b) > p_j(a) \text{ AND } \Gamma_j(a) - \Gamma_j(b) \leq v_j(a), \text{ then } \begin{cases} c_j(aP^-b) = 0 \\ d_j(aP^-b) = \frac{\Gamma_j(a) - \Gamma_j(b) - p_j(a)}{v_j(a) - p_j(a)} \end{cases}$$

- **Case 4.**

$$\text{if } \Gamma_j(a) - \Gamma_j(b) > v_j(a), \text{ then } \begin{cases} c_j(aP^-b) = 0 \\ d_j(aP^-b) = 1 \end{cases}$$

### 2.3.2.3 Incomparability relation, $R$

When having an alternative  $a$  incomparable to alternative  $b$ , the partial preorder gives no clear support to the outranking  $aSb$ . As described in [5], some base values for the partial concordance and discordance have been introduced, namely

$$k^c = \frac{2}{3} \text{ and } k^d = \frac{1}{3}$$

This leads to the following rules of calculation for partial concordance and discordance

$$\text{if } \Gamma_j(a) - \Gamma_j(b) \leq p_j(b), \text{ then } \begin{cases} c_j(aRb) = k^c + \delta_j^c(a, b) \\ d_j(aRb) = 0 \end{cases}$$

$$\text{if } \Gamma_j(a) - \Gamma_j(b) > p_j(a), \text{ then } \begin{cases} c_j(aRb) = 0 \\ d_j(aRb) = k^d + \delta_j^d(a, b) \end{cases}$$

The proposed values for  $\delta_j^c$  and  $\delta_j^d$  for the partial concordance and discordance index, respectively, are:

$$\delta_j^c(a, b) = \frac{(\Gamma_j(b) - \Gamma_j(a) - q_j(b)) \times \alpha}{(p_j(b) - q_j(b)) + (n - 2)}$$

where  $n$  is the number of alternatives in set  $A$ .

$$\delta_j^d(a, b)_j = \frac{(\Gamma_j(a) - \Gamma_j(b) - v_j(a)) \times \alpha}{(v_j(a) - q_j(a)) + (n - 2)}$$

In the two above cases, the value  $\alpha$  has been introduced to control the maximum degree of change permitted to the original partial concordance and discordance index for incomparability.

## Chapter 3

# Software tool implementing ELECTRE-H

This chapter explains the Software tool developed in ITAKA that implements ELECTRE-H. This software has been the initial point of the work done in this master thesis. It can be used for ranking, sorting and choice problems, but in the present work the focus will be made only on the ranking functionalities.

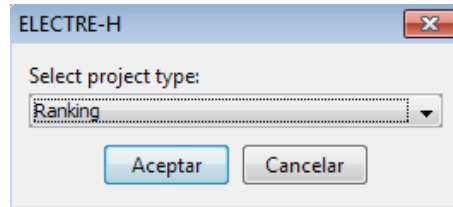


FIGURE 3.1: Selection of the problem type

Once the problem type is determined, the software needs to read the input data from an Excel file containing the definition of the analysed problem. This can be done as presented in Figure 3.2.

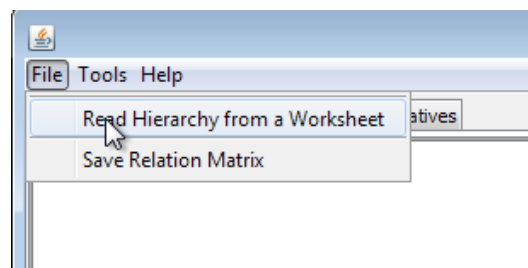


FIGURE 3.2: Read Hierarchy from a Worksheet

A window is opened. The parameters of the input data should be completed there, such as the path of the Excel file, the sheet number and the structure of the Excel file. i.e.,

the cells in the file that belong to the configuration of the groups, criteria, alternatives and evaluations. As an example, Figure 3.3 contains the configuration parameters of the Excel file in the Figure 3.4.

The screenshot shows a software window with the following configuration parameters:

- Path of your excel file:** /scenario\_A2.xls (with a 'Browse...' button)
- Sheet number:** 1
- Groups:**
  - Rows: From: 3, To: 5
  - Columns: From: b, To: e
  - Pseudocriteria:**
    - Indifference: 6
    - Preference: 7
    - Veto: 8
- Criteria:**
  - Rows: From: 11, To: 17
  - Columns: From: b, To: j
  - Pseudocriteria:**
    - Indifference: 18
    - Preference: 19
    - Veto: 20
- Alternatives:**
  - Column: a
  - Rows: From: 23, To: 70
- Evaluations:**
  - Rows: From: 23, To: 70
  - Columns: From: b, To: j

At the bottom of the window, there are three buttons: 'Guess evaluations', 'Read', and 'Help'.

FIGURE 3.3: Worksheet structure parameterization

There are some customizations to be taken into consideration in the Excel file, for instance:

	A	B	C	D	E	F	G	H	I	J
1										
2		<b>GROUPS</b>								
3	<b>NAME:</b>	cost	WaSSIR	EcoStress	goal					
4	<b>PARENT:</b>	goal	goal	goal	*					
5	<b>WEIGHT:</b>	1	1	1	1					
6	<b>Indiff</b>	0	0	0	0					
7	<b>Pref</b>	0	0	0	0					
8	<b>Veto</b>	0	0	0	0					
9										
10										
11	<b>NAME:</b>	ind	dom	agr	ind_WaSSIR	dom_WaSSIR	agr_WaSSIR	Francoli	Ebro	Gaiá
12	<b>PARENT:</b>	cost	cost	cost	WaSSIR	WaSSIR	WaSSIR	EcoStress	EcoStress	EcoStress
13	<b>TYPE:</b>	n	n	n	n	n	n	n	n	n
14	<b>WEIGHT:</b>	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
15	<b>MIN:</b>	17990120.000	17549196.000	505600.000	.250	.000	.000	.261	.003	.075
16	<b>MAX:</b>	18405530.000	22029420.000	808800.000	4.000	.333	.428	.361	.005	.075
17	<b>DIRECTION:</b>	-1	-1	-1	1	1	1	-1	-1	-1
18	<b>Indiff</b>	0	0	0	0	0	0	0	0	0
19	<b>Pref</b>	0	0	0	0	0	0	0	0	0
20	<b>Veto</b>	415410.000	4480224.000	303200.000	3.750	.333	.428	.100	.002	.000
21										
22		<b>ALTERNATIVES</b>								
23	<b>A1</b>	17990120.000	21935256.000	505600.000	.250	.000	.000	.361	.005	.075
24	<b>A2</b>	17990120.000	21935256.000	606400.000	.250	.000	.111	.328	.005	.075
25	<b>A3</b>	17990120.000	21935256.000	708000.000	.250	.000	.250	.294	.005	.075
26	<b>A4</b>	17990120.000	21935256.000	808800.000	.250	.000	.428	.261	.005	.075
		Input Data								

FIGURE 3.4: The Excel input file

- **Definition of criterion type:** "n", "num" or "numerical" for numerical values (integer or float) and "c", "cat" or "categorical" for categorical values.
- **Definition of criterion's direction:** type "Gain" or "1" to set criterion's direction to Gain, that is, to maximize. On the contrary, type "Cost" or "-1" to set criterion's direction to Cost, which means that it should be minimized.
- **Definition of a Root group:** a Root element of the tree must be defined by setting a group's parent to "\*".
- **The format of the Excel file:** it must be "xls" (97-2003 Excel default format).
- **Separation of the groups of data:** it is recommended to leave a blank row between each group of data, i.e., Groups, Criteria and Alternatives.

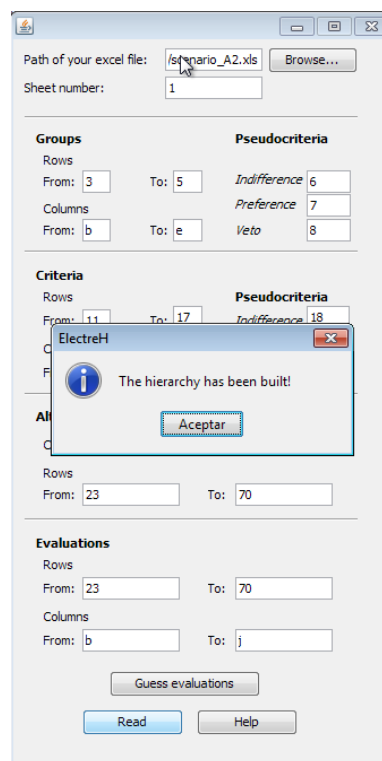


FIGURE 3.5: The software builds the hierarchy from the read worksheet

The *Read* button triggers the creation of the hierarchy according to the Excel file. The built hierarchy is displayed at the left side of the Figures 3.6 and 3.7.

The indifference, preference and veto thresholds belonging to the groups and criteria that are displayed at the right panel, are also read from the Excel file. However, it is possible to change their values. To change only the thresholds of the selected item in the hierarchy, the upper part of the right panel identified by the title **Item thresholds** should be completed. It is also possible to change the thresholds of all the intermediate

criteria or groups. In these cases, **Overall hierarchy thresholds** must be used. The entered values should be confirmed by clicking on the *Apply to* button once the scope of effect is selected. For the former, the *Criteria* option from the dropdown list should be selected, while for the latter, the *Group* option is the one to be used. For consistency, the thresholds should fulfill the following constraint  $0 \leq q_j \leq p_j \leq v_j$ .

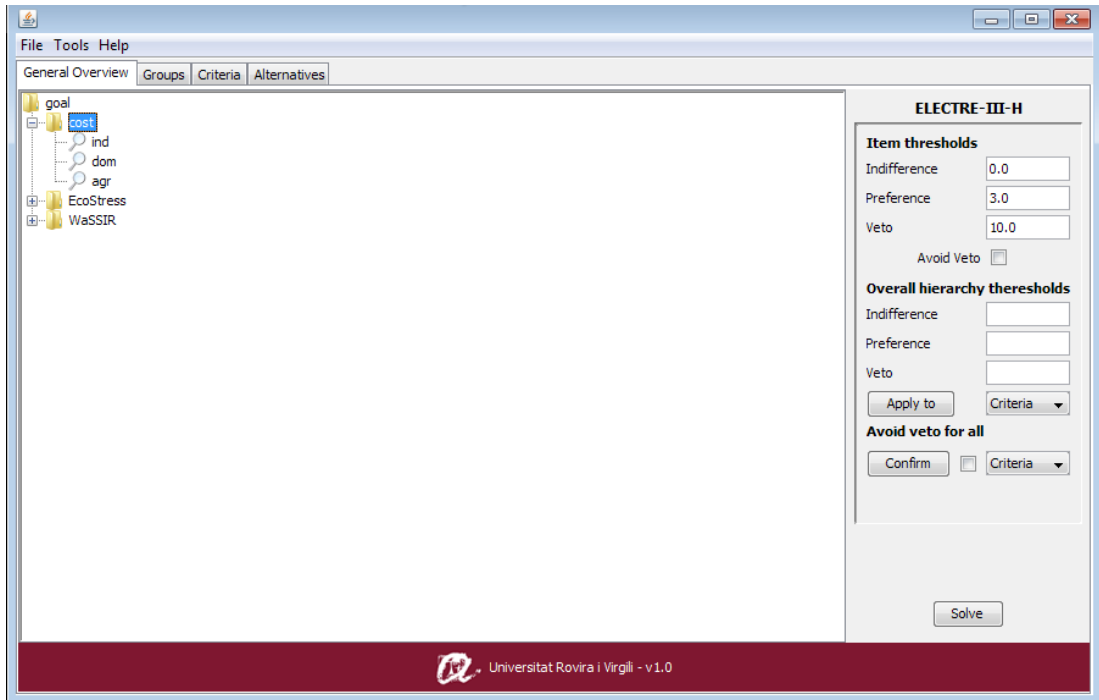


FIGURE 3.6: The thresholds from the group can be modified

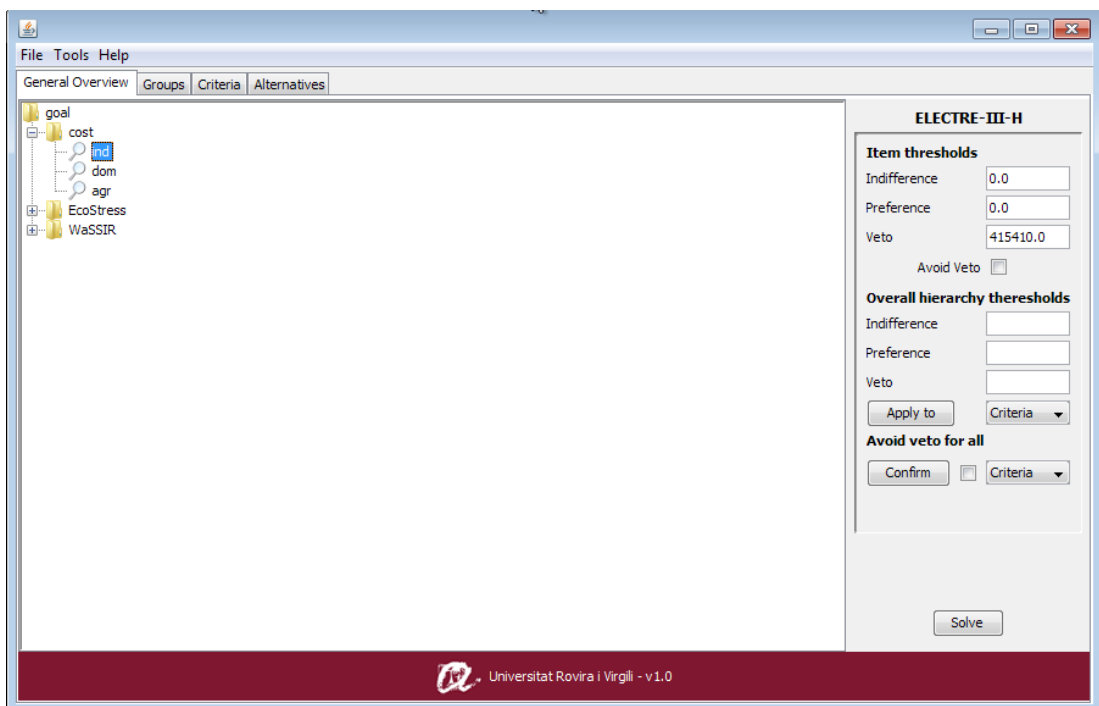


FIGURE 3.7: The thresholds from the selected intermediate criteria

The *Groups* that have been loaded from the Excel input file are displayed in a table form (Figure 3.8). It is possible to edit or remove the existing ones as well as add new groups to the hierarchy.

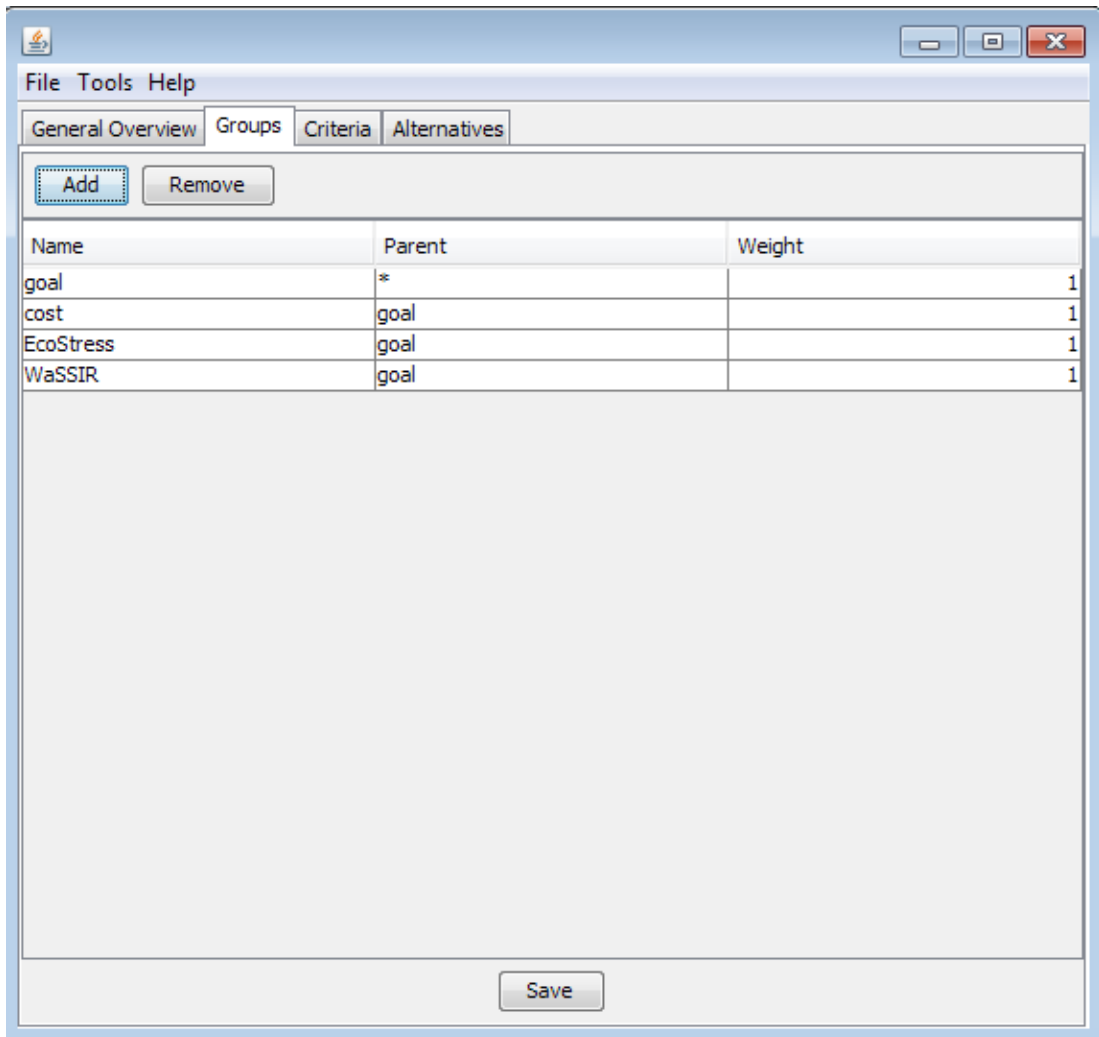


FIGURE 3.8: The groups loaded from the Excel file

The *Criteria* that have been loaded from the Excel input file are also displayed in a table form, as shown in Figure 3.9. It is possible to edit or remove the existing ones as well as add new criteria to the hierarchy. The *Gain* column refers to the direction of the criterion. When it is set to *True* the criterion is expected to be maximized. On the contrary, a *False* value in this column means the lower the evaluation the better is the alternative.

The *Alternatives* and their associated evaluations are presented as in Figure 3.10, following the order specified in the Excel input file.

Clicking on the *Solve* button will start the solving process. Once it finishes, the *Result Panel* is displayed. This panel shows the ordered ranking in such a way that the highest

Name	Group	Type	Weight	Min*	Max*	Gain
ind	cost	Numerical	1			false
dom	cost	Numerical	1			false
agr	cost	Numerical	1			false
ind_WaSSIR	WaSSIR	Numerical	1			true
dom_WaSSIR	WaSSIR	Numerical	1			true
agr_WaSSIR	WaSSIR	Numerical	1			true
Francoli	EcoStress	Numerical	1			false
Ebro	EcoStress	Numerical	1			false
Gaiã	EcoStress	Numerical	1			false

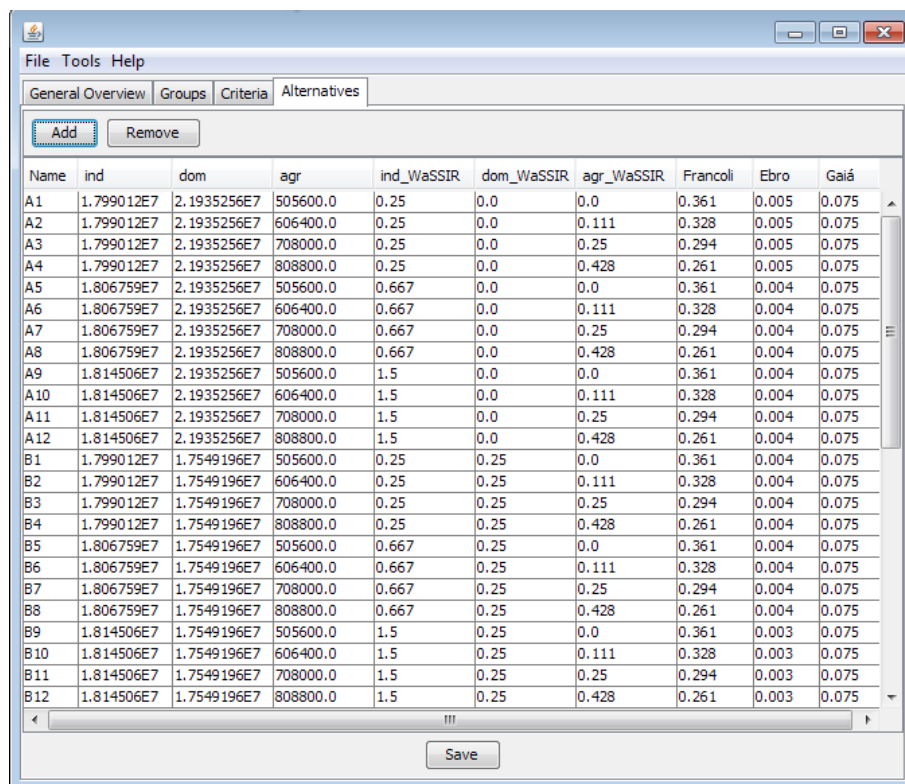
FIGURE 3.9: The criteria loaded from the Excel file

the value of the ranking, the worse the alternative is. It is possible to view the preorder from the root criterion's point of view or the preorders belonging to the intermediate criteria of the hierarchy (Figure 3.12).

It is possible to watch the results from a visual point of view. To do that, clicking on the *Build preorder* button will open a window with the preorder according to the selected criterion's level of the hierarchy.

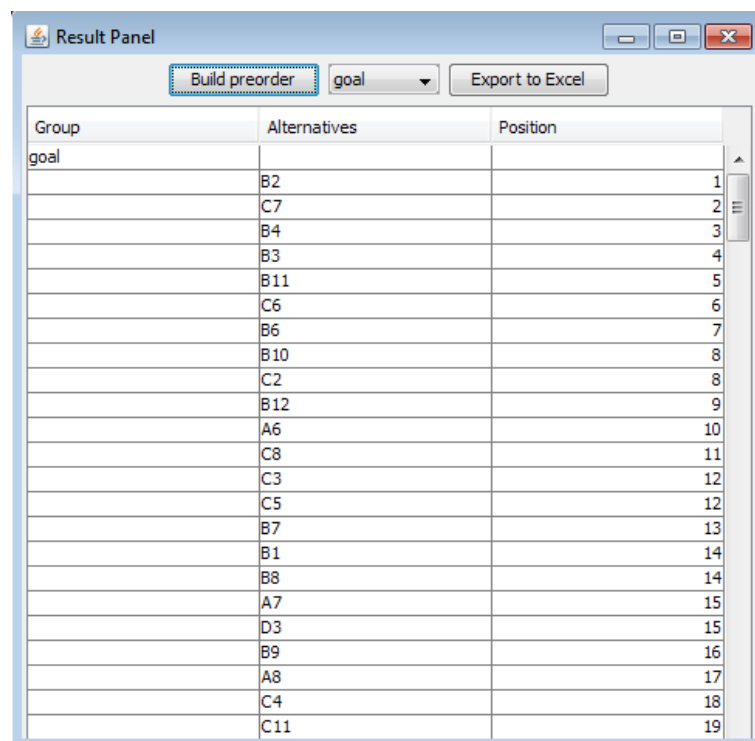
Once the decision problem is solved using the *Solve* button, it is possible to save the relation matrix using the entry *Save preorder matrix* from the *File* menu. A window like in Figure 3.13 will be opened where a group should be selected and a location to save the generated *.matrix* should be picked.

It is also possible to make a comparison between two relation matrices by means of the *Preorder distance*, which can be found under the *Tools* menu. For that, two *.matrix* files



Name	ind	dom	agr	ind_WaSSIR	dom_WaSSIR	agr_WaSSIR	Francoli	Ebro	Gaiá
A1	1.799012E7	2.1935256E7	505600.0	0.25	0.0	0.0	0.361	0.005	0.075
A2	1.799012E7	2.1935256E7	606400.0	0.25	0.0	0.111	0.328	0.005	0.075
A3	1.799012E7	2.1935256E7	708000.0	0.25	0.0	0.25	0.294	0.005	0.075
A4	1.799012E7	2.1935256E7	808800.0	0.25	0.0	0.428	0.261	0.005	0.075
A5	1.806759E7	2.1935256E7	505600.0	0.667	0.0	0.0	0.361	0.004	0.075
A6	1.806759E7	2.1935256E7	606400.0	0.667	0.0	0.111	0.328	0.004	0.075
A7	1.806759E7	2.1935256E7	708000.0	0.667	0.0	0.25	0.294	0.004	0.075
A8	1.806759E7	2.1935256E7	808800.0	0.667	0.0	0.428	0.261	0.004	0.075
A9	1.814506E7	2.1935256E7	505600.0	1.5	0.0	0.0	0.361	0.004	0.075
A10	1.814506E7	2.1935256E7	606400.0	1.5	0.0	0.111	0.328	0.004	0.075
A11	1.814506E7	2.1935256E7	708000.0	1.5	0.0	0.25	0.294	0.004	0.075
A12	1.814506E7	2.1935256E7	808800.0	1.5	0.0	0.428	0.261	0.004	0.075
B1	1.799012E7	1.7549196E7	505600.0	0.25	0.25	0.0	0.361	0.004	0.075
B2	1.799012E7	1.7549196E7	606400.0	0.25	0.25	0.111	0.328	0.004	0.075
B3	1.799012E7	1.7549196E7	708000.0	0.25	0.25	0.25	0.294	0.004	0.075
B4	1.799012E7	1.7549196E7	808800.0	0.25	0.25	0.428	0.261	0.004	0.075
B5	1.806759E7	1.7549196E7	505600.0	0.667	0.25	0.0	0.361	0.004	0.075
B6	1.806759E7	1.7549196E7	606400.0	0.667	0.25	0.111	0.328	0.004	0.075
B7	1.806759E7	1.7549196E7	708000.0	0.667	0.25	0.25	0.294	0.004	0.075
B8	1.806759E7	1.7549196E7	808800.0	0.667	0.25	0.428	0.261	0.004	0.075
B9	1.814506E7	1.7549196E7	505600.0	1.5	0.25	0.0	0.361	0.003	0.075
B10	1.814506E7	1.7549196E7	606400.0	1.5	0.25	0.111	0.328	0.003	0.075
B11	1.814506E7	1.7549196E7	708000.0	1.5	0.25	0.25	0.294	0.003	0.075
B12	1.814506E7	1.7549196E7	808800.0	1.5	0.25	0.428	0.261	0.003	0.075

FIGURE 3.10: The alternatives loaded from the Excel filea



Group	Alternatives	Position
goal		
	B2	1
	C7	2
	B4	3
	B3	4
	B11	5
	C6	6
	B6	7
	B10	8
	C2	8
	B12	9
	A6	10
	C8	11
	C3	12
	C5	12
	B7	13
	B1	14
	B8	14
	A7	15
	D3	15
	B9	16
	A8	17
	C4	18
	C11	19

FIGURE 3.11: The resulting ranking is shown

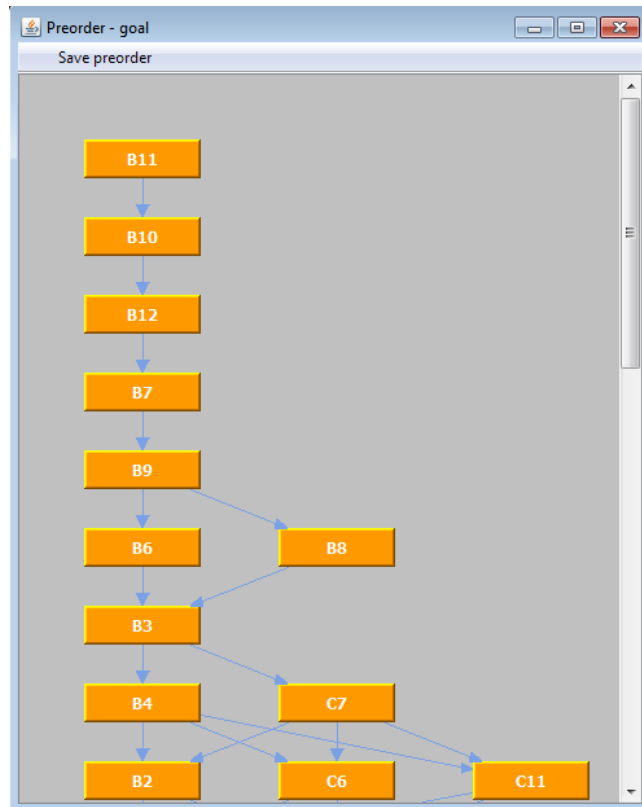


FIGURE 3.12: An example of the generated preorder

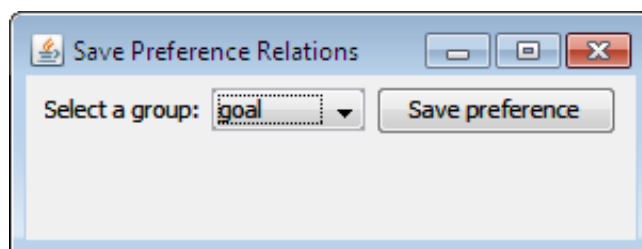


FIGURE 3.13: The opened window for saving the relation matrix

should be loaded and the distance is calculated as described in [19] and shown in the same window (Figure 3.14).

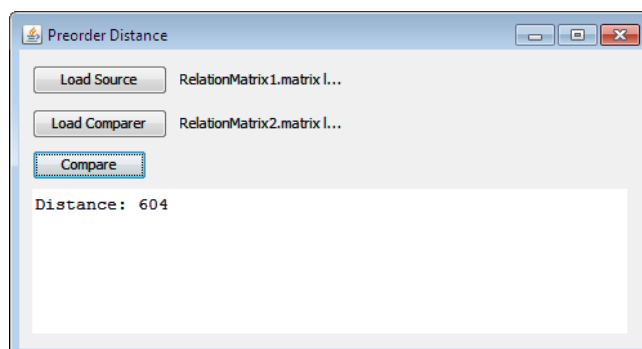


FIGURE 3.14: Preorder Distance calculation

As explained before, it is possible to work with categorical or linguistic variables. The option *Set categoricals* from the menu *Tools* has been designed for this purposed (see Figure 3.15).

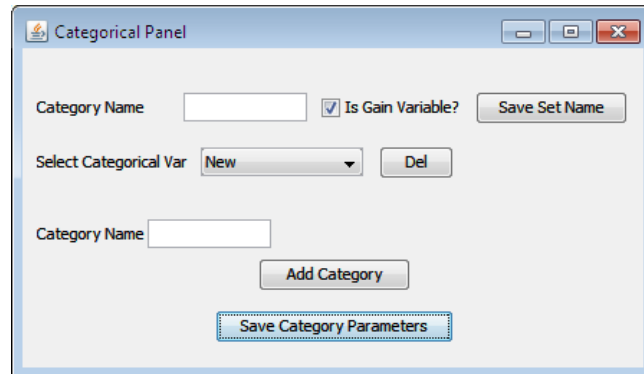


FIGURE 3.15: Panel for adding categoricals

## Chapter 4

# The environmental problem structure

In this chapter we explain the application domain studied in this Master Thesis. This work has been done in collaboration with experts of the AGA research group from the Department of Chemical Engineering at University Rovira i Virgili. This study is done in the frame of an Spanish project called SCARCE. One of the workpackages of this project studies the effects of the Global Change in the distribution of the water coming from the Spanish rivers for domestic, industrial and agricultural use. This thesis focuses on studying the case of the rivers that provide water to the Tarragona city, which are Ebro, Francolí and Gaià.

In the next subsections we will explain the case study and the problematic that the water managers deal with in a future scenario of scarcity due to the global change.

Next, in sections 4.2 and 4.3 we present the first contribution of this master thesis, which is the modeling of this decision problem, in terms of the ELECTRE-III-H data and parameters, which have been explained in chapter 2.

### 4.1 The context

As an introduction to this environmental problem, the time and space context is detailed in the following subsections.



industrial cities like Montblanc, La Riba and Tarragona. The river is the main collector of industrial and municipal treated wastewater and provides irrigation water to the seasonal farms.

The city of Tarragona, located at the mouth of Francolí river was solely dependent on its own water resources before 1988. The sea water intrusion occurred in the groundwater aquifers impelled the municipalities to meet the water demand by inter-basin transfer from neighbouring river basins (e.g., Ebro river and Gaià river). Moreover, Tarragona is the second largest industrial area of Catalonia and most of the industries in Francolí river basin are located close to this city, including a large petrochemical industry. Many other small industries are placed in the upper part of the river basin. The agricultural demand varies all along the river basin depending on the crop type and the cultivated area.

#### 4.1.2 Global change

Global Change refers to planetary-scale changes in the Earth system. The system consists of the land, oceans, atmosphere, polar regions, life, the planet's natural cycles and deep Earth processes. These constituent parts influence one another. The Earth system now includes human society, so global change also refers to large-scale changes in society.

River basin studies have shown that changes not only in climate, but also in population, economic growth, technological change and other socio-economic factors may lead to significant changes in water use and hence in various indicators of future water resources [15].

Population grow and increased prosperity have led to increasing water demands. However, societal and political transformation processes as well as policy regulations resulting in new water-saving technologies and improvements counteract this development by slowing down and even reducing global domestic and industrial water uses [11].

Some factors that will likely have the greatest influence on the future water management system regarding water supply as well as water demand belong to the following categories:

- Natural systems.
- Demographic.
- Economic.
- Technological.

- Social.
- Governance.

As example of natural systems influence it can be mentioned that the changes in climate variability and trends, such as higher temperatures and drier Summers is likely to affect the agricultural sector due to the increase in the demand for irrigation in the Summer. Agricultural irrigation could increase by about 20% by 2020, and 30% by 2050, at the same time as summer rainfall would decrease. However, changes to farming practice, crop type or variety, can reduce the demand for water from agriculture, and research and knowledge transfer can also help address water use.

The way how governance interventions and the consequent social impact can lead to behavioural change can be in Germany, where the water consumption has decreased by 17% over the past 20 years to 122 litres per person per day, mainly by strongly linking water prices to consumption, and also by complementary measures such as encouraging the use of water-saving household appliances and numerous consumer awareness campaigns.

In England, the food industry is a major water user, taking around 10% of all industrial abstractions and another 10% of total industrial water use from the public supply. The Food Industry Sustainability Strategy (FISS), launched in 2006 to improve environmental, social and economic performance, challenged the food industry to reduce its current levels of water usage by setting the industry an overall water reduction target of 20% by 2020, against a 2007 baseline. The Food and Drink Federation responded to this challenge with a partnership initiative to reduce water consumption, and in addition 21 food and drink firms have recently pledged to cut the amount of water they use in manufacturing.

Regarding the demographical force in Tarragona, according to the Statistical Institute of Catalonia, the population could go from 584,660 inhabitants in 2008 to 713,000 inhabitants in 2021, which represents a growth of 22%.

### **4.1.3 The objective of the study**

The main goal is to study different scenarios of future water supply and demand on different conditions due to the global change. Different separated scenarios have been defined by the AGA team by changing the demand prediction and water supply strategy. Finally, a ranking of the options is provided. As said before, we consider three rivers as primary sources of water: Ebro, Francolí and Gaià. The demand of water comes from three different sectors: domestic, industrial and agricultural.

The main characteristics of the scenarios studied are the following:

**Climate change (CC) scenario** As a reference point, the first case that has been considered assumes that the demand in the future is the same as the one in 2013. What the supply concerns, it has been considered for a time span between 2011 and 2040.

**Global change (GC) scenario** The demand varies according to the different policies (i.e. optimistic, pessimistic and neutral) and the time span. For the latter, three time span are involved: *2011-2040*, *2041-2070* and *2071-2100*.

For each future scenario of global change the goal is to obtain a ranking of a set of possible actions with regards to different types of indicators, such as costs, environmental impact, water stress, etc. A hierarchy of criteria has been defined and is explained in section [4.3.5](#).

In the model proposed, the actions refer to different strategies of water distribution to the three sectors. Water may come from different sources other than primary ones (i.e. the 3 rivers), such as desalination or water reservoirs. Next section presents in detail how the actions are defined in terms of the water source and the sector demand of water.

## 4.2 The actions of water distribution in each scenario

The first component of the model are the alternatives, also called actions. Water distribution describes the activity whereby the scarce water resources are allocated among the claimants and the resulting water rights are granted taking into account their needs.

To generate the set of possible actions for each scenario, the experts have defined four general strategies of water distribution:

- **Nature First (A)**: the use of primary sources and reuse of reclaimed water is encouraged, consequently, no desalination is used.
- **Low use of alternative resources (B)**: low desalination for domestic water supply and use of reclaimed water.
- **Medium use of alternative resources (C)**: medium desalination for domestic and industrial water supply and use of reclaimed water.
- **High use of alternative resources (D)**: high desalination for domestic and industrial water supply as well as high use of reclaimed water.

These policies define different general rules of water distribution in three sectors (industrial, domestic and agricultural), which change the percentage of water supply coming from the different types of water sources: primary sources and alternative resources. The first one refers to water extracted from the rivers Francolí, Ebro and Gaià. In particular two alternative resources have been taken into consideration: *Reclaimed water (RW)*, which consists on the reuse of domestic water in industries or for the agriculture; *Desalination (DS)*, which is water obtained from salty marine water.

The experts defined different possible settings for the use of water coming for alternate resources based on the actual demand. The data used as base for the study was retrieved from the Catalan Water Agency and UNEP International Environment Centre, was expressed in €/m<sup>3</sup>, but it has been translated into the hm<sup>3</sup> unit, for convenience of the experts.

- *Reused water in industries.* The reuse of domestic water in industry for Tarragona is the first taken into consideration. The current domestic consumption is estimated in 44 hm<sup>3</sup>/year, from which a maximum of 70% recycle efficiency has been assumed. Thus, the maximum water recovery from domestic water supply is 30,8 hm<sup>3</sup>/year, which would be enough for the 30,5 hm<sup>3</sup>/year current industrial demand. It is feasible to assume that there will be a gradual increase in water recycling and reuse in the industrial sector.

In particular, ACA (the Catalan Agency of Water) has a Water Reclamation Project in Tarragona, which is a prime example of how water scarcity can be solved regionally by reclaiming water that would otherwise be discharges to the sea. A new reclamation plant treats municipal secondary effluent from Tarragona and Salou/vilaseca WasteWater Treatment Plants to supply process water for the Petrochemical industry of Tarragona [20].

The following situations for water reuse in the industrial sector of Tarragona may be considered:

1. *No water reuse (0%):* like in the current scenario.
  2. *Low reuse (20%):* 6.935 hm<sup>3</sup>/year.
  3. *Medium reuse (40%):* 10.585 hm<sup>3</sup>/year.
  4. *High reuse (80%):* 20.075 hm<sup>3</sup>/year.
- *Reused water in agriculture.* For agricultural usage it has been assumed that a maximum of 20% of total water demand in agriculture can be met by treated water from the domestic sector. This percentage corresponds to 6,16 hm<sup>3</sup>/year. It is

important to notice that the current water demand in agriculture is  $17 \text{ hm}^3/\text{year}$  but its supply is only of  $12,63 \text{ hm}^3/\text{year}$ .

The following settings for water reuse in agriculture may be then considered:

1. *No water reuse (0%)*: line in the current scenario.
2. *Low water reuse (10%)*.
3. *Medium water reuse (20%)*.
4. *High water reuse (30%)*.

The amount of reused water in agriculture is notably smaller since there are several constraints such as geographical distance and distribution cost that can prohibit the reuse of recycled domestic water for agricultural purposes.

- *Water desalination*. Water desalination is contemplated only for the domestic and industrial sectors since there is no intensive centralised agriculture area in Tarragona where costly desalinated water can be used. The domestic desalinated water supply can be up to 25% whereas the maximum for industrial water taken into account is 20%. The following situations for water supply from Water Desalination have been considered:

1. *No water desalination*: current scenario.
2. *Low water supply from desalination*: 20% domestic supply, which means up to  $10 \text{ hm}^3/\text{year}$  from desalination.
3. *Medium water supply from desalination*: 20% domestic supply and 10% industrial water (up to  $15 \text{ hm}^3/\text{year}$ ).
4. *High water supply from desalination*: 25% domestic supply and 20% industrial water (up to  $20 \text{ hm}^3/\text{year}$ ).

Those rules (i.e. percentages of reuse and desalination) have been combined according to the 4 general strategies mentioned above (i.e. nature first, low reuse, medium reuse and high reuse). As a result, 12 concrete rules of water distribution for the three sectors have been fixed. They are detailed in Tables 4.6 - 4.9. Therefore, each scenario will have in total  $12 \times 4 = 48$  different actions of water supply. Each considered scenario is treated separately.

#### 4.2.1 Automatic construction of the actions

For each rule, a concrete sector-wise action is constructed on the basis of the following information:

- Total water supply for each sector
- Percentage of water obtained from each source, including primary sources and alternative resources

Each action will be represented as a matrix, where the rows represent the three sectors and the columns contain information regarding:

- Water source, i.e., water yield per river, water coming from desalination and reused water.
- Total supply from primary sources (i.e. from the rivers)
- Total water supply

An illustrative example is provided in Table 4.1 for the case of Climate Change (CC) scenario and B strategy. This structure in rules facilitates the construction of the actions of each strategy for each scenario.

Row/Sector	Industry	Domestic	Agriculture
Supply	30,5 $hm^3/yr$	44,26 $hm^3/yr$	12,64 $hm^3/yr$
Rule B10	High water reuse (60% Water Reuse) + No desalination	80% Primary Source + Low desalination (20%)	Low water reuse (10% Water Reuse)

TABLE 4.1: Input data for an action's construction

In the CC scenario, the data in Table 4.1 is provided to the software, that generates the action denoted as B10 (Table 4.2). This table is automatically constructed (by means of a software that will be explained in the next section) following some guidelines given by the domain expert. First, for the primary sources, the water distribution from rivers is done using the following scheme: for Industry 1  $hm^3$  is taken from Francolí, 1.5  $hm^3$  comes from Gaià and the rest from Ebro. Meanwhile, water for Domestic usage is extracted completely from Ebro and for Agriculture usage only water from Francolí is used.

For the Global Change (GC) scenario, the amount of water yield from Francolí and Gaià for the industrial sector will suffer the following modifications since the water yield are reduced and may vary among rivers. The amount of water extracted from Francolí is

$$1 \times (100 - \text{water yield reduction percentage})$$

and for Gaià

$$1,5 \times (100 - \text{water yield reduction percentage})$$

	Francolí ( $hm^3$ )	Ebro ( $hm^3$ )	Gaià ( $hm^3$ )	RW	DS	Total supply (PS)	Total supply (PS + AR)
Ind	1,00	9,70	1,50	18,3		12,20	30,50
Dom		35,41			8,85	35,41	44,26
Agr	11,38			1,26		11,38	12,64

TABLE 4.2: Action B10, automatically constructed following the rules

For each action it must be guaranteed that the accumulated water coming from each river does not surpass the water yield threshold set in forehand.

#### 4.2.2 Notation

The following nomenclature will be used in this section to define the model of the data:

$p_{xy}$ : amount of water for sector  $x$  extracted from river  $y$ .

$r_{xz}$ : amount of water yield from alternative resources for sector  $x$  and resource  $z$

$$x = \{ind, dom, agr\}$$

$$y = \{Francolí, Ebro, Gaià\}$$

$$z = \{DS, RW\}$$

For example, according to action B10 displayed in Table 4.2, we have that:

$$p_{Ind,Francolí} = 1,00$$

$$p_{Ind,Ebro} = 9,70$$

$$p_{Ind,Gaià} = 0,00$$

$$r_{Ind,RW} = 18,30$$

$$r_{Ind,DS} = 0,00$$

$$p_{Dom,Francolí} = 0,00$$

$$p_{Dom,Ebro} = 35,41$$

$$p_{Dom,Gaià} = 0,00$$

$$r_{Dom,RW} = 0,00$$

$$r_{Dom,DS} = 8,85$$

$$p_{Agr,Francolí} = 11,38$$

$$p_{Agr,Ebro} = 0,00$$

$$p_{Agr,Gaià} = 0,00$$

$$r_{Agr,RW} = 1,26$$

$$r_{Agr,DS} = 0,00$$

### 4.3 The criteria

The second element of the model designed in this master thesis together with the experts of the AGA team is an appropriate set of criteria, their hierarchical structure and the units of measurement of the basic indicators.

Different sets of criteria and different ways of organising the information have been studied. Many working meetings were done and different structures were proposed and iteratively refined. The final list of criteria is explained in this section. There are criteria related with costs and with the environmental impact of the different strategies of water distribution.

#### 4.3.1 Cost of water coming from Primary sources

The primary water source coming from the rivers Francolí, Ebro and Gaià,  $p_{xy}$ , has different prices for each sector. The costs of their usage,  $PC_x$ , are the following:

- *Cost for Industrial sector* ( $PC_{Ind}$ ) :  $587.300e/hm^3 * p_{Ind,y} \forall y$ .
- *Cost for Domestic sector* ( $PC_{Dom}$ ) :  $495.600e/hm^3 * p_{Dom,y} \forall y$ .
- *Cost for Agricultural Sector* ( $PC_{Agr}$ ) :  $40.000e/hm^3 * p_{Agr,y} \forall y$ .

#### 4.3.2 Cost of water coming from Alternative resources

The alternative resources taken into account are Reused Water and Desalination. Their associated costs,  $AC_{xz}$ , are shown in the Table 4.3. These prices must be multiplied by  $r_{xz}$ , to calculate the total cost per sector.

$AC_{xz}$	Desalination	Reclaimed Water
Industry	630.000€/hm <sup>3</sup>	600.000€/hm <sup>3</sup>
Domestic	630.000€/hm <sup>3</sup>	700.000€/hm <sup>3</sup>
Agriculture	630.000€/hm <sup>3</sup>	120.000€/hm <sup>3</sup>

TABLE 4.3: Prices considered for alternative resources per sector

### 4.3.3 Scarcity index

The impact on the environment has been evaluated using the following water supply stress index (WaSSI) due to each sector  $x$ . The scarcity index  $WaSSI_x$  of a certain action  $a_i$  for the scenario  $sc_j$  is defined as:

$$WaSSI_x(a_i) = \frac{WD_x(sc_j)}{WS_x(a_i)}$$

which is the coefficient between the *demand* (WD) and the *total supply from primary sources* (WS). Both *water demand* and *water supply* are sector-wised.

The  $WaSSI_x(a_i)$  can be analyzed in comparison to the current scenario by means of the following ratio:

$$WaSSIR_x(a_i) = \frac{WaSSI_x(a_i) - WaSSI_x(current)}{WaSSI_x(a_i)}$$

A positive value indicates increased water stress while a negative value indicates reduced water stress when compared to current water stress conditions. Therefore, this index has to be maximized.

### 4.3.4 Ecological impact

The EcoStress is a water use index that represents the percentage of water extracted from a river to fulfill the demand. This index estimates the ecological stress on a river. For the analysis of the current problem this index was calculated by summing all *water extracted* (WE) from each river and then dividing by total annual *water flow* (WF) provided in the Table 4.4. This index has to be minimized.

The formula used for the EcoStress calculation of each river  $y$  for action  $a_i$  is:

$$EcoStress_y = \frac{\sum WE_y(a_i)}{\sum WF_y(a_i)}$$

River	WF (hm <sup>3</sup> /year)
Francolí	47,77
Ebro (at Tortosa)	18.200
Gaià	25,17

TABLE 4.4: Total Annual Water flow of different river

### 4.3.5 The hierarchy of criteria in the decision support system

The decision support system used is ELECTRE-III-H, which manages a hierarchical tree of criteria (goals and sub-goals). The proposed hierarchical structure of the data can be seen in Figure 4.2.

Cost is accumulated for each sector as follows:  $C_x = \sum_{\forall y} p_{xy} \times PC_{xy} + \sum_{\forall z} r_{xz} \times AC_{xz}$

Notice that the WaSSIR is calculated for each sector and then aggregated in an upper level. On the other hand, the EcoStress is calculated for each river and then aggregated.

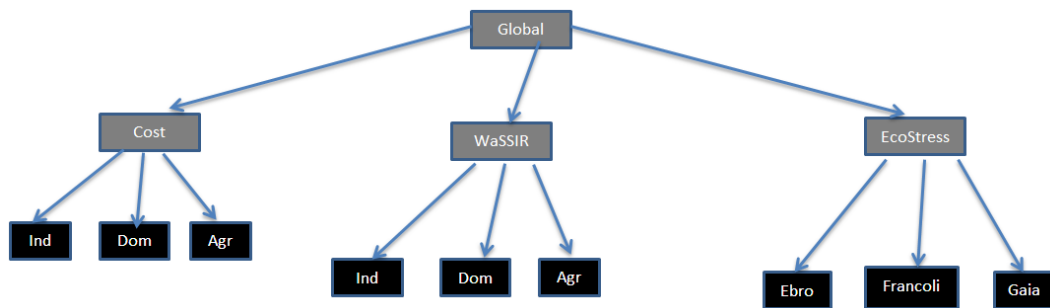


FIGURE 4.2: Used hierarchy

At each node in red color a partial preorder of the all the actions has been produced. The root node in blue has been the aggregation result of all the nodes derived from it.

All criteria has been considered with the same importance by setting the same relative weight to all of them. Besides, the indifference and preference thresholds have been agreed with the decision makers to be 0 for elementary indicators.

## 4.4 The construction of the performance table

The performance table is one of the inputs required in ELECTRE-III-H method. This table has one row for each action (i.e. alternative) and as many columns as elementary criteria, in our case 9 criteria.

Following the example in Table 4.2 with action B10, and the equations of the criteria presented above, the table is automatically completed by a software tool developed in

this thesis (Table 4.5). For each of the 48 rules (12 for each strategy) a new entry in the performance table is constructed.

Action	ind cost	ind cost	ind cost	ind WaSSIR	dom WaSSIR	agr WaSSIR	EcoStress Francolí	EcoStress Ebro	EcoStress Gaià
B10	18145060	17549196	606400	1,50	0,25	0,11	0,328	0,003	0,111

TABLE 4.5: An entry in the performance table

Rule	Industry	Domestic	Agriculture
A1	Low water reuse (20% Water Reuse) + No desalination	100% Primary Source	100% Primary Source
A2	Low water reuse (20% Water Reuse) + No desalination	100% Primary Source	Low water reuse (10% Water Reuse)
A3	Low water reuse (20% Water Reuse) + No desalination	100% Primary Source	Medium water reuse (20% Water Reuse)
A4	Low water reuse (20% Water Reuse) + No desalination	100% Primary Source	High water reuse (30% Water Reuse)
A5	Medium water reuse (40% Water Reuse) + No desalination	100% Primary Source	100% Primary Source
A6	Medium water reuse (40% Water Reuse) + No desalination	100% Primary Source	Low water reuse (10% Water Reuse)
A7	Medium water reuse (40% Water Reuse) + No desalination	100% Primary Source	Medium water reuse (20% Water Reuse)
A8	Medium water reuse (40% Water Reuse) + No desalination	100% Primary Source	High water reuse (30% Water Reuse)
A9	High water reuse (60% Water Reuse) + No desalination	100% Primary Source	100% Primary Source
A10	High water reuse (60% Water Reuse) + No desalination	100% Primary Source	Low water reuse (10% Water Reuse)
A11	High water reuse (60% Water Reuse) + No desalination	100% Primary Source	Medium water reuse (20% Water Reuse)
A12	High water reuse (60% Water Reuse) + No desalination	100% Primary Source	High water reuse (30% Water Reuse)

TABLE 4.6: Nature first strategy

Rule	Industry	Domestic	Agriculture
B1	Low water reuse (20% Water Reuse) + No desalination	80% Primary Source + Low desalination (20%)	100% Primary Source
B2	Low water reuse (20% Water Reuse) + No desalination	80% Primary Source + Low desalination (20%)	Low water reuse (10% Water Reuse)
B3	Low water reuse (20% Water Reuse) + No desalination	80% Primary Source + Low desalination (20%)	Medium water reuse (20% Water Reuse)
B4	Low water reuse (20% Water Reuse) + No desalination	80% Primary Source + Low desalination (20%)	High water reuse (30% Water Reuse)
B5	Medium water reuse (40% Water Reuse) + No desalination	80% Primary Source + Low desalination (20%)	100% Primary Source
B6	Medium water reuse (40% Water Reuse) + No desalination	80% Primary Source + Low desalination (20%)	Low water reuse (10% Water Reuse)
B7	Medium water reuse (40% Water Reuse) + No desalination	80% Primary Source + Low desalination (20%)	Medium water reuse (20% Water Reuse)
B8	Medium water reuse (40% Water Reuse) + No desalination	80% Primary Source + Low desalination (20%)	High water reuse (30% Water Reuse)
B9	High water reuse (60% Water Reuse) + No desalination	80% Primary Source + Low desalination (20%)	100% Primary Source
B10	High water reuse (60% Water Reuse) + No desalination	80% Primary Source + Low desalination (20%)	Low water reuse (10% Water Reuse)
B11	High water reuse (60% Water Reuse) + No desalination	80% Primary Source + Low desalination (20%)	Medium water reuse (20% Water Reuse)
B12	High water reuse (60% Water Reuse) + No desalination	80% Primary Source + Low desalination (20%)	High water reuse (30% Water Reuse)

TABLE 4.7: Low use of alternative resources strategy

Rule	Industry	Domestic	Agriculture
C1	Low water reuse (20% Water Reuse) + desalination (10%)	80% Primary Source + Low desalination (20%)	100% Primary Source
C2	Low water reuse (20% Water Reuse) + desalination (10%)	80% Primary Source + Low desalination (20%)	Low water reuse (10% Water Reuse)
C3	Low water reuse (20% Water Reuse) + desalination (10%)	80% Primary Source + Low desalination (20%)	Medium water reuse (20% Water Reuse)
C4	Low water reuse (20% Water Reuse) + desalination (10%)	80% Primary Source + Low desalination (20%)	High water reuse (30% Water Reuse)
C5	Medium water reuse (40% Water Reuse) + desalination (10%)	80% Primary Source + Low desalination (20%)	100% Primary Source
C6	Medium water reuse (40% Water Reuse) + desalination (10%)	80% Primary Source + Low desalination (20%)	Low water reuse (10% Water Reuse)
C7	Medium water reuse (40% Water Reuse) + desalination (10%)	80% Primary Source + Low desalination (20%)	Medium water reuse (20% Water Reuse)
C8	Medium water reuse (40% Water Reuse) + desalination (10%)	80% Primary Source + Low desalination (20%)	High water reuse (30% Water Reuse)
C9	High water reuse (60% Water Reuse) + desalination (10%)	80% Primary Source + Low desalination (20%)	100% Primary Source
C10	High water reuse (60% Water Reuse) + desalination (10%)	80% Primary Source + Low desalination (20%)	Low water reuse (10% Water Reuse)
C11	High water reuse (60% Water Reuse) + desalination (10%)	80% Primary Source + Low desalination (20%)	Medium water reuse (20% Water Reuse)
C12	High water reuse (60% Water Reuse) + desalination (10%)	80% Primary Source + Low desalination (20%)	High water reuse (30% Water Reuse)

TABLE 4.8: Medium use of alternative resources strategy

Rule	Industry	Domestic	Agriculture
D1	Low water reuse (20% Water Reuse) + desalination (20%)	75% Primary Source + desalination (25%)	100% Primary Source
D2	Low water reuse (20% Water Reuse) + desalination (20%)	75% Primary Source + desalination (25%)	Low water reuse (10% Water Reuse)
D3	Low water reuse (20% Water Reuse) + desalination (20%)	75% Primary Source + desalination (25%)	Medium water reuse (20% Water Reuse)
D4	Low water reuse (20% Water Reuse) + desalination (20%)	75% Primary Source + desalination (25%)	High water reuse (30% Water Reuse)
D5	Medium water reuse (40% Water Reuse) + desalination (20%)	75% Primary Source + desalination (25%)	100% Primary Source
D6	Medium water reuse (40% Water Reuse) + desalination (20%)	75% Primary Source + desalination (25%)	Low water reuse (10% Water Reuse)
D7	Medium water reuse (40% Water Reuse) + desalination (20%)	75% Primary Source + desalination (25%)	Medium water reuse (20% Water Reuse)
D8	Medium water reuse (40% Water Reuse) + desalination (20%)	75% Primary Source + desalination (25%)	High water reuse (30% Water Reuse)
D9	High water reuse (60% Water Reuse) + desalination (20%)	75% Primary Source + desalination (25%)	100% Primary Source
D10	High water reuse (60% Water Reuse) + desalination (20%)	75% Primary Source + desalination (25%)	Low water reuse (10% Water Reuse)
D11	High water reuse (60% Water Reuse) + desalination (20%)	75% Primary Source + desalination (25%)	Medium water reuse (20% Water Reuse)
D12	High water reuse (60% Water Reuse) + desalination (20%)	75% Primary Source + desalination (25%)	High water reuse (30% Water Reuse)

TABLE 4.9: High use of alternative resources strategy

## Chapter 5

# Implementation of new components for ELECTRE-III-H

This chapter describes the implementation of new components to the existing ELECTRE-III-H software. In Figure 5.1, a diagram with the different components of the software is shown. The component with dark background and its name in white is the existing one, which includes the functionality of reading and loading the hierarchy from an Excel input file. The output presented as a preorder is also part of the existing components. On the other hand, the components with light background and black text refers to the new implementations.

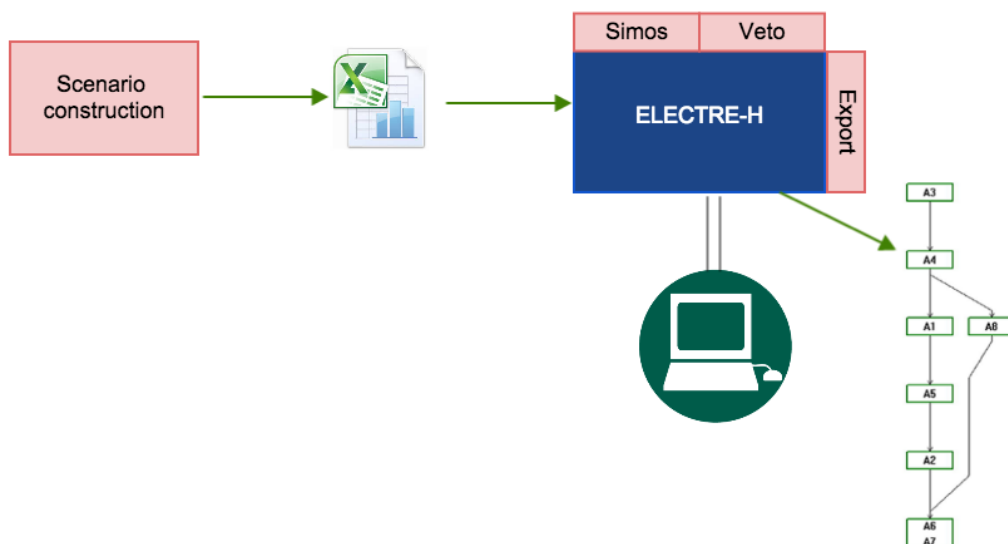


FIGURE 5.1: Architecture of the modules

## 5.1 Integration of the Simos Procedure

The weights in ELECTRE represent the relative importance of each criterion, which can be understood as a voting power of each criterion when it contributes to the majority which is in favour of an outranking. If the importance of the support is higher in one criterion, then more weight should be assigned to that criterion.

The Simos Procedure is a useful tool to assist the decision makers in the definition of an appropriate set of weights. It is considered a tool for problem modelling.

### 5.1.1 The Procedure

Simos proposed in [21, 22] a procedure that allows Decision Makers to express the way in which they wish to prioritize the impact of different criteria on a decision problem. The procedure tries to be a natural and easy way for the Decision Maker and proposes a way of obtaining automatically the relative weight of each criterion on the basis of the information given by the Decision Maker. In [9] a revision of Simos procedure was made, which includes some improvements in the following three aspects:

1. Collection of new kind of information.
2. Procedure in order to obtain the normalized weights.
3. Usage of a new technique that normalizes the weights so as to minimize the rounding off errors.

#### 5.1.1.1 Collecting the information

The person being tested is given  $n$  cards with a criterion's name written on each of them. The user is then asked to rank these cards in an ascending order, that is, from the least important to the most important. If the user considers that some criteria may have the same importance, a subset of cards holding them together should be built. After that, the user is asked to determine the difference in the importance of consecutive criteria. So, white cards can be introduced between two successive cards or a subset of cards with the same importance. A white card symbolizes the difference between the mentioned weights of the criteria. The unit for measuring the intervals between weights is denoted by  $u$ . According to this statement, no white card is equal to a unit  $u$ . One white card means a difference of two times  $u$ , and so on. Later on, the user should attribute a *position* or *rank* to each criterion: the least qualified card will be in *Position 1*, the next

one in *Position 2* and so on. Finally, the user is asked to state "how many times the last criterion is more important than the first one in the ranking" and it is defined as  $z$ .

### 5.1.1.2 Determining the ELECTRE weights of criteria with a Simos Procedure

Once the information collection step is done, the *non-normalized weight* and the *normalized weight* are calculated.

- The *non-normalized weight*  $k(r)$  is calculated using the formula:

$$k(r) = 1 + u(e_1 + \dots + e_{r-1})$$

where  $e'_r$  is the number of white cards between the ranks  $r$  and  $r + 1$  and

$$e_r = e'_r + 1 \forall r = 1, \dots, n - 1$$

$$e = \sum_{r=1}^{n-1} e_r$$

$$u = \frac{z - 1}{e}$$

For these weights, the authors in [9] suggests retaining only two decimal places by rounding off technique to the nearest lower or upper value. The subsets of cards with the same rank will have the same weight  $k(r)$ .

- The *normalized weight*  $k_i$  is derived from the following set of formulas where  $g_i$  is the criterion of rank  $r$  and  $k'_i$  is the weight of this criterion in its non-normalized expression  $k'_i = k(r)$

$$K' = \sum_{i=1}^n k'_i$$

$$k_i^* = \frac{100}{K'} k'_i$$

$k_i''$  is derived from  $k_i^*$  by deleting some of its decimal figures. There are three options in terms of the number of figures after the decimal point that are deleted:

$$\Omega = \begin{cases} 0 & \text{takes into account no figure} \\ 1 & \text{takes into account only one figure} \\ 2 & \text{takes into account only two figures} \end{cases}$$

By using the above mentioned rounding off technique, the following result is obtained:

$$\begin{cases} K'' = \sum_{i=1}^n k_i'' \leq 100 \\ \varepsilon = 100 - K'' \leq 10^{-\Omega} \times n \end{cases}$$

The value  $v = 10^{\Omega} \times \varepsilon$  is an integer at most equal to  $n$ . If  $k_i = k_i'' + 10^{-\Omega}$  is set for  $v$  criteria suitably selected and  $k_i''$  for the another  $n - v$  criteria, it will result in  $\sum_{i=1}^n k_i = 100$  with the normalized weights  $k_i$  showing the required number of decimal places. The choice of  $v$  to set a minimum distorsion of the weights is done with the following algorithm:

1. For each criterion  $g_i$  the ratios  $d_i$  and  $\bar{d}_i$  are calculated

$$d_i = \frac{10^{-\Omega} - (k_i^* - k_i'')}{k_i^*} \quad \text{and} \quad \bar{d}_i = \frac{(k_i^* - k_i'')}{k_i^*}$$

where the ratio  $d_i$  represents the dysfunction concerning the relative error rounded upwards to the nearest whole number and  $\bar{d}_i$  represents also the dysfunction but when rounding downwards.

2. The lists  $L$  and  $\bar{L}$  are created. The list  $L$  is built by the pairs  $(i, d_i)$  ranked according to the increasing values of the ratio  $d_i$ , while the list  $\bar{L}$  contains the pairs  $(i, \bar{d}_i)$  ranked according to the decreasing values of the ratio  $\bar{d}_i$ .  $M = \{i/d_i > \bar{d}_i\}$  and  $|M| = m$ .
3. The  $n$  criteria in  $F$  are partitioned into two subsets  $F^+$  and  $F^-$  where  $|F^+| = v$  and  $|F^-| = n - v$ . Those criteria in  $F^+$  will be rounded upwards to the nearest whole number and the criteria of  $F^-$  will be rounded downwards to the nearest whole number. The authors partitioned  $F$  in the following way:
  - (a) If  $m + v \leq n$  then  $F^-$  is constructed with the  $m$  criteria of  $M$  plus the last  $n - v - m$  last criteria of  $\bar{L}$  not belonging to  $M$ .
  - (b) If  $m + v > n$  then construct  $F^+$  with the  $n - m$  criteria of  $L$  not belonging to  $M$  plus the  $v + m - n$  criteria of  $L$  not belonging to  $M$ .

### 5.1.2 The Simos procedure implementation

The changes made to the software concerning the Simos procedure consists of the possibility of choosing that the values given as input for the Electre-III-H method are normalized using this algorithm. A new entry has been included in the *Options* menu list. Since the algorithm only accepts integer values as ranking positions, a validation was introduced only if the user opts for this procedure. When the input values for the

Electre-III-H method are read from the configuration file, a cardset is built for each criterion that is not a leaf and has more than one child node. A  $z$  value is calculated for each cardset by subtracting the highest ranking value with the lowest one of those criteria that have the same parent node. A list of cardsets as well as the associated  $z$  value are displayed as a list, from which the user can select those of his/her interest as shown in Figure 5.2. When clicking on the *preview* button, the Simos Procedure

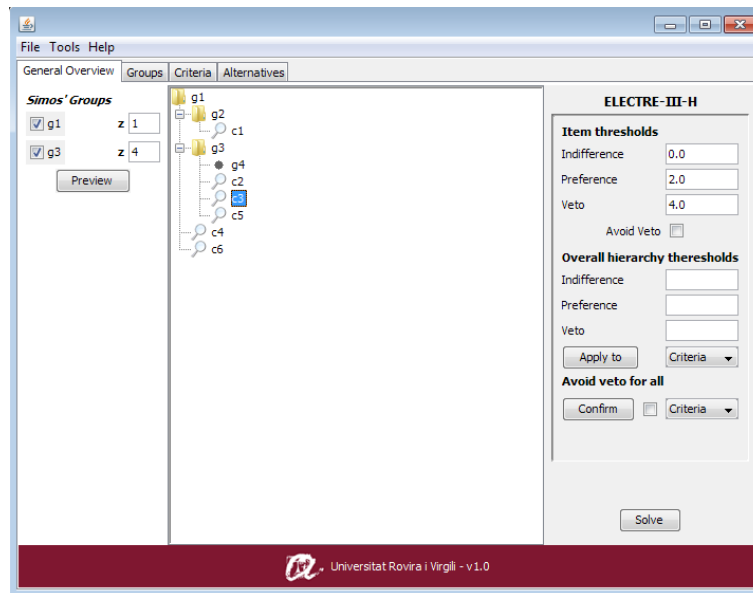


FIGURE 5.2: The list of groups for Simos is on view

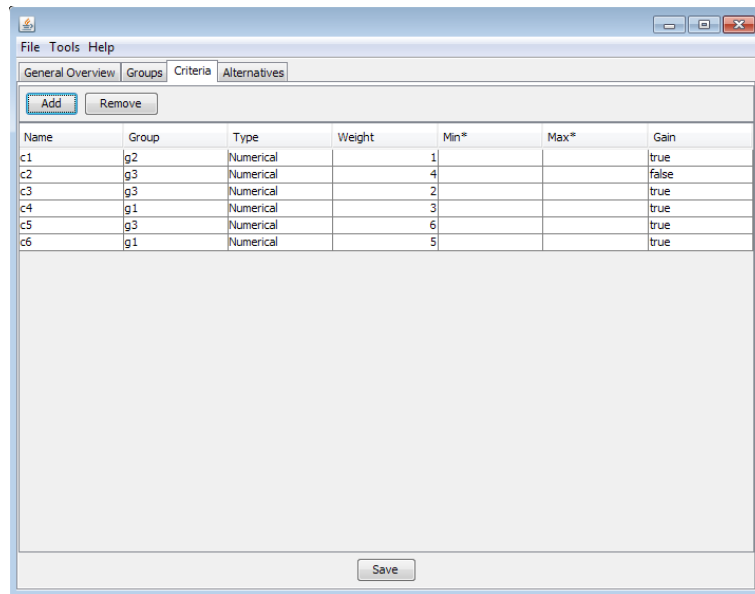
Window is opened. A table with all the selected cardsets with their cards are shown (Figure 5.4). If two or more criteria have the same weight, a subset is built (Figure 5.5). The whitecards have also been worked out using the formula:

$$e'_r = e_r - e_{r-1} + 1$$

The user can change the number of whitecards that are following each of the criterion names.

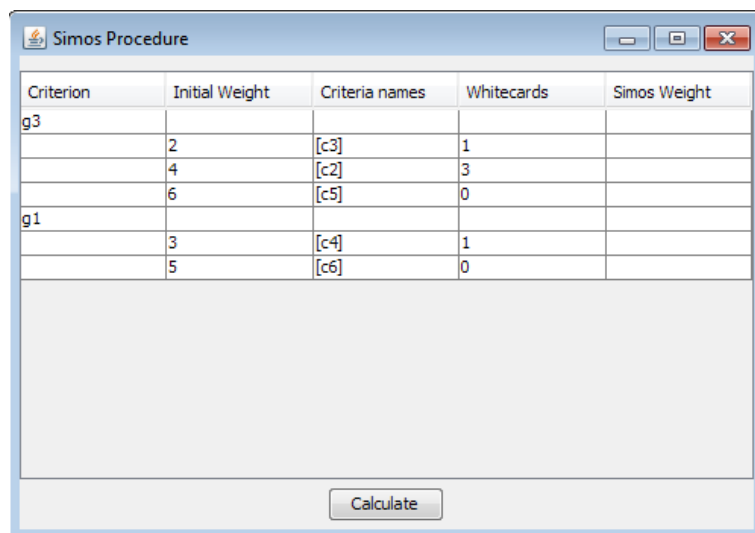
Before the weights calculation using the Simos procedure, the weights of the criteria are the same like those loaded from the configuration file (Figure 5.3).

Clicking on the *Calculate* button will lead to the procedure's calculation. After that, the new normalized weights are displayed in the fourth column of the table (Figure 5.6). These weights are the ones that should be applied in ELECTRE to properly represent the voting power of each criterion. They sum 100 for each parent criterion.



Name	Group	Type	Weight	Min*	Max*	Gain
c1	g2	Numerical	1			true
c2	g3	Numerical	4			false
c3	g3	Numerical	2			true
c4	g1	Numerical	3			true
c5	g3	Numerical	6			true
c6	g1	Numerical	5			true

FIGURE 5.3: The weights of the criteria before using the Simos procedure



Criterion	Initial Weight	Criteria names	Whitecards	Simos Weight
g3	2	[c3]	1	
	4	[c2]	3	
	6	[c5]	0	
g1	3	[c4]	1	
	5	[c6]	0	

FIGURE 5.4: Input parameters for the Simos Procedure have been automatically calculated

The user will then have another choice to make, which is whether those new weight values should replace the original ones in the configuration file. The consequences of applying the Simos weights is shown in Figure 5.7

## 5.2 Generation of the scenarios for the case study

As explained in Chapter 3, the input file accepted by the ELECTRE-III-H Software is an Excel file with the definition of the groups, the intermediate criteria and the alternatives/actions. The model defined for the case study presented in sections 4.2, 4.3 and 4.4

Criterion	Initial Weight	Criteria names	Whitecards	Simos Weight
g1	3	[c4]	1	
	5	[c6]	0	
g3	2	[c3]	1	
	4	[c2, c5]	0	

Calculate

FIGURE 5.5: A subset of criteria with the same weights has been built

Criterion	Initial Weight	Criteria names	Whitecards	Simos Weight
g3	2	[c3]	1	14.8
	4	[c2]	3	25.9
	6	[c5]	0	59.3
g1	3	[c4]	1	33.3
	5	[c6]	0	66.7

Calculate    Use Simos Weights

FIGURE 5.6: Resulting Simos Weights at the most right column

Name	Group	Type	Weight	Min*	Max*	Gain/Loss
c1	g2	Numerical	1			true
c2	g3	Numerical	25.9	4	200	false
c3	g3	Numerical	14.8	0	1,000	true
c4	g1	Numerical	33.3			true
c5	g3	Numerical	59.3			true
c6	g1	Numerical	66.7			true

Save

FIGURE 5.7: Updated criteria values with Simos weights

requires some preliminar process for generating the actions and the calculation of the cost per sector, the index WaSSIR per sector and the EcoStress per river for each action. These values may be different among the actions and depend on the water distribution strategy as well as the supply amount. In order to fill that gap, an new intermediate software module has been developed to automatically construct the performance table for each scenario.

### 5.2.1 The software

This software generates a water supply/demand actions from some input data files. An Excel file representing the performance table and all the criteria definition according to the structure presented in Figure 3.4 is generated, which serves as input file for the ELECTRE-III-H software.

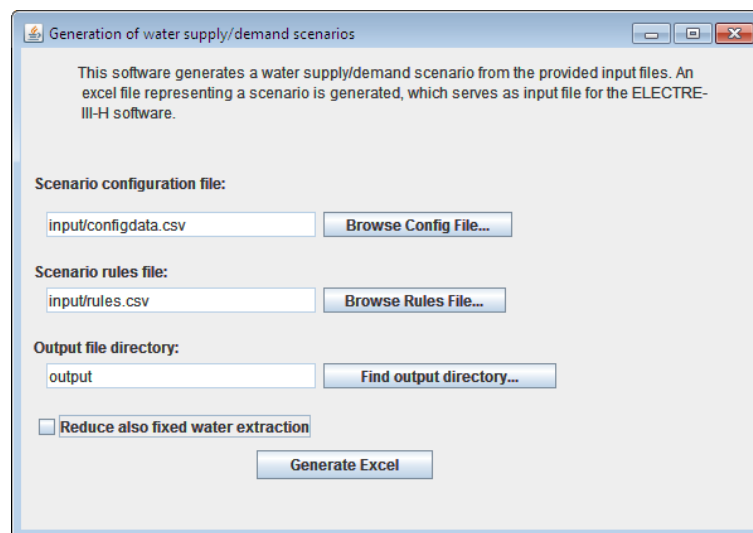


FIGURE 5.8: Main window of the scenarios' construction

The input files along with the output file's path must be selected. When clicking the buttons *Browse Config File...* and *Browse Rules File...*, a window for choosing files is opened. On the other hand, when the button *Find output directory...* is clicked, a window for choosing a folder is opened. If *Reduce also fixed water extraction* is marked, the amount of water extracted for the industrial sector is also reduced according to the water yield reduction percentage, as explained in section 4.2.1. To start with the output file generation, the burron *Generate Excel* should be clicked. A confirmation message indicating the location of the generated file is shown when the process is done.

### 5.2.1.1 Input files

In order to generate a scenario, two files containing the parameters and other basic information have been defined in this thesis:

- *Scenario configuration file*: contains information regarding the scenario, i.e., scenario's name, percentage of water yield reduction with respect to the current scenario, water yield threshold per river, demand per sector, supply per sector, costs per source and sector. Since this information varies among scenarios, one file per scenario is needed.
- *Scenarios rules file*: contains the water distribution rules, from which the actions are constructed. These rules are shared along all scenarios, therefore, only one file is needed.

**The scenario configuration file** The first row contains the water source prices (primary source, desalination and reused water), where each source is in turn subdivided into domestic, industry and agriculture.

The second row consist of values of Current Water Yield (Francolí, Ebro and Gaià)

The third row has the values of the current demand for the following three sectors: industry, domestic and agriculture.

The fourth row contains the scenario's name, the percentage of reduction per river (i.e. Francolí, Ebro and Gaià, in this order) and the threshold yield. For the CC scenarios, the same percentage of reduction is applied for each river, while for the GC scenarios this percentage varies between rivers.

The fifth row consists of the values of the future demand for the following three sectors: industry, domestic and agriculture.

The sixth row refers to the values of the supply for the following three sectors: industry, domestic and agriculture.

The symbol used for the separation between values will be a comma. An example of this file is as follows:

**The scenarios' rules file** It is a comma-separated file with the following structure:

Each row is composed by the name of the rule and three triplets of the form  $\langle Dom, Ind, Agr \rangle$ . The first one refers to % river, the second one to % reuse and the third one to % desalination. Values are given in the range 0...1.

Rule	Industry	Domestic	Agriculture
<Rule name>	<% river>, <% reuse>, <% ds>	<% river>, <% reuse>, <% ds>	<% river>, <% reuse>, <% ds>

TABLE 5.1: A row in the scenarios' rules file

The following is an example containing the first 5 rules:

```
A0,1,0,0,1,0,0,1,0,0
A1,0.8,0.2,0,1,0,0,1,0,0
A2,0.8,0.2,0,1,0,0,0.9,0.1,0
A3,0.8,0.2,0,1,0,0,0.8,0.2,0
A4,0.8,0.2,0,1,0,0,0.7,0.3,0
```

The first row, which rule has name A0, belongs to the current scenario and it is fixed. It is used by some criteria as base value for evaluating the changes in the future scenarios.

### 5.2.1.2 Output file

It is possible to choose the path to save the generated scenario file, which name is set by default and it is formed by scenario\_<name of the scenario>.

### 5.2.2 Example of a scenario's construction

An example of the construction of an scenario, A2, is shown here. As explained before, the name of the scenario is got from the scenario configuration file, which is shown in Figure 5.9. The scenario rules file used in this case is the one in Figure 5.10. when the user clicks on the *Generate* button, an information message is triggered, showing absolute output file path, according to the output directory selected before (Figure 5.11). Finally, an overview of the generated Excel file is shown in Figure 5.12.

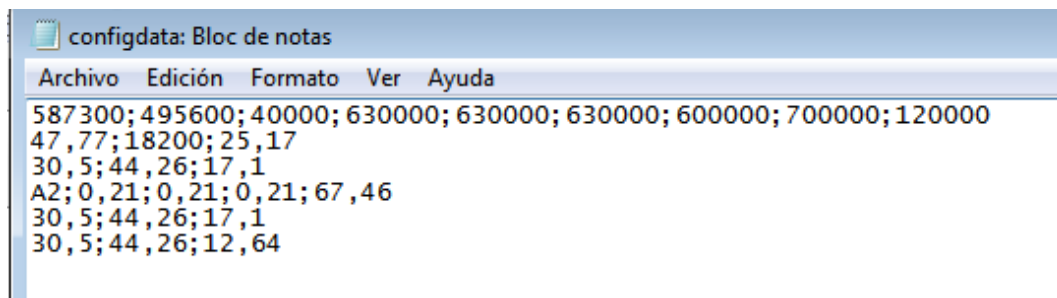
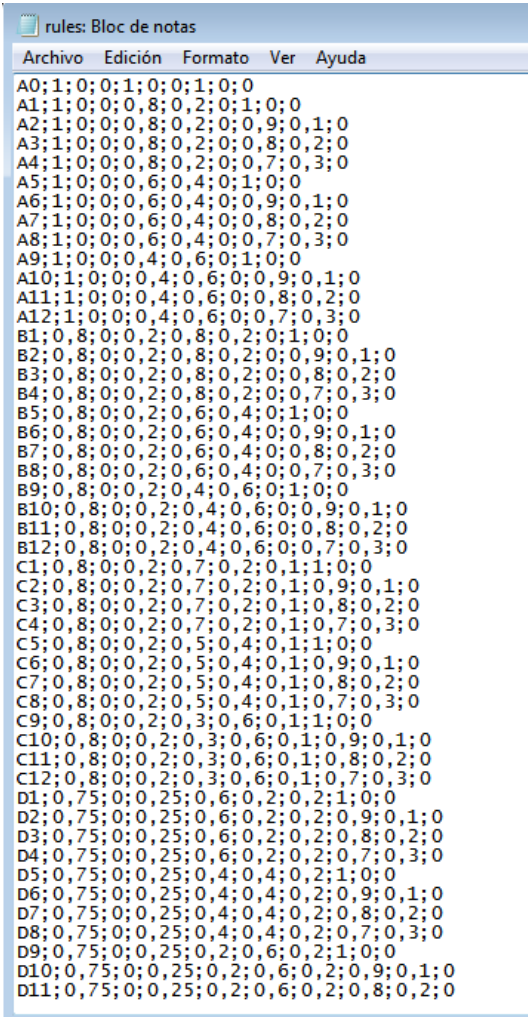


FIGURE 5.9: An example of the scenario configuration file



```

rules: Bloc de notas
Archivo Edición Formato Ver Ayuda
A0:1;0;0;1;0;0;1;0;0
A1:1;0;0;0;8;0;2;0;1;0;0
A2:1;0;0;0;8;0;2;0;0;9;0;1;0
A3:1;0;0;0;8;0;2;0;0;8;0;2;0
A4:1;0;0;0;8;0;2;0;0;7;0;3;0
A5:1;0;0;0;6;0;4;0;1;0;0
A6:1;0;0;0;6;0;4;0;0;9;0;1;0
A7:1;0;0;0;6;0;4;0;0;8;0;2;0
A8:1;0;0;0;6;0;4;0;0;7;0;3;0
A9:1;0;0;0;4;0;6;0;1;0;0
A10:1;0;0;0;4;0;6;0;0;9;0;1;0
A11:1;0;0;0;4;0;6;0;0;8;0;2;0
A12:1;0;0;0;4;0;6;0;0;7;0;3;0
B1:0;8;0;0;2;0;8;0;2;0;1;0;0
B2:0;8;0;0;2;0;8;0;2;0;0;9;0;1;0
B3:0;8;0;0;2;0;8;0;2;0;0;8;0;2;0
B4:0;8;0;0;2;0;8;0;2;0;0;7;0;3;0
B5:0;8;0;0;2;0;6;0;4;0;1;0;0
B6:0;8;0;0;2;0;6;0;4;0;0;9;0;1;0
B7:0;8;0;0;2;0;6;0;4;0;0;8;0;2;0
B8:0;8;0;0;2;0;6;0;4;0;0;7;0;3;0
B9:0;8;0;0;2;0;4;0;6;0;1;0;0
B10:0;8;0;0;2;0;4;0;6;0;0;9;0;1;0
B11:0;8;0;0;2;0;4;0;6;0;0;8;0;2;0
B12:0;8;0;0;2;0;4;0;6;0;0;7;0;3;0
C1:0;8;0;0;2;0;7;0;2;0;1;1;0;0
C2:0;8;0;0;2;0;7;0;2;0;1;0;9;0;1;0
C3:0;8;0;0;2;0;7;0;2;0;1;0;8;0;2;0
C4:0;8;0;0;2;0;7;0;2;0;1;0;7;0;3;0
C5:0;8;0;0;2;0;5;0;4;0;1;1;0;0
C6:0;8;0;0;2;0;5;0;4;0;1;0;9;0;1;0
C7:0;8;0;0;2;0;5;0;4;0;1;0;8;0;2;0
C8:0;8;0;0;2;0;5;0;4;0;1;0;7;0;3;0
C9:0;8;0;0;2;0;3;0;6;0;1;1;0;0
C10:0;8;0;0;2;0;3;0;6;0;1;0;9;0;1;0
C11:0;8;0;0;2;0;3;0;6;0;1;0;8;0;2;0
C12:0;8;0;0;2;0;3;0;6;0;1;0;7;0;3;0
D1:0;75;0;0;25;0;6;0;2;0;2;1;0;0
D2:0;75;0;0;25;0;6;0;2;0;2;0;9;0;1;0
D3:0;75;0;0;25;0;6;0;2;0;2;0;8;0;2;0
D4:0;75;0;0;25;0;6;0;2;0;2;0;7;0;3;0
D5:0;75;0;0;25;0;4;0;4;0;2;1;0;0
D6:0;75;0;0;25;0;4;0;4;0;2;0;9;0;1;0
D7:0;75;0;0;25;0;4;0;4;0;2;0;8;0;2;0
D8:0;75;0;0;25;0;4;0;4;0;2;0;7;0;3;0
D9:0;75;0;0;25;0;2;0;6;0;2;1;0;0
D10:0;75;0;0;25;0;2;0;6;0;2;0;9;0;1;0
D11:0;75;0;0;25;0;2;0;6;0;2;0;8;0;2;0

```

FIGURE 5.10: An example of the scenario rules file

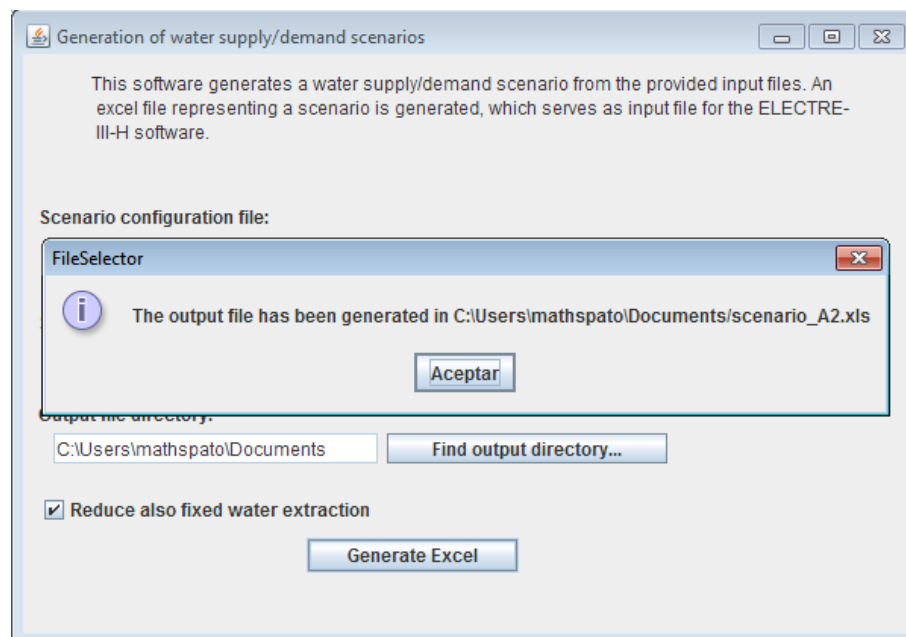


FIGURE 5.11: The software makes the user aware of the output file's path

	A	B	C	D	E	F	G	H	I	J
1										
2		<b>GROUPS</b>								
3	<b>NAME:</b>	cost	WaSSIR	EcoStress	goal					
4	<b>PARENT:</b>	goal	goal	goal	*					
5	<b>WEIGHT:</b>	1	1	1	1					
6	<b>Indiff</b>	0	0	0	0					
7	<b>Pref</b>	0	0	0	0					
8	<b>Veto</b>	0	0	0	0					
9										
10		<b>CRITERIA</b>								
11	<b>NAME:</b>	ind	dom	agr	ind_WaSSIR	dom_WaSSIR	agr_WaSSIR	Francoli	Ebro	Gaiá
12	<b>PARENT:</b>	cost	cost	cost	WaSSIR	WaSSIR	WaSSIR	EcoStress	EcoStress	EcoStress
13	<b>TYPE:</b>	n	n	n	n	n	n	n	n	n
14	<b>WEIGHT:</b>	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
15	<b>MIN:</b>	17990120,000	21935256,000	505600,000	,250	,000	,000	,255	,003	,060
16	<b>MAX:</b>	18405530,000	23421720,000	808800,000	4,000	,333	,428	,356	,005	,060
17	<b>DIRECTIO</b>	-1	-1	-1	1	1	1	-1	-1	-1
18	<b>Indiff</b>	0	0	0	0	0	0	0	0	0
19	<b>Pref</b>	0	0	0	0	0	0	0	0	0
20	<b>Veto</b>	415410,000	1486464,000	303200,000	3,750	,333	,428	,100	,002	,000
21										
22		<b>ALTERNATIVES</b>								
23	<b>A1</b>	17990120,000	21935256,000	505600,000	,250	,000	,000	,356	,005	,060
24	<b>A2</b>	17990120,000	21935256,000	606400,000	,250	,000	,111	,322	,005	,060
25	<b>A3</b>	17990120,000	21935256,000	708000,000	,250	,000	,250	,289	,005	,060
26	<b>A4</b>	17990120,000	21935256,000	808800,000	,250	,000	,428	,255	,005	,060
27	<b>A5</b>	18067590,000	21935256,000	505600,000	,667	,000	,000	,356	,004	,060
28	<b>A6</b>	18067590,000	21935256,000	606400,000	,667	,000	,111	,322	,004	,060
29	<b>A7</b>	18067590,000	21935256,000	708000,000	,667	,000	,250	,289	,004	,060
30	<b>A8</b>	18067590,000	21935256,000	808800,000	,667	,000	,428	,255	,004	,060
31	<b>A9</b>	18145060,000	21935256,000	505600,000	1,500	,000	,000	,356	,004	,060
32	<b>A10</b>	18145060,000	21935256,000	606400,000	1,500	,000	,111	,322	,004	,060
33	<b>A11</b>	18145060,000	21935256,000	708000,000	1,500	,000	,250	,289	,004	,060
34	<b>A12</b>	18145060,000	21935256,000	808800,000	1,500	,000	,428	,255	,004	,060

FIGURE 5.12: An overview of the generated Excel output file

### 5.3 Avoid veto functionality

The purpose of this change is to deny a criterion the right to be against an outranking relation. For that, the user interface with the thresholds' at the right side of Figure 5.13 underwent some changes. As a hierarchical structure is used, the veto can be avoided for any single criterion, for all the intermediate criteria or groups. In any case, there will be no partial discordance at the chosen level of the hierarchy, resulting in a credibility matrix built only taking into account the concordance indexes. The software has been, hence, modified to permit the deactivation of discordance. A careful study of the previous implementation was required and a large testing has been done to validate this functionality.

Following the example shown in Figure 5.13, the veto has been selected to be avoided for all the Groups. Thus, when the user clicks on an intermediate criterion of the hierarchy, below the *Item thresholds*, the user will see that the veto value of the selected criterion is marked to be avoided.

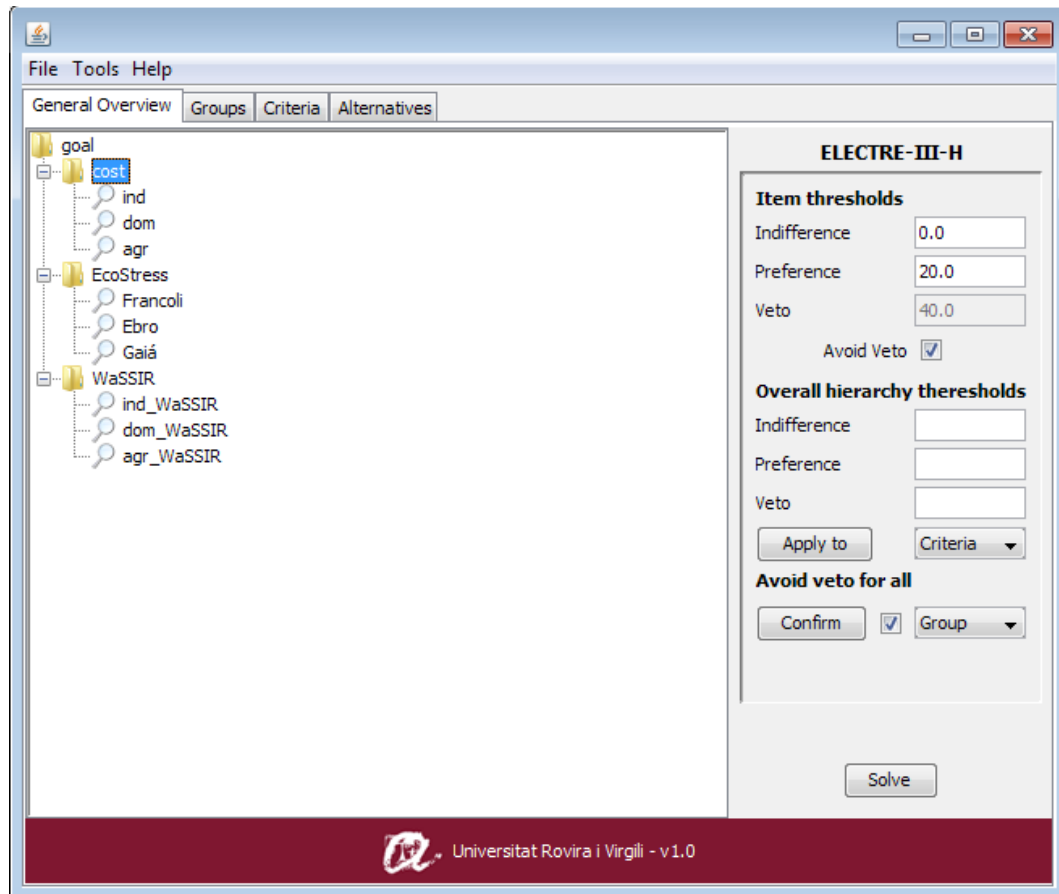
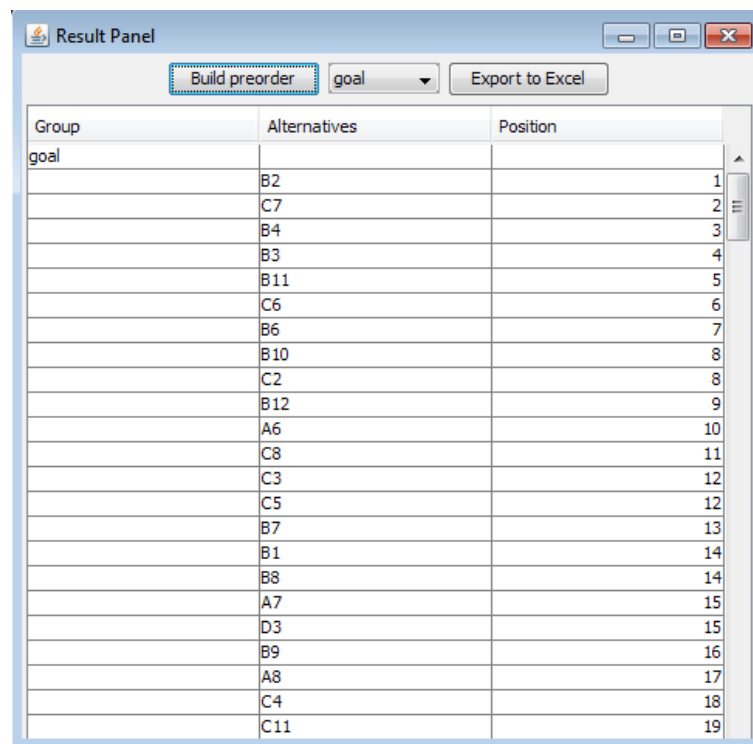


FIGURE 5.13: The veto is avoided for all the intermediate criteria

## 5.4 Export ranking functionality

Due to the large number of alternatives that are analysed in this case study, it was not possible to view the results on the screen, so a new functionality has been designed and implemented. First, the generated output in Figure 5.14 has been ordered according to the ranking position in an ascending order. Additionally, an *Export to Excel* button was added, which causes the exportation to a *csv* file of the final ranking and the ranking at each intermediate node. An example of it can be seen in Figure 5.15.



Group	Alternatives	Position
goal		
	B2	1
	C7	2
	B4	3
	B3	4
	B11	5
	C6	6
	B6	7
	B10	8
	C2	8
	B12	9
	A6	10
	C8	11
	C3	12
	C5	12
	B7	13
	B1	14
	B8	14
	A7	15
	D3	15
	B9	16
	A8	17
	C4	18
	C11	19

FIGURE 5.14: The resulting ranking is shown

	A	B	C	D
1	alternative	ranking	root	
2	B11	1	goal	
3	B10	2	goal	
4	B12	3	goal	
5	B7	4	goal	
6	B8	5	goal	
7	B4	6	goal	
8	C7	7	goal	
9	B3	8	goal	
10	B9	9	goal	
11	B6	10	goal	
12	C6	10	goal	
13	C11	11	goal	
14	B2	12	goal	
15	C8	12	goal	
16	C10	12	goal	
17	C3	13	goal	
18	C12	13	goal	
19	C4	14	goal	
20	C9	14	goal	
21	D3	14	goal	
22	D7	14	goal	
23	C2	15	goal	
24	D4	15	goal	
25	D8	15	goal	
26	D12	15	goal	
27	C5	16	goal	
28	D11	16	goal	
29	B5	17	goal	
30	D2	17	goal	

FIGURE 5.15: The first rows of the exported ranking

## Chapter 6

# Evaluation of water strategies

This chapter presents the obtained results for *Climate change* scenarios, using the ELECTRE-III methodology, several tests with different thresholds are described. These thresholds are limits that are defined to establish cut-off points which aims at distinguishing regions of indifference, preference and refusal of an "*a outranks b*" assertion.

A sensitivity analysis is also carried out, which is a posteriori analysis of the effect on the conclusion when the parameters changes. For this analysis, there is no standard way of comparing preorders, which is the output of the decision problem. Therefore, the preorders have been transformed into rankings and then correlations between those rankings have been calculated. Due to this reason, the sensitivity analysis has been done using different correlation coefficients, which are explained before presenting the results.

The results have permitted us to find the most appropriate configuration of parameters for this problem. The experts of the AGA team have also validated the results proposed by ELECTRE, finding some interesting observations.

### 6.1 Correlation coefficients

There is not a unique and agreed correlation coefficient for comparing ranking. Therefore, the correlation coefficients used for the sensitivity analysis in this work are:

1. Kendall Tau.
2. Spearman.
3. Pearson.

### 6.1.1 Kendall Tau

The Kendall's tau ( $\tau$ ) coefficient, is a statistic used to measure the association between two rankings. A tau test is a non-parametric hypothesis test for statistical dependence based on the tau coefficient. Let  $(x_1, y_1), (x_2, y_2), \dots, (x_n, y_n)$  be a set of observations of the joint random variables  $X$  and  $Y$  respectively, such that all the values of  $(x_i)$  and  $(y_i)$  are unique. Any pair of observations  $(x_i, y_i)$  and  $(x_j, y_j)$  are said to be concordant if the ranks for both elements agree: that is, if both  $x_i > x_j$  and  $y_i > y_j$  or if both  $x_i < x_j$  and  $y_i < y_j$ . They are said to be discordant, if  $x_i > x_j$  and  $y_i < y_j$  or if  $x_i < x_j$  and  $y_i > y_j$ . If  $x_i = x_j$  or  $y_i = y_j$ , the pair is neither concordant nor discordant.

The Kendall  $\tau$  coefficient is defined as:

$$\tau = \frac{(\text{number of concordant pairs}) - (\text{number of discordant pairs})}{\frac{1}{2} n (n - 1)}$$

The denominator is the total number of pair combinations, so the coefficient must be in the range  $-1 \leq \tau \leq 1$ .

1. If the agreement between the two rankings is perfect (i.e., the two rankings are the same) the coefficient has value 1.
2. If the disagreement between the two rankings is perfect (i.e., one ranking is the reverse of the other) the coefficient has value  $-1$ .
3. If  $X$  and  $Y$  are independent, then we would expect the coefficient to be approximately zero.

### 6.1.2 Pearson product-moment correlation coefficient

The Pearson product-moment correlation coefficient is a measure of the linear correlation (dependence) between two numerical measurement variables  $X$  and  $Y$ , giving a value between  $+1$  and  $-1$  inclusive, where 1 is total positive correlation, 0 is no correlation, and  $-1$  is total negative correlation. It is not specific for ranking.

$$\nu_{xy} = \frac{\sum x_i y_i - n \bar{x} \bar{y}}{(n-1) S_x S_y} = \frac{n \sum x_i y_i - \sum x_i \sum y_i}{\sqrt{n \sum x_i^2 - (\sum x_i)^2} \sqrt{n \sum y_i^2 - (\sum y_i)^2}}$$

### 6.1.3 Spearman

The Spearman correlation coefficient is a non-parametric measure of statistical dependence between two variables. It assesses how well the relationship between two variables can be described using a monotonic function. If there are no repeated data values, a perfect Spearman correlation of +1 or -1 occurs when each of the variables is a perfect monotone function of the other. Identical values (rank ties or value duplicates) are assigned a rank equal to the average of their positions in the ascending order of the values. Differences  $d_i = x_i - y_i$  between the ranks of each observation on the two variables are calculated, and  $\rho$  is given by:

$$\rho = 1 - \frac{6 \sum d_i^2}{n(n^2 - 1)}$$

## 6.2 Climate change: analysis of elementary criteria

At the elementary level, the indifference threshold  $q_j$  was agreed to 0 in all the criteria, because any difference in the values is important to be taken into account. The preference threshold  $p_j$  was also set to 0 because no tolerance to a worse value in the evaluation want to be admitted. Finally, the criteria are given a low right of veto so that they are only able to totally veto the majority's opinion if the difference between two evaluations is the maximum permitted in each criterion [ $v_j = \max(g_j) - \min(g_j)$ ].

Criterion's name	Weight	Scale direction	Indifference	Preference	Veto
IndustrialCost	1	minimize	0	0	415410
DomesticCost	1	minimize	0	0	4480224
AgriculturalCost	1	minimize	0	0	303200
IndustrialWaSSIR	1	maximize	0	0	3.750
DomesticWaSSIR	1	maximize	0	0	0.333
AgriculturalWaSSIR	1	maximize	0	0	0.428
FrancoliEcoStress	1	minimize	0	0	0.100
EbroEcoStress	1	minimize	0	0	0.002
GaiaEcoStress	1	minimize	0	0	0.001

TABLE 6.1: The criteria at the elementary level

All criteria have the same weight, which means that every criterion has the same importance for the decision maker.

Once the parameters at the elementary level were set, different approaches were considered for the elementary criteria, going from a stricter approach to a more permissive one. The results are further detailed in the upcoming section 6.3 of this work.

The performance table used is shown in Figure 6.1, which was generated with the software presented in section 5.2.

Alternative	IndustrialCost	DomesticCost	AgriculturalCost	IndustrialWaSSIR	DomesticWaSSIR	AgriculturalWaSSIR	FrancoliEcoStress	EbroEcoStress	GaiaEcoStress
A1	17990120	21935256	505600	0.250	0.000	0.000	0.356	0.005	0.060
A2	17990120	21935256	606400	0.250	0.000	0.111	0.322	0.005	0.060
A3	17990120	21935256	708000	0.250	0.000	0.250	0.289	0.005	0.060
A4	17990120	21935256	808800	0.250	0.000	0.428	0.255	0.005	0.060
A5	18067590	21935256	505600	0.667	0.000	0.000	0.356	0.004	0.060
A6	18067590	21935256	606400	0.667	0.000	0.111	0.322	0.004	0.060
A7	18067590	21935256	708000	0.667	0.000	0.250	0.289	0.004	0.060
A8	18067590	21935256	808800	0.667	0.000	0.428	0.255	0.004	0.060
A9	18145060	21935256	505600	1.500	0.000	0.000	0.356	0.004	0.060
A10	18145060	21935256	606400	1.500	0.000	0.111	0.322	0.004	0.060
A11	18145060	21935256	708000	1.500	0.000	0.250	0.289	0.004	0.060
A12	18145060	21935256	808800	1.500	0.000	0.428	0.255	0.004	0.060
B1	17990120	23124696	505600	0.250	0.250	0.000	0.356	0.004	0.060
B2	17990120	23124696	606400	0.250	0.250	0.111	0.322	0.004	0.060
B3	17990120	23124696	708000	0.250	0.250	0.250	0.289	0.004	0.060
B4	17990120	23124696	808800	0.250	0.250	0.428	0.255	0.004	0.060
B5	18067590	23124696	505600	0.667	0.250	0.000	0.356	0.004	0.060
B6	18067590	23124696	606400	0.667	0.250	0.111	0.322	0.004	0.060
B7	18067590	23124696	708000	0.667	0.250	0.250	0.289	0.004	0.060
B8	18067590	23124696	808800	0.667	0.250	0.428	0.255	0.004	0.060
B9	18145060	23124696	505600	1.500	0.250	0.000	0.356	0.003	0.060
B10	18145060	23124696	606400	1.500	0.250	0.111	0.322	0.003	0.060
B11	18145060	23124696	708000	1.500	0.250	0.250	0.289	0.003	0.060
B12	18145060	23124696	808800	1.500	0.250	0.428	0.255	0.003	0.060
C1	18120355	23124696	505600	0.429	0.250	0.000	0.356	0.004	0.060
C2	18120355	23124696	606400	0.429	0.250	0.111	0.322	0.004	0.060
C3	18120355	23124696	708000	0.429	0.250	0.250	0.289	0.004	0.060
C4	18120355	23124696	808800	0.429	0.250	0.428	0.255	0.004	0.060
C5	18197825	23124696	505600	1.000	0.250	0.000	0.356	0.003	0.060
C6	18197825	23124696	606400	1.000	0.250	0.111	0.322	0.003	0.060
C7	18197825	23124696	708000	1.000	0.250	0.250	0.289	0.003	0.060
C8	18197825	23124696	808800	1.000	0.250	0.428	0.255	0.003	0.060
C9	18275295	23124696	505600	2.333	0.250	0.000	0.356	0.003	0.060
C10	18275295	23124696	606400	2.333	0.250	0.111	0.322	0.003	0.060
C11	18275295	23124696	708000	2.333	0.250	0.250	0.289	0.003	0.060
C12	18275295	23124696	808800	2.333	0.250	0.428	0.255	0.003	0.060
D1	18250590	23421720	505600	0.667	0.333	0.000	0.356	0.003	0.060
D2	18250590	23421720	606400	0.667	0.333	0.111	0.322	0.003	0.060
D3	18250590	23421720	708000	0.667	0.333	0.250	0.289	0.003	0.060
D4	18250590	23421720	808800	0.667	0.333	0.428	0.255	0.003	0.060
D5	18328060	23421720	505600	1.500	0.333	0.000	0.356	0.003	0.060
D6	18328060	23421720	606400	1.500	0.333	0.111	0.322	0.003	0.060
D7	18328060	23421720	708000	1.500	0.333	0.250	0.289	0.003	0.060
D8	18328060	23421720	808800	1.500	0.333	0.428	0.255	0.003	0.060
D9	18405530	23421720	505600	4.000	0.333	0.000	0.356	0.003	0.060
D10	18405530	23421720	606400	4.000	0.333	0.111	0.322	0.003	0.060
D11	18405530	23421720	708000	4.000	0.333	0.250	0.289	0.003	0.060
D12	18405530	23421720	808800	4.000	0.333	0.428	0.255	0.003	0.060

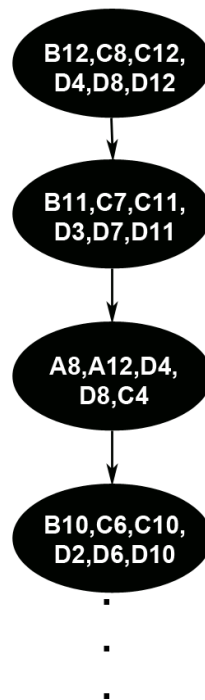
FIGURE 6.1: The performance table used for the *Climate change* scenarios

FIGURE 6.2: Partial preorder of the EcoStress node at the intermediate level

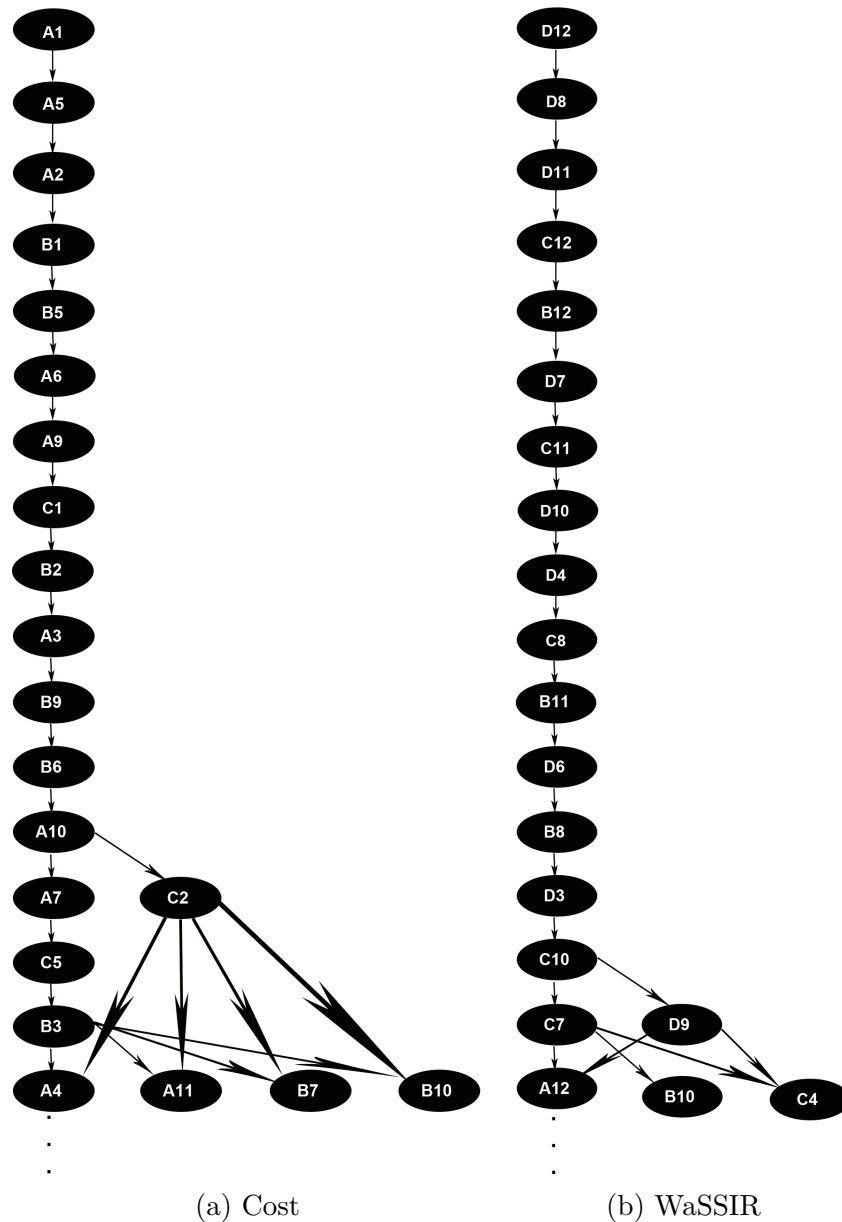


FIGURE 6.3: Partial preorder of the Cost and WaSSIR nodes at the intermediate level

The partial preorders obtained at the elementary level are shown in Figures 6.3 and 6.2. In the EcoStress' partial preorder a large number of indifference relations can be seen. They correspond to cases where the actions have equivalent values on the EcoStress of the 3 rivers. In WaSSIR and Cost the preorder identifies more strict preference relations than EcoStress, leading to a more linear ranking (WaSSIR has 32 positions in the ranking while the Cost criterion has 33, from a total of 48 options).

### 6.3 Climate change: analysis of intermediate criteria

We have performed 8 tests with different configuration of the parameters  $q$ ,  $p$  and  $v$  at the intermediate nodes, as shown in Table 6.2.

The 6 first tests go from the most strict setting (not allowing indifference nor preference and with veto power at all the 3 criteria when difference is of 10 alternatives) to a more tolerant setting (test T6, with preference threshold of 30 and veto activation reduced to a difference higher than 40). In all these 6 cases the parameter values are the same for the three intermediate criteria.

After an analysis of the results, we have designed two more configurations (T7 and T8) that adapt the thresholds to each criterion role and according to the number of ranking positions obtain at each of those nodes.

	$q$	$p$	$v$		$q$	$p$	$v$		$q$	$p$	$v$
<i>Cost</i>	0	0	10		0	0	50		0	5	10
<i>WaSSIR</i>	0	0	10		0	0	50		0	5	10
<i>EcoStress</i>	0	0	10		0	0	50		0	5	10
<b>T1</b>				<b>T2</b>				<b>T3</b>			
<i>Cost</i>	0	25	50		0	20	40		0	30	40
<i>WaSSIR</i>	0	25	50		0	20	40		0	30	40
<i>EcoStress</i>	0	25	50		0	20	40		0	30	40
<b>T4</b>				<b>T5</b>				<b>T6</b>			
<i>Cost</i>	0	10	25		0	10	25				
<i>WaSSIR</i>	0	10	25		0	20	40				
<i>EcoStress</i>	0	5	25		0	5	25				
<b>T7</b>				<b>T8</b>							

TABLE 6.2: Intermediate criteria thresholds

#### 6.3.1 Results

For each of these 8 tests presented above, we will show the group of best alternatives, ordered according to their position in the root node (called Global Ranking). Columns 3 to 5 give the position of each of those alternatives in the rankings obtained at the intermediate level.

## T1. No indifference, strict preference and high veto

Alternative	Global Ranking	Cost Ranking	WaSSIR Ranking	EcoStress Ranking
B11	1	19	11	2
B10	2	17	17	4
B12	3	25	5	1
B7	4	17	18	5
B8	5	22	13	3
B9	6	11	23	6
B6	7	12	20	6
C7	7	21	16	2
A11	8	17	21	5
C11	8	25	7	2

TABLE 6.3: Rankings for T1

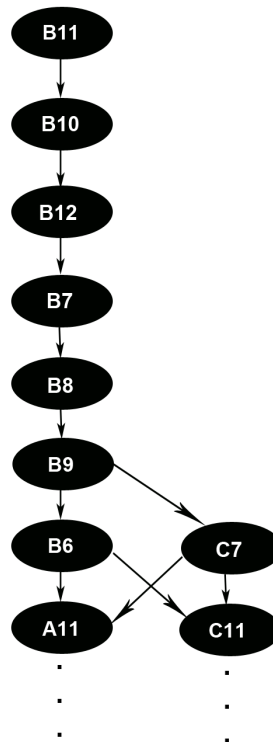


FIGURE 6.4: Global criterion's preorder for T1

In the obtained preorder (Figure 6.4), it can be seen that  $B6$  and  $C7$  are incomparable, it is not clear if " $B6$  outranks  $C7$ " or " $C7$  outranks  $B6$ ".  $B6$  is worst in WaSSIR and EcoStress but is cheaper, while  $C7$  is more expensive but with less environmental impact.

## T2. No indifference, strict preference and low veto

Alternative	Global Ranking	Cost Ranking	WaSSIR Ranking	EcoStress Ranking
B11	1	19	11	2
B10	2	17	17	4
B12	3	25	5	1
B8	4	22	13	3
B7	5	17	18	5
B9	6	11	23	6
C7	6	21	16	2
B6	7	12	20	6
C11	7	25	7	2
A11	8	17	21	5
B5	8	5	27	9
C6	8	18	19	4

TABLE 6.4: Rankings for T2

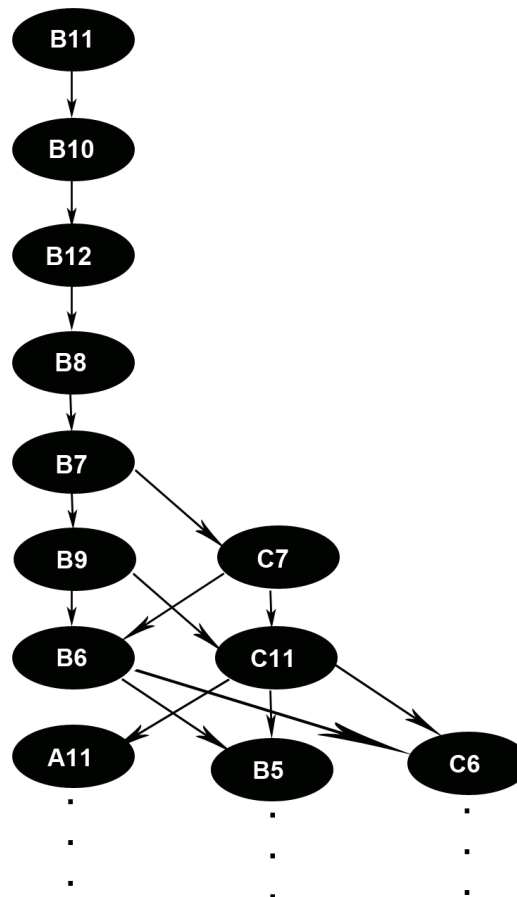


FIGURE 6.5: Global criterion's preorder for T2

$C7$  is preferred to  $B6$ , because we have less veto power. In T1 the cost criterion was vetoing this preference relation (becoming incomparable), but now the veto is not applied and  $C7$  (although it is expensive) is positioned better than  $B6$ .

## T3. No indifference, weak preference and high veto

Alternative	Global Ranking	Cost Ranking	WaSSIR Ranking	EcoStress Ranking
B11	1	19	11	2
B10	2	17	17	4
B12	3	25	5	1
B7	4	17	18	5
B8	5	22	13	3
B9	6	11	23	6
C7	7	21	16	2
C11	7	25	7	2
A11	8	17	21	5
B6	8	12	20	6
A6	9	6	29	6
C6	9	18	19	4

TABLE 6.5: Rankings for T3

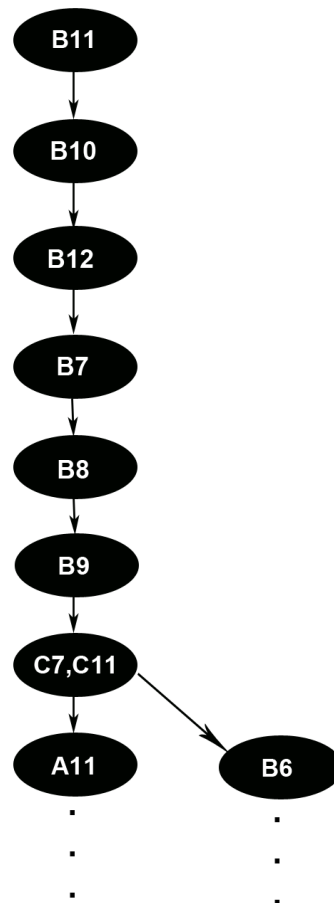


FIGURE 6.6: Global criterion's preorder for T3

$C7$  and  $C11$  are equal in EcoStress, while  $C7$  has cheaper cost but is worst in WaSSIR. Although, the difference is not enough for the veto to be applied. This results in an indifference relation.

## T4. No indifference, weak preference and low veto

Alternative	Global Ranking	Cost Ranking	WaSSIR Ranking	EcoStress Ranking
B11	1	19	11	2
B10	2	17	17	4
B7	3	17	18	5
B12	3	25	5	1
C7	4	21	16	2
B6	5	12	20	6
C6	6	18	19	4
B8	7	22	13	3
B9	8	11	23	6
C11	8	25	7	2
A6	9	6	29	6
A8	9	20	22	3

TABLE 6.6: Rankings for T4

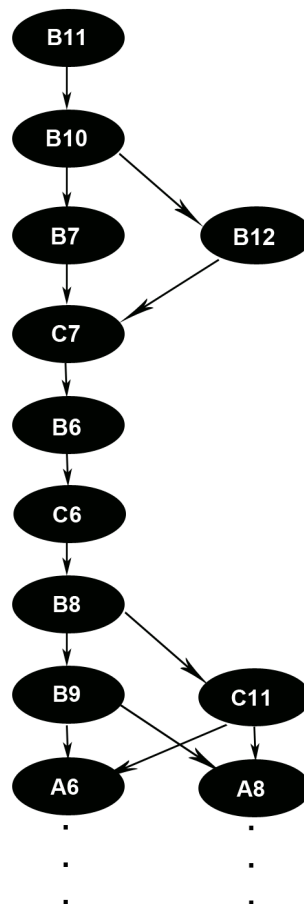


FIGURE 6.7: Global criterion's preorder for T4

This configuration result in an incomparability between  $B7$  and  $B12$ . Although  $B7$  is cheaper, it has also slightly worse EcoStress than  $B12$  but the difference regarding the WaSSIR is in favour of the latter.

T5. No indifference, weak preference and low veto

	<b>Global Alternative Ranking</b>	<b>Cost Ranking</b>	<b>WaSSIR Ranking</b>	<b>EcoStress Ranking</b>
B11	1	19	11	2
B10	2	17	17	4
B12	3	25	5	1
B7	4	17	18	5
C7	5	21	16	2
B6	6	12	20	6
B8	7	22	13	3
C6	8	18	19	4
B9	9	11	23	6
C11	9	25	7	2
A6	10	6	29	6
A11	11	17	21	5

TABLE 6.7: Rankings for T5

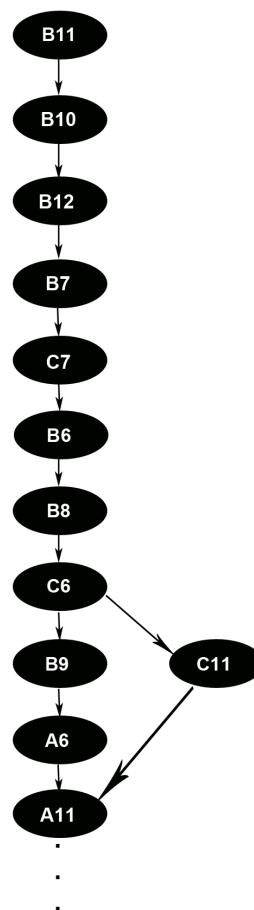


FIGURE 6.8: Global criterion's preorder for T5

T6. No indifference, weak preference and low veto

Alternative	Global Ranking	Cost Ranking	WaSSIR Ranking	EcoStress Ranking
B11	1	19	11	2
B10	2	17	17	4
B12	3	25	5	1
B7	4	17	18	5
C7	5	21	16	2
C6	6	18	19	4
B8	7	22	13	3
B6	8	12	20	6
C11	8	25	7	2
B9	9	11	23	6
A7	10	14	25	5
C12	10	29	4	1

TABLE 6.8: Rankings for T6

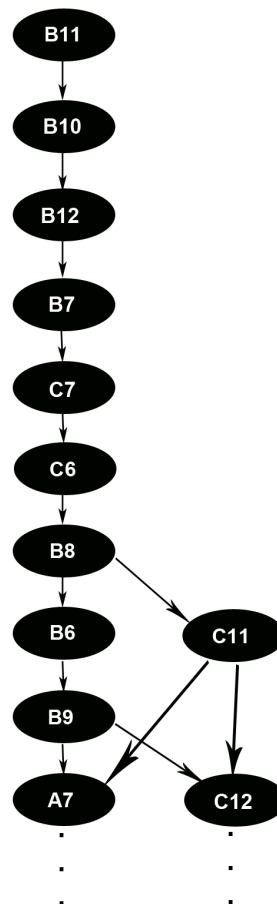


FIGURE 6.9: Global criterion's preorder for T6

T7. Same thresholds for Cost and WaSSIR criteria, different thresholds for EcoStress

Alternative	Global Ranking	Cost Ranking	WaSSIR Ranking	EcoStress Ranking
B11	1	19	11	2
B10	2	17	17	4
B12	3	25	5	1
B7	4	17	18	5
C7	5	21	16	2
B8	6	22	13	3
B9	7	11	23	6
C11	7	25	7	2
A6	8	6	29	6
A11	8	17	21	5
C6	9	18	19	4
B6	10	12	20	6

TABLE 6.9: Rankings for T7

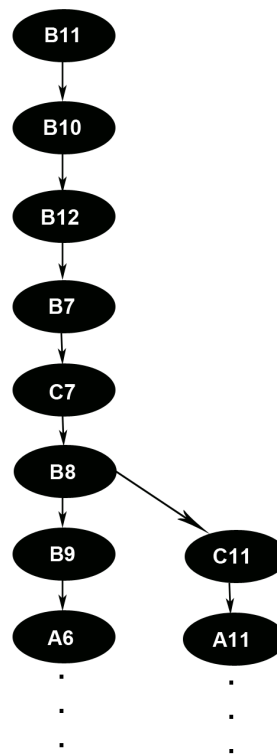


FIGURE 6.10: Global criterion's preorder for T7

After analyzing the obtained results from T1 - T6, the preference threshold for the EcoStress node has been lowered due to the few existing ranking positions since there are many ties (Figure 6.2). Consequently, *B6* has fallen to the 10th position because this configuration is less tolerant with respect to T4, T5 and T6.

## T8. Different thresholds for each criterion

	Global	Cost	WaSSIR	EcoStress
Alternative	Ranking	Ranking	Ranking	Ranking
B11	1	19	11	2
B10	2	17	17	4
B12	3	25	5	1
C7	4	21	16	2
B9	5	11	23	6
A6	6	6	29	6
C6	6	18	19	4
B7	7	17	18	5
B8	8	22	13	3
A11	9	17	21	5
B4	10	21	21	3
C8	10	27	10	1
C11	10	25	7	2

TABLE 6.10: Rankings for T8

This configuration corresponds to one with more tolerance regarding WaSSIR with respect to T7. As it can be noticed in Figure 6.11, *B6* is no longer among the first 10 ranking positions and instead, other alternatives have enhanced their rankings and entered the top 10 (i.e., *B4* and *C8*).

*B9* and *A6* have also moved up some positions despite having a WaSSIR ranking of 23 and 29 respectively due to the less strictness in that criterion.

### 6.3.2 Discussion

A value equal to 0 in the indifference threshold  $q_j$  for the intermediate criteria implies that any difference between the positions of the alternatives in the partial preorders is important to take into account.

In those approaches where the preference threshold  $p_j$  were set to 0, that is, T1 and T2, no tolerance to a worse value is admitted, when calculating the concordance.

It can be seen in the Figures 6.4, 6.5, 6.6, 6.7, 6.8, 6.9, 6.10 and 6.11 that there are three alternatives that are always on top of the ranking (i.e., *B11*, *B10* and *B12*), so they do not suffer any variation despite changing the preference and veto thresholds. Only in T4, the alternative *B12* shares the third position with *B7*, which are incomparables between them.

From the rankings' tables it's also worth to remark that in this environmental problem, the alternative with the best Global ranking does not have the best rankings at all the elementary criteria. The reason why this happens is that the WaSSIR takes into account

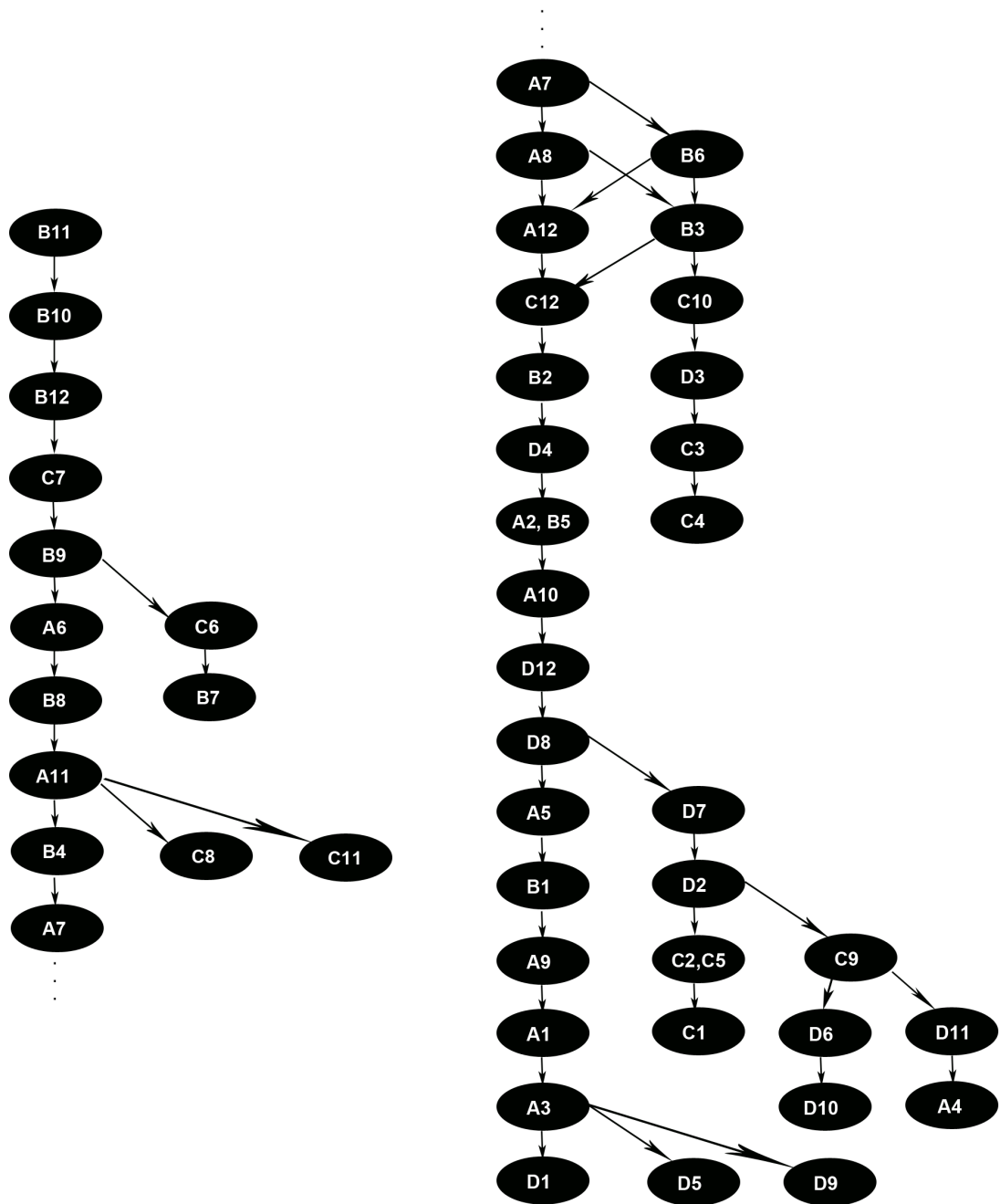


FIGURE 6.11: Global criterion's preorder for T8

only the primary sources. When more water from primary sources are used, the cost will be lower but, on the contrary, the WaSSIR index may decrease and the EcoStress may increase. Oppositely, when more water from alternative resources are extracted, the cost will increase and thus the cost ranking may be worse, but the WaSSIR index may increase. In this last situation, the EcoStress may also decrease.

After this analysis of the results, the recommended options are *B11*, *B10* and *B12*. They correspond to the “low use of alternative resources” strategy. For the industrial sector only 40% should be taken from the rivers, 60% of water reuse and no desalination are

suggested; for the domestic sector 80% of the water should come from the rivers and the rest from desalination; for agriculture between 10% and 30% of the water reuse is recommended.

T1	T2	T3	T4	T5	T6	T7	T8
B1	C3	C5	C9	A4	D6	C4	A1
C4	D2	C4	A2	B1	D10	D11	C1
D6	D9	D4	D10	C9	A1	C5	D6
C1	B1	D11	B1	A9	A4	D10	D11
D2	C5	A4	D1	D9	D9	A4	A3
D10	C2	D10	D9	D10	A9	C1	A4
D9	A4	A3	A9	C1	D5	A3	D10
A4	C1	D9	D5	D1	A3	D1	D1
D1	D1	D1	C1	D5	C1	D5	D5
D5	D5	D5	A3	A3	D1	D9	D9

TABLE 6.11: Worst alternatives

On the other hand, Table 6.11 shows the 10 worst alternatives for each of the eight approaches. The actions *D1*, *D5* and *D9* are always among the last ranking positions, thus they must definitely be avoided. They correspond to the “high use of alternative resources” strategy, where the agricultural sector is exclusively dependent on the primary water sources. Concerning domestic water, 75% of the supplied amount is extracted from primary sources while the rest comes from desalinated water. These alternatives suggest taking 20% of the supply from desalinated water, an increasing percentage of reused water (i.e., 20%, 40% and 60% respectively) and the remaining water supply from the rivers.

### 6.3.3 Correlation study

A first study of sensitivity shows that the ranking of the best alternatives remains the same when the threshold values at the intermediate level are changed. These threshold values have been set from highly strict (T1) to highly tolerant (T7), as presented in Figure 6.12. The rankings have a high correlation with T8 (the best configuration of thresholds), from which we can conclude that the global ranking is consistent.

It can be observed that the Pearson’s and Spearman’s coefficient almost fit graphically, the reason is that these two coefficients have a close relationship. On the other hand, although the Kendall’s Tau coefficients are smaller, they are coherent with respect to the two aforementioned measures. A greater coefficient at Kendall’s Tau corresponds also to a greater coefficient at Pearson’s and Spearman’s, while a smaller coefficient at Kendall’s also matches smaller coefficients at Pearson’s and Spearman’s.

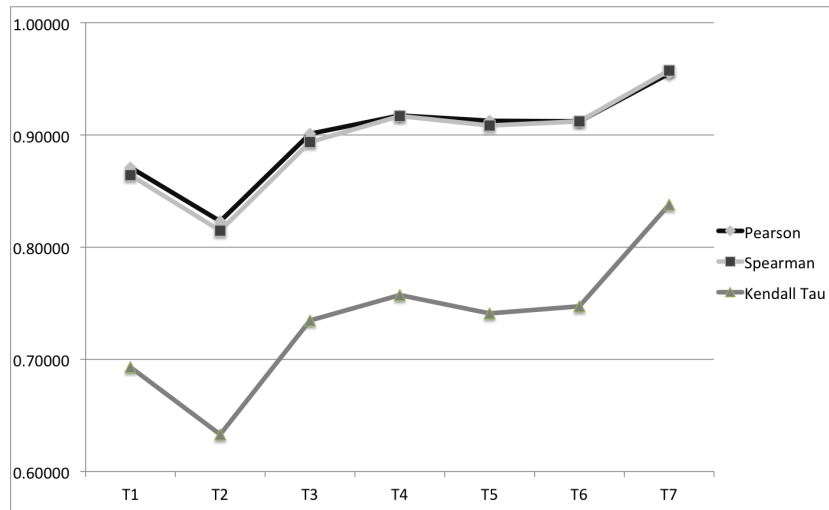


FIGURE 6.12: Correlation with T8

## 6.4 Comparison with Net Flow Score

The same environmental problem has also been solved using Net Flow Score (NFS) by means of the Diviz software. This method makes use of the same operations as in the classical ELECTRE-III to calculate the concordance and discordance indexes and therefore the credibility matrix, however, the exploitation procedure is different. The credibility matrix is converted to a binary one according to the set cut level, which results in a graph with incoming and outgoing arrows in each node. Each alternative from that graph is assigned a qualification that consists of the difference between its strength (number of alternatives outranked by the considered alternative, represented in the graph by the incoming arrows) and its weakness (number of alternatives that outranked the considered alternative), which are the outgoing arrows in the graph.

Since the analyzed problem has initially been thought of being worked out using a two-layered hierarchical structure, two workflows have been built to target this lack in the Diviz software. The NFS method has been used to obtain a ranking of the alternatives in the first layer according to three main topics: cost, Water Supply Stress (WaSSIR) and Ecological Stress (EcoStress). The obtained results have been used in a second layer to obtain a global ranking.

### 6.4.0.1 The first layer

The workflow shown in Figure 6.13 corresponds to the cost criteria. First, the concordance and discordance indexes are calculated identical than in ELECTRE-III-H (same thresholds as Table 6.1). Given the result of the two indexes mentioned before, the

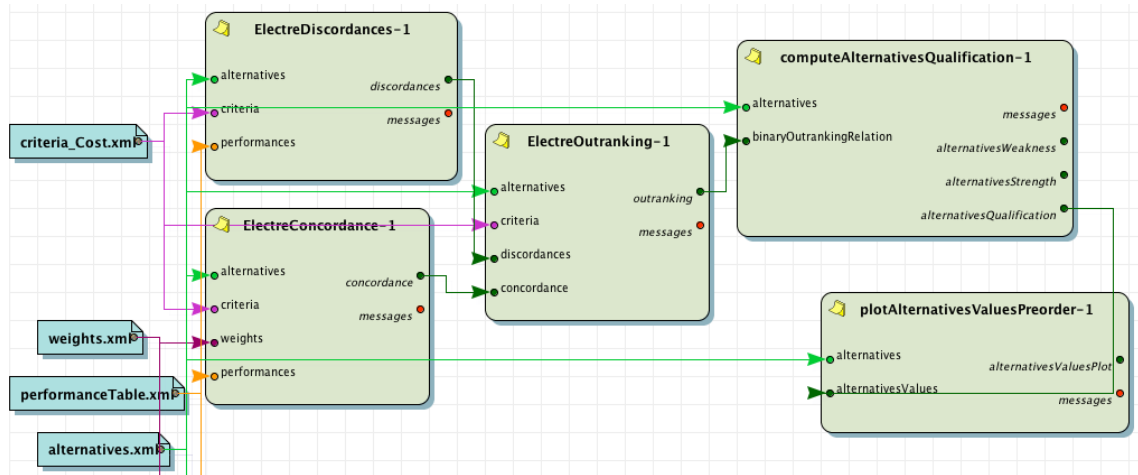


FIGURE 6.13: The workflow used in the first layer

credibility matrix is calculated. The module *computeAlternativesQualification* calculates the qualification of each alternative using NFS. This output is used to draw a preorder. The workflow mentioned before has been repeated for the WaSSIR and EcoStress criteria, each of the criteria uses a different criteria configuration file, namely *criteria\_WaSSIR.xml* and *criteria\_EcoStress.xml* respectively.

The obtained complete preorders can be seen in Figure 6.14. Since those belonging to Cost and WaSSIR have many ranking positions, only the first twenty are shown. As occurred with ELECTRE-III-H, the preorder obtained for EcoStress presents many ties.

On the contrary, unlike the results obtained with ELECTRE-III-H, the lack of incomparabilities can be noticed, which is a piece of information not present in the complete preorder.

Table 6.12 shows the qualification of each alternative. This table is also the performance table used in the second layer.

#### 6.4.0.2 The second layer

The three obtained qualifications for each overall criterion (Cost, WaSSIR and EcoStress) have been used as input in the second layer and the same indifference, preference and veto thresholds as T8 has been used.

The structure of the workflow in this layer is the same as the one used in the first layer (see Figure 6.15).

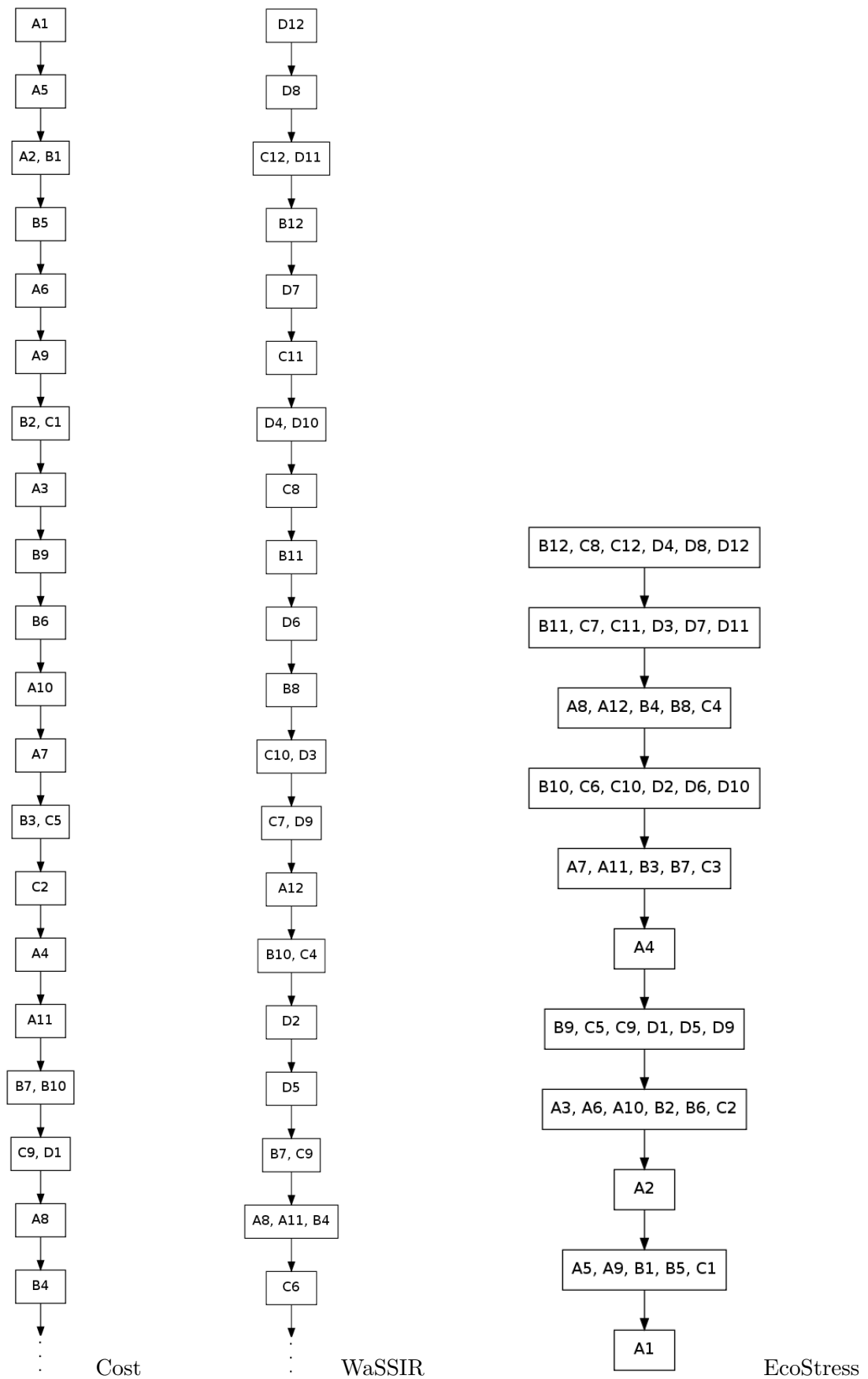


FIGURE 6.14: Partial preorder obtained in the first layer

Alternative	Cost	WaSSIR	EcoStress
A1	47	-47	-47
A2	34	-34	-34
A3	21	-21	-21
A4	8	-8	-8
A5	38	-34	-38
A6	26	-23	-21
A7	14	-12	-4
A8	2	-1	13
A9	25	-17	-38
A10	15	-9	-21
A11	5	-1	-4
A12	-5	7	13
B1	34	-34	-38
B2	23	-23	-21
B3	12	-12	-4
B4	1	-1	13
B5	28	-23	-38
B6	16	-11	-21
B7	4	1	-4
B8	-8	13	13
B9	17	-8	-12
B10	4	4	6
B11	-9	16	24
B12	-22	28	42
C1	23	-29	-38
C2	11	-18	-21
C3	-1	-7	-4
C4	-13	4	13
C5	12	-14	-12
C6	-1	-3	6
C7	-14	8	24
C8	-27	19	42
C9	3	1	-12
C10	-9	12	6
C11	-21	23	24
C12	-33	34	42
D1	3	-6	-12
D2	-9	3	6
D3	-21	12	24
D4	-33	21	42
D5	-3	2	-12
D6	-16	14	6
D7	-29	26	24
D8	-42	38	42
D9	-8	8	-12
D10	-21	21	6
D11	-34	34	24
D12	-47	47	42

TABLE 6.12: The performance table used in the second layer

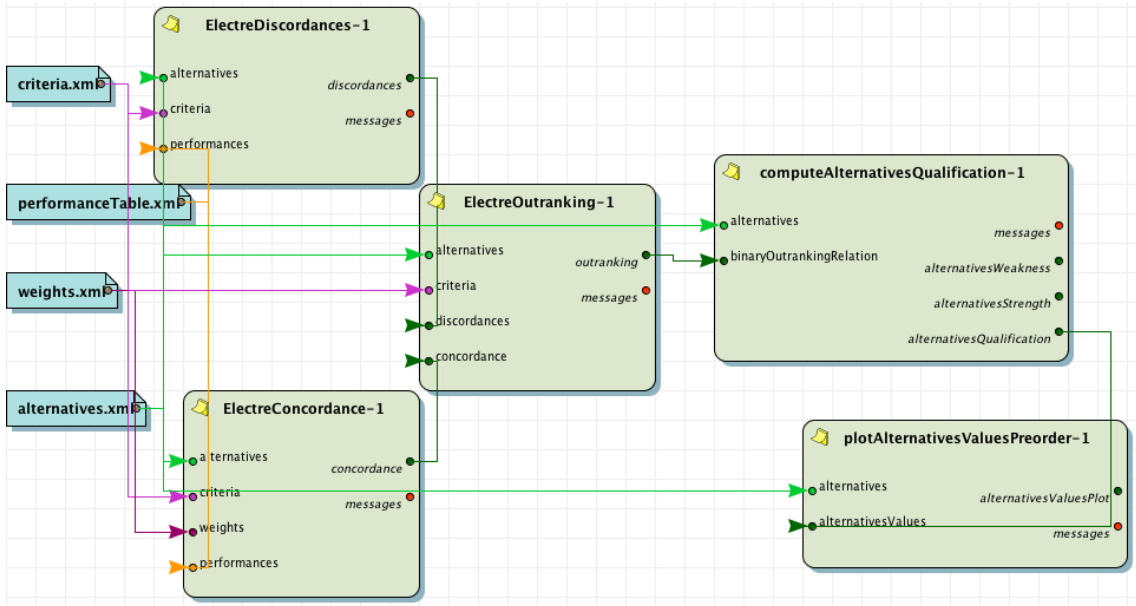


FIGURE 6.15: The workflow used in the second layer

The complete preorder obtained with the NFS method (Figure 6.16) differs from the one obtained using the ELECTRE-III-H software (Figure 6.11). The latter presents more incomparability relations at the lower positions of the ranking. NFS does not accept incomparabilities and thus the alternatives are forced to have a preference, inverse preference or indifference relation. The alternatives  $A8$  and  $A12$  are not ranked among the first 10 positions using ELECTRE-III-H, however, they gained positions with NFS since they are placed 2nd and 4th respectively, thus these two alternatives are overvalued with NFS.

On the contrary, we can say that *"the best are the best"* since the best 3 alternatives are invariant between the two methods.

The alternatives  $D1$ ,  $D5$  and  $D9$ , which are placed among the worst five ranking positions with NFS are considered as the worst alternatives with ELECTRE-III-H.

Summarizing, NFS presents the inconveniences that it does not accept incomparable relations. Additionally, the lack of a hierarchical structure has to be compensated with a two-step solution. Moreover, a cut threshold must be set for the exploitation procedure. The results may suffer important variations according to the value of the cut threshold, which in many cases are decided arbitrarily. Therefore, we conclude that the structure is much richer with ELECTRE-III-H.

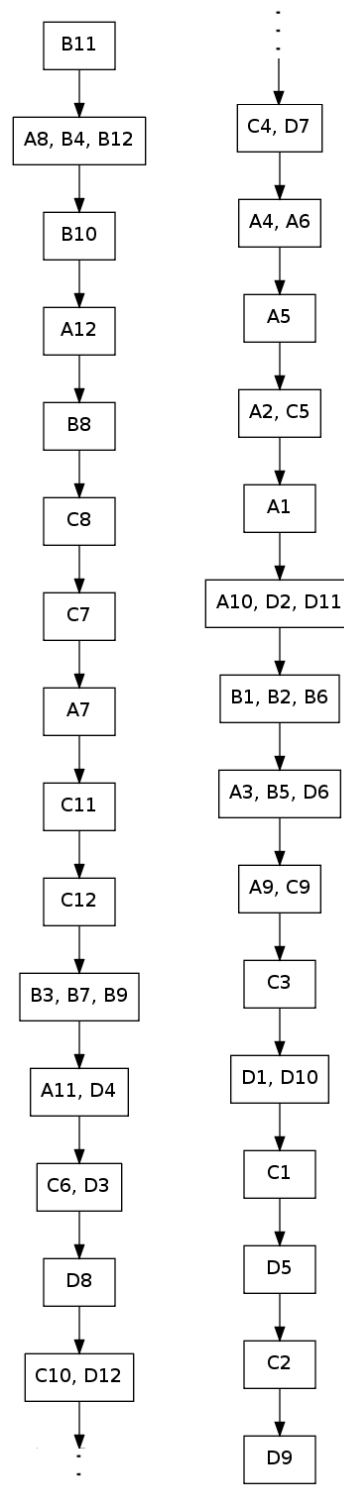


FIGURE 6.16: The whole obtained global preorder with NFS

## Chapter 7

# Conclusions and future work

In this thesis, the modeling of the presented environmental decision problem is carried out. For that, numerous meetings with the members of the AGA research group, which are the decision makers, has been held in order to understand the problematic and to refine the model before agreeing with the most suitable one according to their needs, which is the one proposed in this work.

To conduct this work, several goals were formulated and now it can be said that they have been completely accomplished:

- A study of the outranking methods and the extension of ELECTRE-III to a hierarchical structure of criteria has been done in the first place.
- A formalization of the water resources management's problem using the MCDA model has been proposed. For that, a hierarchical subset of criteria as well as a set of alternatives and their corresponding evaluations were built. By means of the implemented new components for the ELECTRE-III-H software, it was possible to pre-process the input data provided by the experts and generate the scenarios for this case study.
- This work has also served as a revision of the ELECTRE-H software that is being developed in the ITAKA group, which could cover many of the particularities of this specific problem to analyze the problem.
- After many tests, the most appropriate parameters for this problem have been established, according to the ELECTRE outranking method: weights, indifference thresholds, preference thresholds, veto thresholds, etc.
- The ELECTRE-H method has been applied to the input dataset considering different water management strategies and different scenarios.

The decision support system presented in this thesis has shown quite interesting results from the environmental point of view. The appropriate allocation of water in future conditions of climate change is crucial since water scarcity is highly expected for a major part of the world. The Mediterranean rivers are more prone to drought, specially the small rivers such as the ones that provide water to Tarragona city. The proposed method is useful for water managers as it gives the possibility to integrate different management criteria and water allocation strategies into a single modeling framework and explore the different adaptation measures without losing transparency in the analysis.

It was of particular interest the fact that the problem has been targeted using a two-layered hierarchy and it has been important for the experts to make it possible for them to analyze different indexes separately (i.e. WaSSIR and EcoStress).

The present work has been submitted as a conference paper, the related information is: *A hierarchical decision support system to evaluate the effects of climate change in water supply in a Mediterranean river basin*

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*Submitted to: International Conference of the Catalan Association for Artificial Intelligence (CCIA), 2014. In review.*

This work is part of a research project that studies the allocation of water among competing uses (industry, agriculture and municipal) due to global change (not only climate, but also demographic and economic). Global change will affect the current patterns of water demand. So, as future research work, the extension of this model of evaluation based on ELECTRE-III-H to other scenarios of global change can be suggested, including different demand driving factors. Thus, different policies can be used to generate optimistic, pessimistic and neutral demand scenarios.

From a personal perspective, this work been useful to apply knowledge acquired from the different subjects I took to persue the degree of *Master in Computer Security and Intelligent Systems*. Also, it has been particularly interesting and challenging to work in a multidisciplinary team with the modeling of real projects.

# Bibliography

- [1] Alcamo J., Flöke M., Märker M., *Future long-term changes in global water resources driven by socio-economic and climatic changes*. Hydrological Sciences Journal 52 (2), pp. 247–275. 2007.
- [2] Arondel C., Girando P., *Sorting Cropping Systems on the Basis of Impact of Groundwater Quality*, European Journal of Operational Research 127, pp. 467–482, 2000.
- [3] Bangash R. F., Passuello A., Hammond M., Schuhmacher Marta, *Water allocation assessment in low flow river under data scarce conditions: A study of hydrological simulation in Mediterranean basin*. Science of the Total Environment 440, pp. 60-71, 2012.
- [4] Cavallaro F., *A comparative assessment of thin-film photovoltaic production processes using the ELECTRE-III method*, Energy Policy 38, pp. 463–474, 2010.
- [5] Del Vasto Terrientes L., Valls A., Slowinski R., Zielniewicz P., *Extending Concordance and Discordance Relations to Hierarchical Sets of Criteria in ELECTRE-III Method*, MDAI, pp. 78-89. Girona, Spain, 2012.
- [6] Del Vasto Terrientes L., Valls A., Slowinski R., Zielniewicz P., *The ELECTRE-III method for making decisions based on outranking relations with hierarchically structured criteria*, Submitted to Expert Systems with Applications, Elsevier, 2014.
- [7] Figueira J., Greco S., Ehrgott M. (eds.), *Multicriteria decision analysis: State of the Art Surveys*. Springer, Berlin, 2005.
- [8] Figueira J., Greco S., Roy B., Slowinski R., *ELECTRE Methods: Main Features and Recent Developments*. Chapter 3 [in]: C.Zopounidis, P.M.Pardalos (eds.), Handbook of Multicriteria Analysis, pp. 51-89. Springer, Berlin, 2010.
- [9] Figueira J., Roy B., *Determining the weights of criteria in the {ELECTRE} type methods with a revised Simos' procedure*, European Journal of Operational Research Volume 139, Issue 2, pp. 317-326, 2002.

- [10] Figueira J., Roy B., Mousseau V., ELECTRE Methods. In J. Figueira, S. Greco and M. Ehrgott (Eds.), *Multiple Criteria Decision Analysis: State of the Art Surveys*, pp. 133-162. New York, U.S.A.: Springer Science + Business Media, Inc., 2005.
- [11] Flöke M., Kynast E., Bärlund I., Eisner S., Wimmer F., Alcamo J., *Domestic and industrial water uses of the past 60 years as a mirror of socio-economic development: A global simulation study*. *Global Environmental Change* 23, pp. 144–156, 2013.
- [12] Khalili N.R., Duecker S., *Application of multi-criteria decision analysis in design of sustainable environmental management system framework*, *Journal of Cleaner Production* 47, pp. 186-198, 2013.
- [13] Marquès M., Bangash R.F., Kumar V., Sharp R., Schuhmacher M., *The impact of climate change on water provision under a low flow regime: A case study of the ecosystems services in the Francoli river basin*, *Journal of Hazardous Materials* 263 (1), pp. 224–232, 2013.
- [14] Norese M.F., *ELECTRE-III as a support for participatory decision-making on the localization of waste-treatment plants*, *Land use policy* 23, pp. 76–85, 2006.
- [15] OECD (Organization of Economic Cooperation and Development), *Water consumption and sustainable water resources management*. Report of the OECD, Paris, France, 1998.
- [16] Roy B., *Analyse et choix multicritère*, *Informatique et Gestion* num. 57, pp. 21-27, 1974.
- [17] Roy B., *Methodologie Multicritèrie d'Aide à la Décision*, Economica, Paris, 1985.
- [18] Roy B., The outranking approach and the foundation of ELECTRE methods, *Theory and Decision* 31, pp.49-73, 1991.
- [19] Roy B., Slowinski R., *Criterion of distance between technical programming and socio-economic priority*, *Revue française d'automatique, d'informatique et de recherche opérationnelle*. *Recherche opérationnelle* 27 (1), pp. 45-60, 1993.
- [20] Salgado B., Majamaa K., Sanz J., Molist J., *Design and start-up experiences of 19,000m<sup>3</sup>/d Camp de Tarragona-Vilaseca Water Reclamation Plant*, *Desalination and Water Treatment* 51, pp. 1519-1526, 2012.
- [21] Simos J., *L'évaluation environnementale: Un processus cognitif négocié*. Thèse de doctorat, DGF-EPFL, Lausanne., 1990a.
- [22] Simos J., *Evaluer l'impact sur l'environnement: Une approche originale par l'analyse multicritère et la négociation*. Presses Polytechniques et Universitaires Romandes, Lausanne, 1990b.

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- [23] Varies O., Kajander T., Lemmela R., *Climate and water: from climate models to water resources management and vice versa*, Climatic Change 66, pp. 321-344, 2004.
- [24] Vincke P., *Outranking approach*. Chapter 11 [in]: Gal T., Stewart T. J., Hanne T.(eds.), Multicriteria Decision making. Advances in MCDM models, algorithms, theory and applications., pp. 305-333. Springer US, 1999.



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