Assessment of water-energy planning using qualitative multiple criteria decision aiding in a village of Costa Brava (WORKING PAPER)

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Abstract

Multi-criteria decision-making under uncertainty are accepted as suitable techniques in conflicting problems that cannot be represented by numerical values, in particular in water-energy planning. In this paper, a qualitative multi-criteria group decision-making with qualitative linguistic labels is proposed. This method addresses uncertainty with different levels of precision and ranks multi-criteria alternatives. Each decision maker's judgment on the performance of alternatives with respect to each criterion is expressed by qualitative linguistic labels. The new method takes into account qualitative and quantitative variables provided by the decision makers simultaneously. Decision maker judgments are incorporated into the proposed method to generate a complete ranking of alternatives. A real case study in a Costa Brava village (Catalonia, Spain) for improving the water problem in this touristic Mediterranean coastal area, has been performed. In this application, different water scenarios are ranked taking into account qualitative and quantitative levels of variables using simulation water-energy model and qualitative assessment.

Keywords:
Multi-criteria decision-making, linguistic labels, qualitative reasoning, TOPSIS, water planning

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1. Introduction

Multi-criteria decision-aiding (MCDA) approaches, introduced in the early 1970s, are powerful tools used for evaluating problems and addressing the process of making decisions with multiple criteria. MCDM involves structuring decision processes, defining and selecting alternatives, determining criteria formulations and weights, applying value judgments and evaluating the results to make decisions in design, or selecting alternatives with respect to multiple conflicting criteria (Carlsson and Fuller 1996; Yilmaz and Dagdeviren 2011). Moreover, MCDM techniques have a strong decision support focus and interact with other disciplines such as intelligent systems dealing with uncertainty. Some of the currently used MCDM methods, in which

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the present study can be included, support decision makers in all stages of the decision-making process by providing useful data to assess criteria with uncertain values (Kara and Onut 2010).

Tourism is a major activity for some Mediterranean areas economy. The growth of tourism on the last few decades has had many positive effects, while it has caused drawbacks to environment when this growth has not been planned in a sustainable way. The analysis of influential factors can help to assist the design of advanced solutions for the planning and management of sustainable tourism in these areas (Chan & Lam, 2010). These solutions can have an impact both on inhabitants and tourists, which will benefit sustainable tourism from the economic, social and environmental points of view. Tourism is both dependent on fresh water resources and an important factor in fresh water use. Fresh water is also needed to maintain the gardens and landscaping of hotels and attractions, and is embodied in tourism infrastructure development, food and fuel production (Bramwell, & Lane, 2012; Pegas and Castley 2014).

In particular, tourism provides environmental impact such as energy consumption, water consumption, pollution and waste outputs (water quality and air quality). Within the accommodation sector, private homes and hotels are the primary contributors to energy and water use (Gossling, Peeters, Hall, Ceron, Dubois, Lehmann & Scott, 2012). In cases where water can be re-used, changed water properties can be more relevant in sustainability terms than the amount of water actually consumed. The impact of tourism on water availability and water quality is dependent on a wide range of factors, such as the relative abundance and quality of water in the respective tourism region, current and anticipated future water abstraction rates (Stephen, Kent & Newnham, 2004; Chris & Sirakaya, 2006).

Fresh water resources are becoming scarce in many countries, as a result of population growth, increasing pollution, poor water management practices, and climatic variations. Despite increasingly efficient water use in many developed countries, the demand for fresh water has continued to climb as the world's population and economic activity have expanded. According to some recent projections, in 2025 two thirds of the world's population will be suffering moderate to high water stress and about half of the population will face real constraints in their water supply. The situation is particularly critical in the Middle East and North Africa. Almost all conventional water resources have already been exploited in Saudi Arabia, the Arab Emirates, Oman, Qatar, Kuwait, Bahrain, Yemen, Jordan, Israel, Palestinian Territories and Libya; they are expected to be fully exploited in several other countries within the next few years. The water crisis has also affected some temperate regions with normally plentiful resources, such as Europe and North America, where periods of drought are becoming more frequent and are lasting longer. Many parts of France, Italy, Spain and the UK have suffered successive droughts over the last few years, with the result that some watercourses have dried up and the level of groundwater supplies has reached a critical point. One approach used to evaluate water scarcity is the exploitation rate of water resources (the ratio between the volume of available renewable water resources and annual withdrawals). When the exploitation rate exceeds 20% of existing reserves, water management becomes a vital element in country's economy.

Various strategies have been developed over the years in response to growing water demand, such as building infrastructures to transport water to deficient areas. Because such projects require much time and money, alternative solutions are being proposed, such as desalinating seawater or brackish water, water reuse and water conservation measures using water-efficient technologies such as drip irrigation and low-volume flush systems. In discussing alternatives, it is important to examine not only technical solutions but also socio-economic issues such as willingness to pay, public perceptions, risk analysis, assessment of monetary and non-monetary benefits, as well as the environmental impacts. The water reuse option is often not only the most cost-effective solution, but it has the advantage of valorizing the social and environmental value of water, enhancing a region's resource availability and minimizing waste water outflow with additional environmental benefits.

Most of the studies only considered the numerical indicators which can be measured based on available information of the city but on the other hand it is very important to take into account qualitative indicators by asking experts about their preferences. In this study, the quantitative indicators have been measured by simulation and the qualitative indicators values obtained by asking experts of different group from technical and economic section, environmental section, hotels and managers (at least one expert from each group), using qualitative interval basic and non-basic labels to measure qualitative alternatives for final ranking (Aggregation methods).

The study of ranking processes is considered also an interesting issue particularly in artificial intelligence. One of the active sub-fields of research in AI is linguistic modeling. It refers to some variables which nature is not crisp (especially for social and environmental aspects) when uncertainty is occurred due to either lack of information or imprecision in DM' assessments [**? ?**]. Frequently, these uncertainties are captured by using linguistic labels or fuzzy sets to evaluate the set of criteria or indicators [**?**]. It is also necessary to distinguish between internal uncertainties (related to DM values and judgments) and external uncertainties (related to imperfect knowledge concerning consequences of actions) [**?**].

Linguistic approaches have been widely used in MCDM methods in several fields such as power generation for tri-generation systems [**? ? ?**], urban planning [**? ? ?**], Life Cycle Impact Assessment [**?**] and many others. In water-energy planning, different aspects of environmental assessments have been considered in various studies, for example developing the local energy sources to rank energy alternatives [**?**], evaluating water resources [**?**], assessing renewable energy alternatives [**? ? ?**]. Although many studies applied decision aiding methods in water-energy planning, there is a gap between the study of quantitative variables using optimization water model and qualitative variables by linguistic assessment under uncertainty, simultaneously.

As previously stated, the purpose of this study is to elaborate a qualitative multi-criteria method for the performance assessment of different scenarios, taking into account the inherent complexity and uncertainty of the decision-making problem. To this end, this section introduced the context, theoretical framework together with relevant studies. In Section 2, first a method for selecting and weighting variables to obtain the set of qualitative and quantitative variables is introduced. Second, these variables have been measured for the given alternatives and finally a multi-criteria decision aiding method based on linguistic assessments is presented to compare and rank alternatives. Section 3 presents an application of proposed method to select the best scenario for water planning in Costa Brava, Catalonia, Spain. Finally, in Section 4, conclusions are drawn and suggestions made for further work.

2. A Multi-criteria decision aiding method based on linguistic assessments

Multi-criteria decision-making methods support decision makers in all stages of the decision-making process by providing useful information. However, criteria are not always certain as uncertainty is a feature of the real world. Multi-criteria decision-making methods under uncertainty are accepted as suitable techniques in conflicting problems that cannot be represented by numerical values, in particular in water-energy analysis and planning.

2.1. *Selecting and weighting variables*

Surveys, qualitative median and a consensus degree based on length of connected union Adaptation of Borda-Kendall

2.2. *Measuring variables for the given alternatives*

2.2.1. *Quantitative variables measurement*

The quantitative simulation model used in this case study produces several outputs. Some variables from the model are tracked for each alternative in order to use in the multi-objective comparative analysis. The quantitative variables tracked include:

- i Investment Costs: Investment costs for each alternative (e.g. building a new water transfer pipeline or a new desalination plant) are calculated as an amortized annuity based on an expected lifespan of each investment and estimated interest rate.
- ii Operation Costs: Operation costs for each alternative is based on a parameter specifying the cost per unit volume of water processed (Eurs/m^3) for each process.
- iii Energy Consumption: Energy consumption for each alternative is based on a parameter specifying the energy consumption per unit volume of water processed (KWh/m^3) for each process.
- iv Water losses: Water losses for each alternative are calculated based on a parameter which defines the percentage loss of water for each process.

2.2.2. *Qualitative variables measurement*

2.3. *Comparing and ranking alternatives*

The objective of ranking problems is to aid decision maker to simplify the "most attractive" actions in to equivalent classes. The ranking consists in ordering a set of solutions. The aim is finding the goodness of all alternatives, which is usually presented as a ranking from the best to the worst. They are completely or partially ordered with respect to the preferences. The final output is the ordering procedure. In the following section, we are going to present qualitative TOPSIS decision aiding method which is suitable for ranking alternatives.

2.3.1. *Quantitative Water Simulation Model*

The water model can be conceptualized as presented in Figure 1 showing the flow of water through different processes. Each node represents a mass-balance equation with the different colored lines representing parameters and variables. All flows into a node must equal all flows out of the node.

In Figure 1 water enters the system from local sources such as groundwater or surface water, or externally from desalination or water transfers from other regions. Green boxes represent water leaving the system as un-captured, treated or un-treated waste water. Non-served water is represented by the dashed-line box. Demand sectors are grouped together inside the solid-lined box. At each node water may be lost as leakages or evapotranspiration and is shown by a short green line. At each node the process may also consume energy shown by a short red line.

For each spatial and temporal unit the mass-balance is checked according to Equation 1. For each temporal sub-unit (p) the water entering the system from precipitation, desalination as well as transfers from other regions is equal to water leaving the system as losses, uncaptured, treated and untreated waste-water.

$$\delta S(p)/\delta p = P(p) + D(p) + I_{in}(p) + Q_{in}(p) - V(p) - Q_{out}(b, p) \quad (1)$$

Where..

b : Spatial sub-unit, p : Temporal sub-unit, S : Storage, P : Precipitation

D : Desalination, I_{in} : Inter-basin transfers in, Q_{in} : Runoff in

V : Evapotranspiration, I_{out} : Inter-basin transfers out, Q_{out} : Runoff out

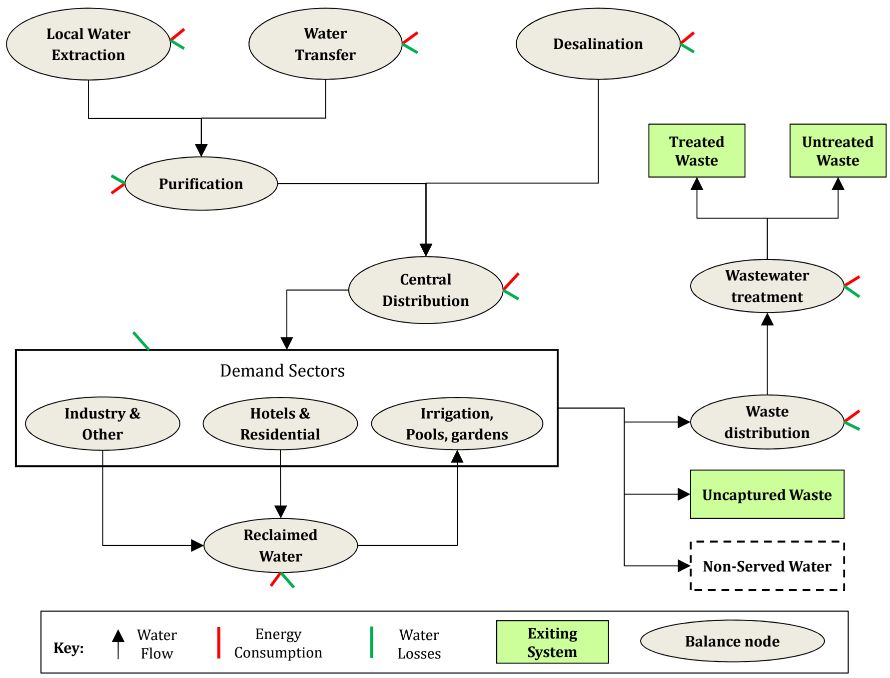


Figure 1: Water sub-module conceptual framework showing the flow of water volume tracked through different water processes.

Table 1 summarizes the parameters used in the simulation followed by a brief discussion of how the parameters were chosen. It was attempted to find the most relevant local parameters for

Table 1: Water system process parameters

Process	Investment Cost (Eur/hm^3/yr)	Operation Cost (Eur/hm^3)	Energy (KWh/m^3)	Losses (%)
Local Water Extraction	14,000	180,000	0.23	12.5
Desalination	1,800,000	300,000	5	50
Transfer from LLanca	250,000	2,500	0.1	25
Reuse Treatment	600,000	200,000	3.2	15
Reuse Delivery	17,000	330,000	0.4	25
Freshwater Purification	500,000	140,000	2.1	13
Wastewater treatment	600,000	200,000	3.2	14
Delivery	17,000	330,000	0.4	25

each process. If data was available for Port de Selva, it was used. If not then data was searched for the Catalonia region and then for Spain and then parameters from examples for other countries.

Local Water Extraction

Local water extraction was assumed to be a combination of groundwater extraction and surface water abstraction parameters. For groundwater extraction the average groundwater depth was assumed to be 40m based on the data series from Ministerio de medio ambiente, Gobierno de España [**?**] for 2003-2012. Groundwater pumping costs involve investment of the well and pumping system and the operation and maintenence costs. Well construction costs will depend on a number of factors such as the drilling method used, geology, depth to aquifer, size of borehole, pumping volume etc. Pumping operation costs in general are to a large part dictated by the energy needed to pump the water up, which in turn depends on the depth of the water table. Investment costs for groundwater pumping systems, considering an interest rate of 4% and a lifetime of 15 years results in an annuity of about 0.02 Eur/m^3 (about 10 times less than a desalination plant).

Hernandez(2010) [**?**] citing a study by the Spanish ministry of the Environment estimates average groundwater abstraction costs varying from 0.08 Eur/m^3 for urban water supply to 0.12 Eur/m^3 for irrigation. Estimates from Hernandez(2010) [**?**], Mora 2013 [**?**] and Robinson 2002 [**?**] were used to estimate the investment and operation costs for groundwater extraction.

Energy consumption for groundwater pumping was calculated using Equation 2 [**?**] relating the energy required for pumping $E(MWh)$ with the volume of water pumped $W(hm^3)$, pumping head $h(m)$, and a coefficient ϕ. The coefficient term constitutes the pump efficiency γ, water density ρ (kg/m^3) and gravity $g(m/s^2)$.

$$E = \phi \times W \times h \tag{2}$$

Where:

- $\phi = \gamma \times \rho \times g/1000$
- γ = between 0.4 to 0.7
- $\rho = 1000\ kg/m^3$

- $g = 9.8\ m/s^2$
- W = Volume of water hm^3
- h = Pumping head m

Water lost in groundwater pumping was considered as returned to the aquifer and thus taken as 0. The energy lost in pumping water that does not reach the top was considered in the pumping efficiency.

For surface water the parameters were assumed to be the same as used for surface water delivery systems discussed in the next section.

Average values for ground and surface water parameters were used for the combined local water extraction parameter.

Water Delivery

The 2007 report [**?**] by the ministry of the environment summarizes the costs associated with several different water services in Spain. These are divided into surface water collection, subsurface water collection, urban water supply, municipal sewage collection, sewage treatment, distribution of agricultural water and discharge control. This same distribution of costs is used in the analysis of the recuperation of costs in the individual river basin plans for the cycle 2015-2021 published in 2014 and 2015 [**?**]. The operation and maintenence as well as the investment costs associated with urban water supply are extracted from these studies for the parameters to be used for water distribution within a basin.

Energy consumption basically depends on the energy required to lift and move water between two points. The energy thus depends on the sections of the transfer in which there is a positive change in height. However, at the basin scale it is too complicated to calculate the net elevation gain for individual systems and an average value per cubic meter of water is used.

In Hardy 2010 [**?**] a range of values for energy used in the distribution system is given from 0.064 kWh/m^3 to 0.32 kWh/m^3. Another study, Muñoz 2010 [**?**], estimates energy consumption in water distribution to range between 0.2 kWh/m^3 and 0.8 kWh/m^3 while for the Ebro River long distance transfer energy consumption is estimated between 2.5 kWh/m^3 to 3 kWh/m^3. A World Bank study from 2012 [**?**] also notes the dependency of energy consumption on the share of gravity-fed supply in the system. For surface water the study estimates 10% of total energy consumption is spent on raw water extraction, 10% on water treatment and 80% on clean water transmission and distribution.

As discussed in Section **??** the European Environment Agency (EEA) [**?** **?**] estimates water losses in urban water networks as high as 50% for Bulgaria, about 22% for Spain and as low as 5% for Germany. The Asian Development Bank [**?**] estimates water losses in Asia, from 25% in East Asia to 40% in Central and West Asia. In a study from California from 2004 [**?**] estimates are given as varying typically between 6 % to 15 % but in some cases as high as 30 %.

Water losses will depend heavily on the local conditions, age, components and maintenance of the distribution system and a conservative estimate of 25% is used for the current case study.

Water Reuse, Purification, Wastewater Treatment

Municipal wastewater or sewage can come from a variety of different sources (households, schools, offices, hospitals and commercial facilities) with a variety of different possible biological and chemical contaminants. After being treated, reclaimed water can be used for different uses, for which the quality of water is ensured according to regulations. There are several different treatment options available which can be used in different combinations corresponding to the desired results and quality standards. Different processes are categorized into preliminary, primary, secondary, tertiary or advanced methods.

In 2007, the Spanish Royal Decreee 1620/2007 [**?**] clearly stated the official quality requirements for the use of reclaimed water in for different purposes. These have been adopted in the National Plan for Reutilization of Water in Spain [**?**] in which different treatment process options are also recommended.

A study from 2011 [**?**] explores the values of the operation and maintenance costs for twenty four different water treatment plants. The study analyzes the distribution of the costs between energy, staff and other operation and maintenance costs. In the study operation and maintenence costs average around 0.24 $Eurs/m^3$ of which about 20 % is the OnM costs of energy. Another study from 2011 [**?**] gives similar results with OnM costs totaling 0.24 $Eurs/m^3$ with energy and about 0.2 $Eurs/m^3$ without energy. Investment costs were about 0.4 $Eurs/m^3$ for a production of 8.4 hm^3 using an amortization period of 20 years, interest rate of 6% and discount rate of 3.5%. Cabrera 2012 [**?**] estimate an average life time of between 20 to 30 years for water treatment plant and use and average OnM cost of 0.423 $Eurs/m^3$.

The Spanish Ministry of industry, toursim and commerce published a report in 2010 [**?**] detailing the energy consumption in water treatment processes grouped by the size of the population being served. The report uses some standard values including an approximate value of $0.2m^3$ of wastewater produced per person.

A report from 2011 [**?**] gives the water balance of different wastewater treatment processes as measured in treatment plants in South Africa. The report finds that no water is lost in certain processes such as removal of TSS with cartridge filters, removal of residual BOD/COD with activated carbon filters or disinfection (UV and other chemicals). In general the most water consumptive processes are membrane filtration processes such as ultrafiltration (4%) and reverse osmosis (30%).

The different sources mentioned here were used to estimate the parameters used. Freshwater purification was assumed to require less stringent treatment processes. Waste water treatment and water reutilization was assumed to required more efficient treatment processes and this is reflected in the chosen parameters.

Water Long-Distance Transfers

Costs for water transfer lines were based on local studies and interviews with the Consorci Costa Brava [**?**] [**?**]as well as the economic analysis of water transfer systems in Spain as reported in detail in the National Hydrological Plan (NHP) written in 2000 [**?**] and updated in 2005. Costs associated with long distance transfers are closely related to the path chosen for the pipelines, the number of tunnels, bypass wiers, culverts, trenches, aqueducts, siphons and other infrastructure needed. The primary operation costs will depend on the energy used in lifting the water through the cummulative water head long the transfer, less the energy generated using hydroelectric units. The NHP differentiates between, investment costs, operation costs associated with energy and other operation costs associated with administration and maintenence. Non-energy operation and maintenance costs are proposed at 1% of the total investment costs and administration costs are estimated at 0.2% of the total investment costs [**?**].

Prinicipal investment costs were estimated to be EUR 4,000,000 [**?**] for a transfer line from the municipality of LLanca. An annuity was then calculated using a lifetime of 50 years and interest rate of 6%. A corresponding operation and maintenence cost of 1% of the annuity was used.

Energy consumption required to move water between two points mainly depends on the cumulative elevation change that the water has to be lifted through [**?** **?**]. Some energy is also spent in overcoming internal friction within the pipeline. The cumulative elevation gain in turn depends on the pipeline routing. As pointed out in Stillwell (2010) [**?**] the shortest distance using a straight line approach may be considered with the possibility of giving the least energy consumption, however, this would be impractical from a property rights perspective and instead pipeline routing is more likely to follow existing rights of way such as major road networks. Water transfer to the Port De Selva region is expected to come from the city of Llanca.

The distance and elevation gains along the route is calculated using the open source GIS software [**?**] as shown in Figure 2. The map provides both the cumulative and net elevation gains along the route. The cumulative elevation gains are used to estimate the maximum energy (kWh/m^3) needed to transfer water across the selected routeand the net gains are used for a low end estimate of the energy needed (kWh/m^3), in which it is assumed that full energy is recovered on the downhill portions. The average value between the two is used as the final estimate for the energy (kWh/m^3) needed to overcome gravity in the inter-basin transfers.

The energy consumption is calculated using the Equation 3 [**?**] for overcoming gravity in long distance transfers and Equation 4 [**?**] for the Darcy-Weisbach turbulent flow energy consumption. In Equation 3, $\frac{\Delta Ep}{\Delta t}$ is the change in potential energy in Joules per unit time, p is the fluid density, Q is the flow rate, g is acceleration due to gravity and Δh is the net or cummulative change in height. In Equation 4, h_f is the head loss due to friction, f is the friction factor, v is the average fluid velocity, ΔL is the pipe length and D is the inside pipe diameter. Parameter values were taken from the study by Stillwell 2010 [**?**] as shown in Table 2.

$$\frac{\Delta Ep}{\Delta t} = \rho Q g \Delta h \tag{3}$$

$$h_f = f \frac{v^2}{2g} \frac{\Delta L}{D} \tag{4}$$

The average energy for different transfer sections in the National Hydrological Plan is given at about 1 kWh/m^3 [**?**], while Muñoz 2010 [**?**] gives a range of 2.5 kWh/m^3 to 3 kWh/m^3 for the Ebro river transfer.

Table 2: Parameters used for water-transfers (Stillwell 2010 [**?**])

Parameter	**Value**	**Units**
Acceleration due to gravity, g	9.81	m/s^2
Density, ρ	997.08	kg/m^3
Flow rate, Q	0.8763	m^3/s
Friction factor, f	0.0115	unitless
Pipe diameter, D	3.66	m
Velocity, v	0.305	m/s
Viscosity, μ	8.94E-04	kg/m-s

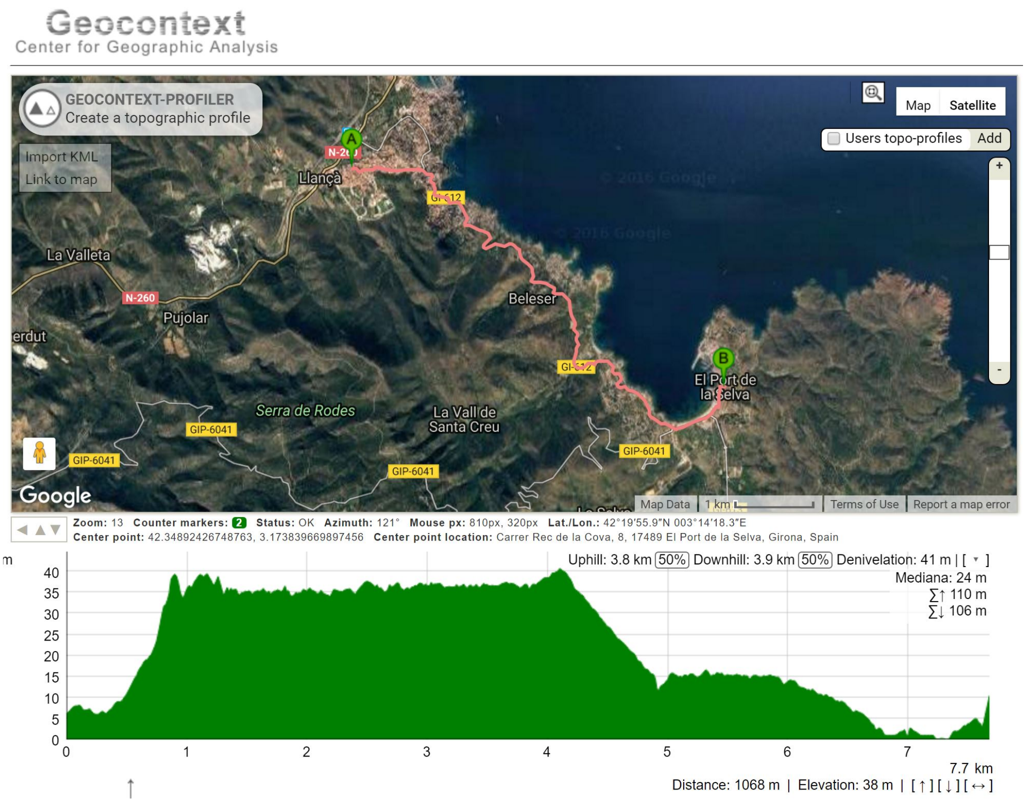


Figure 2: Water transfer potential route from Llanca to Port de Selva [?]

2.3.2. *Qualitative TOPSIS methodology*

In order to considering linguistic rather than numerical values, a new function in which linguistic terms are associated to qualitative labels is needed to operate the alternatives. To do so, the new algorithm takes this premise into account in this section. A mathematical formulation is developed that contributes to decision analysis in the context of *multi-granular linguistic labels* and *group decision making* for ranking problems.

?] introduced a qualitative approach for ranking alternatives that was inspired by the reference point method. This approach ranks a set of alternatives by using a distance function. It uses linguistic assessments of alternatives and minimizes the distance between them and a certain target point that models the best performance for each criterion considered.

The method used in the study of **?**] for ranking alternatives, based on comparing distances against "a single optimal reference point", has been modified in the method proposed in this thesis, to capture the idea of the TOPSIS approach according to the "best" and "worst" reference points. To do so, the proposed method called Q-TOPSIS is defined after some preliminaries are introduced.

2.3.2.1. Preliminaries. The absolute order-of-magnitude models are constructed via a partition of an interval in $\mathbb{R}$ which defines the set of basic labels. The partition is defined by a set of real landmarks. These evaluations are given by means of a set of qualitative labels with different levels of precision belonging to a certain order-of-magnitude space $\mathbb{S}$.

Definition 1. *Let* $[a_1, a_{n+1}]$ *be a real interval and* $\{a_1, \ldots, a_{n+1}\}$ *a set of real landmarks, with* $a_1 < a < a_{n+1}$. *The basic labels are defined by* $B_i = [a_i, a_{i+1}]$, $i = 1, \ldots, n$.

Each basic label B_i corresponds to a linguistic term. In a generic sense, if $r < s$, then $B_r < B_s$, meaning that B_s is strictly preferred to B_r, such as "extremely bad" < "very bad".

Definition 2. *The non-basic labels describing different levels of precision are defined as* $[B_i, B_j] = [a_i, a_{j+1}]$ *where* $i, j = 1, \ldots, n$, *and* $i < j$. *The label* $[B_i, B_j]$ *corresponds to the concept "between* B_i *and* B_j*".*

Considering a set of alternatives $\{A_1, \ldots, A_l\}$, each alternative is defined by a set of r criteria, and each criterion is evaluated by the judgments of a team of m experts. These evaluations are given by means of a set of qualitative labels with different levels of precision belonging to a certain order-of-magnitude space $\mathbb{S}_n = [B_i, B_j] \quad i, j = 1, \ldots, n+1, i \leq j$, considering $[B_i, B_i] = B_i$.

In this way, each alternative A_i, $i = 1, \ldots, l$ is represented by a k-dimensional vector of labels in $(\mathbb{S}_n)^k$, $A_i \leftrightarrow (A_{i_{11}}, \ldots, A_{i_{1m}}, \ldots, A_{i_{r1}}, \ldots, A_{i_{rm}})$.

k being the number of criteria times the number of experts: $k = r \cdot m$. Distances between linguistic k-dimensional vectors of basic and non-basic labels are computed by using the location function in n. Each linguistic label corresponds to a location. The AOM qualitative space is used for the process of moving from the ordinal scale of the original data set to a cardinal scale by codifying the labels using location function that is defined as follows.

Definition 3. *The location function definition in* $\mathbb{S}_n$ *is the function;*
$l : S_n \to Z^2$ *such that:*

$$l([B_i, B_j]) = (-\sum_{s=1}^{i-1} \mu(B_s), \sum_{s=j+1}^{n} \mu(B_s)) \tag{5}$$

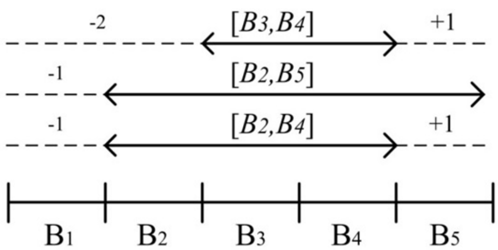
where μ is any measure defined over the set of basic labels, for instance, $(B_i) = ([a_i, a_{i+1}]) = a_{i+1} - a_i$.

In other words, the location function of a qualitative label $[B_i, B_j]$ is defined as a pair of real numbers whose components are, respectively, the opposite of the addition of the measures of the basic labels to its left and the addition of the measures of the basic labels to its right. By applying a function l to each component of the k-dimensional vector of labels, each alternative A_i is codified via a 2k-dimensional vector of real numbers:

$$L(A_i) = (l(A_{i_{11}}), \dots, l(A_{i_{1m}}), \dots, l(A_{i_{r1}}), \dots, l(A_{i_{rm}}) \tag{6}$$

For example, the location of the basic label is B_5 defined by $(-4, 0)$ and the non-basic label, $[B_2, B_4]$, is the pair $(-1, 1)$ (see Figure 3).

Figure 3: Locations



2.3.2.2. Q-TOPSIS distances to reference labels. The Q-TOPSIS method proposed in this thesis, can process information represented by qualitative terms in the absolute order-of-magnitude that was introduced in previous subsection.

We consider the QPRL as the k-dimensional vector $A^* = (B_n, \dots, B_n)$, and the QNRL as the k-dimensional vector $A^- = (B_1, \dots, B_1)$, which are considered as reference labels to compute distances. Their location function values are in:

$$L(A^*) = (-\sum_{s=1}^{n-1} \mu(B_s), 0, \dots, -\sum_{s=1}^{n-1} \mu(B_s), 0) \tag{7}$$

$$L(A^-) = (0, \sum_{s=2}^{n} \mu(B_s), \dots, 0, \sum_{s=2}^{n} \mu(B_s)) \tag{8}$$

Both the Euclidean weighted distances of each alternative location $L(A)$ to A^* and A^- locations are then calculated, i.e. $d(L(A), L(A^*))$ and $d(L(A), L(A^-))$, by applying Eq. 4 to the vectors $(X, Y) = (L(A), L(A^*))$ and $(X, Y) = (L(A), L(A^-))$ respectively:

$$d(X, Y) = \sqrt{\sum_{i=1}^{r} w_i \sum_{j=1}^{2m} (X_{ji} - Y_{ji})^2} \tag{9}$$

Where w_i is the weight corresponding to the $i-$th indicator, and X_{ji}, Y_{ji}, $j = 1 \ldots 2m, i = 1 \ldots r$, are respectively the components of X and Y. Finally, the QCC of each alternative is obtained by Eq. 10, and the alternatives are ranked according to the decreasing order of QCC_i values.

$$QCC_i = \frac{d_i^-}{d_i^* + d_i^-} \qquad i = 1, \ldots, m. \tag{10}$$

Where d_i^* and d_i^- are respectively the distance between the alternative location $L(A_i)$ and the QPRL location $L(A^*)$ and the QNRL location $L(A^-)$.

The ranking of alternatives can be determined according to the pre-order defined by the values of QCC_i, and the closer to A^* and further from A^- the alternative A_i, the greater the value of QCC_i.

In such a case, common in TOPSIS method, the alternative A_i with the maximum QCC_i is chosen as the best option.

3. Case study: Port de Selva

3.1. Problem Statement

The case study is based in the municipality of Port de Selva located in the Costa Brava region of Catalonia in northeastern Spain. The municipality has an area of 41.6 km^2 and a population of 980. The region receives seasonal tourists which increases pressures on local resources.

Existing demand for local water resources is approximately 300,000 m^3 [**?**]. The demands are distributed by sector (industry, residential, industry, irrigation) and by month based on the data provided in the river basin plans for the Catalonia region [**?**]. The distribution of demands is shown in Figure 4.

Precipitation in the area is between 350 mm to 550 mm per year. In years of drought water is over-exploited from the groundwater aquifer causing concern for sea water intrusion. The amount of water recharging the aquifer is estimated to be 300,000 m^3 [**?**] i.e. just enough to meet the local demand. Changes in precipitation due to climate change for the Catalonia region are estimated based on the predictions made by Centro de Estudios y Experimentación de Obras Públicas (CEDEX) [**?**] which predict on average about a 10% decrease from January to June and about a 5% increase from July to December.

A small pipeline from the municipality of LLanca exists to provide additional relief but this is not sufficient to meet additional demands [**?**]. Investment costs for a pipeline with sufficient capacity is estimated to cost approximately EUR 4,000,000.

An existing water purification treatment plant exists which has a rated capacity of 2.625 m^3/d and is recorded as treating a maximum load of about 50,000 m^3 in August (Data from 1996-2016) [**?**]. Some additional water reuse capacity of 25 m^3/h is available and is recorded as treating a maximum volume of about 16,000 m^3 of wastewater (data from 2004-2016) [**?**].

Wastewater that is treated for reuse comes from the municipal system which collects water from residences, hotels and industry. Comparing with Figure 4, it can be seen that even if all the

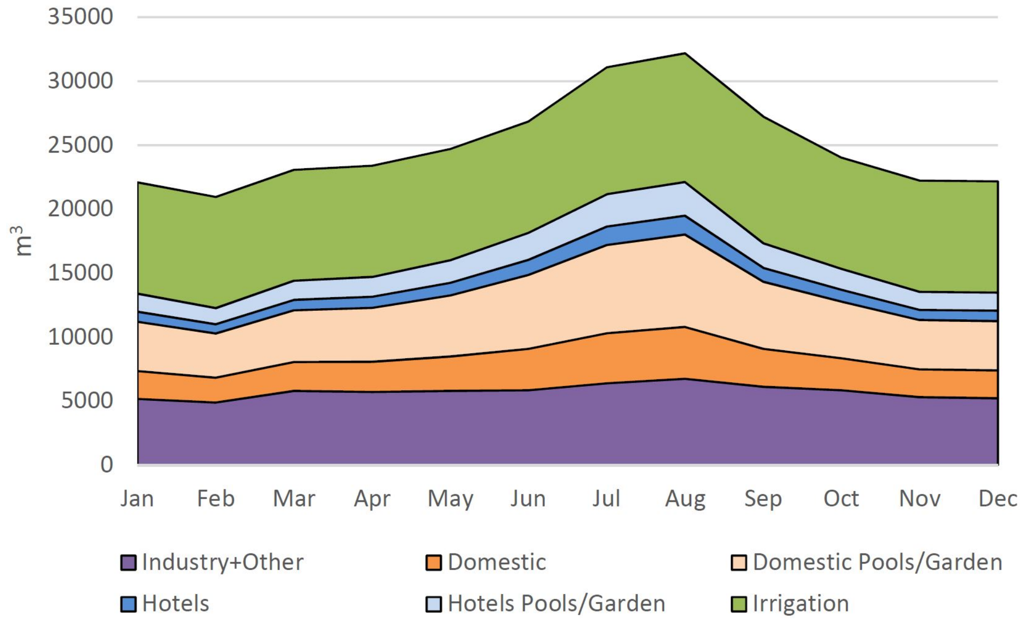


Figure 4: Monthly distribution of water demands in Port de Selva

water used in the municipal system was diverted for reutilization this would mean a volume of about 16,000 m^3, which is within the capacity of existing reutilization treatment plants.

Even before any further analyis, this means that the installation of additional capacity would only be needed if additional demands in the municipal system created sufficient additional waste water.

3.2. Scenarios

Simulations of different scenarios Regarding to expert's preferences in this region, four scenarios are presented for additional water needed during high water demand seasons: 1- Business as Usual (Involves some water reuse) 2- Additional reused water 3- Desalination 4- Transfer water from north of Costa Brava

3.3. Survey

The survey in the case of Port de la Selva

Second step; Asking experts in Costa Brava consortium (about three experts in each group of Water planners, hotel managers and environmental NGO) about the importance of different variables in 5 aspects (Economic, Technical, Environmental, Social, Political). The questionnaire have been sent them by email and phone interview.

Degree of consensus for selecting the variables: 1. Survey analysis: Finding the most important factors which are more than 3.5 and their weights by average and consensus degree among experts (18 among 33):

2. The process of selecting and weighting the final variables:

In order to handle with uncertainty and ambiguity of the responses from experts, linguistic terms have been used in the process of experts' assessment. From the list of 33 variables from the literature and proposed by experts, the final variables have been ordered using simultaneously two criteria: First, the qualitative median, and secondly, the length of the connected union among the experts' assessments.

This order has been performed imposing the higher qualitative median and the less length of the connected union among qualitative assessments as a measure of a degree of consensus among a set of experts' opinions. This order has been used to select the final variables and to compute their weights for the decision-making process.

4. Results

4.1. Quantitative Model Results

Results from the quantitative model are summarized in Table 3 for a 5% increase in demands and in Table 3 for a more unlikely 100% increase in demands. The results are also shown in Figure 5.

As seen in Table 3 and in Figure 5a to c, there is not enough water to meet the combination of expected growth in water demands and changes in rainfall. In the Business as usual (BAU) scenario this results in non-served water. For a 5% increase in demands, wastewater generated from the municipal system is a maximum of 12,000 m^3, which can be covered by the existing reuse capacity. Thus no additional reutilization capacity is needed for this case. The most expensive option is installing a desalination plant, which also consumes the most energy and has the highest water losses. Water transfer from Llanca offers an alternative with which all the additional water demand can be met at a lower cost than desalination. Water transfers will still require additional energy and comes with the risk of future water problems at the region from where the water is collected. The current transfer line is built from Llanca which is only 7 km away. A longer transfer line will obviously mean higher costs, more energy consumption and greater water losses.

The alternative for additional water reuse becomes interesting when the amount of wastewater generated becomes greater than the existing capacity. An additional case is analyzed in which the demand is increased by 100%. The results for this case are shown in in Table 4 and in Figure 5d to f. As seen in Figure 5d additional reuse capacity is able to relieve a part of the non-served water. The remaining results are similar to before with water transfer from the city of LLanca being the cheaper than desalination and also losing less water.

Table 3: Summary of quantitative results (5% increases in demands)

Alternative	**Investment Cost (MEur)**	**OnM Cost (MEurs)**	**NSW Cost (MEur)**	**Losses (%)**	**Energy (GWh)**
BAU	-	0.24	0.65	0.19	1.37
Additional Reuse	-	0.24	0.65	0.19	1.37
Desalination	0.86	0.43	-	0.47	3.90
Transfer	0.10	0.33	-	0.36	2.12

Table 4: Summary of quantitative results (100% increases in demands)

Alternative	**Investment Cost (MEur)**	**OnM Cost (MEurs)**	**NSW Cost (MEur)**	**Losses (%)**	**Energy (GWh)**
BAU	-	0.26	5.95	0.21	1.44
Additional Reuse	0.02	0.26	5.74	0.21	1.45
Desalination	2.43	0.87	-	1.05	9.05
Transfer	0.27	0.57	-	0.74	4.04

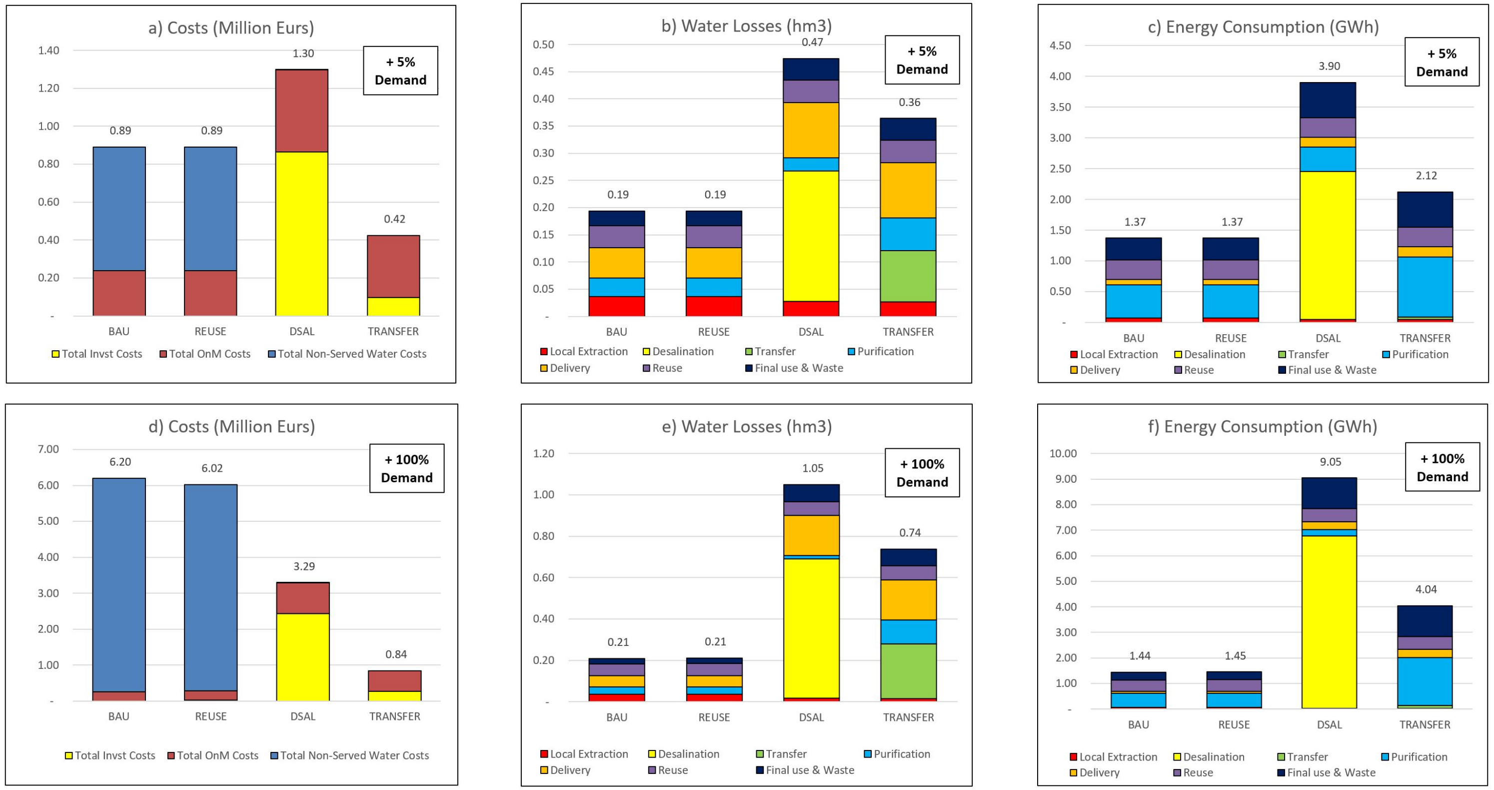


Figure 5: Results

4.2. *Decision Matrix evaluated by experts for the case of El port de la Selva*

- Data from Zarrar (using their model for 4 criteria) and - Arayeh asking 2-3 experts about evaluation of selected criteria for each scenario, using basic and non-basic labels (linguistic terms).

4.3. *Normalized decision matrix*

In this step we need thresholds for quantitative variables (Indifference threshold) for normalizing their value to the range of linguistic terms.

4.4. *Group weighted decision matrix*

4.5. *Application of Q-TOPSIS to rank scenarios*

Calculation of QCCi Ranking alternatives

5. Conclusions

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