Water Management Strategies Using Multi-Criteria Decision Analysis in Santa Cruz Island (Galapagos Archipelago)

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Abstract
Islands threatened by tourism around the world are under significant stress due to overutilization of (scarce) water resources. The continuous increase of water demand in Puerto Ayora, the main touristic centre of the Galápagos, has become a threat for the water supply system, portraying the current situation unsustainable on the long-term horizon. For this reason, a Multi-Criteria Decision Analysis (MCDA) is tested as a suitable methodology in the presence of scarce data, leading to a set of indicators and intervention strategies, aiming to mitigate the future water demand coverage. The current analysis revealed the most sustainable solution, including environmental, technical, economic and social criteria, by using the DEFINITE software. The results indicate that best option for most of the stakeholders’ groups is the option combining all proposed-sustainable options like greywater recycling, specific demand reduction and rainwater harvesting.

Keywords: Multi-criteria decision analysis; Water supply indicators; Tropical islands; Intervention strategies; Galápagos.

1. Introduction
Tropical islands worldwide are threatened by the significant increase of tourism. Since tourist activities are high in water demand, municipalities and regional authorities are having difficulties to cope with these water-supply-growth trends [1]. For this reason, tourism is becoming a serious threat, as well as a limiting factor for further urban development [2]. However, the coverage of future water demand with supply needs to be ensured in the different sectors, including tourism in order to ensure economic growth. This paper evaluates different proposed intervention strategies, using Multi-Criteria Decision Analysis (MCDA), which aim to solve the future water crisis in Santa Cruz Island (Galápagos Archipelago).

1.1. Multi-Criteria Decision Analysis
The MCDA is an often-used tool to carry out analysis for decision making purposes. It is an integrated assessment, which is a form of combined sustainability evaluation [3]. It encompasses complete assessment of (multiple) suggested alternatives, providing a set of tools for any decision making process. These analyses evaluate different values and factors, and is usually carried out on situations with high uncertainty and conflicting goals, as well as multiple interests and perspectives [3]. The main objective of this methodology is to establish the most sustainable solution of a certain issue, considering cost-benefit options and considering the preferences of all participants [4].

The MCDA method has been considered as subjective; however, it has rapidly increase since the 1990s, especially in environmental issues because it provides a reliable method that allows to rank different proposed alternatives in the presence of numerous objectives and constraints [5]. MCDA methods have been tested to be suitable for water resources management and planning, and are usually considered the preferred method due to its transparency and accountability to decision procedures [6].

Moreover, the main advantage of this methodology is the capacity to involve several stakeholders. This allows the participatory process of different groups of people with different perspectives, resulting in a more thorough understanding of the points of view held by the implicated parties [7]. Also, it helps policy makers to involve different criteria within new policies, since it provides clear solutions to a previously defined problem.
1.2. Study Area Description

Puerto Ayora is the main town in Santa Cruz Island (Galápagos Archipelago). It has approximately 12,000 inhabitants INEC -Censo de población y vivienda del Ecuador 2010 [8] and attracts visitors from all over the world. The annual growth rate of local population increased from 2.5% in 1960 to almost 5% in 2010, while tourism growth rate was between 8% and 11% during the same period [9]. This uncontrolled expansion has affected basic services, including water supply. Currently, the water supply system has a coverage of 95%, but is intermittent (average of three hours/day) [10]. Freshwater is scarce and the main source is brackish-water extracted from crevices. The situation is further worsened by the low quality of distributed water, due to its brackish nature and faecal contamination [11].

Based on the study carried out by Mena [9] and Retamal, et al. [12], several population growth rates were envisaged based on different stakeholder’s priorities and objectives. The proposed growth scenarios have become the basis for the modelling of future coverage of water demand with supply. Retamal, et al. [12], considered several alternatives as solution strategies for the future water deficit. However, the previous analysis calls for an integrated multi-disciplinary analysis due to the environmental vulnerability of this archipelago. According to Linkov, et al. [4], any issue that involves natural resources assessment as part of the decision making process, applies for MCDA analysis, because the alternatives can be reviewed based on the preferences of relevant stakeholders.

1.3. Research Objective

The Galapagos Islands, as many tourist islands, have scarce information regarding water supply and demand. Because of this, water resources planning and management is particularly lacking in the absence of proper data. This type of analyses aids to propose solutions for future challenges regarding optimal water balance, overcoming water scarcity caused by high-tourism rates, and also helping to preserve such places for future tourism. Since Puerto Ayora is the main tourist centre of this archipelago, the current MCDA analysis will serve as a template for other, the water supply system has a

| Table-1. Options proposed for solving water supply and demand crisis in Puerto Ayora |
|--------------------------------|---------------------------------|-----------------|---------------------------------|-----------------|
| **Option**                | **Description**                 | **Input values** | **Assumptions**                 | **Total Costs** |
| 1) Leakage Reduction      | Reduction from 28%³ to 13% (1% annually). | Energy consumption: 0.66 KWh/m³ (current use of energy). The same values for all four growth scenarios | Installation of automatic and computerized leakage and control system (e.g. pressure and flow monitoring) and replacement of old pipes (17,800 m of PVC pipes). | 0.66 |
| 2) Desalination Plant     | Installation of a new SWRO desalination plant (BWRO was not considered to avoid extra pressure on the basal aquifer and increase of salinity) with energy recovery system. Open seawater intake (35,000 ppm), 55% recovery rate, 99% salt rejection. | small growth (9,000 m³/day) 2) moderate growth (16,000 m³/day) 3) fast growth (28,000 m³/day) 4) very fast growth (50,000 m³/day) Energy consumption: 3 KWh/m³ | Cost includes plant, land, civil works and amortization costs, chemicals for pre and post water treatment, energy requirement, brine dissolution and discharge, cooling towers(including electricity and steam), spares and maintenance (including membrane replacement every 5 years), and labour. | 1) 1.27, 2) 1.25, 3) 1.23, 4) 1.22 |
|                          |                                 |                 |                                 | Municipality of Santa Cruz and local providers |

References:
- INEC -Censo de población y vivienda del Ecuador 2010 [8]
- Mena [9]
- Retamal, et al. [12]
- Linkov, et al. [4]
- Reyes [10]
- Galápagos Islands, as many tourist islands, have scarce information regarding water supply and demand.
3) **Water Meter Installation**

Installation of water meters per premise with a rate of 10% annually. The same unit cost for all growth scenarios.

| Installation of Flodis-singe jet turbine device | 0.04 | Municipality of Santa Cruz |

4) **Rainwater Harvesting**

Installation of a household rainwater harvesting tank for indoor and/or outdoor use (2 m³)

Water collected from roofs only. The collected rainwater used for toilet flushing, hand and kitchen basin, showers and outdoor use. The cost includes purchase cost of tank, pumping, delivery and installation, household plumbing, and mains water switching devices, energy consumption, maintenance and pump replacement (every ten years).

| Capacity calculated as 4000 m³ (approx. 2000 households) | 0.21 | 1) Tam, *et al.* [17] 2) Retamal, *et al.* [12] 3) Hauber-Davidson and Shortt [18] |

5) **Greywater Recycling**

Installation of single house on-site greywater treatment using a submerged membrane (MBR), including disinfection unit

Greywater collected from kitchen and hand basins and showers, which account to approximately 48% of total water demand). Household treatment assumed with membrane bioreactor plant (biological treatment, aeration, and membrane filtration. Treated greywater used on-site for toilet flushing and outdoor use.

| Based on household greywater treatment capacity of 350 L capacity and 2000 households; 5 inhabitants per household and 163 Lpcpd). Flow capacity of 200 L/population equivalent | 1.08 | 1) Fletcher, *et al.* [19], 2) Boehler, *et al.* [20], 3) Gnirss, *et al.* [21], 4) Fountoula kis, *et al.* [22] |

6) **Water Demand Reduction**

Reduction of specific demand of municipal water

Assumed the change of water tariff structure to reduce the average specific demand

| Reduction from 163 Lpcpd to 120 Lpcpd (assuming 1% annual reduction on water demand starting on year 3, in order to complete the reduction at the end of the planning horizon | - | - |

Taken from Reyes, *et al.* [23].

### 2. Methodology Development

The following steps used to carry out the MCDA are listed below:
2.1. Criteria Definition and Alternatives’ Selection for Puerto Ayora-Santa Cruz Island

First, the problem was defined as the water-supply deficit in the town of Puerto Ayora in the year 2045. The primary objective was to find the most suitable and sustainable solution to overcome lack of water supply. The five intervention strategies shown in Table 1 and Figure 1 were obtained from the study carried out by Reyes, et al. [23]. Therefore, the basis for the input data for the MCDA were the results obtained in the previous-mentioned study, for the end of the forecast period (2045). The four selected criteria for this study were: (1) environmental, (2) technical, (3) economic and (4) social. Afterwards, each of these criteria was further described with relevant and measurable indicators, which allowed to evaluate the performance of each suggested solution.

Then, different software were evaluated, and the DEFINITE software was selected as the tool for this analysis. DEFINITE was developed to help improve the quality of decision, by methodical procedures which lead experts through a number of interactive assessment sessions [23]. It uses an optimization approach, which integrates all the information provided by the involved stakeholders into a full set of value functions leading to a scientific based ‘best’ alternative [24].

Figure 1. Intervention strategies selected and modelled with WaterMet² software used as input information for the MCDA (Reyes Perez, 2017)

2.2. Effects Table, Score Definition and Standardization

After defining the criteria and its corresponding indicators, each strategy was scored under each indicator in the ‘effects table’. In this table, which is the core of the MCDA, the input information for the DEFINITE is assessed as the performance of each intervention strategy against all the pre-defined indicators in a qualitative or quantitative way. The data used for scoring and populating the ‘effects table’ were obtained from Reyes, et al. [25], including the following Key Performance Indicators (KPIs): water demand, water losses, energy use and costs. In the study by Reyes, et al. [23], results were obtained for four growth scenarios. However, in the analyses for this paper, only the results from the moderate-growth scenario were used (4% annual growth for tourism and 3% for local population). The missing information such as potential waste quantities from the different selected strategies, as well as local laws and regulations, among others, were taken from the literature. Some information regarding the social and technical criteria were taken from interviews with local experts.

The scoring for each indicator was done using different types of scales/units. As a first step, the indicator values were defined either as qualitative or quantitative, assigning the scale/unit that will be used for the analysis. The scales/units used were: (1) ratio, (2) interval, (3) ordinal, (4) binary scale, and the (5) ---/+++ scale. The ratio scale refers to the proportionality of values, the interval scale portrays the ranges of amounts, the ordinal scale ranks the effects of an strategy against certain indicator, the binary scale indicates whether the effect does or does not occur and the ---/+++ scale estimates the values which could not be determined quantitatively. Table 2 explains the meaning of the last mentioned scale Reyes [10].

After defining the scale/unit to each indicator, the nature of each indicator as Cost (C) or Benefit (B) relation was determined. Cost refers to indicators portraying a negative correlation between the score and the effect (higher
the score of the indicator, the worse the effect produced). On the other hand, benefit (B) refers to a positive correlation (the higher the score, the better the effect produced). Later, the ‘effects table’ was populated with the scores assigned to each indicator, corresponding to each intervention strategy.

Finally, the standardization of the indicators was carried out, since the values on the ‘effects table’ were not yet comparable and the units were not uniform. Therefore, each indicator was standardized with a unit-less value between 0 and 1. For this, different options available within the software were used to convert the original indicator scores [24] such as: the maximum method, the goal standardization, the convex function and the yes/no standardization. Table 2 presents the selected criteria, indicators, cost/benefit relation, units/scales, the standardization method used, as well as the ranges of scores for each indicator.

Table 2. Criteria categories, indicators, units/scale, standardization method and ranges selected for MCDA for the water supply system in Puerto Ayora

| Indicator                                      | Cost/Benefit Correlation | Unit/scale      | Standardization Method | Minimum Range | Maximum Range |
|------------------------------------------------|--------------------------|-----------------|------------------------|---------------|---------------|
| **ENVIRONMENTAL CRITERIA**                     |                          |                 |                        |               |               |
| Land use                                       | C                        | m²              | Goal                   | 0             | 10,000        |
| Discharge of wastewater                       | C                        | m³/day          | Goal                   | 0             | 50,000        |
| Seawater intrusion                             | C                        | Ordinal         | Exponential value      | 2             | 5             |
| Energy consumption                             | C                        | kWh/ m³         | Maximum                | 0             | 3             |
| Chemical use                                   | C                        | Binary          | Yes=0, No=1            | No            | yes           |
| Impact on endemic species                     | C                        | Ordinal         | Exponential value      | 1             | 5             |
| Impact on marine/land ecosystems              | C                        | Ordinal         | Exponential value      | 1             | 5             |
| **TECHNICAL CRITERIA**                        |                          |                 |                        |               |               |
| Improvement on hours of service               | B                        | Binary          | Yes=0, No=1            | No            | yes           |
| Coverage of demand with supply                | B                        | % of demand     | Goal                   | 30            | 100           |
| Water losses                                   | C                        | % from water produced | Goal | 9             | 28            |
| Robustness of the WS system                   | B                        | Ordinal         | Exponential value      | 1             | 5             |
| O&M of the WS system                           | B                        | Ordinal         | Exponential value      | 2             | 5             |
| Alternative water sources contribution to overall balance | B                     | % annually     | Goal                   | 5             | 50            |
| Compatibility with the existing system        | B                        | 0/++            | Maximum                | 0             | ++            |
| **ECONOMIC CRITERIA**                         |                          |                 |                        |               |               |
| Capital cost                                   | C                        | M €             | Maximum                | 0             | 21.6          |
| O&M cost                                       | C                        | M €/year        | Maximum                | 0             | 5.4           |
| NRW income generation                          | B                        | €/year          | Maximum                | 0             | 312,412.16    |
| WDM income generation                          | B                        | 0/++            | Maximum                | 0             | ++            |
| Employment generation                          | B                        | 0/++            | Maximum                | 0             | ++            |
| Increase in water tariffs                      | C                        | --/0            | Maximum                | --            | 0             |
| Increase in tourist capacity                   | B                        | # of tourists   | Goal                   | 7,335         | 15,000        |
| **SOCIAL CRITERIA**                           |                          |                 |                        |               |               |
| Social acceptability                           | B                        | 0/++            | Maximum                | 0             | ++            |
| Willingness to pay                             | B                        | 0/++            | Maximum                | 0             | ++            |
| Transparency on project implementation process | B                      | 0/++            | Maximum                | 0             | ++            |
| Water quality improvement                      | B                        | 0/++            | Convex                 | 0             | ++            |
| Annual infection and other water-related diseases risk | C                      | --/0            | Convex                 | --            | 0             |
| Compatibility with current legislations       | B                        | Binary          | Yes=0, No=1            | No            | yes           |

Taken from Reyes, et al. [23].
2.3. Weight Allocation

The weights were obtained from different stakeholders’ preferences. For this, a questionnaire was distributed to 32 previously-selected stakeholders, clustered into four different categories. The questionnaire had six questions regarding valuation and importance of the criteria and its indicators, rating them from 1 (the least important) to 5 (the most important). Finally, the answers from each stakeholder group were processed, allocating different weights for each criteria and indicator.

The results of the weights allocation were further calculated based on the average of the respondents belonging to each group, carrying out a different MCDA session for each stakeholder group. This was the key part for the ranking of alternatives in the MCDA as shown in Figure 2.

![Figure 2](image)

Figure 2. Ranked preferences of selected stakeholders based on distributed questionnaire in Puerto Ayora [10]

| Stakeholders | Environmental | Technical | Economical | Social |
|--------------|---------------|-----------|------------|--------|
| Experts      | 0.273         | 0.273     | 0.212      | 0.242  |
| Decision Makers | 0.251     | 0.240     | 0.240      | 0.270  |
| Domestic End Users | 0.250   | 0.250     | 0.220      | 0.280  |
| Hotels       | 0.263         | 0.253     | 0.242      | 0.242  |

Taken from Reyes, et al. [23]

3. MCDA Sessions’ Results and Discussion

3.1. Distribution of Weights Based on Stakeholders’ Input

In order to standardize the results from stakeholders’ responses into values from 0 to 1, appropriate methods included in the DEFINITE software were used. For the criteria, defined as weight-level 1, the direct weighting method was chosen, due to its characteristic of assigning quantitative weights directly, according to the numerical input used by the stakeholder feedback. In the direct weighting, the sum of the weights of the criteria for each particular stakeholder session is equal to one. Moreover, the indicators were defined as weight-level 2, where the expected value method was used. This method ranks the effects in order of their importance, assigning quantitative values to each. Some effects may have the same ranking, which means they have equal importance in the analysis. Then, the total weight was calculated based on the product of weight-level 1 and weight-level 2. The result obtained from this calculation became the actual weight for the MCDA evaluation [23].

3.2. Ranking of the Alternatives

The software has several methods to rank: the Weighted Summation, Electre 2, Evamix and Regime. For this step, the weighted summation method was chosen, which is based on the MAUT (Multi Attribute Utility Theory) model. This method was selected because it is considered to be the most appropriate, due to its reliability, straightforwardness and transparency [24, 26].
Figure 3. Ranking of alternatives based on (a) experts, (b) decision makers, (c) domestic end users and (d) hotels preferences (Taken from Reyes [10]).

This method uses the effect scores to rank the proposed intervention strategies, processing the standardized table into a ranking of alternatives. A total of four sessions (one for each stakeholder group: decision-makers, experts, end-users and hotels) were conducted, and all alternatives were ranked using the same method in order to facilitate comparisons and conclusions [23]. The results of the ranking of the alternatives are illustrated in Figure 2.

Figure 3 shows that Gal 2 alternative prevails for decision makers and experts, due to the large contribution of the technical and social criteria (the only alternative covering 100% of water demand at the end of the planning horizon, and the only one improving water quality). For domestic end-users, priority was given to both alternatives Gal 4 and Gal 5, mainly due to the high preference by these groups to the environmental criteria, followed by the technical and economic criteria, respectively. Surprisingly, for the hotel end-users, a significantly high preference is given to the environment, grading Gal 5 alternative as the first option, and not the desalination option, as expected. Gal 5 scores reasonably well in all of the defined criteria, resulting in the most consistent distribution of ranking across all of the sessions (taking the first or the second position). On the other hand, for the domestic and hotel end-users, Gal 2 is always one of the last options. Gal 4 tends to be the last option for all sessions, expect for domestic end-users, where it is positioned as first.

In conclusion, for every analysis where either technical or social criteria have more influence, Gal 2 alternative is ranked higher, while Gal 5 takes the lead when environmental criteria has higher weighting.
The ranking summary is shown in Figure 4. The alternative ranking the highest and showing more stability is Gal 5, which occupies the first and second places, followed by Gal 3, which is ranked third and second. On the other hand, Gal 2 is first for decision-makers and the experts group of stakeholders. However, it also takes the last place for both sessions involving the local population (hotels and end-users), capturing the noticeable different preferences, especially regarding the environmental criteria. These results show that for the local population, the preservation of the environment is more important than the stakeholders involved with research and decision-making.

3.3. Uncertainty Analysis

The DEFINITE software can also assess the sensitivity of the ranking of alternatives, when varying the effect scores and weights of the indicators. In order to evaluate the influence of uncertainties to a lower or higher extent, the percentages of the effect scores were examined with a ±50% variation. This was done based on the fact that some of the input data used to populate the effects table was assumed. Also, since some results showed small difference between the rankings (0.1 to 0.2), the uncertainty analysis was carried out in order to examine the impact on the ranking, when the effect scores were changed. This also reflected the consequences of higher-or-lower population growth impacts, since this analysis was done using only the moderate growth scenario.
In conclusion, the most robust alternatives are Gal 2 and Gal 5 keeping their original positions (first, and last) in most of the uncertainty analysis sessions. Furthermore, Gal 3 and Gal 4 were moderately sensitive to the defined uncertainty variations because they often changed in the ranking, moving one position higher or lower depending on the stakeholders’ preferences. Therefore, all of the options would never tend to have a dramatic change in their original position. Finally, Gal 1 was the alternative with the highest level of ranking uncertainty. In most of the analyzed sessions, this alternative competed for almost every position, originating from the wide uncertainty assumption.

Some of the preferred alternatives do not reach a 100% water demand coverage at the year 2045, but they assume lower environmental impacts, lower costs, and lower water tariffs (except desalination). If any of these alternatives would be adopted, this would mean that a large tourist expansion in Puerto Ayora is not possible, as many decision-makers prefer.

### 3.4. Sensitivity Analysis

The final analysis encompassed the sensitivity analysis of the selected criteria weights, provided by the stakeholders. Figure 6 shows the results only for the decision-makers’ session. Only this group was considered for the current paper because they have the final word on the decisions adopted.

![Sensitivity Analysis Diagrams](image)
In Figure 6, steeper slopes are observed in some of the graphs than in others. A steeper slope means that the criteria are more sensitive to a minor change on the weight, influencing greater on the final ranking of the alternatives. The X-axis indicates the extent of variation of the weight, and the vertical line is the original weight provided by the stakeholder’s feedback. On the other hand, the Y-axis indicates the original score obtained by each alternative in the original analysis.

The Gal 2 alternative loses its advantage over Gal 5, which was ranked first. Under the environmental criteria sensitivity, Gal 2 alternative is ranked in the first place only until the weight value increases by 0.5. Within the range from 0.32 to 0.65, Gal 5 alternative would be ranked first. With the values of environmental criteria below 0.26 there is a steep inclination of the desalination alternative, meaning that it is firmly positioned on the first place. Regarding the technical criteria, it is more sensible and could be, by a very small change, replaced by Gal 5. Therefore, over this weight, the desalination alternative (Gal 2) provides the best results in technical criteria group, especially regarding the indicators of coverage of demand with supply (100%), improvement of hours of service (continuous water supply), and robustness of the water supply system. Since it is the only alternative that significantly increases water supply, the higher the weight allocation of technical criteria, the more it stabilizes this alternative on the first place. On the other hand, lower values of technical criteria, switches the rank in favor of alternatives with higher scores in environmental criteria. For the economic criteria, the sensitivity is low, which is shown by much less steep lines. Since Gal 2 is the most expensive alternative, desalination is the preferred option under the economic criteria only up to 0.3 values (the original value is 0.23). Finally, regarding the social criteria, when the weight value drops below 0.15, Gal 2 loses its advantage over alternative Gal 5. Therefore, the social criteria can be considered an important one, since once more; a small change can alter all the results. This criterion includes paramount public health indicators, and those can be improved only by the desalination option. Nevertheless, this alternative can be easily substituted with less environmentally hazardous and cheaper options with small alteration of the weight scores of the main stakeholders’ groups.

4. Summary and Conclusion

The MCDA methodology has proven to be a suitable decision support tool that can be applicable in environmentally-sensitive areas such as the Galapagos Islands. This study provides a thorough analysis regarding future water supply and demand options for Santa Cruz Island, under various growth scenarios. Also, it provides
clear results under pre-defined indicators, which will aid decision-makers and relevant authorities to make a scientific and supported decision to confront the future water crisis. However, the indicators, as well as their original values and ranges, have been proven to be case dependent and case sensitive.

In this paper, different sets of measures for improving the water supply system of Puerto Ayora were analyzed with four main groups of criteria. The aim was to obtain the most sustainable solution for mitigating the impact on the water supply by future local population and tourism growth. Also, it aimed to analyze the alternative which will provide an optimal balance between water supply and demand for the future conditions, with lowest impact on the fragile ecosystem, and with the most affordable cost.

As results showed, the Gal 2 and Gal 5 alternatives were ranked on the first position by the different stakeholder groups. Gal 2, which includes desalination, was preferred by decision makers and experts groups. On the other hand, Gal 5 was preferred by the two groups of local population (domestic end-users and hotels), which included all of the options, except desalination. These differences in the results can be attributed to the technical and environmental preferences given. Where the technical criterion has more weight, the desalination option tends to take the lead. However, if more weight is given to environmental or social criteria, Gal 5 takes the first position. Furthermore, based on the sensitivity analysis, Gal 2 tends to lose the first position easily by small changes on the weight values, because Gal 5 portrays a moderate environmental impact (low levels of wastewater discharge, lower impact to environment and sea water intrusion), moderate costs of implementation and operation and maintenance, but only 60% of water demand coverage at the end of the project horizon. On the other hand, Gal 2 is the only alternative that guarantees 100% coverage of water demand with supply, as well as improvement of the water quality to meeting drinking water requirements at the end of the project horizon (in 30 years). Therefore, decision-makers and experts give preference to this option. Nevertheless, despite these obvious advantages, due to the higher costs and negative environmental impacts identified, it can easily be replaced by Gal 5 in most of the sessions, suggesting the consideration of this type of fragile ecosystem by the different participants.

Regarding the uncertainty analysis, Gal 2 and Gal 5 have the highest probability to be ranked first or second in all of the sessions, as well as for the last ranked options, have probability to take the fourth or fifth place, but never the first place. This means that the results are certain and would not change drastically even if the effects scores are increased or decreased by 50%. As for the sensitivity analysis, it shows some criteria to be more sensitive than others. For instance, if more priority is given to environmental criteria, Gal 2 could never take the lead because of the negative impacts on the environment. This suggests that stakeholders prefer less quality, continue with the current situation, with little improvement in more sustainable terms, than installing a desalination plant. Moreover, it also showed that both groups analyzed (decision makers and experts) have high sensitivity to small weight changes, since Gal 2 may easily be replaced by any other alternatives. Moreover, the technical, social and environmental criteria showed higher sensitivity than the economic criteria, based on the steepness of the lines, suggesting that if the priorities of costs are changed, it would not have an impact on the final results, and that priority is given by stakeholders to other factors. Furthermore, sensitivity analysis of the effect scores did not show significant effect as the criteria weights.

Even though this analysis was done with just a moderate growth scenario, the total coverage of the demand according to the results from the WaterMet software on the previous study done by Reyes [10] at the end of the project horizon would be limited to 60%. Consequently, other alternatives should be considered in conjunction with the desalination option, especially concerning the water quality improvement. For instance, a dual water supply system could be explored, where the drinking fraction of the demand could be covered by desalination and the rest by the current brackish-water system. Moreover, the consumption at household level could be reduced by introducing a volumetric or increased-block water tariff structure. Finally, the suggested tourist growth should be limited, and the current trend of tourist arrivals should be reconsidered. It would be necessary to adopt a minimum threshold value of the demand coverage for each of the assessed alternatives, and further develop the alternatives based on this predefined threshold. Also, it would be interesting to assess the full potential of the rainwater harvesting as a centralized system with more detailed studies.

Finally, more studies would be needed to arrive at more accurate values of certain quantitative indicators. Those studies would need to encompass various types of long-term modeling (hydraulic, hydro-geological, physical, demographic and economic, etc.). More detailed determination of social acceptance criteria is needed as well, in order to come up with proper descriptive values for the qualitative indicators. Appropriate methods would encompass public surveys, workshops, meetings at community levels, lectures with feedback, public discussions, etc.

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