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A multicriteria analysis method as decision-making tool for sustainable desalination: the Asinara island case study

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ABSTRACT

The use of renewable sources is definitely an important solution to replace or to integrate the energy supply from fossil sources, that applies notably to desalination plants. The selection about the technology to use and the energy source to resort depends at first on a technical analysis (is it possible?) and then on an economical evaluation (is it worthwhile?). As alternative choice to the mere techno-economical comparison among different plant layouts the implementation of a multi criteria analysis is proposed in order to encompass a wide range of aspects of the relevant categories (technical, environmental, social etc.) and to develop a more general approach. The method has been applied to the Asinara Island, whose area is subject to peculiar environmentally protective restrictions, due to the presence of the Asinara national park and the preservation of an historical and cultural heritage, apart from water scarcity. In such a background the need for multi criteria methods to analyse a project is conspicuous. The procedure to take into account aspects that are difficult to quantify otherwise is described and applied, pinpointing strengths and drawbacks.

Keywords: Small island; RES desalination; Multicriteria; Sustainable energy planning

1. Introduction

Desalination of seawater or brackish water is one of the most important unconventional sources of drinking water in many parts of the world and plays already an important role in solving fresh water scarcity in areas where other water supply alternatives are not available. Seawater can be desalted and supplied in large quantity, and with a very high quality, but this requires a great amount of energy, which is mainly obtained from fossil fuels. The efficiency of desalination plant improved steadily in recent years but the dramatic increase of desalinated water supply creates a series of problems: the most significant are those related to energy consumption and environmental pollution caused by fossil fuels.

The exploitation of renewable energy sources has to be considered to satisfy the energy needs, with the perspective of enhancing the environmental sustainability of desalination. Desalination matched to renewable energy sources (RES) stands for an essential chance to all those geographical areas which are characterized with a shortage of conventional water resources. Such a problem is particularly intensified in coastal areas and islands that are subject to a tourist anthropic pressure focused into the summer period. However matching a desalination plant with a renewable energy conversion system involves a further set of problems due to the site specificity and to the stochastic availability of any renewable source [1].

The selection of the renewable technology depends on several factors, including plant size, feed water salinity,

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remoteness, availability of grid electricity, technical infrastructure, and the type and potential of the local renewable energy resource [2]. Furthermore, some combinations are better suited for large size plants, whereas some others fit better to small-scale applications.

In the kind of analysis which is needed it is not easy to assess the weight of all those aspects which are related to the territory as the environmental protection, preservation of the landscape and of the social-historical pattern even if they can prove to be fundamental to achieve a correct integration of the plant into the territory and an actual sustainability. The implementation of a multi criteria analysis can be proposed in order to take into account a wide range of aspects through a more general approach [3].

The present work aims at developing a method that can be used as effective support tool in the preliminary decision phase of a feasibility study. It sets itself forward as a decision making aid for the policy makers and stakeholders involved in the production, supply and management chain of the water resource. The main classes to be referred to the analysed aspects were picked out, as the environmental, the economical and the technological ones, as well as those related to the features of the site and to the energy consumption (compared to the RES capacity). Each class is formed with homogeneous factors which contribute to the definition of the specific aspect. Such a subdivision enables to award in a simpler way the weight to all single factors within each class. Setting a scale for weights allows to calculate a unique number which characterizes the investigated scenario and enables to compare alternative configurations, other things being equal.

The present study is included in the concluding phase of the project “Models for energy and environmental impact reduction of fresh water supply from sea source, and governance modelling for alternative technologies integration in the coastal territory in harmony with landscape constraints” [4]. Here the application to a case study, namely the Asinara Island, of the multicriteria analysis is presented in order to select the most suitable desalination technology and RES technology after obtaining the same result with a more traditional engineering evaluation. Prescriptive, environmental, economic, technical, energetic aspects are included into the selection criteria as well as the specific features of the site.

2. Desalination: critical and potential issues

At present desalination is a still contentious issue. Two are the main reasons: desalinating is expensive (the energy cost affects expenditure to the highest extent, as continuously increasing) and it has an impact on the environment as any other industrial plant [5,6]. Such an impact weighs in terms of land, visual, living space occupation. Opinions about the convenience of building such plants are different and/or divergent, and that occurs even in those backgrounds where the matter of water supply is ancestral, enduring with the probability of further worsening.

Desalination, carried out on a commercial basis starting from the fifties, is a mature technology, spread all over the world. It is a market geared towards innovation with investments into research and development by manufacturers which aim at increasing their field of action by patenting systems which lead to the efficiency improvement. The most ambitious goal lies in making desalination more affordable than traditional systems, since the cost is just the main hindrance to its widespread diffusion, in spite of its main source of strength: providing fresh water available immediately, made drinkable just in the location where its need is the greatest.

On the demand side the total need of fresh water grows with a speed higher than the capacity of exploiting the fresh water available in nature. For that reason the industrial desalination of sea or brackish water plays a key role in providing fresh water to a large number of communities all over the world [7]. In the period 1950–1990 the world’s water consumption has been trebling while the world’s population attained, at October 31st 2011, 7 billions of inhabitants. It should reach, by 2100, 10.1 billions with an intermediate amount of 9.3 billions of inhabitants in 2050 [8]. The worldwide capacity of fresh water production from desalination plants has been increasing steadily in nearly linear way for the period 2000–2014.

Specialists of desalination have always agreed on a fact: some conditions make it cheaper to use desalination than other systems to get water [9].

- In the case of islands far away from mainland (the construction of underwater pipelines uneconomical) where, because of geomorphologic and meteorological features, the water storage in reservoirs is not possible(a very costly alternative would be the use of tankers).
- In the areas that are rich in fossil fuels, in turn sources of energy for thermal desalination plants where vapour recovery is possible to generate power.
- There is no other option.
- The cost of all other resources is high.
- Standard of living is high.

2.1. Desalination in the Mediterranean area

Desalination, for a long time, is one of the main sources of fresh water in many parts of the Mediterranean basin, is marked out by a steady growth. On the base of information drawn from the 19th IDA worldwide desalting plant inventory [10] for the aforementioned Mediterranean area, the all-out volume of desalinated water amounts to 11,650,467 m^3 d^{-1}. The 70.46% of the total desalinated water. i.e., 8,207,979 m3 d^{-1}, originated from seawater desalination.

The greatest producers and their shares are:

- Spain (40,94%)
- Algeria (15%)
- Israel (10%)
- Libya (6.95%)
- Italy (6%)

There are desalination plants in really hot climates, in areas with lacking rainfalls [11] but also in areas where con-

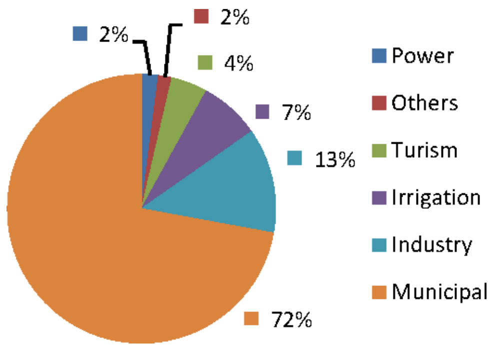

Fig. 1. Percentage for desalinated water use by sectors.

ventional water resources are not able to fulfil the seasonal peak of water need due to tourist demand [12].

Desalinated water is mainly used in the Municipal sector as shown in Fig.1.

2.2. Desalination and governance: from the rationalised use of water to finding the technology

In the Mediterranean area various examples of inclusion of desalination techniques into the overall water system can be found [13,14].

However a desalination plant can have to face a strong resistance to its achievement because of a set of problems, namely:

- thermal effect: atmospheric emissions;
- chemical effect: discharge of brine with a double saline concentration with respect to sea water and resulting modification of the marine ecosystem;
- landscape effect: volumes and contours are imposing.

The pre-treatment processes and the brine disposal management have been considered in detail and modelled as essential in the desalination system achievement. In [15,16] and in [17] pre-treatment and post treatment concerning desalination systems are considered with special emphasis on membrane systems.

The engagement of communities and stakeholders in decision-making processes that concern the integrated management of water resource is essential to get through the problems. It is also the opportunity to awaken citizens to a rational and appropriate use of water, which must be underlying any decision-making choice.

2.3. State of the art for matching of RES and desalination technologies

Renewable energies stand as the new frontier for desalination, particularly in areas endowed with a high RES potential [18]. As one of the main obstacles for wide-spreading desalination plants is related to a high energy cost of operation, the use of RES may be a solution in order to keep such a cost low.

Among a variety of water purification technologies, there are two main categories of desalination technology compatible with different renewable energy sources as follows:

- Thermal: multi-stage flash distillation (MSF), multiple effect distillation (MED) and vapour compression distillation (VC);
- Membrane : electrodialysis (ED) and reverse osmosis (RO).

Solar thermal energy (STE) is suitable for thermal based technologies of desalination (MSF, MED) while photovoltaic and wind power, as they immediately produce electric power, are suitable for membrane technology (RO and ED) as well as for mechanical steam compression (MVC).

Solutions integrating the technologies mentioned above with RES are in the experiment, not yet in commercialised phase. Anyway several engineering systems to exploit wind and solar energy have been devised and realised at various complexity and size levels.

Wind and photovoltaic systems can be matched to meet the requirements of isolated systems [19], the design of the combined system takes into account the user features and economic objects. On the same concept a hybrid desalination system, including an hydro turbine and a storage device, has been designed and studied with emphasis on demand and supply seasonal fluctuations [20]. A multiple-objective optimisation has been carried out to take into account technical, economical and management parameters. The mechanical vapor compression desalination system (MVC) are adapted for remote areas, in [21] the electrical and mechanical system is interconnected to the local electrical grid in an Egyptian site characterized by a high shortage in water resources.

Examples of demonstrative plants have been reported in recent years, the SDAWES project in Canary islands is quite well known [22]; a tested desalination system prototype, specifically intended to be powered exclusively by wind energy is capable of generating a grid similar to conventional ones, without the need of diesel sets or batteries to store the energy generated and meet the loads.

Different layouts can be obtained by matching different energy sources, as wind and sun, and desalination techniques, so that comprehensive computational models have been implemented and applied to obtain a reliable economical assessment [23]. The sector of renewable sources and desalination matching is continuously developing; as the desalination driven by the wind resource is concerned an overall scenario is sketched in [24] while in [25] the systems fed with solar energy are reviewed in a worldwide perspective.

3. Case study: the Asinara island

The Asinara island has been the subject of a previous work [26] dealing with an energy analysis and a feasibility study about different plant configurations, designed to provide for the needs of water dependent systems in a sustainable way.

The area of the small island, shown in Fig. 2, nearby Sardinia mainland, is 53.2 km^2. Asinara island becomes

Fig. 2. Map of Asinara island with its temporary villages (courtesy of Google).

National Park by a Presidential Decree on 3rd October 2002. The current and future activities on the island are described in the "plan of the park" (PPA), a document that has proactive but non prescriptive value and "constitutes the guidance, discipline and management framework for the actions of individuals and institutions that operate in the territory of the park". The cultural options provided in the PPA are all united by a vision of preservation of the natural, environmental and historical heritage in its physical, biological, ecological, human, social and economic integrity through an organization of the territory functional for this purpose.

The consequent development policies proposed in the PPA include not only the restoration and maintenance of natural, ecological and environmental structures, conservation of plant and animal species, emerged and submerged landscape protection but also the promotion of educational, training and scientific research as well as tourism activities compatible with the purposes of protection and restoration of ecological and hydrological balance and maintaining the memory heritage.

After evaluating the water demand based on two different scenarios for park developments, a possible equipment has been dimensioned to satisfy water needs using desalination as an integration of the natural fresh water availability from rain [26].

To satisfy the energy needs of the communities in the island, with the perspective of enhancing the environmental sustainability of desalination the use of renewable energy sources has been considered.

Since the plant operation is intermittent, it has been estimated that an off-grid solution would bring higher installed power and the need for a storage system, while the possibility of local exchange makes the on-grid solution more interesting. The solution investigated includes the use of solar and wind energy. Such a choice could be further discussed but here is assumed as starting point for the following development.

Two different desalination technologies were investigated, namely mechanical vapour compression (MVC) and reverse osmosis (e RO): both of them can be fed with alternative sources. Matching two renewable sources with two desalination devices gives rise to four configurations:

- MVC + PV
- MVC + WIND
- RO + PV
- RO + WIND

The calculation of the radiation incident on the PV modules was evaluated according to the common geometrical correlations which take account the relative motion between sun and earth as a function of time and the position relative to the earth of the module. The yield of the modules, needed for the calculation of electricity from a given incident radiation, was calculated according to the equation proposed in [27].

The prediction of the energy output from wind source has been obtained with reference to the hourly samples of wind speed, temperature and absolute pressure, extracted by mean of a reanalysis through a commercial software [26]. The prediction of the annual energy production has been assessed on a monthly basis following the theoretical setting expounded in [28].

In calculating the specific energy cost the subsidizations for the use of RES, promoted by the Italian managing authority of the energy services, have been taken into account. In detail, for both photovoltaic and wind systems the net metering option has been considered; it allows to get an economic compensation, i.e. a trade-off between the value of the produced energy which is given to the grid and the value of the energy which is drawn and consumed in a period different from that when the production occurs. As the wind energy production is concerned, there is the possibility of exploiting the subsidization of an all-inclusive rate for medium and small size plants.

As for the MVC technology, the plant behaviour was simulated by a stationary model developed in Matlab environment on the base of the work proposed by El-Dessouky et al. in [7]. The performance of the reverse osmosis (RO) plant was obtained through a computer code, implemented in Matlab environment, based on the mathematical model proposed by Avlonitis [29].

The overall desalination costs are shown in Fig. 3 for the different plant configurations and, just for wind source, for two alternative subsidizations.

The best combination is the RO + WIND match, as the histogram in fig. 3 shows : it is the result of a techno-eco-

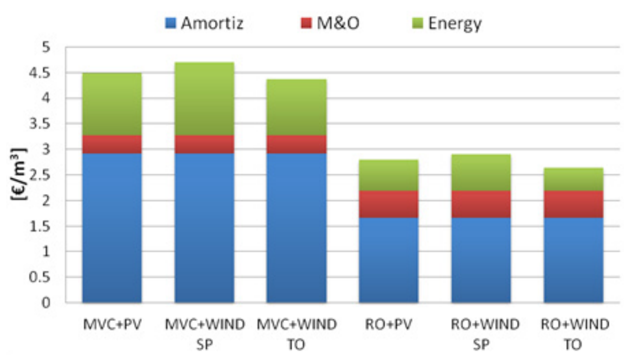

Fig. 3. Overall cost of desalinated water by various RES systems (SP net metering, TO all-inclusive rate).

nomic analysis. The RO technology proved to have lower capital and energy costs but higher management costs if compared with MVC [26].

The multicriteria analysis, which takes into account these elements, since technical and economic criteria are included in the procedure, extends the range of survey and allows to obtain a different but not conflicting evaluation.

4. Multicriteria analysis

In land-use planning an effective method to use as aid to the selection among different options could be the multicriteria analysis [30,31]. Also known as MCDM (Multi Criteria Decision Making) it is an useful evaluation method to compare different scenarios, which takes into account various criteria, sometimes conflicting and difficult to place side by side. It is an instrument to lead after simulations the decision-making process by policy makers.

The basic elements that form MCDM are:

- Objective to be achieved;
- Decision-makers, subjects who are interested to the assessment of alternatives and to the final choice;
- alternatives, objects of assessment and choice;
- criteria, estimation elements which contribute to set the assessment of alternatives;
- the weighing system, to measure the importance given to the different criteria by the decision-maker.

4.1. The implementation of the method

Criteria have to be as general as possible in order to apply them to cover the many specific situations that are encountered. The weights to each macroriterion have a general character too, while the scores in the following calculation depend on the application with its specific features.

4.1.1. Setting of macrocriteria

The first step consisted of setting macrocriteria, directly related to the classes of the problem which are involved in decision-making. Such criteria are ultimately determined by the bodies that deal with these issues that can be political or technical.

The macrocriteria have been identified by the authors taking into account discussions with local authorities, during a summer school dealing with the set of problems of the park, and the gaming simulation [32].

- Legislation/policies for the management of the integrated water system.
- Social characteristics.
- Characteristics of the location.
- Technical criteria.
- Environmental impact.
- Energy criteria.
- Economic criteria.
- Financial criteria.

Each of these macrocriteria is made up of several specific criteria (subcriteria). Because of the numerousness of the criteria and the complexity of the problem it has been decided to apply the analytic hierarchy process (AHP) method [33] in two steps: it will be described in detail in the next subparagraphs.

4.1.2. Assessment of the values (weights) to assign to criteria

For each macro criterion comparison matrices have been created in order to ease the comparison among subcriteria, by means of the “pair-wise” method. The result of such a method enables to assign a weight to each criterion. Even though we intend to deal with a general matter and presenting an evaluation procedure we will hint at a specific case of desalination plant in the context of a nature conservation area. The comparison matrices for all the eight

Table 1
Matrix comparing legislations and policies

	Legislations/ policies for the integrated water system	1	2	3	4	Total	Weights (%)
1	Integrated management of different sectors	1	2	2	2	7	37.84
2	Clients and management by third parties	0.5	1	2	1	4.5	24.32
3	Techniques and rules to follow drawing up a contract	0.5	0.5	1	0.5	2.5	13.51
4	Production and supply by private sector	0.5	1	2	1	4.5	24.32
Total						18.5	100

Table 2
Matrix comparing social characteristics

	Social characteristics	1	2	3	4	Total	Weights (%)
1	Awareness of the rational use of water	1	1	2	2	6	33.3
2	Techniques and rules to follow drawing up a contract	1	1	2	2	6	33.3
3	Bargaining/ decision-making power of the supplier/manager	0.5	0.5	1	1	3	16.7
4	Bargaining/ decision-making power of users of the service	0.5	0.5	1	1	3.0	16.7
Total						18,0	100

macrocriteria listed above are now analyzed entering into detail. Each column of them picks on the numbers of subcriteria so that as many pair-wise comparisons as the boxes of the resulting grid can be made.

Neutrality, i.e. the situation where the compared subcriteria have the same weight is worth 1, 2 denotes a subcriterion prevailing on its opposite, 0.5 a subcriterion losing to its opposite.

The sum of points gained by each subcriterion in all its pair-wise comparisons is put at the end of each line, exactly in the second to last column.

The method has a general substance but the attribution of scores depends on the specific case study, in particular as some comparison matrices are concerned (definitely matrices in Tables 2, 3 and 6).

A point to be underlined is the one that the macrocriteria of Tables 1–8 include inter-disciplinary assessments that usually are dealt with separately. Really comparison matrices range from legal/social aspects (Tables 1, 2), geographic/environmental (Tables 3, 5), technical (Tables 4, 6), economic (Tables 7, 8). Usually engineering proposals and feasibility studies are developed in terms of a cost benefits analysis neglecting some of the above mentioned aspects.

4.2. Calculation of scores concerning different plant configurations

Once weights are defined by means of the comparison matrices, the calculation or assessment of the regarding score is taken for each technological matching; in the fol-

Table 3
Matrix comparing location characteristics

	Characteristics of the location	1	2	3	4	5	6	7	8	Total	Weights (%)
1	Geomorphology	1	1	1	0.5	0.5	1	1	2	8.0	11.35
2	Accessibility/Mobility/Transport system	1	1	1	0.5	1	1	1	2	8.5	12.06
3	Demand of civil sector (resident population)	1	1	1	0.5	0.5	1	1	1	7.0	9.93
4	Demand of tourist activity (seasonal)	2	2	2	1	1	2	2	1	13.0	18.44
5	Demand of farming activity	2	1	2	1	1	2	2	1	12.0	17.02
6	Demand of industrial activity	1	1	1	0.5	0.5	1	0.5	1	6.5	9.22
7	Environmental/ecological systems ((Parks, Special Protection Areas -Zps, Sites of Community Importance-Sic)	1	1	1	0.5	0.5	2	1	2	9.0	12.77
8	Specialised personnel availability and organisational structures	0.5	0.5	1	1	1	1	0.5	1	6.5	9.22
Total										70.5	100

Table 4
Matrix comparing technological and operational criteria

	Technical/operational criteria	1	2	3	4	5	6	7	8	9	10	11	Total	Weights (%)
1	Simplicity of operation	1	0.5	1.0	0.5	2	0.5	0.5	0.5	1	1	2	10.5	7.7
2	Energy demand and effectiveness of the process with respect to energy consumption	2	1	2	1	2	1	1	1	2	2	2	17.0	12.4
3	Robustness, maintenance needs	1	0.5	1	1	2	1	1	1	2	0.5	2	13.0	9.5
4	Reliability	2	1	1	1	1	1	2	2	2	1	2	16.0	11.7
5	Compact size of the plant	0.5	0.5	0.5	1	1	0.5	1	1	0.5	0.5	1	8.0	5.8
6	Commercial availability of the technology	2	1	1	1	2	1	1	1	2	0.5	2	14.5	10.6
7	Site characteristics required	2	1	2	0.5	1	1	1	1	2	1	1	13.5	9.9
8	Infrastructure required (roads, hydro and electric grid …)	2	1	1	0.5	1	1	1	1	1	0.5	1	11.0	8.0
9	Requirements for specialised personnel	1	0.5	0.5	0.5	2	0.5	0.5	1	1	0.5	1	9.0	6.6
10	Produced water quality	1	0.5	2	1	2	2	1	2	2	1	2	16.5	12.0
11	Easy transportation to site	0.5	0.5	0.5	0.5	1	0.5	1	1	1	0.5	1	8.0	5.8
Total													137.0	100

Table 5
Matrix comparing issues for environmental impact

	Environmental criteria	1	2	3	4	5	Total	Weights (%)
1	Effluents/ waste produced	1	2	2	1	1	7.0	25.5
2	Visual impact	0.5	1	2	0.5	1	5.0	18.2
3	Noise	0.5	0.5	1	1	1	4.0	14.5
4	Land requirement	1	2	1	1	0.5	5.5	20.0
5	Interaction with natural environment	1	1	1	2	1	6.0	21.8
Total							27.5	100

Table 6
Matrix comparing energy use characteristics

	Energy Criteria	1	2	3	4	Total	Weights (%)
1	RES potential availability	1	2	2	2	7.0	36.8
2	RES cost for desalination	0.5	1.0	0.5	0.5	2.5	13.2
3	RES operational characteristics	0.5	2	1	2	5.5	28.9
4	Local power grid adequacy	0.5	2	0.5	1	4.0	21.1
Total						19.0	100

Table 7
Matrix comparing economic criteria

	Economic criteria	1	2	Total	Weights (%)
1	Investment cost	1	2	3.0	66.7
2	Operation/ maintenance cost	0.5	1	1.5	33.3
Total				4.5	100

Table 8
Matrix comparing budgetary criteria

	Financial criteria	1	2	3	Total	Weights (%)
1	Public financing	1	1	2	4.0	40
2	Private financing	1	1	2	4.0	40
3	Self-funding	0.5	0.5	1	2.0	20
Total					10.0	100

lowing four combinations of renewable sources and desalination technologies are considered as deduced from the technical analysis carried out in the previous section. Such a score, as stated above, can range from 0 to 4 for each subcriterion.

When it is not possible to attribute a scoring through a procedure based on computable quantities, the score is given on the basis of how much the subcriterion can affect the selection among the submitted combinations. The highest score, in the aforementioned scale, is attributed to the combination, which, with respect to the specific subcriterion, responds in the most effective manner.

For the sake of explaining the multicriteria procedure just one of the 8 matrices where each technological combination is evaluated with respect to subcriteria, is shown and discussed (Table 9). If we take into account the starting numbering of macrocriteria in Table 9 for instance the W4 weights are concerned. A single column is up to each of the different technological combinations, where the weights obtained for each subcriterion are present. In the present case, taken as example, various subcriteria belong to the technical class (macro criterion). Where possible the attribution of the score, in the range from 0 to 4, has been drawn from the comparison of results obtained in the analysis described in [26] and summarized in the previous section.

The score has to be multiplied by the corresponding weight of the subcriterion; the sum of all products allows to define the result for the macro category (macro criterion) and for the technological matching, as we can infer from the following formula:

$$R_{MC} = \Sigma W_k \cdot S_{kC} \tag{1}$$

where R denotes the result, W the weight, S the score, k the subcriterion and C the technological combination (matching).

As a matter of fact different technological combinations (Des + RES) enjoy the same score for some subcriteria and

Table 9
Matrix of assessment of different technological combinations as regards technical criteria

Technical criteria	MVC + PV	MVC+ WIND	RO + PV	RO + WIND
Simplicity of operation	3.0	3.0	2.5	2.5
Energy demand etc	1.9	1.9	4.0	4.0
Robustness, maintenance	3.0	3.0	2.7	2.7
Reliability	3.0	3.0	3.0	3.0
Compact size of the plant	3.0	3.0	3.0	3.0
Commercial availability	2.0	2.0	4.0	4.0
Site characteristics required	3.2	2.7	3.0	2.5
Infrastructure required	3.0	2.7	3.0	2.7
Specialised personnel	3.0	3.0	2.7	2.7
Produced water quality	4.0	4.0	2.0	2.0
Easy transportation to site	4.0	3.0	4.0	3.0

macrocriteria. Such an aspect on the one hand would bring us to judge macrocriteria inconsequential as far as the choice among different submitted alternatives is concerned but on the other the same macrocriteria represent factors that have to be taken into account in the more general issues where the assessment includes, among the possible alternatives, water supply from conventional sources.

Once again one of the 8 composed tables that belong to the procedure is shown in Table 10 as an example. It has been obtained by juxtaposing the grid concerning the weights attribution for each technological combination with the grid where the score gained by each technological combination is multiplied by the subcriterion percent weight. Table 10 shows micro criteria and the respective weight sum for the different technological combinations.

This step consists of finding an all-out result for each technological combination, deducible from the weighing of values referring to the weights defined in Table 11, according to the following expression:

$$T_C = \sum P_M \cdot R_{MC} \quad (2)$$

Table 10
Extended matrix of the weight sum for macrocriteria and technological combinations

	MVC + PV	MVC + WIND	RO + PV	RO + WIND
Legislation/policies for the integrated water system	3.03	3.03	3.03	3.03
Social characteristics	2.67	2.67	2.67	2.67
Characteristics of the location	3.18	2.35	3.38	2.55
Technical/operational criteria	3.0	2.8	3.1	2.9
Environmental criteria	1.9	1.8	2.2	2.6
Energy Criteria	2.3	2.2	3.9	3.7
Economic criteria	1.7	1.7	3.7	3.7
Financial criteria	3.0	3.0	3.0	3.0

Table 11
Matrix of suitability weights PM

	Suitability	Weights (%)
1	Legislation/policies for the integr. water system	5.00
2	Social characteristics	10.00
3	Characteristics of the location	15.00
4	Technical/operational criteria	10.00
5	Environmental criteria	15.00
6	Energy Criteria	20.00
7	Economic criteria	20.00
8	Financial criteria	5.00
	Total	100

where T_C denotes the final result for the specific techno-logical combination, P the weights associated to each macro category (macro criterion).

The suitability weights are set on the basis of several evaluations and are susceptible to the point of view of policy makers. Here their frame is the case study of the Asinara island considered in some detail before. The definitions of weights is a particularly complicated matter and in turn can emerge from a direct debate among the various stakeholders and players in the decision making process.

The purpose of the multicriteria analysis consists of rationalizing the decision-making process as well as facilitating selections and guidelines of the part of those who commission the same analysis, however the multicriteria analysis has its own drawbacks, as the limitation of providing less transparent results. This is due mainly to its more free approach that is susceptible of a greater margin of discretion by the decision maker. Indeed macrocriteria and weighing levels are assumed through a political process by those who are taking part to the decision-making/evaluating procedure [34]. Judgments and choices therefore can depend on the purpose which one aims to achieve, in other words they are affected by it and by the scenario but, above all, by the subjects just involved in the process. Identifying the alternatives, choosing the selection criteria and associating to them values and weights, through a pairwise comparison, is anyway the product of a balanced compromise among views that can be divergent too. Thus if the choice is not made by one single decision-maker but the involvement of more stakeholdersis is required using a multidisciplinary approach, then resorting to the gaming simulation could be helpful.

The gaming simulation (GS) plays an important role in the participatory processes, being an efficient method of comparing alternatives or divergent approaches [35]. It is an efficient instrument to study and analyze a set of problems pertinent to any branch of knowledge and could play a major supporting role to the multicriteria analysis, in terms of method understanding and characterization of process phases, from the selection of criteria to the attribution of weights by policy makers. The game, conceived in order to simulate the dynamics of multicriteria analysis, could find a wide potential use: for approach and knowledge, training and implementation of results.

In Table 11 the suitability weights (P) for each macro sector (M) are shown: they refer to the case study considered in the following section.

In order to further understand the procedure and the method taken in selecting micro criteria and awarding weights it is worthwhile to specify how branches of knowledge interact.

The research group, comprising different expertise areas which range from mechanical engineering to urban planning, from architecture to economics, simulated what can occur in the decision-making process, when technicians of different background, that are represented in the political sphere, confront each other at a round table.

Each macro criterion and the weight awarded to it, is the result of the mediation among remarks, evaluations and choices on the part of the single different members of the research group, according to the rules determined by common accord.

Table 12
Matrix of results for technological combinations

	MVC + PV	MVC + WIND	RO + PV	RO + WIND
Legislation/policies for the integrated water system	0.15	0.15	0.15	0.15
Social characteristics	0.27	0.27	0.27	0.27
Characteristics of the location	0.48	0.35	0.51	0.38
Technical/operational criteria	0.30	0.28	0.31	0.29
Environmental criteria	0.29	0.27	0.33	0.39
Energy Criteria	0.47	0.43	0.77	0.75
Economic criteria	0.33	0.33	0.73	0.73
Financial criteria	0.15	0.15	0.15	0.15
Total	2.43	2.24	3.22	3.11

The suitability matrix is particularised for the different technological solutions in order to find out a final criterion to decide among different alternative solutions. The percent weights of Table 11 must be multiplied by the PM of Eq. (2).

Table 12 stresses the final result for each technological combination and shows the partial results referred to the macrocriteria.

4.3. Comparison among different technological solutions

Bearing in mind that in the previous section the criteria and weights have already been referred, at least in part, to the Asinara island case, the comparison among the different technological solutions is finally presented. On this occasion we achieve an evaluation which is no more merely economic (in currency terms) but is based on scores that account for mixed criteria.

The technological combination that gains the highest score is reverse osmosis desalination coupled with photovoltaic production system. The RO + WIND combination is the second best while the combinations with MVC have a similar lower performance (Fig. 4).

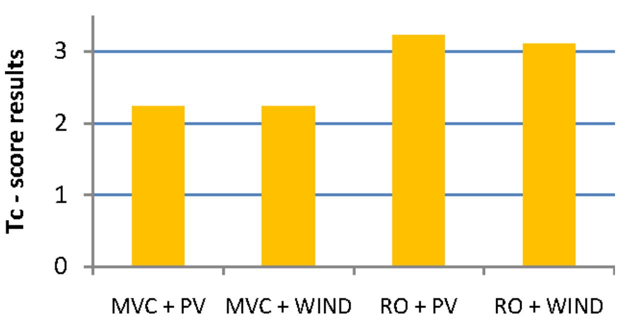

Fig. 4. Comparison of final results of multicriteria analysis concerning technological combinations for Asinara Island.

The fact that such a result differs from that obtained by the techno-economic analysis proves that the multicriteria analysis, even in a relatively simple scenario, provides useful guidelines to designers, stakeholders, policy makers etc., which are linked to the environmental, economic and social context and not just to the technological product.

5. Conclusions

A multicriteria analysis for the selection of the most convenient matching of renewable sources and desalination technologies has been developed with reference to an area of special environmental interest and vulnerability. The list of considered criteria includes legal, social, environmental, operational, economic aspects as well as the specific location features. The application to a case study emphasized the limits and problems that the awarding of weights and scores to criteria concerning not calculable or estimable quantities involves. Therefore the participation of as many as possible stakeholders provided with a decision-making power acquires a special significance.

The application of the method to a small island water systems allowed to show its potential usefulness as a decision support system for the selection of a proper desalination system beyond a more usual cost/benefits analysis. A previous technical study, which actually has been used to implement the multicriteria analysis together with other instruments, had provided a different rank among technological solutions Des-RES. The application to a quite simple case restates the complexity of the project and development of desalination fed with renewables that has to be faced taking into account many issues in order to be admissible.

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