How to Manage Conflicting Values in Minor Islands: A MCDA Methodology Towards Alternative Energy Solutions Assessment

Marco Rossitti[1](✉) and Francesca Torrieri[2]

[1] DAStU, Politecnico di Milano, Via E. Bonardi 3, 20133 Milano, Italy
marco.rossitti@polimi.it

[2] DII, Università Degli Studi di Napoli Federico II, Piazzale V. Tecchio 80, 80125 Napoli, Italy

Abstract. The growing awareness towards the energy issue has led to a dramatic change in structuring decisional problems related to energy supplies by giving greater importance to the environmental impacts of projects and their effects on life quality. This kind of matter is enriched in complexity when Decision Makers (DMs) have to deal with cultural heritage in fragile areas. Indeed, this fact leads to consider an array of cultural values related to the area's peculiarities and deal with all the difficulties associated with marginalized territorial contexts. In this perspective, the paper aims to provide an analytic framework to support DMs in defining the favorable energy supply solution for a historical rural landscape. The methodological framework is based on a Multicriteria Decision Aiding Methodology (MCDA), which considers the conflicting values of such a decisional issue. This support tool is applied to a project in Pantelleria island, which has recently been the focus of different policies for energy efficiency. Indeed, Pantelleria richness in natural energy sources makes it possible to shift to sustainable energy supply models different from the current one. Furthermore, the island is an extraordinary example of a historical rural landscape but, at the same time, is undergoing a marginalization process. The evaluation process considers the multiple dimensions of sustainability through a MCDA methodology for assessing three different context-aware energy scenarios: a wind-based scenario, a solar-based scenario, and a traditional scenario. In conclusion, the main results from the evaluation process and the future research perspectives are discussed.

Keywords: Energy supply · Sustainability · Multi-criteria evaluation · Conflicting values · Minor islands

1 Introduction

The increasing attention to environmental issues has led to experimenting with innovative and economically sustainable solutions on energy and water in a circular economy perspective. Indeed, the *European Green Deal* foresees, among the actions necessary to achieve a more sustainable future, rethinking policies for "clean" energy supply in all sectors of the economy, including industry, infrastructures, transports, and constructions [1].

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In this context, the European project for minor islands [2] represents an experiment of great interest for the transition to a sustainable energy model because of their particular vulnerabilities, together with the rich availability of natural resources and landscape significance. Indeed, most of the minor islands' energy systems grounds on a traditional model based on fossil fuels, with inefficient and costly energy production. However, in most cases, renewable resources (such as sun, wind, tides, biomass, waste, and other renewable sources) are locally available, offering a solid potential to be exploited by promoting sustainable and innovative energy models.

The ongoing experiences display many current issues in complex territories, such as minor islands not interconnected to the *National Transmission Network* (NTG). The most significant challenges deal with the choice of technological, organizational, and financial solutions that can enhance the use of environmental resources locally available and improve the attractiveness of marginal areas, but not neglecting the protection of the landscape. So, the transition to a sustainable energy strategy is a technical, cultural, and landscape challenge [3].

The sustainability of renewable energy sources is valuable not only in terms of avoiding carbon emissions but also in terms of changes that occur in the landscape structure. Only through a strategic and culturally integrated approach, it will be possible to achieve the objectives of energy transition in the Minor Islands compatibly with the protection and enhancement of the landscape and the environment. In such sensitive areas, the energy transition intervention proposals must be conceived as "Landscape Projects". This concept hints that such interventions cannot merely focus on the energetic aspect of the decision issue but must necessarily consider all the impacts produced on the reference territorial context, considered in its landscape dimension [4].

The challenge is to define technical solutions that are efficient from an energy point of view and respectful of the complex values of the historical and rural territories that characterize the smaller islands. In particular, Sijmons et al. described five dimensions of energy transition: economic, political, technical, infrastructural, and emotional [3]. According to Kemp and Loorbach: "Energy Transition management consists of a deliberate attempt to work towards a transition offering sustainability benefits, not just environmental benefits but also economic and social benefits" [5].

In this context, the paper aims to provide an analytic framework to support DMs in defining the favorable energy supply solution for minor islands resting on a Multicriteria Decision Aiding Methodology (MCDA), which considers the conflicting values of such a decisional issue. This support tool is applied to a real case study: a project in Pantelleria island, which has recently been the focus of different policies for energy efficiency.

More in detail, after outlining the legislative reference framework at the European and national level for the energy transition in minor Italian islands, Sect. 2 focuses on the Pantelleria by explaining its suitability as a case study for testing the defined framework. Then, in Sect. 3, the methodological framework towards alternative energy solution assessment is described, and, in Sect. 4, its application to a project in Pantelleria island is illustrated. Section 5 discusses the results of applying the methodological framework to the case study. Finally, in Sect. 6, some conclusions on the novelty of the proposed approach, its replicability, and room for improvement are drawn.

2 The Case Study: Pantelleria Island

2.1 The Regulative Process Towards Energy Transition in Italian Island Contexts

Since the late 1970s, when the leading development model based on the intensive use of natural resources was rocked by the energy crisis [6], the regulative system, both at the national and international scale, has been forced to deal with the energy consumption issue and to promote sustainable development.

At the European level, the regulative process of tackling energy consumption has dramatically intensified in the last twenty years. Indeed, the European lawmaker has defined different measures, tackling energy consumption from several perspectives.

In this light, it is worth mentioning the Directive 2009/29/EC to promote reducing greenhouse emissions [7], and the Directive 2012/27/UE, geared towards promoting energy efficiency to reduce energy consumption and decrease energy imports [8]. More recently, the body of measures towards energy consumption reduction and energy transition enriches itself of the Communication 2016/860 *Clean Energy For All Europeans*, the Communication 2017/283 *Europe on the Move, an agenda for a socially fair transition towards clean, competitive, and connected mobility for all* [9, 10], and the Communication 2019/640 *The European Green Deal,* placing at its core the transition towards a clean and circular economy [1].

In the Italian context, this great concern about energy consumption and the need to move towards alternative and renewable energy sources is reflected in several legislative measures. Among them, the measures addressing the energy issue in Italian marginal areas, as the M.D. 14/02/2017 *Minor Islands* and the Directorial Decree n.340 14/07/2017 from the Ministry of the Environment, are of particular interest.

More in detail, the former, the D.M. 14/02/2017 *Minor Islands,* sets ambitious objectives towards renewable energy sources promotion in minor Italian islands, not connected to the national power grid, to reduce their energy dependence and environmental impact [11]. The latter, the Directorial Decree n. 340 14/07/2017, instead introduces and regulates the incentive towards energy efficiency, sustainable mobility, and climate change adaptation interventions in minor islands [12].

Both these legislative measures, in addressing the energy transition issue in minor islands, well recognize their potentials towards green and sustainable development and, at the same time, calls for proper tools to support decisions about alternative energy supply solutions [13].

2.2 Pantelleria: Between Natural Sources and Cultural Values

The pre-mentioned M.D. 14/02/2017 *Minor Islands* defines a list of minor Italian islands for its application, including Pantelleria island in the Sicily Region.

This island, located between Sicily and Africa (Fig. 1), owns a strong potential for renewable energy sources, like sun, wind, and geothermal energy. Thus, it stands as a perfect field for sustainable energy supply models' implementation [14]. However, at the moment, the island has no independence in terms of energy supply, and electricity comes from an oil-powered plant [15].

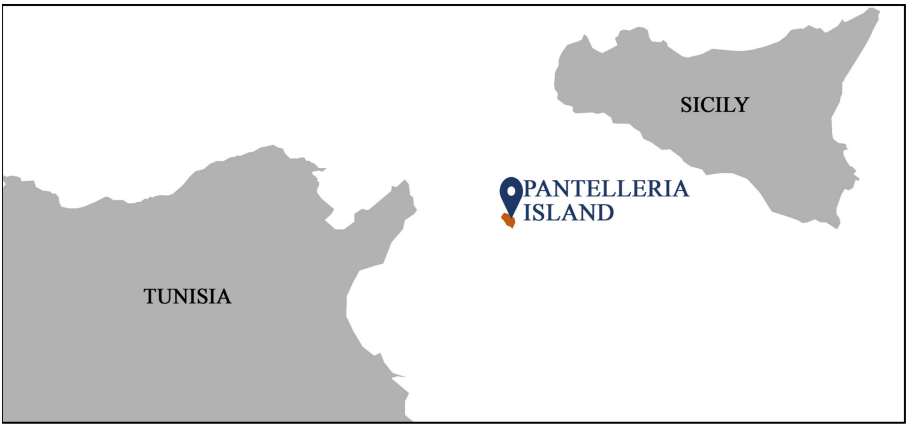

Fig. 1. Location of Pantelleria Island in the Mediterranean sea

Once acknowledged its potentials in terms of local renewable sources and the limits from the current energy supply model, the island in 2013 joined the European Covenant of Mayors for Climate & Energy [16]. Then, in 2015 it adopted the *Action Plan for Sustainable Energy*. This plan provides an integrated local strategy towards energy transition based on different fields of intervention. Its long-term vision is to create a 'zero-emission island' by promoting renewables for electricity production in place of diesel fuel and energy efficiency in water treatment, public lighting, and the building sector [17].

Furthermore, within the European initiative *Clean Energy for EU Islands* [1], in 2020, Pantelleria defined a *Clean Energy Transition Agenda,* aiming at its complete decarbonization and energy independence to high penetration of renewable energy sources and technological innovation. More in detail, this *Agenda* sets electricity production from renewable sources (wind, solar, and wave motion) and buildings' independence as pillars for energy transition [18].

The widespread and constant commitment of Pantelleria public administration in energy transition makes it appropriate to choose this island to apply a methodology towards alternative energy solution assessment.

However, in its application, the methodology cannot prescind from the values system the island is endowed with [19]. Indeed, the aesthetic and cultural significance of the Pantelleria landscape is such to make it worth the inscription in the *National Register for Historical Rural Landscapes* [20]. Nevertheless, the need to protect such a unique example of a historical rural landscape can be menaced by its alteration in favor of energy transition [21]. For this reason, an effective methodology towards alternative energy solution assessment, properly managing the conflicting values stemming from complex territorial contexts, finds in Pantelleria a perfect case study to be tested.

3 The Methodological Framework Towards Alternative Energy Solutions Assessment

The definition of a methodology towards alternative energy solutions assessment, able to adequately consider and manage the conflicting values stemming from complex territorial contexts, calls for a robust scientific framework (Fig. 2): it can be found in Simon's decision-making model [22].

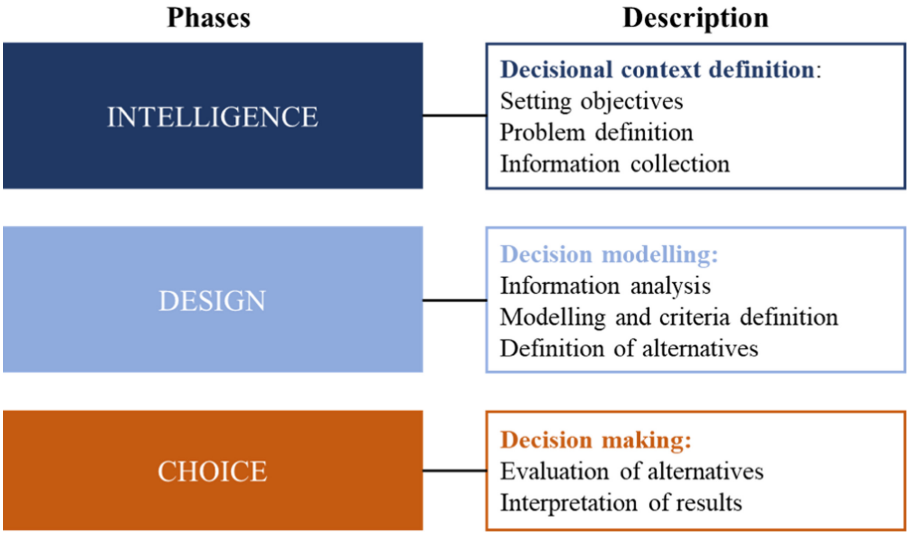

Fig. 2. Simon's decision-making model

Thus, according to the pre-mentioned model, the definition of the methodological framework for this work's purposes follows three main phases, as described below.

3.1 The Intelligence Phase

After setting the research's objective, supporting decision-makers in deciding among alternatives scenarios for the transition to green and circular energy supply models, this phase is geared towards the decisional context definition. In this light, in-depth knowledge of the energy issue from a sustainable perspective [23] and of the territorial context under study is fundamental. More in detail, the already set experiences or the existing regulative tools or plans stand as a crucial reference point for developing the decision-making process through a context-aware and feasible approach.

3.2 The Design Phase

Based on the analysis of the information collected through the *Intelligence phase,* this second step aims to model the methodological framework and define the energy supply alternatives to be assessed.

This phase moves from selecting the reference methodological approach for the evaluation of alternatives. It is identified in the MCDA. Indeed, applying a multi-criteria model makes it possible to consider the different and conflicting perspectives related to various energy scenarios' implementation and measure the alternatives' performance according to heterogeneous criteria set. For this reason, multi-criteria has found wide application in supporting decisions towards energy transition [24–27].

Once defined the model to be used, this phase delves into defining the criteria for the assessment and the related indicators for measuring alternatives' performances. More in detail, the criteria definition stems from a literature review process about the application of MCDA to alternative energy scenarios' assessment [28–31]. This process, indeed, allows recognizing the most relevant criteria used for similar decisional issues. Then, the criteria so defined are implemented to consider the conflicting values stemming

Table 1. Definition of criteria, indicators, scale, and units of measurement

Criteria	Sub-criteria	Indicators	Scale	U.M	min/max
Technical-Economic	Construction cost	Construction cost	*Ratio*	€	min
	Management and maintenance cost	Management and maintenance cost	*Ratio*	€/year	min
	Construction time	Natural and consecutive days	*Ratio*	days	min
	Service life	Number of years	*Ratio*	years	max
	Continuity of energy supply	Numbers of working hours per year	*Ordinal*	(0, +++)	max
	Access to funding	Presence of funding	*Binary*	Yes/No	max
Cultural-Environmental	Sustainability in facing climate change	CO2 emissions reduction	Ratio	Kg/year	max
	Noise impact	Qualitative	*Ordinal*	(---,0)	min
	Ecosystem impact	Qualitative	*Ordinal*	(---,0)	min
	Visual impact	Qualitative	*Ordinal*	(---,0)	min
	Sustainability from production and disposal	Amount of pollutants emitted in the atmosphere	*Ordinal*	(0, +++)	max

from the application to complex contexts characterized by marginalization dynamics and high cultural and aesthetic significance [32]. The result from this intermediate step in the design process is displayed in the table below (Table 1).

Finally, the design phase is devoted to the definition of the energy supply alternatives to be evaluated. With this purpose, comprehensive knowledge of the territorial potentialities and the existing plans about energy transition is an essential requirement.

3.3 The Choice Phase

Based on the outputs from the design phase, this last step in the decision-making process aims at evaluating the different designed alternatives according to the criteria set. In this light, a specific MCDA method is selected for the calculation phase [33]: the *Electre method*. This method is based on a pairwise comparison of the alternatives to be assessed. Indeed, its grounding idea is to measure the degree to which scores and their associated weights confirm or contradict the dominant pairwise relationship among alternatives. More in detail, a dominance relationship for each couple of alternatives is derived using both a net *concordance index*, representative of how much an alternative is better than the others, and a net *discordance index*, expressing to what degree an alternative is worse than others. From their combination thus, a final ranking of the alternatives is obtained [34]. *Electre method* choice lies in the fact that it enables handling both quantitative and qualitative criteria and in its flexibility [35]. In addition, this MCDA methodology has been widely used in literature for supporting similar decisional issues [36–38].

Concerning one of the fundamental steps in the MCDA process, the weighting phase, aimed at considering the relative importance of the different criteria, the defined methodological framework rests on the SRF procedure. Indeed, by using a set of cards and indirectly determining numerical weights through a visual comparison, this procedure enables the involvement of different stakeholders in the decision process [39].

4 The Methodological Framework Application: A Project for Pantelleria Island

The previously defined methodological framework was tested on a case study to test its effectiveness, represented by a landscape regeneration project in Pantelleria island, focusing on the energy supply issue.

Thus, after collected and processed the preliminary and necessary information about the island and processed through a SWOT Analysis, different alternative energy supply scenarios were defined. More in details, the island's potentialities in terms of natural sources, clearly stated in the official documents towards Pantelleria energy transition and verified through a direct survey on the island, led to the definition of the following scenarios:

1. A *solar-based scenario*, based on installing PV modules on shelters and the ground, in proximity to the existing masonry retaining walls for the terraces (Fig. 3). According to the energy demand required by the project's functions, the number of PV modules



Fig. 3. Example of PV modules integration on shelters (Authors' elaboration)

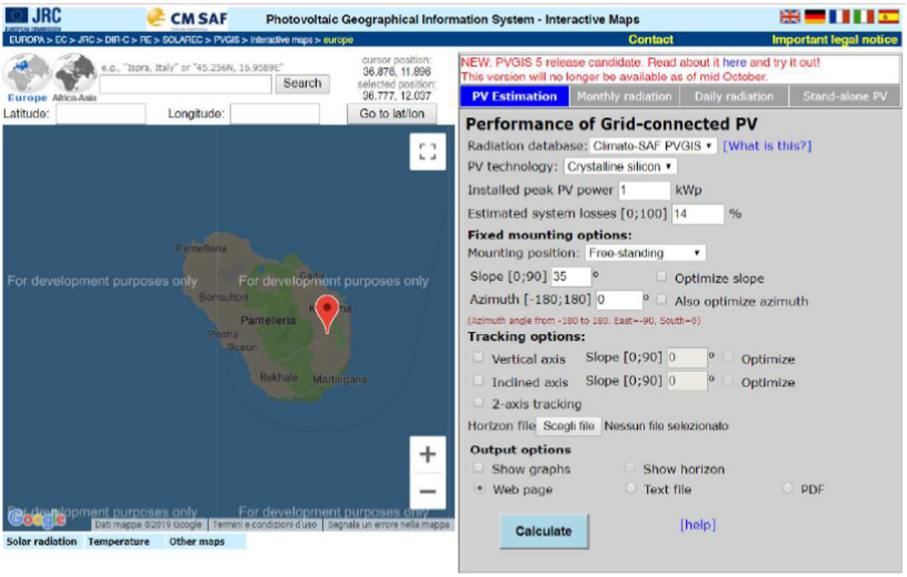

Fig. 4. *PVGIS* calculation tool for estimating the amount of PV modules to be installed

to be installed was calculated through the calculation tool *Photovoltaic Geographical Information System (PVGIS)* [40].

This tool, indeed, allows determining the number of PV modules necessary to answer a given energy demand based on the geographic location, the technology used, and the typology of installation (Fig. 4).

2. A *wind-based scenario* resting on the installation of three wind micro-turbines with a rated power of 5.5 kW. Indeed, by considering Pantelleria's average wind speed of 6 m/s [20], the three micro-turbines can cover the estimated energy demand (Fig. 5).

Furthermore, they will be placed on the non-cultivated terraces in the upper part of the project area, thus benefitting from good wind exposure.



Fig. 5. Integration of the wind micro-turbines in the project area (Authors' elaboration on a picture taken by Marco Rossitti)

3. A *traditional scenario*, based on the current system of electricity production through an oil-fired power plant. This power plant is located in Pantelleria industrial district, and it is made up of six diesel groups and two gas turbines, providing electricity for the whole island [17].

According to the defined methodological framework, after defined the assessment procedures (Table 2), the performances of the three alternative energy scenarios related to each sub-criterion were calculated, as shown in Table 3 and Fig. 6. More in detail, if for some sub-criteria, an accurate estimation in quantitative terms was possible, for others, the uncertainty related to their quantitative assessment led to the definition of qualitative scales as reference.

The criteria's weights were defined by interacting with two Pantelleria municipality officials by resorting to the SRF procedure [39].

This procedure, indeed, by grounding on the use of the set of cards, makes it easier understanding the weighting procedure and, thus, the involvement of different stakeholders [41]. Concerning the case study, the SRF method was used with two officials,

Table 2. Description of the assessment procedure for each sub-criteria

Sub-criteria	U.m	Description
Construction cost	€	Sum of all the costs to be borne for materials purchase, building activities, and connection to the island's energy grid. The related indicator is represented by the construction cost itself, expressed in euros. The performances are determined by referring to the cost items included in the *Prezzario Unico dei Lavori Pubblici* from Sicily Region (2019)
Management and maintenance cost	€/year	The sub-criteria, coincident with the indicator for its measurement, is expressed in €/year. The performances are calculated by referring to similar realized interventions for the *Solar-based* and *Wind-based* scenarios. The performance calculation grounds on the energy cost item shown in Pantelleria PAES for the *Traditional scenario*
Construction time	Days	The performances are calculated thanks to the *Man-days* method, starting from the data provided by the *Prezzario Unico dei Lavori Pubblici* from Sicily Region (2019)
Service life	Years	The performances are estimated in years by referring to service life values for the different installations provided by the scientific literature in the field
Continuity of energy supply	(0, +++)	This sub-criteria considers possible breaks in the energy supply that can affect the electric grid's functioning. The three performances are assessed through qualitative scores, based on a rough estimation of the *yearly activity hours*
Access to funding	Yes/No	The performances are measured through a *binary scale*, expressing if, for each designed scenario, funding opportunities are available or not

(*continued*)

Table 2. (*continued*)

Sub-criteria	U.m	Description
Sustainability in facing climate change	Kg/year	The performances are measured by resorting to the indicator *Reduction of CO_2 emissions*, measured in Kg/years. More in detail, the performance assessment moves from the calculation of electric power generated through renewable sources. Then, this value is turned into the *Reduction of CO_2 emissions* through the relationship of 0.267t = 1kWh, which is valid for diesel-based electricity production
Noise impact	(---,0)	The performances are assessed through qualitative scores based on a rough estimation of each scenario's average noise level
Ecosystem impact	(---,0)	The performances are assessed through a qualitative scale, where scores are related to the different degrees of disturbance caused to bird flights by the different scenarios
Visual impact	(---,0)	The performances are assessed through a qualitative scale, where scores are related to different degrees of integration with the landscape and architecture of the designed installations
Sustainability from production and disposal	(0, +++)	The three performances are expressed in qualitative scores, based on a rough estimation of the percentage of components, for each facility that can be recycled

representative of the technical section and the political section of Pantelleria municipality's office. Indeed, such an approach enabled to bring in the analyses different perspectives towards the same decision issue.

Indeed, while the *technical official* showed a more significant concern towards the technical and economic aspects of the issue through the definition of the weight, the *political official* gave greater importance to the cultural-environmental dimension.

Table 3. Performance matrix

Sub-criteria	U.m	Solar-based	Wind-based	Traditional
Construction cost	€	35000	145000	0
Management and maintenance cost	€/year	450	200	5600
Construction time	days	16	42	0
Service life	years	20	30	20
Continuity of energy supply	(0, +++)	+	++	+++
Access to funding	Yes/No	Yes	Yes	No
Sustainability in facing climate change	Kg/year	8570	7930	0
Noise impact	(---,0)	0	--	--
Ecosystem impact	(---,0)	0	--	---
Visual impact	(---,0)	-	---	--
Sustainability from production and disposal	(0, +++)	+	++	+

5 Results and Discussion

The application of the Electre method, starting from each alternative's performances and considering the two different systems of weights defined by the two stakeholders, returned the solar-based scenario as the favorable one for the transition towards alternative energy supply solutions (Fig. 7).

This scenario performs as the best alternative when dealing with *Cultural-Environmental* sub-criteria. Indeed, it stands as the most environmental-friendly scenario concerning the multi-dimensional impacts defined in the decision problem (Fig. 6).

Concerning the *Technical-Economic* performances, instead, the solar-based scenario stands as the *middle-of-the-road* alternative among the ones considered.

However, when considering the energy transition issue in its whole complexity, thus including both cultural-environmental and technical-economic aspects, the solar-based scenario stands out as the favorable one.

Furthermore, this result is quite robust, as shown by the stakeholders' involvement in the weighting procedure. Indeed, even if the two different stakeholders had different views and goals, resulting in two diverging systems of weights, they both come to the same result in terms of alternatives ranking.

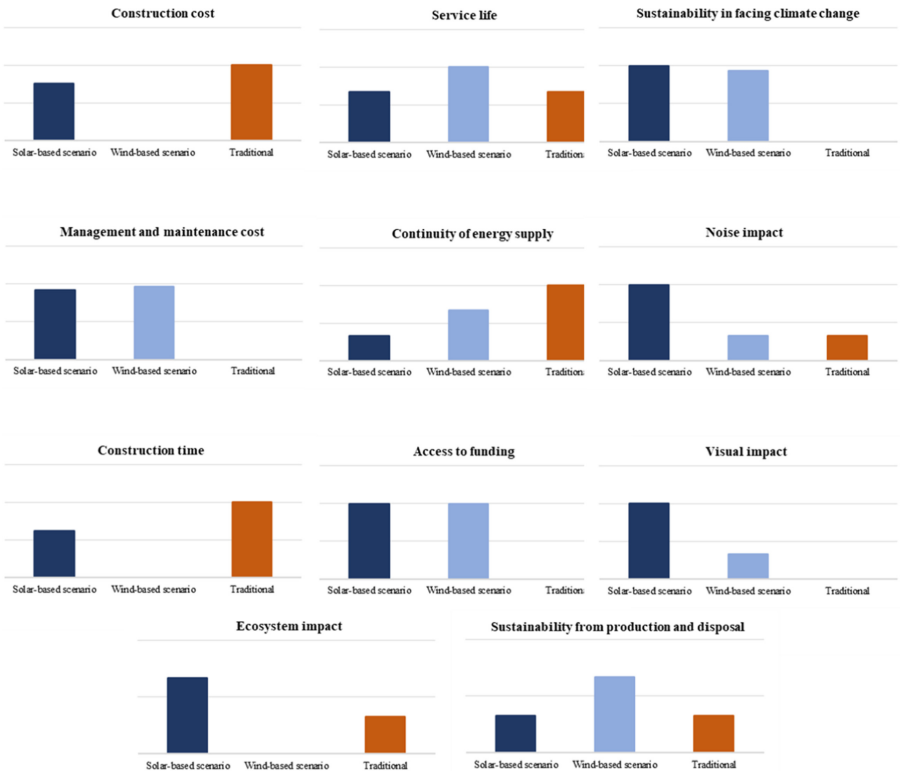

Fig. 6. Graphic visualization of the performances of the three alternatives for each criterion

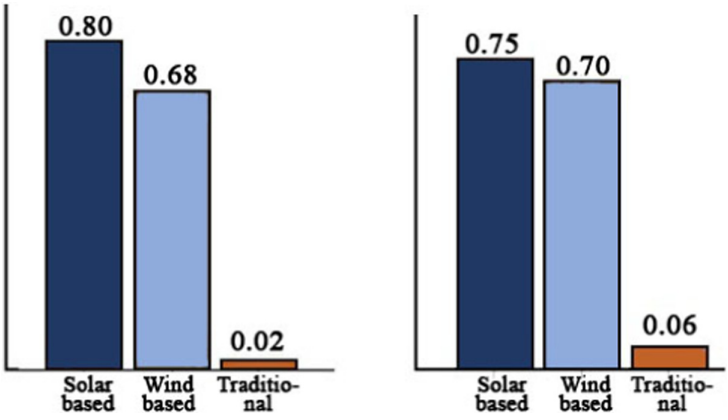

Fig. 7. Alternatives' ranking according to a 'political' (ranking on the left) and a 'technical' stakeholder (ranking on the right)

6 Conclusions

The paper proposes a methodological framework towards alternative energy solution assessment, based on MCDA, properly managing the conflicting values stemming from complex territorial contexts and test it on a project area in one of minor Italian islands: Pantelleria.

In the light of the growing attention towards green energy transition in minor islands, both in the European and national policymaking, such a framework can represent a useful and practical tool for supporting these peculiar policies in the energy field. Indeed, even if there are many applications of MCDA to support decisions among alternative energy solutions in the scientific literature, they often merely focus on a specific dimension of these solutions' impact. Instead, this methodology's novelty lies in considering the conflicting values stemming from the energy issue applied to complex territorial contexts, as Pantelleria is. Furthermore, its strength also lies in its replicability to similar contexts at the national and international levels. Indeed, the general framework can be easily exported to other contexts by carefully adapting the reference criteria to the specificities of the context under study in light of a *place-based* approach [42].

Besides these advantages, this methodology still shows room for improvement, especially when dealing with the cultural and environmental dimensions of the decisional issue. More in detail, from the environmental point of view, the results from the MCDA can be integrated with the ones from a Life Cycle Assessment, thus analytically considering the environmental impacts from different energy supply alternatives [43–45]. Instead, concerning the cultural dimension, more significant efforts can be made to include the impact of the different energy alternatives on the landscape in aesthetical terms and potential effects on its tangible and intangible value. Finally, a deepening could be devoted to the social impacts of such solutions at the territorial scale on the local community [46].

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