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MCDM-Based Analysis of Site Suitability for Renewable Energy Community Projects in the Gargano District

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Abstract

The increasing urgency of the energy transition, particularly in ecologically sensitive regions, demands spatially informed planning tools to guide renewable energy development. This study presents a Multi-Criteria Decision-Making (MCDM) approach to assess the suitability of the Gargano district in southern Italy for the implementation of Renewable Energy Communities. The analysis combines expert-based weighting and the Weighted Linear Combination method to evaluate seven key criteria grouped into environmental, socioeconomic, and technical dimensions. The resulting suitability scores, calculated at the municipal scale, highlight spatial disparities across the district, revealing that areas with the highest potential for Renewable Energy Community (REC) deployment are largely situated at the boundaries of the Gargano National Park. These zones benefit from stronger infrastructure, higher energy demand, and fewer environmental constraints, particularly with regard to wind energy initiatives. Conversely, municipalities within the park exhibit lower suitability, constrained by strict landscape regulations and lower population density. The findings provide valuable insights for regional planners and policymakers, supporting the adoption of targeted, environmentally compatible strategies for the advancement of citizen-led renewable energy initiatives in complex territorial contexts.

Keywords: renewable energy communities; multi-criteria decision-making; energy planning; photovoltaics; wind energy; mapping; inner areas; virtual energy storage; decarbonization

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1. Introduction

The accelerating impacts of climate change have made the transition toward Renewable Energy Sources (RESs) a global imperative. Fossil fuels still meet over 80% of the world's energy demand, and their continued use is responsible for approximately 90% of CO_2 emissions and a major share of greenhouse gases accumulating in the atmosphere [1]. While early industrialization positioned developed countries as the largest per capita energy consumers and CO_2 emitters, it is now essential for these nations to lead the transition toward cleaner and more sustainable energy models, especially as global energy demand is projected to continue rising in the coming years. Italy, as part of the European Union, has made substantial commitments to reduce its carbon footprint and promote decentralized, renewable energy systems [2,3]. In this context, Renewable Energy Communities (RECs) have emerged as promising frameworks that allow citizens, local authorities, and small businesses to collaboratively produce, manage, and consume renewable energy [4]. RECs have also garnered increasing attention in academia, emerging as a prominent and progressive area of research. Scholars are investigating various dimensions of REC implementation [5,6], encompassing legislative frameworks [7], critical factors for effective establishment [8,9], mathematical and business models [10], and decision support frameworks [11]. Comparative analyses of modelling tools for evaluating REC performance [12] further contribute to this growing body of knowledge. Empirical validation of these studies frequently involves case studies [13], predominantly focused on assessing energy performance at both the building [10] and neighbourhood [11,14] scales, also through comparative methodologies [10]. Additional research avenues include the optimization of solar energy distribution [15], assessments of economic feasibility [16,17], and considerations of energy justice [18].

However, RES integration and REC establishment, especially in areas with high environmental and cultural value, poses both practical and planning challenges. Regulatory, technological, and socio-environmental barriers continue to hinder their adoption, particularly in areas characterized by complex territorial dynamics [19]. The Gargano district, in southern Italy, offers a compelling case for exploring these dynamics. Known for its exceptional biodiversity [20], cultural heritage [21], and protected natural environments [22], the region presents both significant potential and notable constraints for renewable energy deployment. Most of the region lies within the boundaries of the *Parco Nazionale del Gargano*, one of Italy's largest and most ecologically diverse national parks, established under the Italian Framework Law on Protected Areas [23]. The region includes protected coastal and inland ecosystems, unique karst geomorphologies, and the *Tremiti Islands Marine Reserve* [24]. As such, any intervention involving new energy infrastructure must be carefully assessed to avoid compromising the area's biodiversity, landscape integrity, and cultural heritage. The Gargano area holds untapped potential for RES deployment, particularly through solar rooftop systems, offshore wind in the Gulf of Manfredonia, and biomass derived from agricultural residues. Leveraging these resources effectively requires detailed planning and site assessment to ensure projects are both technically viable and contextually appropriate. Given the region's regulatory sensitivity, complex land uses, and varied topography, identifying the potential for REC establishment demands a rigorous, multi-criteria approach [25].

This paper presents a Multi-Criteria Decision-Making-based approach for evaluating the site suitability of RECs projects, with a specific focus on the Gargano district as a case study. Unlike existing studies, which typically examine smaller scales such as neighbourhoods or buildings, this research offers a framework for assessing the broader potential of extensive areas using indicators specifically designed for assessing REC potential. Furthermore, the study addresses a critical gap by focusing on regions that are typically constrained and less populated, such as inner areas, differing significantly from the more urbanized locations traditionally targeted for REC projects. Inner areas present unique challenges for REC implementation as they often have specific constraints, such as the presence of cultural heritage sites, environmental restrictions, and protected reserves. This study thus contributes to the field by providing a tailored methodology for assessing REC viability in these less conventional settings and extends the scope of REC suitability assessments, offering a generalized methodology that can be applied to all areas with similar characteristics.

The structure of the paper is as follows: Section 2 describes the study area and the regulatory framework; Section 3 includes the methodological approach and criteria selection; Section 4 presents the results of the analysis; Section 5 concludes with key findings, limitations, and implications for regional energy planning.

2. The Gargano District and the Regulatory Framework

The Gargano district, located along the Adriatic coast in the northern part of Italy's Apulia region, is characterized by a unique combination of rich biodiversity, cultural heritage, and diverse landscapes [26]. This territory encompasses mountainous terrains, dense forests such as the *Foresta Umbra*, and an extensive coastline marked by beaches, cliffs, and coves [27]. Economically, the region is shaped by agricultural activities, particularly olive cultivation [28], viticulture [29], and wheat farming [30], which also offer potential biomass resources for energy production. Moreover, the local economy is heavily reliant on seasonal tourism [31], and this imbalance between the coastal and inland zones presents further constraints [32]. Visual impacts from renewable energy infrastructure, particularly wind turbines, are a known source of opposition in protected or touristic areas, often complicating the acceptance and implementation of energy projects, even well-planned ones [33]. Although strong coastal winds and high solar exposure indicate the district's potential for renewable energy initiatives, the development of such infrastructure is strictly regulated due to the environmental significance of the territory, substantial portions of which lie within the boundaries of the Gargano National Park. The park encompasses 18 municipalities, each having part (or, in a few cases, the entirety) of their territory included within its borders. Among these, 12 municipalities are part of the so-called *Gargano Inner Area* [34], a classification under Italy's National Strategy for Inner Areas aimed at fostering sustainable development in regions remote from essential public services [35]. With a combined population of approximately 80,000 residents across 1300 km^2, these 12 municipalities face both infrastructural challenges and opportunities for localized energy transition.

The deployment of renewable energy in the Gargano region must reconcile the region's development goals with strict environmental and cultural preservation requirements. This is governed by a multi-level regulatory framework. At the European level, Directive (EU) 2018/2001 (RED II) [36] promotes renewable energy adoption and supports the establishment of RECs. Nationally, Italy has implemented this directive through Legislative Decree 199/2021 [2], which facilitates renewable energy deployment and encourages the modernization of energy infrastructure while introducing streamlined authorization procedures in areas with specific characteristics. Complementing this, the "Decreto Aree Idonee" [3] sets general national criteria for identifying suitable areas for renewable energy projects while granting regions the autonomy to define specific local criteria. In response, the Apulia Region has enacted a set of regulations to manage the integration of renewable energy installations, most notably Regional Regulation 24/2010 [37] and the Regional Landscape Plan (PPTR–DGR 176/2015) [38]. RR 24/2010 provides a detailed framework for categorizing renewable energy projects by technology, capacity, and grid connection and identifies locations where installations are prohibited. The PPTR complements this regulation by emphasizing the protection of landscape, cultural identity, and agricultural land. To mitigate landscape and ecological degradation, the PPTR also introduces the concept of Landscape- and Ecology-Oriented Productive Areas (APPEA), intended to centralize large-scale energy developments. Table 1 summarizes the main law restrictions in the area, while Figure 1 shows the map of the protected Rete Natura 2000 areas, overlaid with the locations of existing RES installations.

Table 1. Overview of key national and regional regulations and their provisions.

RES	Source		Restriction/Permission
Solar	R	RR 24/2010 [37]	🟠 Zoning of areas suitable for different categories of PV systems
	R	RR 24/2010 as modified per RR 29/2012 [39]	🔴 No PV systems in zone 'A' as per urban planning regulations
	N	DLgs 199/2021 and ss. mm. [2]	🔴 No ground-based PV systems on agricultural land 🟢 Unless within the creation of a REC 🟢 Allows certain categories of PV systems in protected areas, if located in malls' vicinity
	R	DGR 1875/2022 [40]	🟠 Defines 'Obligatory Conditions' for PV interventions in Natura 2000 sites
Wind	R	RR 24/2010 [37]	🟠 Zoning of areas suitable for different categories of wind turbines: • Up to 20 kW; • Up to 60 kW; • Up to 200 kW.
	R	DGR 1875/2022 [40]	🟠 Defines 'Obligatory Conditions' for wind turbines in Natura 2000 sites
Biomass	R	RR 12/2008 [41]	🟠 Defines the typologies of biomass and max. distances (short supply chain)
	N N	DLgs 199/2021 [2] and ss. mm. CER Decree 414/2023 [4]	🟠 Defines the categories and quantities of biomass to be used

R = regional statute; N = national statute.

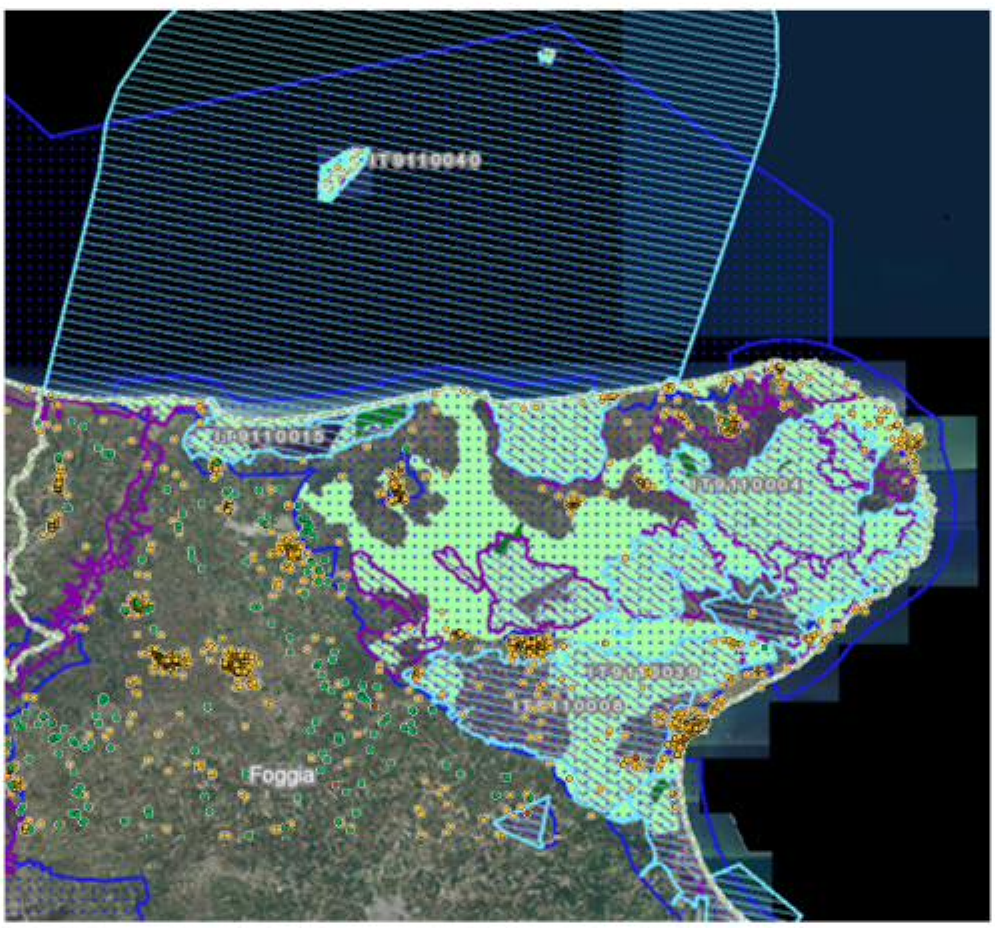

Figure 1. Map of Natura 2000 sites and locations of RES installations. Shaded area represents different types of protection (also overlapping); yellow dots indicate PV installations and green ones represent wind turbines (redrawn from [28,29]).

3. Methodology

3.1. Multi-Criteria Decision-Making Approach

This study adopts a Multi-Criteria Decision-Making (MCDM) approach to assess site suitability based on expert judgement and the Weighted Linear Combination (WLC) method to combine the results [42]. Multi-Criteria Decision-Making tools combine qualitative and quantitative inputs, providing an approximate yet effective method for addressing complex decision-making problems, with the goal of selecting the best alternatives and prioritizing the criteria by introducing a hierarchical decision-making structure [43]. This structure systematically links objectives, categories, and criteria, enabling the determination of the importance weights of the decision criteria [44]. These approaches have been widely employed to address a broad range of complex decision problems [45,46], including those related to energy planning and location of renewable energy facilities [42,44,47]. Given the growing interest in practical and accessible decision support tools, there is a clear preference for methods that minimize cognitive demands, thereby lowering the barrier to their adoption in applied contexts [48]. In line with this need, the evaluation of the relative importance of criteria in this study is conducted using a Direct Rating technique [49]. This method enables the integration of subjective expert opinions with objective spatial data while avoiding the cognitive burden and potential inconsistency of pairwise comparison matrices, such as those used in the Analytic Hierarchy Process (AHP) [50]. In this study, a panel of 16 domain experts (11 researchers and 5 technicians) is asked to assign an absolute importance score to each of the seven selected criteria described in Section 3.2. All participants work directly with RES and RECs at a technical level, mainly as engineers or architects. This selection is deliberate, as several of the questions require specific technical knowledge to be answered accurately; involving individuals without such expertise could have led to a distorted weighting of the criteria. The scoring is based on a predefined scale from 1 to 9, as reported in Table 2. This scale reflects the perceived contribution of each criterion to the overall objective, where 1 indicates that the criterion is not important at all and 9 that it is of utmost relevance.

Table 2. Level of importance to be attributed to each criterion by the experts.

Value	Level of Importance	Description
1	Not important at all	Completely irrelevant; has no influence
2	Slightly important	Has minimal impact and can generally be disregarded
3	Marginally important	Of minor importance; may be taken into consideration
4	Moderately important	Holds some significance but is not critical
5	Fairly important	Relevant and should be duly considered
6	Important	Has a significant impact and must not be overlooked
7	Very important	Crucial within the context, with considerable influence
8	Highly important	Nearly essential, exerting strong influence
9	Extremely important	Fundamental and indispensable for the outcome

Once all expert responses are collected, to aggregate the assigned scores and obtain a robust measure of each criterion's importance, the geometric mean is used, according to Equation (1).

$$R_j = \sqrt[n]{\prod_{i=1}^{n} r_{ij}} \tag{1}$$

where R_j is the aggregated score (geometric mean) for criterion j, r_{ij} is the score assigned to criterion j by expert i, and n is the total number of experts (in our case 16).

This method is particularly suitable when dealing with rating scales and multiplicative relationships, as it reduces the influence of extreme values and better captures consensus in expert judgement. The geometric mean is preferred over the arithmetic mean in cases where inputs span several orders of magnitude or when data are not symmetrically distributed. However, it is worth noting that in this study, the results obtained using the geometric mean are identical to those derived from the arithmetic mean, and do not significantly differ from the median in 6 out of the 7 criteria. This consistency indicates a relatively high level of agreement among experts for those indicators.

To derive the final weight for each criterion (w_j), the aggregated values are normalized by dividing each criterion's total by the sum of all aggregated scores, according to Equation (2), where m is the total number of criteria. This normalization process ensures that the resulting weights sum to 1, allowing their direct use in the WLC method.

$$w_j = \frac{R_j}{\sum_{j=1}^{m} R_j} \quad (2)$$

The WLC method is then used to compute a composite "Suitability for REC" index for each municipality, as explained at the bottom of the next section.

3.2. Definition of the Criteria and Suitability Score Calculation

The identification of relevant variables for decision-making is based on a thorough review of the existing literature cross-checked with an analysis of characteristics, potentials, and constraints of the Gargano district at the municipal level. Three main groups of factors—environmental, social, and technical criteria—are identified as key to the assessment, each comprising two or more sub-criteria, for a total of seven criteria.

Environmental factors [51–54] are central to the analysis, as they provide critical information on the natural resources available for energy generation. Specifically, solar irradiation and wind speed significantly influence the performance and feasibility of solar and wind systems; however, since the whole area has similar irradiation (1586.1 to 1627 kWh/sqm per year) and wind speed (3 to 7 m/s among 10 and 50 m a.g.l.), those parameters are not included among the indicators for which expert judgement is required. Conversely, the presence of extensive protected areas plays a key role, underlining the need of safeguarding them by placing the RES installations only in areas which are deemed as adequate, as per the RR 24/2010 and ss.mm.

Socioeconomic criteria [19,42,54–56] focus on local energy consumption patterns, since a key factor is the capacity of local demand to sustain a shared energy system. For a REC to function effectively, the annual energy consumption of its members should be significantly higher than the energy produced. This ensures that the generated energy is fully utilized and that the initiative remains economically and operationally viable. To assess this, population density and municipal energy consumption are used as indicators. These help estimate the size and characteristics of the potential user base, based on the principle that the fewer residents (compared to the total municipal population) are needed to meet the participation threshold, the greater the likelihood of forming a successful and self-sustaining community.

Technical criteria [54–57] evaluate the presence of existing RES installations in the area as a proxy of available infrastructure, access to transportation routes, proximity to the electrical grid, and availability of suitable space for installing renewable energy systems. These factors are all essential in determining the feasibility of the project. In addition, the technical criteria also consider the minimum scale of the wind turbines necessary to ensure the economic sustainability of a REC. Although small-scale systems can be used to launch a REC, the costs associated with installation and management make such configurations less viable. Consequently, the scale of the allowed wind systems is treated as an indicator.

The selected criteria, though tailored to the specific characteristics of the Gargano district, are easily replicable and adjustable for other areas with similar or different features.

For each criterion (C_j), different possible configurations ($\overline{c_t}(j)$) describing the characteristics of the area have been listed and rated. The score ($s_t(j)$), ranging between 0 and 1, conveys the higher or lower ability of the asset to host a REC based on the assumptions previously explained [58]; namely, the lower the rate, the lower the suitability of the area. According to its characteristics, every examined municipality obtains a score in each criterion. The 7 criteria are reported in Table 3, together with the possible configurations of each criterion and the corresponding scores.

Table 3. Selected criteria for solar–wind energy projects; possible configurations and assigned values.

Category	Criterion $[C_j]$		Information Source	Configuration $[\bar{c}_t\ (j)]$	Score $[s_t(j)]$	Map Colour
Environmental	E1	Presence of suitable areas for PV installation on roofs *	Google Maps Urban planning documents	PV area/inhabitants < 0.5 0.5 ≤ PV area/inhabitants < 1 PV area/inhabitants ≥ 1	0.33 0.66 1	
	E2	Presence of suitable areas for wind turbines installation of at least 20 kW	RR 24/2010 [37]	No areas Area < 10% municipal territory 10% ≤ Area < 40% Area ≥ 40%	0 0.33 0.66 1	
Socioeconomic	SE1	Population density (D)	Municipalities' webpages	D < 50 inhabitants/sqkm 50 ≤ D < 100 inhabitants/sqkm D ≥ 100 inhabitants/sqkm	0.33 0.66 1	
	SE2	Municipal energy consumption **	ARERA [59]	Energy consumption < 10 GWh/y 10 ≤ Energy consumption < 20 GWh/y Energy consumption ≥ 20 GWh/y	0.33 0.66 1	
Technical	T1	Presence of existing PV installation	GSE [60]	No Yes	0 1	
	T2	Presence of existing wind turbines ≥ 20 kW	GSE [60]	No Yes	0 1	
	T3	Scale of the permitted wind turbines	RR 24/2010 [37]	Only roof installation Up to 20 kW Up to 200 kw More than 200 kW	0 0.33 0.66 1	

* The criterion prioritizes large-roofed buildings (ideally public structures like city halls, hospitals, schools, sports complexes, barracks, and open parking areas) for horizontal PV system placement. Surfaces facing N, NE, or NW, or those prone to shading during peak sunlight hours, are excluded. ** Municipal energy consumption is calculated by multiplying the average annual per capita electricity consumption in 2023 for the province of Foggia (1694 kWh) by the number of residents in each municipality.

The "Suitability for REC" index for the k-th municipality (S_k) is calculated using the Weighted Linear Combination method by multiplying the score ($s_t(j)$) obtained in each criterion by the corresponding weight based on expert judgement (w_j) and summing the results, according to Equation (3).

$$S_k = \sum_{j=E1}^{T3} w_j \times s_t\ (j) \leq 1 \quad (3)$$

3.3. Map Drawing

The data for the seven criteria are visually represented through a series of monochromatic choropleth thematic maps, each corresponding to a specific criterion. In these maps, municipalities are shaded according to the score they received for the respective criterion. The colour intensity indicates the magnitude of the score, allowing for an immediate spatial interpretation of the data distribution across the study area, as detailed in Table 3. It is worth noting that for criteria E1, SE1, and SE2, the Natural Breaks (Jenks) method is used to cluster the data and segment the scores [61]. For criterion SE2, this method has been manually adjusted to better align with the specific objectives of the analysis. In contrast, criteria E2 and T3 employ Manual Classification, due to the particular nature of their data. To generate the "Suitability for REC" map, the classification method uses Equal Intervals [61], which assumes that the difference between the upper and lower thresholds is consistent across all ranges. In this case, the minimum and maximum suitability thresholds are determined based on the possible obtainable scores and the range between these thresholds is divided into four categories, each associated with a distinct suitability level and colour. The thresholds are 0.165 and 1; the boundaries are set at [0.165–0.374] red (low), (0.374–0.583] orange (medium-low), (0.583–0.792] yellow (medium-high), and (0.792–1] high (green).

4. Results and Discussion

The criterion-specific suitability maps presented in Figure 2 reveal significant spatial variability across the Gargano region for all seven criteria evaluated. A comparison with the boundaries of the Gargano National Park, which encompasses much of the northern and central-eastern parts of the promontory (see Figure 1), clearly shows that the areas with the highest suitability, particularly in terms of technical and infrastructural factors, are generally located outside the park's protected zones.

For the environmental criteria, concerning the presence of areas suitable for PV and wind installations, municipalities with smaller populations are favoured in obtaining a high score in criterion E1. This happens for Tremiti Islands (483 inhabitants), Rodi Garganico (3318 inhabitants), and Lesina (6215 inhabitants). However, similarly populated municipalities with limited public structures and services only obtain a medium-high (e.g., Rignano Garganico, 1743 inhabitants) or even medium-low score (e.g., Peschici 4274 inhabitants). In criterion E2, a distinct spatial gradient emerges: eastern municipalities (from Cagnano Varano and Monte S. Angelo, to Vieste), which have a high percentage of their territory falling within the boundaries of the park, score low (red and orange) due to landscape constraints, topography, and conservation regulations that limit large-scale wind development. In contrast, municipalities situated in the western part of the region, where the land lies largely outside the park's jurisdiction, exhibit higher suitability (yellow to green), reflecting more favourable conditions for wind energy deployment in areas with fewer environmental restrictions.

Regarding the socioeconomic criteria, criterion SE1 (population density) favours municipalities that are either geographically small (e.g., Rodi Garganico, 14 km^2; Tremiti Islands, 3 km^2) or have larger populations (e.g., Manfredonia, 53,226 inhabitants), which receive higher suitability scores. In contrast, the park's interior, typically less urbanized, exhibits low population density (orange), suggesting limited potential community engagement in these zones. Criterion SE2 (energy consumption) presents a more scattered pattern, though higher energy consumption levels (green) are again associated with urbanized and coastal municipalities such as Manfredonia and Vieste. Conversely, inland areas of the park, characterized by smaller towns and lower population densities, generally show lower suitability (orange to yellow).

With regard to existing infrastructure, criterion T1 (presence of existing PV installation) shows a consistently high suitability score (green) across the district, suggesting widespread photovoltaic deployment even within the park's boundaries. It is worth noting that Tremiti Islands receive a maximum score despite hosting only a single PV installation (with further installations planned). In contrast, criterion T2 (presence of existing wind turbines $\geq$ 20 kW) reveals a stark east–west divide. Eastern municipalities, located entirely or mostly within the park, receive a score of 0, reflecting the limited historical development of wind energy in these areas. Western municipalities, however, situated on the periphery of the park, receive full scores (1), as most existing wind installations are concentrated there. It is noteworthy that Monte S. Angelo receives the maximum score based on a single 25 kW wind turbine. Lastly, criterion T3 (scale of allowed wind turbines) reflects similar spatial constraints: the north-eastern sector, largely overlapping with the park, exhibits low suitability (orange to red), indicative of stricter planning and regulatory restrictions on wind turbine sizes. In contrast, higher scores (green) are observed in the western part of the region, where regulations are more permissive, allowing for larger-scale installations. It is worth mentioning that no municipality obtains a medium-high score (0.66), as the few areas where only turbines up to 200 kW are permitted are located within municipalities that also contain unconstrained zones, resulting in an overall higher score.

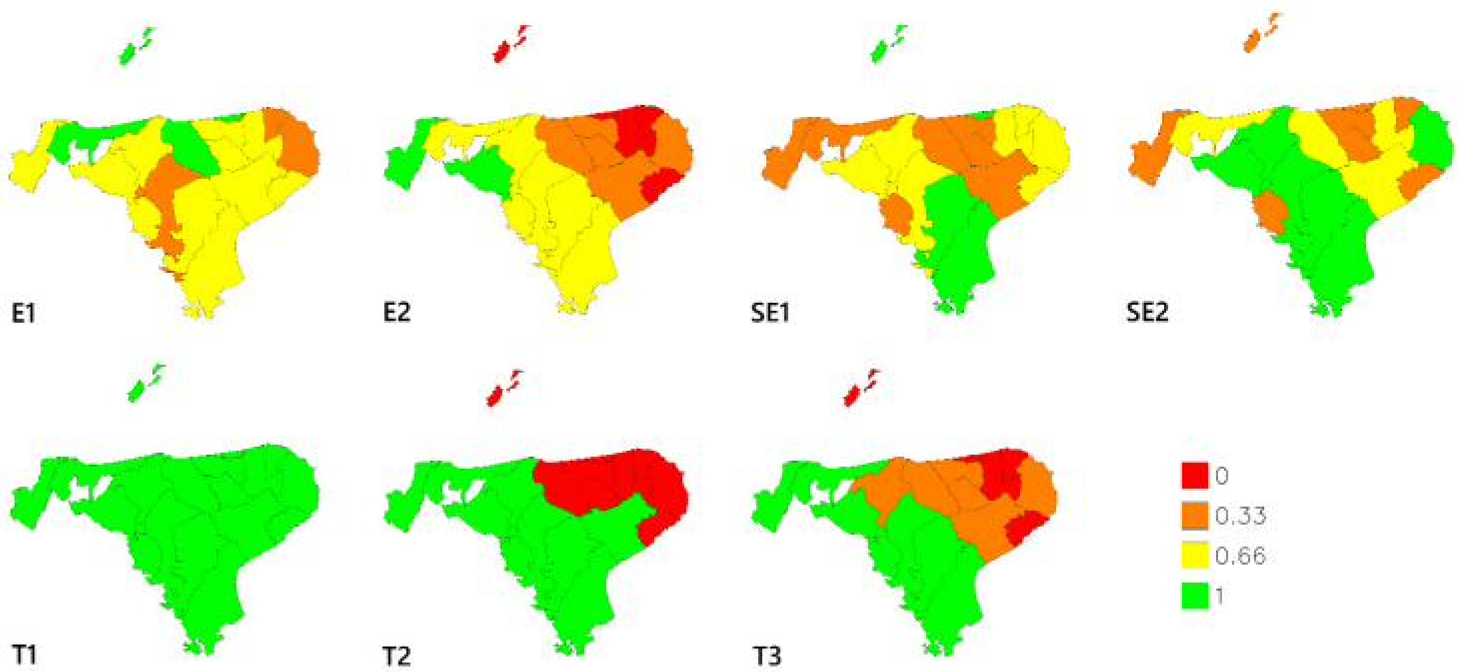

Figure 2. Maps of the values of reference indicators for the Gargano district.

The results of the expert judgement survey, conducted using the Direct Rating technique, determine the weights to be used in the WLC method, which are then applied to compute the aggregated scores for each municipality. The final set of weights is presented in Table 4.

Table 4. Final weights derived from the expert judgement survey for the WLC method.

E1	E2	SE1	SE2	T1	T2	T3
0.20	0.15	0.15	0.15	0.10	0.10	0.15

The weighted integration of the seven criteria via the WLC method produces the aggregated suitability map shown in Figure 3. This composite view confirms and strengthens the insights gained from individual indicators.

The highest suitable areas (green), largely corresponding to the southern and western municipalities, align closely with zones previously identified as favourable based on individual criteria, particularly E2, T2, and T3. These areas benefit from a combination of relatively high energy demand, advantageous grid access, and fewer land use restrictions, especially with regard to wind turbine installation. In contrast, the north-eastern portion of the district exhibits predominantly medium-low (orange) to low (red) suitability levels, owing to restrictive planning regulations, lower population density, and limited technical capacity for wind energy. This result, where all highly suitable municipalities have substantial portions of their territory lying outside or along the periphery of the Gargano National Park, confirms that environmental constraints within the park have a significant influence in hindering overall REC suitability. This is consistent with previous partial maps focused solely on environmental criteria, where park boundaries acted as a limiting factor. This pattern highlights the influence of protected status on the feasibility of RECs, reinforcing the need for context-sensitive approaches when planning renewable energy transitions in ecologically sensitive regions. The municipality of Monte Sant'Angelo falls at the threshold between medium-low and medium-high suitability, which is why it is depicted with yellow-orange striping). Its intermediate position results from a mix of favourable and limiting factors—moderate energy demand, constrained but existent wind installations, and partial location within the park. Such borderline cases suggest that tailored, small-scale REC models might still be viable with careful design and stakeholder coordination.

Apricena	0.881
Manfredonia	0.881
S. Giovanni Rotondo	0.881
Lesina	0.798
S. Marco in Lamis	0.764
Serracapriola	0.731
Sannicandro Garganico	0.730
Rignano Garganico	0.680
Monte S. Angelo	0.580
Cagnano Varano	0.548
Vieste	0.514
Tremiti Islands	0.500
Rodi Garganico	0.500
Vico del Gargano	0.430
Carpino	0.430
Ischitella	0.430
Mattinata	0.381
Peschici	0.315

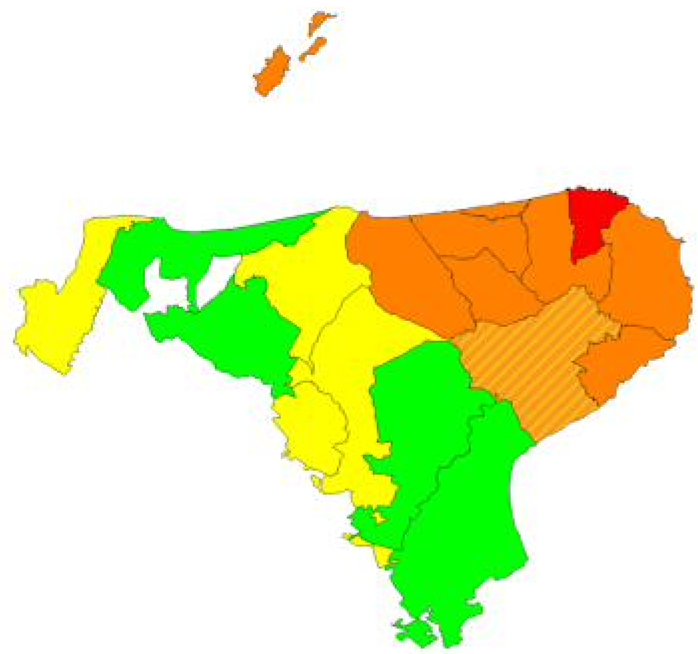

Figure 3. Suitability map of the Gargano district considering the criteria under study. (Monte Sant'Angelo is depicted with yellow-orange striping because it falls at the threshold between medium-low and medium-high suitability).

The results underscore the critical need for territorial differentiation in REC promotion strategies. Municipalities on the park's periphery present immediate opportunities for pilot REC projects, particularly where infrastructure and energy consumption levels are adequate. Conversely, areas deep within protected zones require alternative approaches, such as leveraging rooftop PV on public buildings or integrating REC development with broader sustainability goals (e.g., eco-tourism or agricultural cooperatives).

The analysis also validates the effectiveness of the adopted MCDM framework. By integrating environmental, socioeconomic, and technical considerations, the approach reveals not only where REC development is most feasible, but also why, offering clear, spatially grounded insights to inform planning decisions.

5. Conclusions

This study set out to evaluate the potential suitability for Renewable Energy Communities on a large scale and for areas significantly different from those traditionally chosen for REC projects. The research, targeting areas showing unique constraints, such as lower population densities and specific environmental or cultural considerations, offers a flexible framework for REC suitability evaluation in diverse contexts. In the present study, the Gargano district, an area characterized by a unique blend of ecological sensitivity, cultural heritage, and variable infrastructure, is used as a case study. By applying a Multi-Criteria Decision-Making framework, based on the Weighted Linear Combination method and informed by expert judgement, the analysis integrated environmental, socioeconomic, and technical criteria to generate a composite suitability index for each municipality. The findings indicate that according to the experts' judgement, the most important criterion for locating a REC is the availability of suitable areas for PV installation (E1), while the least important is the presence of existing installations, both solar (T1) and wind (T2). Applying this to the Gargano district, brings about that the most favourable zones for REC deployment are located primarily along the periphery of the Gargano National Park. These areas combine greater energy demand, better infrastructure, and more permissive regulatory conditions, particularly with respect to wind energy deployment. While some municipalities within the park show moderate potential, especially for rooftop photovoltaic systems, overall REC suitability is constrained by lower population density, limited energy consumption, and strict environmental protection policies. The spatial distribution of suitability, as revealed in the aggregated map, demonstrates a coherent alignment with earlier partial assessments and supports the validity of the adopted methodology. This analysis not only highlights the feasibility of implementing RECs in the Gargano district but also underscores the need for context-sensitive, territorially aware energy planning in those peculiar areas, harmonizing technical viability with environmental conservation imperatives.

The limitations of this study include the fact that the spatialization of the suitability results at the municipal level does not allow for the identification of specific sites, such as individual neighbourhoods, building clusters, or parcels of land suitable for RES plants siting and REC installation. To assess the feasibility of REC projects at this finer scale, a more detailed spatial analysis would be necessary, incorporating higher-resolution data and considering additional site-specific constraints and opportunities. Therefore, the proposed methodology should be considered as a preliminary screening tool, capable of highlighting priority areas for further investigation rather than directly informing implementation.

Depending on the desired results, the analysis could be refined by integrating additional indicators, such as the presence of industrial zones, commercial facilities, or large public infrastructures that could act as prosumers within a REC. These actors are often critical for ensuring the economic viability and energy balance of community-based systems. In this study, for the sake of simplicity and data availability, the analysis was limited to the presence of large-roofed buildings, ideally public structures such as city halls, hospitals, schools, sports complexes, barracks, and open parking areas, deemed suitable for hosting horizontal PV systems.

A further development of the study should also evaluate the potential deriving from biomass energy, which has been neglected here due to the complexity of assessing biomass availability and logistics at the municipal level. Unlike PV and wind energy, the feasibility of biomass systems depends on infra-municipal factors, such as the location of agricultural and forestry residues, the proximity of biomass-processing facilities, and transport considerations. These factors require a more localized approach and data granularity than was within the scope of the present work, which aimed to provide a municipality-based rating framework. Including biomass in future assessments could contribute to a more comprehensive evaluation of renewable energy potential, particularly in rural or agricultural contexts, and support more diverse and resilient REC configurations.

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