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Research Article

GIS-based MCDM Approach for Wind Farm Site Selection - A Case Study

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Abstract

The objective of this study is the development and implementation of a geographic information system (GIS)-based methodology to determine suitable sites for wind farms by using multicriteria decision making (MCDM) techniques. Many eligibility criteria are considered in this approach, such as GIS analysis is performed in combination with MCDM techniques, both for the criteria weighting process (using the analytical hierarchical process) and for the standardization/classification of the criteria values into a common scale, in order to finally apply the weighted linear combination technique. The MCDM output is a suitability map, which provides the spatial distribution of the final score, showing zones ranging from non-suitable locations to highly suitable areas after categorizing them into five classes. Furthermore, three scenarios regarding the criteria selection and their hierarchy are investigated: technical, techno-economic, and techno-economic-environmental. For each of these scenarios, different criteria are assigned different levels of importance, and the corresponding results are compared and evaluated. The proposed approach is presented through a case study for the regional unit of Chania (Crete Island, Aegean Sea, Greece), for which the necessary geospatial data were collected, created, and processed. This analysis highlights the capabilities of GIS in performing site selection for onshore wind farms while considering the regulations, legislations, and other constraints.

Keywords

GIS; multicriteria analysis; site selection; wind turbines; wind farm; Crete; Chania

1. Introduction

1.1 General

Climate change has resulted in increased public awareness regarding the negative impact of traditional power generation methods on the environment. In recent years, due to climate change and global warming-related concerns, in combination with the continuing fall in the costs of renewable energy equipment such as wind turbines and solar panels, there has been a considerable increase in the use of renewables [1]. In general, the penetration of renewable energy sources (RESs) in the global energy balance has been a priority in recent decades [2]. As a global strategy, the Paris Agreement was adopted by 196 parties at Conference of Parties (COP) 21 in Paris on 12 December 2015, and was entered into force on November 4, 2016. The main goal of the agreement is to limit global warming to below 2°C, preferably to 1.5°C, compared to pre-industrial levels, by adopting economic and social transformation plans aimed toward a swift transition to sustainable energy to achieve a balance between emissions and removals by 2050. Especially in Europe, Directive 2001/77/EC [3] on the promotion of electricity produced from RESs set specific targets for each goal, along with a specific timeframe, for each of 27 European Union (EU) member states. These goals concerned the percentage of RESs in the total energy production of each country, as well as the alteration of procedures in order to facilitate the adoption of renewable energy production stations. Directive 2009/28/EC [4] on the promotion of the use of energy from renewable sources amended and subsequently repealed Directive 2001/77/EC and Directive 2003/30/EC. This EU directive set the key for climate objectives to be achieved by 2020 and mandated reduction of greenhouse emissions by 20% compared to 1990 levels, increase in RESs penetration by 20%, and improvement in energy efficiency by 20%. Finally, Directive (EU) 2018/2001 of the European Parliament and the Council of December 11, 2018 on the promotion of the use of energy from renewable sources [5] set the renewable energy target to be achieved by 2030 to a minimum of 32% of gross final consumption, 32.5% for energy efficiency, and at least 40% reduction in greenhouse gas emission. According to Capizzi et al. [6], between 2005 and 2018, RESs capacity among European countries drastically increased from 180 to 465 GW, with wind and solar power systems constituting 90% of the annual increase in RESs power capacity. Thus, the exploitation of RESs can help the EU meet many of its environmental and energy policy goals; energy production efforts from RESs are now focused on onshore and offshore wind farm installations.

Assessment of feasible locations for onshore and offshore wind farm installations is particularly relevant for islands. Due to their location in the open sea and coastal areas, islands present excellent conditions with suitable climatic potential for the installation of energy converters to achieve energy self-sufficiency [7]. Furthermore, due to their remoteness from the mainland, islands are traditionally heavily dependent on fossil fuels for meeting their energy requirements and are therefore dependent on importing fuels at high prices [8]. As such, recent studies have focused on methodologies that accurately identify areas of high potential, especially for offshore wind farm installations. Nezhad et al. [9] used satellite technologies to estimate the potential of marine renewable energies by using cup anemometers and buoys, an approach that is especially important for areas that lack in situ observations. Nezhad et al. [10] estimated the offshore energy potential estimation by using the ERA-Interim reanalysis dataset for a 40-km radius of the island of Samothraki, Northern Greece.

In the context of increasing the share of energy from renewable sources and among European countries, Greece is a country with distinctive features as it has a large number of non-interconnected islands (NIIs), which are small and therefore cannot benefit from the cost advantage of large-scale generation capacity and commonly rely on diesel-fueled generators, which are expensive and not environmentally friendly. Moreover, these islands cannot meet their energy requirements using local energy deposits, especially during the summer months, due to tourism-related increase in energy demand. Furthermore, most of them are connected to the mainland power grid or obtain their electricity primarily from inefficient and expensive local diesel generators. The Greek energy sector is still largely dependent on fossil fuels, most of which are imported. Domestic energy sources include lignite, which accounted for approximately 29% of electricity generation in 2018, and RESs such as hydro-power, wind, solar energy, and biomass, which accounted for 11.3%, 12.4%, 7.5%, and 0.6%, respectively. Regarding energy consumption in 2019, natural gas corresponded to 35%, and the contribution of lignite decreased from approximately 30% to 19%, while RESs' share remained above the EU 2020 target (approximately 23%). Electricity generation from RESs, including wind energy, has increased because of the high wind potential of many sites. Greece has some of the most suitable sites for wind energy generation in Europe, with average capacity factors of approximately 25% and 30% for the mainland and the islands, respectively, while the wind energy potential is estimated at 10000-12000MW, which also includes offshore wind energy of high potential. In the last five years, many wind turbines have been installed on the NIIs, out of which almost 62% are on the island of Crete [11]. In 2016, wind energy ranked second among RESs in terms of total electricity generation, accounting for 38.3% of RESs electricity and 9% of total electricity generation in Greece. Thus, the wind energy sector in Greece is poised to grow considerably in the coming years, with increasing penetration of installed wind capacity, especially after considering the potential impact of climate change [12].

As part of wind power development, site selection for wind farm installation is a complex process that is based on numerous technical, environmental, and socioeconomic parameters, as well as on the relevant national legislation, both for onshore and offshore investments; site selection is also driven by the availability of data. To serve this objective, various approaches have been applied for identifying suitable sites for wind farms in a geographical region (e.g., [13-16]), most of which mainly use geographic information system (GIS) and multicriteria decision making (MCDM) techniques for gathering, analyzing, and combining data for a suitability map creation which is also among the objectives of this study.

1.2 Case Study

The purpose of this study is to present an integrated GIS-based MCDM methodology for evaluating eligible sites for wind farm installation by considering numerous design criteria and examining various combinations of these criteria. Three scenarios regarding suitable locations determination, namely technical, techno-economic, and techno-economic-environmental, are investigated to highlight the influence of both the selected set of design criteria and the criteria weighting that is applied. The results revealed that, apart from the spatial constraints, site selection strongly depends on which criteria are chosen. Criteria weighing is also decisive in the MCDM technique. The idea behind this approach is to provide a flexible GIS-based decision making scheme through the implementation of different scenarios that consider sets of wind farm design criteria that are based on easily accessible data. This framework enables decision-makers to evaluate alternatives that best fit their priorities. The need for research and applications relevant to wind energy development is always important, especially as it concerns the NIIs' targets to achieve energy independence.

Chania, one of the four regional units of the island of Crete (Aegean Sea, Southern Greece), was selected as a case study. It has a population of 156585, and tourism is the most important economic activity that continues to grow. Chania borders only the regional unit of Rethymno to the east, while it is bounded in the north by the Cretan Sea and by the Mediterranean Sea in the west and south. The regional unit also includes the southernmost island of Europe: Gavdos Island. The topographical relief of the region, the existence of several settlements, monuments and protected areas, the road network of varying density, and other infrastructure, in combination with the availability of the necessary spatial data, make Chania an ideal case study to present the methodological framework and, at the same time, to incorporate the national legislation in the analysis.

2. Materials and Methods

2.1 MCDM Scheme

MCDM was created in the 1960s and is used to resolve decision problems that implement geographical data (known as spatial decision problems). These problems, which can be resolved by using the combination of MCDM and GIS, are based on the principle that multiple feasible alternatives may exist, and each alternative must be evaluated according to certain spatial criteria. In the GIS-based MCDM technique, several geographic data points (inputs) are transformed into results (outflow) on the basis of a specific decision by using the relationships between GIS and MCDM. Each of the incorporated data points is referred to a specific thematic map (layer) that describes the decision criteria. These criteria are expressed as scaling factors or constraints that depend on the problem and represent conditions to be quantified and contribute to the decision-making process [17]. The constraints, which limit the analysis to specific regions, are expressed as Boolean maps with the value "1" for suitable locations and the value "0" for the locations that should be excluded from the analysis. Essentially, factors are the design criteria that define the degree of suitability of each cell of the study area. Before considering a combination of criteria, they are standardized to a common scale. After defining and combining the criteria, results are depicted through suitability maps for various scenarios to evaluate alternatives and decide the final proposal, as shown in Figure 1.

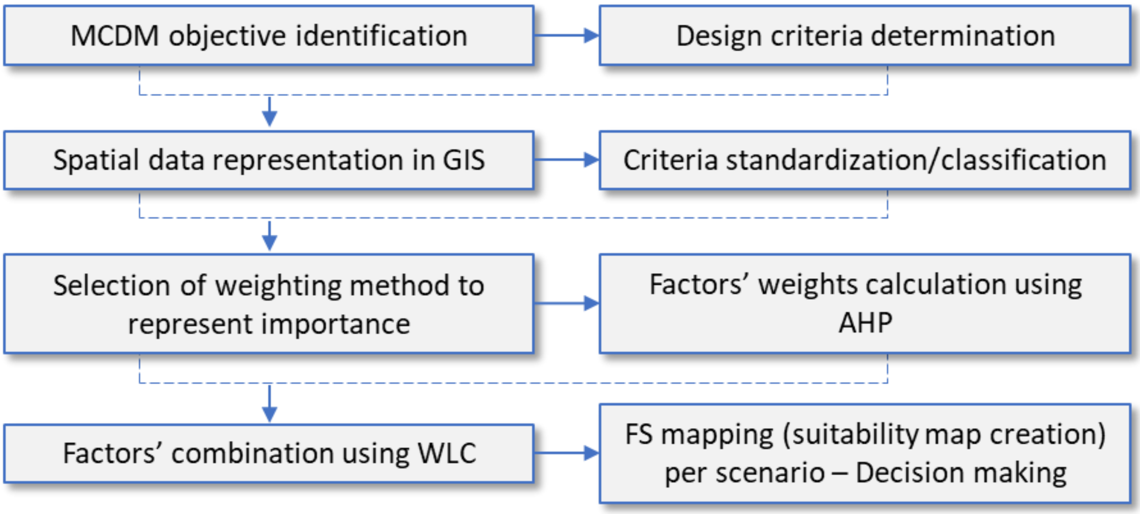

Figure 1 Main steps of the decision-making process.

As shown in Figure 1, the GIS-based MCDM process for wind farm site selection can be divided into several stages. After the determination of the design criteria, which are analyzed in the next paragraph, the hierarchy among them must be defined to calculate their weights. All criteria are transformed into standardized values and are combined using the weighted linear combination (WLC) method, a widely used method that is based on the factors' weighted aggregation, to finally create a suitability map.

Weighting of factors: To apply the WLC method, weights of the factors are calculated using the analytical hierarchy process (AHP) [18], which is based on the principle that the decision maker's experience and knowledge are as important as the available data, and is widely used in studies (e.g., [19-22]). The AHP generally comprises four steps: (1) creation of the hierarchy model for the problem consisting of the basic components that allow pairwise comparison, (2) comparison of each component, (3) composing the evaluation criteria, and (4) determining a suitable site. In the current analysis, the method is used to create the hierarchy and compare the design criteria to access their weights. The main advantage of this approach is the ability to capture both subjective and objective aspects of a decision through criteria comparison and the creation of a pairwise comparison matrix that is based on a scale of relative importance (Table 1).

Table 1 Pairwise comparison scale (data adopted from Saaty [21]).

Intensity of importance	Description
1	Equally important factors
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extremely more important factor

Combination of factors: After the calculation of weights, a suitability map is created using a combination of the factors. The formula for calculating the final score (FS) for every position in the study area is as follows [23]:

$$FS = \sum WiXi \tag{1}$$

where *W* is the weighting parameter, *X* is the value parameter, and *FS* is the FS (suitability score) for each scenario.

In case there are Boolean constraints as well, the aforementioned equation should be modified as follows:

$$FS = \sum WiXi \times \prod Ci \tag{2}$$

where *C* corresponds to the Boolean constraints, such as buffer zones in which wind turbine installation is not permitted.

Standardization of factors: To obtain a suitability map with an FS ranking between 0 and 1, all criteria should be graded on the same scale of [0, 1]. Depending on the criteria characteristics, different standardization processes are used. The simplest among them is a linear transformation which, as proposed by Voogd [24], is a scale based on the minimum and maximum values as scaling points. The following formulas are used to apply the simple linear scale:

$$xi = \frac{FVi - FVmin}{FVmax - FVmin} \times SR \tag{3.a}$$

$$xi = 1 - \frac{FVi - FVmin}{FVmax - FVmin} \times SR \tag{3.b}$$

For linear transformation of each criterion into the range of [0,1], the choice between Equations (3.a) and (3.b) depends on whether the optimum value is the maximum or the minimum value of the criterion, respectively. In the GIS-based MCDM approach, this procedure is applied for each factor separately by using map algebra in a GIS environment. Furthermore, when factor values are of district types (i.e., categories, or a group of values or specific values), then either classification or reclassification is performed to transform the values to the same scale of [0,1]. Based on the abovementioned steps, a decision is derived from the assessment of the composed suitability, that is, the degree to which a location belongs to a suitable or non-suitable set.

2.2 Design Criteria

Decision-making using GIS for wind farm site selection is a complex process as it combines multiple and conflicting objectives and integrates numerous data types. For this purpose, several criteria have been defined and weighted according to the methodology described above. Five constraints (Figure 2) and eight factors (Figure 3) are defined herein as design criteria based on the current national legislation framework [25], and they are combined to assess the degree of suitability for wind farm installation in the regional unit of Chania. Initially, all constraints are transformed into Boolean maps (raster datasets) to represent the following rules:

a. Exclusion of areas demarcated for absolute nature protection that belong to the Natura 2000 network in accordance with Directive 2006/613/EC of the European Parliament: The shapefile regarding the margins of these areas is transformed into a raster file with code “0” for Natura areas and code "1" for the remaining locations of the regional unit of Chania. As previously described, code "1" denotes the cells in the raster analysis where wind farm installation is allowed.

b. Buffer zone of 1000 m from each town/settlement boundaries: This criterion is used in two ways: as a constraint to prohibit wind farm installation within a 500-m radius from each settlement and as a factor to express the need for an installation not far from the settlements for which the electricity requirements must be met as the closer the wind farms, the lower the energy loss during transmission.

c. Buffer zone of 500 m from World Heritage Sites and other monuments of major importance (e.g., monasteries), as well as from the delimited archaeological sites for protecting the cultural heritage: According to the national legislation, construction activities must be avoided near monuments so as not to change their field of view.

d. Buffer zone of 300 m from existing road networks as there is a need to easily access the road network during construction and operation; however, a neighboring area should be excluded to avoid nuisance.

e. Buffer zone of 200 m from telecommunication sites is applied, as discussed in Bertsiou et al. [2]. A wind farm close to a telecommunication station results in the reduction of the required accompanying works during construction; however, the national legislation proposes an exclusion zone from existing telecommunications stations, as part of the environmental impact study for each project. In the present analysis, the exclusion zone is set as 200 m to avoid any nuisance from one project to the other.

Accordingly, to proceed with the implementation of the MCDM for the evaluation of eligible sites for wind farm installation, the following factors are introduced:

a. Elevation (F1): Wind potential is expected to be higher at higher altitudes; thus, this criterion shields the desire to maximize the produced energy. To express this factor, a digital elevation model provided by the National Cadastre & Mapping Agency S.A. of Greece was used. The dataset is characterized by a pixel size of 5 × 5 m, a geometric accuracy RMSE of ≤2.00 m, and an absolute accuracy of approximately 3.92 m for a 95% confidence level.

b. Slopes (F2): This is a technical factor as installing wind turbines in flat locations or in areas with mild surface slope is preferable. The raster dataset regarding slopes is derived from the first factor by using GIS techniques.

c. Wind potential (F3): To ensure maximum wind power capacity, high wind potential is required in order to maximize the energy generated by the wind turbines. The wind data is obtained from the Center for Renewable Energy Sources and Saving, which is a Greek national entity for the promotion of RESs, rational use of energy, and energy conservation. The available dataset provides the wind potential based on the average annual wind speed (in meters per second) at the height of 80 m.

d. Forests' proximity (F4): Euclidean distance from forest areas is the fourth factor. Wind turbine installation is preferred in locations away from forested areas and woodlands with a vegetation pattern comprising native or exotic coniferous and/or broad-leaved trees. The information on forests is obtained from the CORINE Land Cover 2018 [26] dataset; the CLC classes 311, 312, and 313 for broad-leaved forests, coniferous forests, and mixed forests, respectively, are selected herein.

e. Settlements' proximity (F5): After considering the exclusion zone described in the previous paragraph on constraints, the information on settlements obtained from the CORINE Land Cover

2018 [26] dataset is used to calculate the Euclidean distance from the outer boundary of each settlement. This factor denotes sites outside of the 1000-m buffer zone from the settlement boundaries, with the maximum value being assigned to the limit of the buffer zone and zero being assigned to the maximum distance and inside the buffer zone.

f. Roads' proximity (F6): This factor is defined in the same way as described for the settlements' proximity. First, a 300-m buffer zone is initially created using the information on road networks obtained from Geofabrik OpenStreetMap Data [27]. Then, the Euclidean distance from this outer boundary is calculated, and the roads' proximity factor is finally standardized.

g. Airport's proximity (F7): This factor is defined in the same way as described for the distance from forests. Wind farm installation is avoided in areas close to airports. Here too, the CORINE Land Cover 2018 [26] dataset is used to select the local airport(s) polygon(s) in order to export a separate raster layer that is used to define the corresponding Euclidean distance and to finally standardize this factor with a gradually increasing value from 0 to 1 as the distance from airport(s) increases.

h. Land values (F8): This factor represents the value of each land cover type that can potentially be taken by the eminent domain. To create the corresponding dataset, the CORINE Land Cover 2018 [26] dataset is used for information regarding the distribution of land use and, for each type, a value in the range of 0-1 is attributed, with the highest values being assigned to lands with the lowest values (e.g., natural grasslands and Sclerophyllous vegetation), as shown in Table 2.

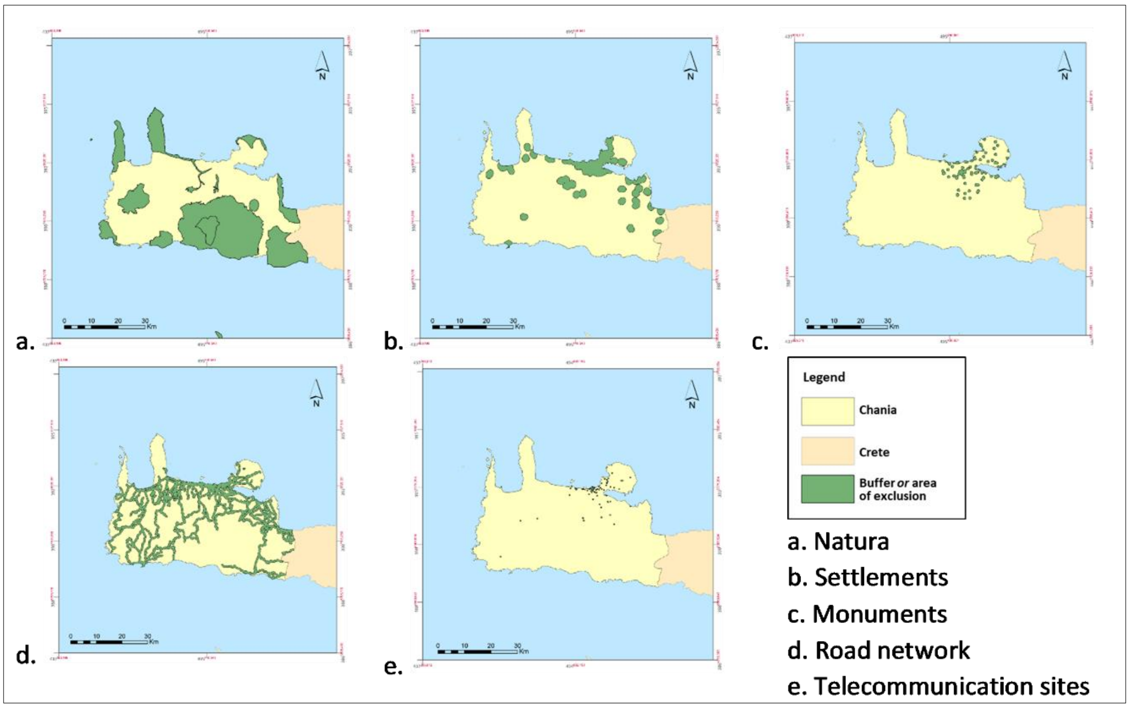

Figure 2 Buffer zones/areas of exclusion for each constraint.

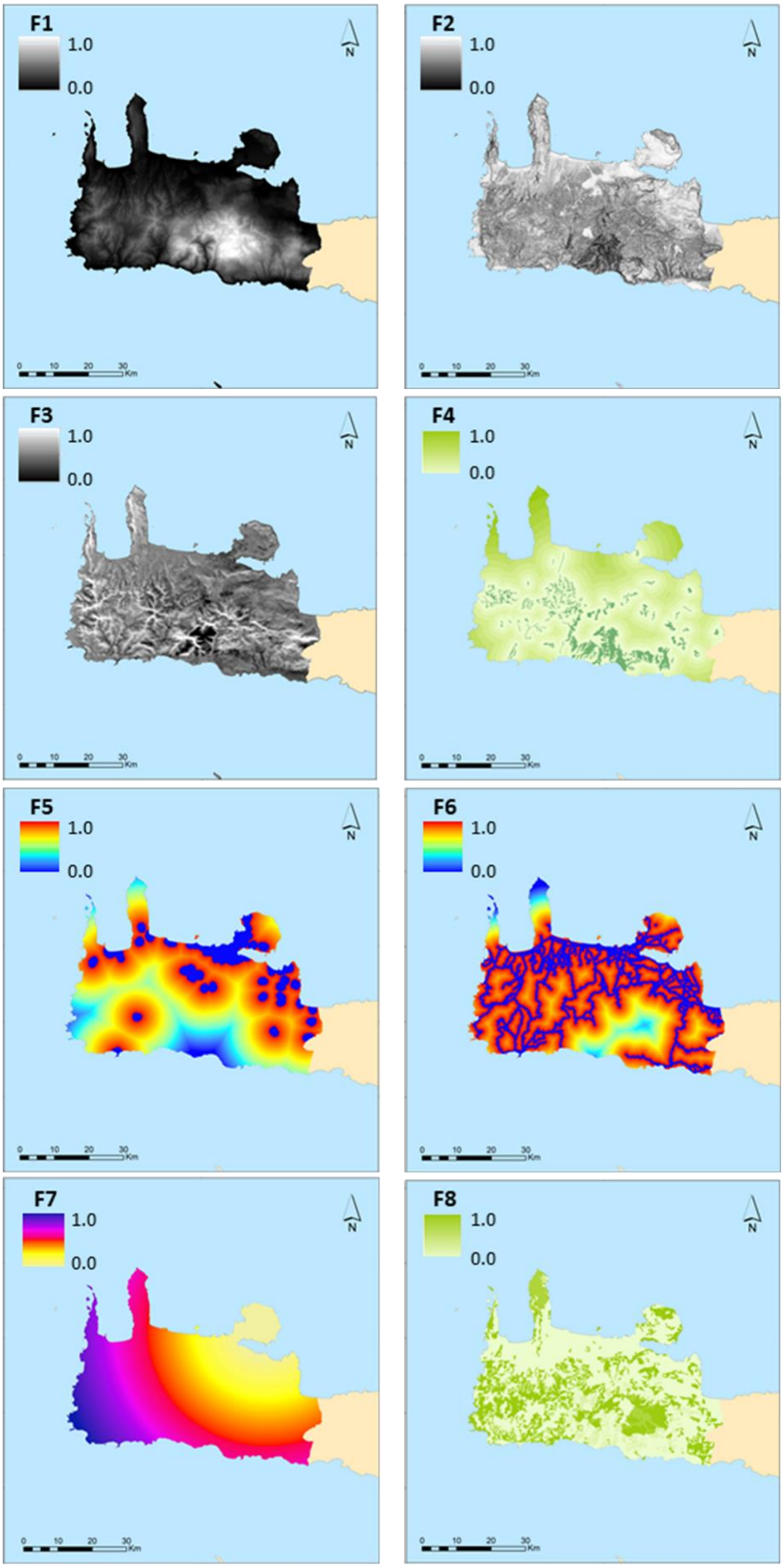

Figure 3 Factors F1-F8 (standardized values).

Table 2 Values for F8 factors depending on the type of land cover.

Code	Description	Value
111	Continuous urban fabric	0.0
112	Discontinuous urban fabric	0.0
121	Industrial or commercial units	0.0
122	Road and rail networks and associated land	0.0
123	Port areas	0.0
124	Airports	0.0
131	Mineral extraction sites	0.0
132	Dump sites	0.4
133	Construction sites	0.0
142	Sport and leisure facilities	0.0
211	Non-irrigated arable land	0.4
212	Permanently irrigated land	0.4
221	Vineyards	0.4
222	Fruit trees and berry plantations	0.4
223	Olive groves	0.4
231	Pastures	0.4
242	Complex cultivation patterns	0.4
243	Land principally occupied by agriculture with significant areas of natural vegetation	0.4
311	Broad-leaved forest	0.0
312	Coniferous forests	0.0
313	Mixed forest	0.0
321	Natural grassland	1.0
322	Moors and heathland	0.9
323	Sclerophyllous vegetation	1.0
324	Transitional woodland/shrub	0.5
331	Beaches, dunes, sands	0.0
332	Bare rock	0.9
333	Sparsely vegetated areas	0.9
334	Burnt areas	0.0
512	Water bodies	0.0
522	Estuaries	0.0
523	Sea and ocean	0.0

2.3 Scenarios

In this study, the selection of the design criteria is based on the current legislation and on criteria that are commonly introduced in relevant applications. To highlight the influence of the selected criteria on suitability mapping, three scenarios are investigated. These scenarios are expressed through different sets as well as through different hierarchies among the selected criteria. In the MCDM technique, first, the collection and analysis of geospatial data, determination of the constraints, and standardization of the criteria are performed. Then, the criteria weights are calculated using the AHP method, followed by the composition of the criteria in order to produce a resulting map for each scenario.

The current methodology employs a hierarchical model to implement the problem, allowing pairwise comparisons among the criteria that are selected for each scenario, as shown in Table 3. This table presents the pairwise comparison according to the fundamental scale of Saaty, the corresponding metric for evaluating the performance, and the factors' weights resulting from the application of the method for each scenario.

Table 3 Pairwise comparison matrices and criteria weights for each scenario.

Scenario S1

	F1	**F2**	**F3**		**Wi**
F1	1	1/4	1/8	W_{F1}	0.0718
F2	4	1	1/4	W_{F2}	0.2267
F3	8	4	1	W_{F3}	0.7015
				λmax	3.0542
				Ci	0.0271
				CR	0.0467

Scenario S2

	F1	**F2**	**F3**	**F5**	**F6**	**F7**		**Wi**
F1	1	1/2	1/8	1/6	1/6	1/7	W_{F1}	0.0329
F2	2	1	1/5	1/2	1/2	1/3	W_{F2}	0.0734
F3	8	5	1	2	2	1	W_{F3}	0.2992
F5	6	2	1/2	1		1/3	W_{F5}	0.1326
F6	6	2	1/2	2	1	1/2	W_{F6}	0.1738
F7	7	3	1	3	2	1	W_{F7}	0.2882
							λmax	6.1281
							Ci	0.0256
							CR	0.0207

Scenario S3

	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**		**Wi**
F1	1	1/2	1/8	1/3	1/6	1/6	1/7	1/5	W_{F1}	0.02743
F2	2	1	1/5	1/3	1/2	1/2	1/3	1/3	W_{F2}	0.04990
F3	8	5	1	1/2	2	2	1	1/3	W_{F3}	0.14885
F4	3	3	2	1	3	3	0.5	1/3	W_{F4}	0.15118
F5	6	2	1/2	1/3	1	1/2	1/3	1/5	W_{F5}	0.07229
F6	6	2	1/2	1/3	2	1	1/2	1/3	W_{F6}	0.09342
F7	7	3	1	2	3	2	1	1/3	W_{F7}	0.16418
F8	5	3	3	3	5	3	3	1	W_{F8}	0.29275
									λmax	8.5275
									Ci	0.0754
									CR	0.0534

As shown through the values of the factors' weights, the first scenario (S1) is a technical one that focuses on the criteria contributing to the output based on the technical specifications of a wind farm. In addition, the wind potential (which is one of the priorities in all scenarios), surface slope, and elevation are used to describe the technical scenario. The second one (S2) is the techno-economic scenario, wherein three additional factors are introduced in the WLC: distance from roads, settlements, and airports. Finally, the third scenario (S3) is a combination of technical, economic, and environmental factors; here, the focus on the consideration of all the criteria, but relatively higher importance is attributed to the criterion of distance from airports.

3. Results and Discussion

The objective of the present case study is to combine the GIS and MCDM techniques for identifying suitable sites for wind farm installation after considering a set of design criteria. This analysis shows that the degree of suitability is affected by various aspects, such as the criteria that are selected, the standardization/classification method that is applied to transform the values of each factor to a common scale for all criteria, and the weights that are attributed to each criterion, which is one of the most important steps in MCDM. Although each case study is unique and requires different criteria to be set (for instance, as part of national legislation or in accordance with specific technical requirements), the proposed framework describes the way various criteria can be introduced in a GIS-based MCDM approach. Further, for comparison, three scenarios are described and compared.

Figure 4 shows the suitability maps that are the output of the WLC among factors considered in the three scenarios (Table 3). As expected, the number of criteria and their hierarchy, which influences the calculated weights, control the FS spatial distribution. How the suitability maps can be interpreted is directly linked to the FS scale; however, the classification among FS values in suitability zones influences the suitability pattern. FS takes values between 0 and 1, in accordance with the same scale of standardized factors; as such, areas with an FS value of 1 and 0 are characterized as the most suitable and non-suitable areas, respectively. For illustration purposes, five classes (suitability zones) are created:

The first one (zone A; non-suitable locations) corresponds to locations with constraints, i.e., areas that are excluded from the analysis (e.g., Natura network) or buffer zones (e.g., forests). As shown in Table 4, the total area for zone A remains the same in all examined scenarios.

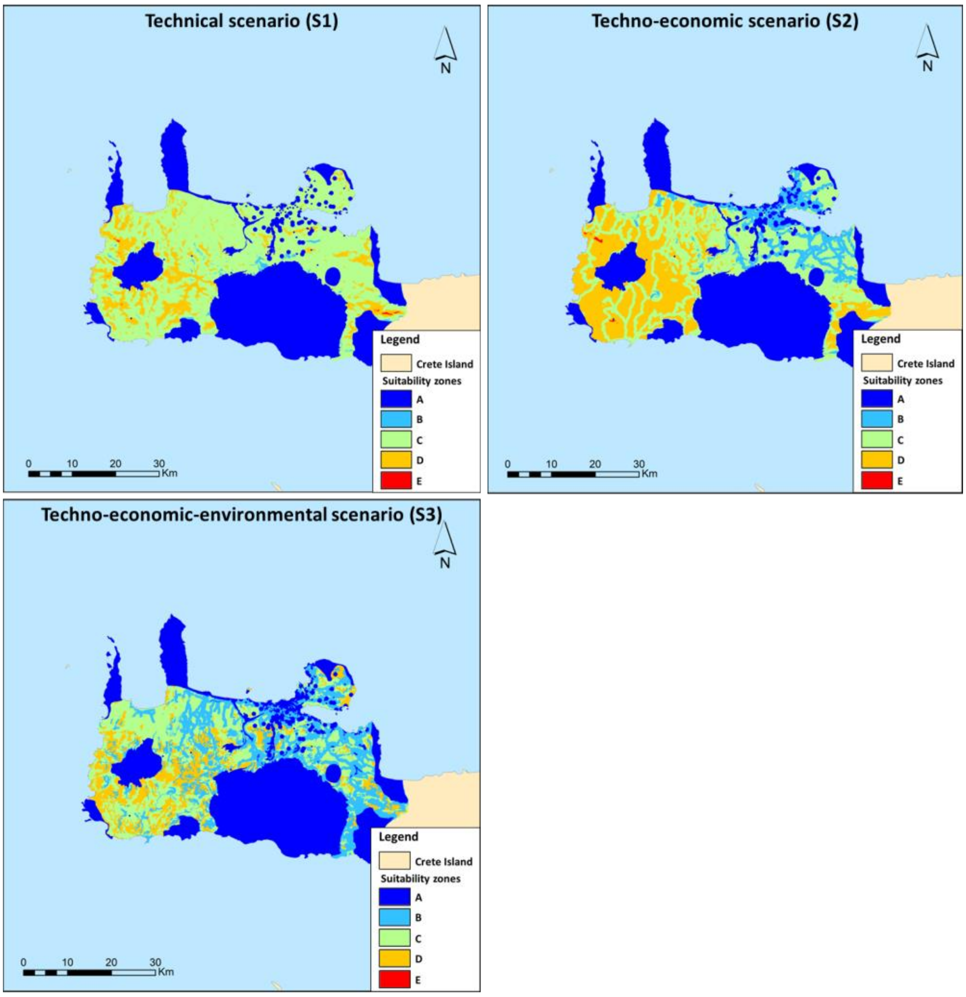

Figure 4 Suitability maps for the three scenarios.

Table 4 Percentage area per suitability zone for the three scenarios.

Suitability Zone | Scenario	S1	S2	S3
A	42.7%	42.7%	42.7%
B	0.8%	8.5%	21.9%
C	45.5%	27.4%	22.9%
D	11.0%	21.3%	12.5%
E	0.1%	0.1%	0.0%

The other zones (i.e., B, C, D, and E) are classified to correspond to low, moderate, high, and very high suitability. However, there is no scenario indicating extended areas of very high suitability; only limited areas are defined in the technical and techno-economic scenarios. All scenarios could identify appropriate sites for wind farm installation in the eastern part of the regional unit of Chania, in a mountainous region that is characterized by rich wind potential; further, all criteria regarding proximity are satisfied.

The major scientific problem underlying this analysis is that the different concepts that are investigated through these three scenarios lead to different results. The integrated use of GIS and MCDM for RES planning and development plays an important role in providing guidelines regarding spatial planning and site evaluation, especially in the case of extensive field exploration. The capabilities of this approach include (i) the ability to combine as many criteria as required and (ii) the flexibility in attributing hierarchy among the criteria, depending on the objectives of each case study.

4. Conclusions

In this study, a GIS-based MCDM technique is proposed for assessing the degree of suitability for wind farm installation in the regional unit of Chania. The proposed technique considers restrictions, national legislations, and other factors; these factors are selected and weighted based on three scenarios that are introduced to investigate the method's flexibility and capabilities in optimal site selection.

The nature of the design criteria, the number of criteria, and their hierarchy are the three factors that control the resulting suitability pattern. However, the GIS-based MCDM technique is vital in relevant applications, especially for preliminary suitability assessment. The decision-makers set the spatial context, and the suitability map denotes the optimal positions. The final selection from among areas with high scores is linked to other aspects, such as the available space and the distance from any points of interest. Regarding suitable areas found in the case study for the regional unit of Chania, many suitable locations with adequate areas and best locations in terms of wind resources were observed high in the mountains in large open fields; however, the spatial extent and FSs of the best areas varied for different scenarios.

This paper provides an overview of the capabilities and limitations of relevant techniques in decision-making regarding wind farm site selection; it also highlights the variation in resulting patterns when different concepts are examined. Future research on design criteria hierarchy and weighing will help in evaluating different scenarios and in extending the guidelines provided for criteria selection and hierarchy. The concept of suitability analysis introduced herein will further contribute to the evaluation of the degree of suitability of sites to changes in the criteria. Finally, further analysis of the additional spatial criteria introduced in the proposed method will allow analyzing their potential impact on the resulting suitability score describing the best locations.

Author Contributions

E.F. and E.K. conceived of the presented idea. E.K. planned and carried out the computations. E.F. verified the analytical methods, encouraged E.K. to investigate several scenarios and supervised the findings of this work. E.F. wrote the initial version of the manuscript. Both authors discussed the results and contributed to the final manuscript.

Competing Interests

The authors declare that there is no conflict of interest.

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