INTRODUCTION

Penetration of Renewable Energy Sources (RES) in the global energy balance has been a priority throughout the last decades. Directive 2009/28/EC\(^1\) set the key for climate objectives by 2020 and includes reduction of greenhouse emissions by 20\% compared to 1990 levels, increase of RES penetration by 20\% and improvement of energy efficiency by 20\%. According to Paris Agreement signed in 2016, each country must report on the contribution to mitigation of global warming.\(^2\) Governments agree on trying to keep the increase in the global average temperature below 2°C above
preindustrial levels and to aim to limit the increase to 1.5°C, since this would significantly result in reduced risks and impacts of climate change. The ultimate goal is the balance between emissions and removals by 2050. In December 2018, under Renewable Energy Directive 2018/2001/EU (RED II)\textsuperscript{1} the renewable energy target by 2030 set to a minimum of 32\% of gross final consumption, 32.5\% for energy efficiency, and at least 40\% reduction of greenhouse gas emission. Over the period 2005-2018, European countries more than double their RES capacity from 180 GW to 465 GW.\textsuperscript{4} Installed wind-powered systems reach 179 GW, hydropower systems 130 GW, not including pump storage, and solar photovoltaic systems reach 115GW. Wind and solar power systems correspond to 90\% of the annual increase in RES power capacity.

On the other hand, there are many islands in the Aegean Sea, which depend on oil products for their Local Power Stations (LPS) or even depend on LPS of neighboring islands via a submarine connection. This results in high-cost electricity generation and blackouts during high energy demand periods.\textsuperscript{5} The rich wind potential of such areas should be utilized for their energy independency and the improvement of living conditions. It has been found that this source of energy reduces environmental pollution, as it presents good potential in the minimization of greenhouse gases,\textsuperscript{6} while it also presents a reduced quantity of water consumption. It is also clean, environmentally friendly, cheaper, and has the minimum impact on the habitat than other RES.\textsuperscript{7} Also, as far as the existence of local wind farms is perceived and experienced by local residents, it is found that although some of them remain inquietude about such installation, for many others becomes a familiar and unremarkable part of the landscape.\textsuperscript{8} Furthermore, studies have shown that the most profitable regions for onshore wind farm siting in Greece, taking into account the Net Present Value and the Internal Rate of Return, are the islands in the Aegean Sea\textsuperscript{9} and coastlines regions in South Central Greece, in East Peloponnesse and South Attica.\textsuperscript{10}

A large number of previous research work has already studied the potential of wind energy. Kwon\textsuperscript{11} presents a framework to assess the wind resource of a wind turbine using uncertainty analysis by the variability of natural wind and power performance. Toft et al\textsuperscript{12} assess the uncertainty of the wind climate parameters at each turbine position by using the local wind measurements, the speed-up factors, and by calculating the distance between the position of the measurements and the position of the wind turbine. Fernández-González et al\textsuperscript{13} develop a predictability index as a tool that can forecast the wind potential for several days in advance providing estimations of wind energy production. Katopodis et al\textsuperscript{14} investigated the impact of climate changes on wind resources in Greece. Also, many feasibility studies have been performed as far as an installation of a wind farm is concerned. Gatzer et al\textsuperscript{15} present risks associated with onshore and offshore wind farm projects and risk management solutions focusing on the European market. There are also many research papers where a wind farm is part of a desalination system as a sustainable solution for meeting water demand. Kourtis et al\textsuperscript{16} propose a wind-powered desalination system, which is combined with rainwater harvesting as a supplementary source of water under five different water resource management scenarios and six climate change scenarios. Furthermore, previous research work using wind turbines in the context of Hybrid Renewable Energy Systems to meet electrical and/or water needs has been carried out. Significant results are obtained for the operation and optimization of such systems in remote areas. Abnavi et al\textsuperscript{17} perform a techno-economic feasibility study in a remote rural area in Persian Gulf Coast-Iran with a sensitivity analysis in the rise of the fuel prices. Rashid et al\textsuperscript{18} propose an optimization of an HRES, at coastal areas in Bangladesh, in terms of minimum cost of energy and maximum reduction of fuels and CO\textsubscript{2}. Sarris et al\textsuperscript{19} present simulation results of an HRES in Patmos island for covering water and electricity demands. Tsikalakis et al\textsuperscript{20} investigate the impact of introducing an HRES in the autonomous power system of Crete, in Greece. However, all the above studies do not consider the optimal siting of the wind farm.

Different approaches have been applied for the definition of the possible locations of a wind farm. Felber et al\textsuperscript{21} determine in their work the dimensioning of safety distance regulations in combination with the further development of wind power systems for the protection of nearby residents. Manchado et al\textsuperscript{22} provide a method that focuses on the measurement and incorporation of visibility during the design process of a wind farm. Musselman et al\textsuperscript{23} introduce an optimization model for wind farm siting by terms of reducing power system impacts of wind variability. However, these studies do not consider the parameter of the environmental constraints and the current legislation framework for the siting of a wind farm.

This research work presents a method for evaluating eligible sites for wind turbines installation for different combinations of criteria. A GIS-based MCDM methodology is proposed to be implemented for the design of a wind farm according to a set of proposed geomorphological, technical, and spatial criteria and the investigation of the influence of the selected design criteria and the weighting method to determine the suitable locations. The AHP is used for the illustration of the impact of the selected method to the design. It is a decision-making framework, proposed by Saaty.\textsuperscript{24} Wind resource is the first feature that should be assumed, and which should be capable to provide a sufficient amount of generated power from the conversion through the wind turbine. The methodology is applied on Fournoi Korseeon island, in Aegean Sea, in Greece. In this location, sufficiently high wind potential is observed, which should be exploited by the establishment of wind turbines to meet the island's electricity needs and to provide better living conditions for residents who suffer from their dependency on LPS of neighboring islands. Greece legislation
framework, as far as the siting of a wind farm is concerned, contains specific criteria that should be met in order such an installation to be legal. The results strongly depend on which criteria is chosen and on the data that is provided. The idea behind this approach is to provide a flexible decision framework through different scenarios and to give the capability to the “decision maker”—manufacturer and/or local community and/or ministry, to choose the hierarchy of the criteria that best fits their specific area and their specific priorities.

2 | STUDY AREA AND LEGISLATION FRAMEWORK

Fournoi Korseon (Figure 1) is a cluster of islands located in the eastern Aegean Sea. The main settlement is Fournoi with an area of 30.5 km² and approximately 1400 inhabitants, while this number reaches 4000 in summer due to tourism. There are 8 more settlements, some of which are uninhabited, and the rest have between 3 and 150 inhabitants. These are Chrysomilia, Kamari, Agios Minas, Keramidou, Thymaina, Plagia, Agios Ioannis Thermastis, and Mpali. The island is characterized by the Mediterranean climate with winters mild and summers warm and dry. According to Hellenic National Meteorological Service (HNMS), the average annual temperature is 18°C, the mean monthly minimum is 10°C in February and the mean monthly maximum is 28°C in July. The prevailing wind directions are mainly westerly and northerly by mean annual speed over 10 Beaufort. The island is submarine connected with the Public Power Corporation via the nearby island of Samos, to cover its electricity demands.

FIGURE 1 Study area
According to current legislation framework, for the siting of wind turbines, based on its exploitable wind potential and its spatial and environmental characteristics, Greece is divided into the following major categories:

a. The mainland, including Euboea.
b. Attica, which is a more specific category of the mainland because of its metropolitan nature.
c. The inhabited islands of the Ionian and the Aegean Sea, including Crete.
d. Offshore marine space and uninhabited islets.

Fournoi Korseon belongs to category c as a South Aegean island.

In all the above areas, there are exclusion zones and areas of incompatibility. It is prohibited to install wind farms in:

a. The declared World Heritage Sites and other monuments of major importance, as well as the delimited archaeological sites.
b. Areas of absolute nature protection.
c. The boundaries of Wetlands of International Importance (Ramsar Wetlands).
d. The cores of national farms and the delimited monuments of nature and esthetic forests.
e. Priority Areas in the territory of Greece that belong to NATURE 2000 network in accordance with Directive 2006/613/EC of the European Parliament.
f. Within town plans and settlement boundaries before 1923 or below 2000 inhabitants.
g. Areas of organized development of productive activities in the tertiary sector.
h. Informally designed, within the context of off-plan construction, tourist and residential areas.
i. The bathing shores included in the bathing water quality monitoring program coordinated by the commanding ministry.
j. The parts of the quarry areas and the mining zones.
k. Other areas or zones that are currently subject to a special land use scheme, which does not permit the location of wind farms.

Also, it is advisable to use existing roads for wind farms with the necessary improvements and extensions. The design of these projects is carried out in such a way to avoid as much excavation as possible and the width of the access roads should be limited to the extent necessary. At the same time, all necessary flood protection and erosion prevention works must be carried out in order to avoid the fear of deteriorating the landscape due to the project. Vegetation deterioration should be kept to a minimum (shrubs and trees should be planted in accordance with the instructions of the local Forest Service) and the esthetics of the landscape restored.

The legislation framework, mentioned above, is taken into consideration. An examination of which characteristics exist on the island of Fournoi Korseon is processed (for example the island has no wetlands, no Ramsar nor sacred monasteries etc). The final selection of the criteria is made, in order to proceed to the implementation of the MCDM for the evaluation of eligible sites for wind turbine installation. The following six criteria/factors are taken into account:

- Wind potential – $C_{\text{wind}}$. The maximum possible wind potential is required in order to maximize the energy generated by the wind turbines.
- Altitude – $C_{\text{alt}}$. It is expected that the maximum wind potential will be observed at locations with the highest altitude, so this criterion shields the desire to maximize the produced energy.
- Distance from settlements – $C_{\text{set}}$. The closer the wind turbines to a settlement whose electricity needs are to be met, the lower the loss of energy from transmission via cable. However, there is an exclusion zone, according to the legislation framework, which prohibits the installation of wind turbines within 500 m of each settlement.
- Distance from road network – $C_{\text{road}}$. The shorter the distance is from the road, the easier it is to install a wind farm, as it is not necessary to construct accompanying works (road excavation etc) Furthermore, the legislation does not prohibit the installation to more than 10 000 km from the road network, which in the current case is satisfied in advance as it is a small island.
- Distance from telecommunication sites – $C_{\text{tele}}$. The distance from existing telecommunication stations operates within the same logic as the distance from the road network. The location of a wind farm as close as possible to a telecommunication station results in the nonrequirement of accompanying projects being constructed. However, by law, there is also an exclusion zone from a telecommunication station, which is designated as part of the environmental impact study for each project. In the present study, the exclusion zone is set to 200 m to exclude any nuisance from one project to the other.
- Distance from archaeological sites – $C_{\text{arch}}$. The legislation protects archaeological sites and prohibits installation within 500 m. Also, it is preferable to aim at long distances from an archaeological distance, in order for the cultural heritage to be protected. It is generally avoided the construction of any kind of technical work near monuments, so as not to distort the field of view from them.

The process of factor standardization and constraint enforcement is presented in Table 1.
The digital elevation model (DEM) of the Fournoi region used in this research work is obtained by the National Cadastre & Mapping Agency SA of Greece. The pixel size is $5 \times 5$ m, geometric accuracy RMSE is $z \leq 2.00$ m and the absolute accuracy is about 3.92 m for a 95% confidence level. The layer of wind data is obtained by Geodata, as calculated by the Centre for Renewable Energy Sources and Saving (CRES) based on an extensive program of in situ measurements and application of mathematical model. The map in Figure 2 reflects the wind potential based on the average annual wind speed in meters per second, at a calculated height of 40 m. The layer of settlements is obtained from the CORINE Land Cover 2018, choosing categories of continuous urban construction and intermittent urban construction. However, only the settlement of Fournoi appears and the remaining 8 settlements are digitized by the authors using the basemap from ArcGIS Online. The layer of road network obtained from Geofabrik OpenStreetMap Data. The layer of archaeological sites is created by the authors based on the current legislation framework and on ministerial decisions and approvals, where specific areas of land are characterized as archaeological sites. The layer of mobile telecommunications is created by the authors based on the Antenna Construction Information Portal of the National Committee of Telecommunications & Postals. The digital elevation model (DEM) is raster data. The layers of the wind potential, the settlements, the road network, the telecommunications sites, and the archaeological sites are vector layers with no spatial resolution. Both types of spatial data, raster and vectors, are linked to tabular databases that store attribute information about the locations delineated by the grid cells, nodes, and polygons, and they have a common Projected Coordinate System.

### METHODOLOGY

The GIS–MCDM methodology model is shown in Figure 3, while every step is described below.

#### TABLE 1: Criteria/Factors of wind farm design

| Criteria/Factor     | Standardization procedure | Constraints                                      |
|---------------------|---------------------------|--------------------------------------------------|
| Wind potential ($C_{\text{wind}}$) | Equation (6)             | Wind potential over 2 km/h                       |
| Altitude ($C_{\text{alt}}$)       | Equation (6)             | No constraints, high wind potential is encountered at high altitudes |
| Settlements ($C_{\text{set}}$)    | Equation (7)             | Distance from the boundary > 0.5 km               |
| Road network ($C_{\text{road}}$)  | Equation (7)             | Distance < 10 km                                 |
| Telecommunication sites ($C_{\text{tele}}$) | Equation (7)             | Distance > 0.2 km                                |
| Archaeological sites ($C_{\text{arch}}$) | Equation (6)             | Distance > 0.5 km                                |

First, input criteria are selected covering environmental and technical parameters as well as the current legislation framework in Greece. It is important to select those sites that are in high altitude and subsequently have the highest wind potential. Also, these sites must not be within the boundaries of the settlements, archaeological sites, protected landscapes, or even airports. So, the data of the study area are collected and using GIS, buffer zones are defined, where wind turbine installation is excluded by legislation. For the remaining positions, a score is created based on the weight of each criterion that is considered for the installation.

There are four methods for the development of the weights: the ranking, the rating, the trade-off method, and the pairwise comparison. The simplest method is the ranking, where the rank of each criterion is based on the decision maker’s preferences. In the rating methods, the weights are estimated, based on a predetermined scale. In trade-off methods, direct trade-off assessments between alternative pairs are used. In pairwise comparison methods, a pairwise comparison is used for the creation of a ratio matrix. In this research paper, this last method is used. This method’s advantage is that it can provide an organized structure for group discussions and can help the decision-making group to focus on areas of agreement and disagreement when they set the criterion weights. This technique is developed by Saaty in the context of a decision-making process known as the AHP.

Weighted Linear Combination (WLC) is the method with which the decision criteria and their weights are combined into a final score to yield a suitability map.

The final score (FS) is calculated by Equation (1). where $w$ is the weighting parameter, $a$ is the value parameter, $i$ is the selected scenario, $j$ is the selected layer (criterion) in the model, $n$ is the total number of the criteria and FS is the final score for each scenario, which shows the suitability index. In cases, where constraints are also applied, then the suitability
index $A$ is multiplied with the product of the constraints, as shown in Equation (2).

$$FS = \sum_{j=1}^{n} w_j a_{ij} \cdot \prod c_j$$

where $c_j$ is the score of Boolean constraints, such as the buffer zones where no wind turbine is allowed to be installed.

The final score of this method is used for the determination of the optimum sites for installation. The estimation of each weight is calculated using the AHP method. In AHP it is assumed that the final decision depends on the available data as well as the decision maker’s experience and knowledge. Decision makers are wind turbine designers. They use MCDM analysis and they develop standardized procedures for solving a problem (eg, site selection) by combining factors (eg, geomorphological, technical, spatial criteria). It is a process, where geographic data (inputs) are combined and transformed into a resulting decision (output). This is a defined relationship between input and output maps. In the GIS, data are separate thematic maps referred to as layers. The idea behind this approach is to provide a flexible decision framework through different scenarios and to give the capability to the decision makers, to choose the hierarchy of the criteria that best fits their specific area and their specific priorities. GIS capabilities of data acquisition, storage, retrieval, manipulation, and analysis, as well as MCDM ability of combination geographical data and the decision maker’s preferences into one-dimensional value of alternative decisions are of critical importance for the methodology. The identification of the general problem and the individual objective is the first step of the analysis. In this study, the designers select the criteria based on the current legislation framework. Different scenarios are investigated that represent any potential different
purposes of decision makers. After the collection and analysis of geospatial data, the next step is the determination of any enforced constraints and the standardization of the criteria scores, as shown in Table 1. Then, the composition of the criteria and the relevant weights are determined, to produce the results. AHP is based on the principle that decision maker’s experience and knowledge are as important as the available data. Various studies have applied this method.36-38 The current methodology is based on the construction of a hierarchical model to implement the problem, which allows pairwise comparisons, that are based on a fundamental comparison scale introduced by Saaty and it is shown in Table 2. The comparisons are based on the relative importance of the two criteria involved in determining suitability. The main feature of this approach is the ability to capture both subjective and objective aspects of a decision.39 The outputs, derived by AHP method, are linearly combined to calculate the final score and determine the optimal sites for the wind farms.

The final step of the AHP method is the calculation of the consistency ratio (CR). The CR of each scenario is the comparison between the consistency index of the matrix CI and the consistency index of a random matrix RI and is expressed by Equation (3). It defines the probability that the matrix ratings are generated randomly.

\[
CR = \frac{CI}{RI}\quad (3)
\]

The CR should take values up to 10% to guarantee the hierarchy and the calculated weights to be accepted, otherwise, it should be re-evaluated. It is also possible to determine where the inconsistencies arise by analyzing the matrix.

The CI is calculated by Equation (4)

\[
CI = \frac{\lambda_{\text{max}} - n}{(n - 1)}\quad (4)
\]

where \( n \) is the total number of the criteria

The \( \lambda_{\text{max}} \) is calculated by Equation (5)

\[
\lambda_{\text{max}} = \sum_{j=1}^{n} \frac{\sum_{i=1}^{n} w_{ij} a_{ij}}{w_{ij}}\quad (5)
\]

The consistency index of a random matrix RI depends on the number of the criteria and is given by Table 3.

Standardization of each criterion aims to categorize it in a common scale between values 0-1 and is implemented using GIS environment. By this procedure, criteria are created by comparable size to calculate the final score. There are a variety of procedures for standardization.40 They use the minimum and the maximum values as the scaling points. The simplest between them is the linear transformation.33

To perform this procedure the use of linear transformation is applied by Equations (6) and (7).

\[
x_i = \frac{(FV_i - FV_{\text{min}})}{(FV_{\text{max}} - FV_{\text{min}})} \cdot SR\quad (6)
\]

\[
x_i = 1 - \frac{(FV_i - FV_{\text{min}})}{(FV_{\text{max}} - FV_{\text{min}})} \cdot SR\quad (7)
\]

where \( FV_{\text{min}}, FV_{\text{max}} \) are the minimum and maximum values of the factor, respectively. \( FV_i \) is the value of each raster cell, \( x_i \) is
the corresponded standardized value and SR is the standardized range. For SR between 0 and 1, the transformation of each criterion into its standardized value is achieved, through Equations (6) and (7), depending on whether the optimum value is the maximum or the minimum value of the criterion, respectively. This procedure is applied through GIS environment, for each criterion.

Finally, using Map Algebra Toolset by GIS environment and Equation (2), which include constraints, the development of the final map is implemented. This map shows the scores of each site and areas with the highest FS should be selected for the wind farm installation.

Three scenarios are implemented for different hierarchy of criteria. The hierarchy of each scenario is shown in Table 4.

The first scenario (SC I) is the technical scenario where the focus is on criteria that will give the project the best performance. Besides, the wind potential, which is a priority in all scenarios, settlements, and roads are the criteria of higher hierarchy, so that there is no loss in power transmission via cables. The second scenario (SC II) is the cultural scenario, and here the criterion of distance from archaeological sites is taken into account with a higher weight. Finally, the third scenario (SC III) is the financial scenario, so the interest is focused on the lowest cost of the project. For this reason, high altitudes are avoided; however, wind potential is a priority. Locations close to the road network or to existing telecommunications stations are preferred, to avoid further projects that are needed, when a wind farm project is installed, such as road excavation.

Based on the above three scenarios three more suitability maps are implemented considering one more constraint. This is the proximity to the main settlement of Fournoi. The selection of this constraint is based on the fact that it is preferred for such a project to be close to the settlement, where are the most residents. The main settlement with the greatest number of inhabitants, 1400 comparing to 3 of Aghios Minas and 151 of Thimena, has increased energy demands. Taking into account the limitation of the distance from the settlement and installing such a project near the area with more energy requirements, energy losses due to transmission via remoted areas are diminished.

Sensitivity analysis is performed to the weights to evaluate how suitable sites are susceptible to changes in the weights of each criterion. The analysis examines a ±5% and ±10% change in the proposed values for $C_{\text{wind}}$ and $C_{\text{arch}}$ of SC I. Finally, new final scores and suitability maps are created.

### Results and Discussion

Wind turbine site design using GIS and MCDM is affected by the criteria that are selected, the standardization method that is used to transform the value of each criterion to a common scale and the weighting and analytical method used for the calculation of the FS. As shown in Table 4, the criteria that are used in this analysis are the wind potential, the altitude, the distance from the settlements, the distance from the road network, the distance from telecommunications sites, and the distance from archaeological sites. The criterion of wind potential is a priority in all scenarios, as the maximum possible wind potential is required to maximize the energy generated by the wind turbines. Three scenarios are implemented, based on the hierarchy of criteria. For each scenario, pairwise comparison is performed and weights for each criterion are extracted. Regarding the AHP method, this is applied to calculate the weight of each factor. WLC is the method with which the decision criteria and their weights are combined into a FS to yield a suitability map. The hierarchy of criteria for each scenario is shown in Table 4 in the previous section. Since FS takes values between 0 and 1 and in order to have the same basis of comparison, five classes/zones are created. The first one is the zero zone (zone A) and is shown in gray color for each suitability map (Figures 4-9). This zone corresponds to 27.9% of the total area of the island and it is the same for each scenario. It represents all the buffer zones where wind turbines are not permitted to be installed. The other four zones (zone B, C, D, E) are classified in values of FS up to 0.25, 0.50, 0.75 and the last one up to the higher values that each FS can reach, and it appears in the legend of each Figure. Also, three more suitability maps are represented considering the proximity to the main settlement of

### Table 4

Hierarchy of criteria for each scenario

| Scenario I (SC I) | Scenario II (SC II) | Scenario III (SC III) |
|-------------------|---------------------|-----------------------|
| $C_{\text{wind}}$ | $C_{\text{wind}}$   | $C_{\text{wind}}$    |
| $C_{\text{alt}}$  | $C_{\text{alt}}$    | $C_{\text{road}}$    |
| $C_{\text{set}}$  | $C_{\text{arch}}$   | $C_{\text{set}}$     |
| $C_{\text{road}}$ | $C_{\text{road}}$   | $C_{\text{tele}}$    |
| $C_{\text{tele}}$ | $C_{\text{set}}$    | $C_{\text{alt}}$     |
| $C_{\text{arch}}$ | $C_{\text{tele}}$   | $C_{\text{arch}}$    |
Fournoi, as one more constraint. In this case, zone A is the same as in previous scenarios and corresponds to 27.9% of the total area of the island. However, there are only 3 more zones, zone B with FS values up to 0.25, zone C up to 0.5 and zone D up to the higher values that each FS can reach. Finally, a sensitivity analysis is implemented, in order to evaluate how a change in a criterion affects the results.

4.1 | Scenario I

Pairwise comparison for Sc I is performed and the weights extracted are shown in Table 5, with the corresponding consistency ratio (CR) equal to 0.089 and less than 0.1. Sc I is more technical-oriented, as it obeys the wind potential of the study area and attributes higher priority to it. On the other hand, the distance from the archaeological sites is the factor with the lower weight.

In Figure 4 the suitability site map of Sc I is shown. In gray is zone A, which corresponds to 27.9% of the total area of the island. All the other classes show suitability sites according to the classification. Zone B corresponds to 2.6%, zone C is the one with the higher area that reaches 41% of the total island, while the percentage for zone D is 26.9% and 1.7% for zone E, which is the best class for installation. The maximum value of FS is circa 0.91.

4.2 | Scenario II

The pairwise comparison and the weights for Sc II are shown in Table 6, with the corresponding CR equal to 0.066. Sc II is more cultural-oriented, as, besides the wind potential, which is a priority in all scenarios, it obeys the distance from the archaeological sites and attributes higher priority to it. On the other hand, the distance from the telecommunication sites is the factor with the lower weight.

In Figure 5 the suitability site map of Sc II is shown. The percentage for zone B is 7.9%, 51.4% for zone C, 12.5% for zone D and only 0.3% for zone E, while the maximum value of FS is 0.84 and lower than the corresponding value of Sc I. That means that cultural constraints reduce FS for this island.

4.3 | Scenario III

The pairwise comparison and the weights for Sc III are shown in Table 7, with the corresponding CR equal to 0.081 and less
than 0.1. ScIII is more economic-oriented, so the interest is focused on the lowest cost of the project. Although wind potential is a priority, high altitudes are avoided. Also, locations close to the road network or to existing telecommunications stations are preferred, to avoid further projects that are needed when a wind farm project is installed, such as road excavation. In this scenario, distance from archaeological sites is the factor with the lower weight.

In Figure 6 the suitability site map of ScIII is shown. The percentage for zone B is 0.2%, 13.8% for zone C, 54.1% for zone D and 4% for zone E, the highest value comparing to the other two scenarios. Also, this scenario has the highest percentage in zone D, compared to the other two scenarios where the highest values appear in zone C. In ScIII almost 60% of the island belong to zone D and E. The maximum value of FS is 0.93 and higher than the corresponding values of ScI and ScII. Also, it is obvious that this scenario has the most positions in the last two zones, D and E. So, it can be assumed that suitable sites with high wind potential can be combined with lower altitudes and can give even more location for installation in the last zone E.

4.4 Proximity to the main settlement

Three more suitability maps are implemented considering one more constraint. This is the proximity to the main settlement of Fourni since it is preferred for such a project to be close to the settlement where are the most residents. Considering the limitation of the distance from the settlement and installing such a project near the area with the greater energy requirements, energy losses due to transmission via from remoted areas are diminished.

Figure 7A,B,C show the suitability maps for ScI, ScII, and ScIII, respectively. In gray is zone A, which corresponds to 27.9% of the total area of the island, the same as in the first three scenarios. It is important to note that in these three
FIGURE 8  Suitability map of $S_{C_l}$ for change of $C_{wind}$ (A) $-10\%$, (B) $-5\%$, (C) $+5\%$, (D) $+10\%$
FIGURE 9  Suitability map of $S_c$ for change of $C_{arch}$ (A) $-10\%$, (B) $-5\%$, (C) $+5\%$, (D) $+10\%$
additional scenarios, there are only 4 zones, as FS is not higher than 0.744, while the corresponding value of the three initial scenarios is 0.929. This is because an additional constraint has been introduced, which results in lower values for FS. For ScI more than 69% of the total area belongs to zones B and C, while the corresponding values for ScII and ScIII are 71% and 61%, respectively. Zone D corresponds to 1.81% for ScI, 0.19 for ScII, and 10.48 for ScIII.

4.5 Sensitivity analysis

In this research work, the factors $C_{\text{wind}}$ and $C_{\text{arch}}$ for ScI are selected to be presented for sensitivity analysis. The first is a crucial criterion for wind farms installation and the second is the criterion with the lowest weight. So, a sensitivity analysis of the most important and the least important criterion is therefore attempted to evaluate how a change in each one affects the results. Figure 8A,B,C,D shows the suitability maps of ScI for change of $C_{\text{wind}}$ of $-10\%$, $-5\%$, $+5\%$, and $+10\%$, respectively. Zone D varies from 28.48% for a 10% reduction of the weight of wind potential to 25.41% for a 10% increase, while the initial area is 26.87%. Similarly, Zone E varies from 1.63% for a 10% reduction of the weight of wind potential to 1.75% for a 10% increase, while the initial area is 1.68%. It is obvious that the increase of the weight of $C_{\text{wind}}$ may decrease the positions in Zone D but increase correspondingly the positions in Zone E. This is to be expected because the higher the wind potential is, the more the optimal locations will be. The maximum value of FS is between 0.90 and 0.92 for every change of $C_{\text{wind}}$.

Figure 9A,B,C,D shows the suitability maps of ScI for change of $C_{\text{arch}}$ of $-10\%$, $-5\%$, $+5\%$, and $+10\%$, respectively. Zone D varies from 27.09% for a 10% reduction of the weight of $C_{\text{arch}}$ to 26.64% for a 10% increase, while the initial area is 26.87%. Similarly, Zone E varies from 1.72% for a 10% reduction of the weight of $C_{\text{arch}}$ to 1.64% for a 10% increase, while the initial area is 1.68%. The maximum value of FS
is circa 0.91 for every change of $C_{arch}$. It is obvious that the increase of the weight of this criterion, decrease both the positions in Zone D and Zone E. This is explained by the fact that the monuments of the island are scattered throughout the area, so an increase in the weight of distance from archaeological sites results in a reduction of the optimal locations.

5 | CONCLUSIONS & FUTURE RESEARCH

This research study is concerned about the optimal siting of wind turbines in the island of Fournoi Korseon, in North Aegean, Greece. The paper aims to suggest eligible sites for wind turbines according to a set of proposed geomorphological, technical and spatial criteria, taking into consideration environmental constraints and the current legislation framework. There is a combined use of MCDM and GIS and an estimation of criteria weights for three different scenarios, the technical-oriented, the cultural-oriented, and the economic-oriented. These three scenarios are also implemented considering the location of the main settlement of the island and setting as an extra constraint the minimum distance from it, to reduce energy losses via transfer cables. Finally, a sensitivity analysis is performed for two criteria, to determine how a change in each one of them affects the results.

Six criteria are used in this analysis, wind potential, altitude, distance from the settlements, distance from the road network, distance from telecommunication sites, and distance from archaeological sites. The criterion of wind potential is a priority in all scenarios, as the maximum possible wind potential is required to maximize the energy generated by the wind turbines. In all scenarios, Zone A corresponds to 27.9% of the total area of the island, it is the same for each scenario and it represents all the buffer zones where any wind turbine is permitted to be installed. In the initial scenarios, without the extra constraint, Zone E, which is the zone that depicts the most suitable sites has the lowest values, however, in ScIII zone E has its higher value of 4%. Zone D, the preceding zone, presents high values and especially in ScIII this value is 54.1%, which means over half of the island has suitable sites for installation with FS between 0.50 and 0.75. ScIII is the scenario with the largest number of suitable areas, although the criterion of altitude is in the fifth in priority. So, it can be assumed that suitable sites with high wind potential can be combined with lower altitudes and can give even more location for installation in the last zone E.

Three more suitable maps are represented considering the proximity to the main settlement of Fournoi, as one more constraint, since it is preferred for such a project to be close to the settlement where are the most residents. Also, in this case, ScIII has the largest number of suitable sites. Zone D, which in this case is the zone that depicts the most suitable sites, reaches the value of 10.48% for ScIII. However, the maximum value of FS in these additional scenarios is 0.744 in ScIII, while the corresponding value for the initial scenario is 0.929. Finally, a sensitivity analysis for ScI is implemented for two criteria, to evaluate how a change in each one affects the results. The first is $C_{wind}$ with the highest weight and the other is $C_{arch}$ with the lowest weight. An increase in the weight of $C_{wind}$ increases the optimal locations, while an increase in the weight of $C_{arch}$ decrease the optimal locations. It seems that new suitability maps have more to do with the type of criterion chosen than with the weight of the criteria itself.

Further research can be in the direction of annual energy output using various wind turbine models for each scenario, but it is out of the scope of the current research. Also, the integration of the best-case scenario into an HRES to meet the electrical needs of the island and to counteract the stochastic wind power and the exploitation of its maximum capacity will be addressed in a subsequent paper.

ACKNOWLEDGMENTS

The research work was supported by the Hellenic Foundation for Research and Innovation (HFRI) under the HFRI PhD Fellowship grant (Fellowship Number: 266).

ORCID

Maria Margarita Bertsiou
ORCID: https://orcid.org/0000-0002-2575-0524

REFERENCES

1. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. Official Journal of the European Union. L 140/16. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN. Accessed November 14, 2019
2. Paris Agreement. FCCC/CP/2015/L.9/Rev.1. UNFCCC secretariat. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement. Accessed November 14, 2019
3. Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources. Official Journal of the European Union. L 328/82. https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32018L0201&from=EN. Accessed November 14, 2019
4. Renewable energy in Europe — 2019. Recent growth and knock-on effects, Eionet Report - ETC/CME 2019/8. European Topic Centre on Climate Change Mitigation and Energy; 2019. https://www.eionet.europa.eu/etc/etc-cme/products/etc-cme-reports/renewable-energy-in-europe-2019-recent-growth-and-knock-on-effects. Accessed November 14, 2019
5. Bertsiou M, Feloni E, Karpouzos D, Baltas E. Water management and electricity output of a Hybrid Renewable Energy System (HRES) in Fournoi Island in Aegean Sea. Renewable Energy. 2018;118:790-798.
6. Panwar NL, Kaushik SC, Kothari S. Role of renewable energy sources in environmental protection: a review. *Renew Sustain Energy Rev*. 2011;15(3):1513-1524.

7. Saidur R, Rahim NA, Islam MR, Solangi KH. Environmental impact of wind energy. *Renew Sustain Energy Rev*. 2011;15(5):2423-2430.

8. Wheeler R. Reconciling windfarms with rural place identity: exploring residents’ attitudes to existing sites. *Sociologia Ruralis*. 2017;57(1):110-132.

9. Bertsiou M, Feloni EG, Baltas E. Cost-benefit analysis for a hybrid renewable energy system in Fournoi island. In: *Proceedings of the Sixth International Conference on Environmental Management, Engineering, Planning and Economics (CEMEPE)* and to the *SECOTOX Conference, Thessaloniki, Greece*; 2017:25-30.

10. Sakka EG, Bilionis DV, Vamvatsikos D, Gantes CJ. Onshore wind farm siting prioritization based on investment profitability for Greece. *Renewable Energy*. 2020;146:2827-2839.

11. Kwon SD. Uncertainty analysis of wind energy potential assessment. *Appl Energy*. 2010;87(3):856-865.

12. Toft HS, Svenningsen L, Sørensen JD, Moser W, Thøgersen ML. Adoption of a specific spatial planning framework and sustainable development for renewable energy and its environmental impact strategic study. Official Gazette 2464. Issue B 03.12.2008 (Greece).

13. Gatzert N, Kosub T. Risks and risk management of renewable energy projects: the case of onshore and offshore wind farms. *Renew Sustain Energy Rev*. 2016;60:982-998.

14. Kourtis IM, Kotsifakis KG, Feloni EG, Baltas EA. Sustainable water resources management in small Greek islands under changing climate. *Water*. 2019;11(8):1694.

15. Abnawi MD, Mohammadshafie N, Rosen MA, Dabbaghian A, Fazelpour F. Techno-economic feasibility analysis of stand-alone hybrid wind/pv-hybrid/diesel/battery system for the electrification of remote rural areas: case study Persian Gulf Coast-Iran. *Environ Prog Sustain Energy*. 2019;38(5):13172.

16. Rashid S, Rana S, Shezan SKA, Karim ABS, Anower S. Optimizing wind farm siting to reduce power system impacts of wind variability. *Wind Energy*. 2019;22(7):894-907.

17. Ali Y, Butt M, Sabir M, Mumtaz U, Salman A. Selection of suitable site in Pakistan for wind power plant installation using analytic hierarchy process (AHP). *J Control Decis*. 2018;5(2):128-132.

18. Rehman S, Khan SA. Multi-criteria wind turbine selection using weighted linear combination and ordered weighted averaging. *J Math Psychol*. 2017;15(3):234-245.

19. Cendrero A. Visibility analysis and visibility software for the optimization of wind farm design. *Renewable Energy*. 2013;60:388-401.

20. Grothmann R, Dietz T. Water for survival: the paradox of the common property. *Rural Sociology*. 2012;77(3):417-439.

21. Grothmann R, Dietz T. Water for survival: the paradox of the common property. *Rural Sociology*. 2012;77(3):417-439.

22. Malczewski J. GIS and Multicriteria Decision Analysis. United States of America: John Wiley & Sons; 1999.

23. Malczewski J. GIS-based land-use suitability analysis: a critical overview. *Prog Plan*. 2004;62(1):3-65.

24. Al-Shaeeb AR, Al-Adamat R, Mashagbah A. AHP with GIS for a preliminary site selection of wind turbines in the North West of Jordan. *Int J Geosci*. 2016;7(10):1208.

25. Ali Y, Butt M, Sabir M, Mumtaz U, Salman A. Selection of suitable site in Pakistan for wind power plant installation using analytic hierarchy process (AHP). *J Control Decis*. 2018;5(2):117-128.

26. Rehman S, Khan SA. Multi-criteria wind turbine selection using weighted sum approach. *Int J Adv Comp Sci Appl*. 2017;8(6):128-132.

27. Malczewski J. GIS-based multicriteria decision analysis: a survey of the literature. *Int J Geogr Inform Sci*. 2006;20(7):703-726.

28. Grothmann R, Dietz T. Water for survival: the paradox of the common property. *Rural Sociology*. 2012;77(3):417-439.