Appropriate site selection for onshore wind farm applications and energy carrying capacity estimation: The case of Andros (Greece)

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Abstract

Wind energy is one of the most promising forms of Renewable Energy Sources (RES), resulting in increasing global wind farm installation rates. The purpose of this paper is the application of various restrictions established by the Greek institutional framework for the siting of wind farms in Greece with the use of Geographical Information Systems (GIS). The application focuses on Andros Island in Greece, which has over the time attracted strong interest on this issue. The process involves blocking areas defined by the Greek current legislative framework and the combination of exclusion criteria defined by the national legislation such as distance from settlements and technical infrastructure as well as areas of environmental and cultural interest and international literature review such as the distance from rivers and the wind speed. It also provides the exclusion of areas with low wind speed in order the cost efficiency of any wind power plant is reached. Moreover, the areas generated as appropriate for wind farm siting are compared with the areas occupied by wind farms in Andros in different licensing stages. Finally, the energy carrying capacity of the areas obtained as appropriate through the proposed methodology is estimated.

Keywords: Renewable Energy Sources (RES), wind farm siting, exclusion criteria, carrying capacity, Andros, Geographic Information Systems (GIS)

1. Introduction

Energy is an essential part of modern life as it relates to almost all human activities and the demand for clean energy sources has been steadily increasing throughout the world. More specifically if one studies wind power installations in EU, one can see that annual wind power installations in the EU has increased steadily over the past 15 years from 3.2 GW in 2000 to 12.8 GW in 2015 (EWEA, 2015).

It is a formidable challenge to identify the areas where it is technically, economically and environmentally feasible to develop wind energy projects, as the criteria used for the assessment include various physical, economic, environmental impact, resource, visual and planning considerations. A great number of studies found in the literature has applied central government regulation policies for locating wind farms (e.g Aydin *et al*, 2010; Szkliniarz and Vogt, 2011; Gass *et al*., 2013) worldwide. The main institutional tool that provides the main spatial restrictions in the Greek territory is the Special Framework for Spatial Planning and Sustainable Development for Renewable Energy Resources (SFSPSD-RES, 2008) and has been used in many research cases studies (e.g Latinopoulos and Kechagia, 2015; Tsoutsos *et al*., 2015).

The aim of this study is to implement the institutional restrictions in the island of Andros-Greece to identify the appropriate areas for windfarm siting. The existing windfarm applications are also compared with the compatibility areas resulted from this study and finally the energy carrying capacity of the latter is estimated.

2. Study area

Andros is the northernmost island of the Cyclades in Greece and covers an area of 379.21 km^2, with a total coastline of 176 km. It is located between Evoia and Tinos and it is primarily mountainous, with verdant ravines, valleys and abundant surface and ground water. The largest part of the island is covered in rural land, at a percentage of about 65%, followed by forests and semi-natural areas covering 34%, while artificial surfaces only cover about 1% of the island's total area.

The resident population of the island is approximately 10000 people but during the year the island of Andros shows two main trends: downward trend in the population during the winter period, mainly due to the reduction of employment opportunities, and increasing trend in the summer period, due to the increase in touristic traffic.

In Andros there are eight (8) protected areas, two (2) of which belong to the Natura 2000 network. Andros is also full of monuments, archeological sites and ruins that testify the strong cultural heritage of the island.

The wind capacity of Andros is very high since the largest part of the island has winds with a speed of 8-10m/sec or even higher than 10m/sec. The only exception is the northern and central part of the island, where the wind speed in certain areas is approximately 7-8m/sec. These speeds are considered as appropriate for wind farm installations as typical wind turbines exploit the wind potential which is more than 5-6 m/sec.

As given from the Regulatory Authority for Energy of Greece, there are no geothermal, solar thermal, small hydroelectric, hybrid or biomass plants on the island of Andros. A photovoltaic plant in the northern part of the island has been granted a decision of rejection, and there is one wind farm operating on the island. The wind farm infrastructures related to the island of Andros are presented in Table 1 and are categorized according to their authorisation process.

Table 1. Wind farms of Andros

Authorisation Process	Number of wind farms
Production license	15
Operational license	1
Rejected	24
Under evaluation	10

Figure 1 presents the existing wind farm applications as well as the density of wind farm installations for every Municipal Unit of Andros. It is observed that the highest carrying capacity is measured at the Municipal Unit of Idrousa (>100), followed by the Municipal Units of Andros and Korthi (20-40).

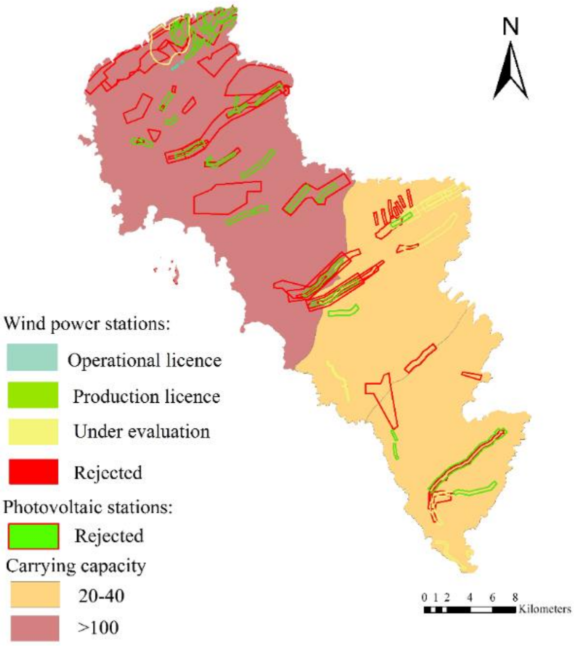

Figure 1. Current situation of windfarm applications and carrying capacity

3. Methodology of site selection

The basic tool of this study is the SFSPSD-RES. According to this legislative tool, in Step 1, the areas that are considered as incompatible for the siting of wind turbines are identified in Step 1. In Step 2, areas that are located in distance equal to SFSPSD-RES restrictions from specific areas as archaeological sites, traditional agglomerations etc. are excluded in order to reduce the negative effects of wind turbine installation like visual disturbance, noise etc. Areas with wind velocity lower than 6m/sec are also excluded from site selection after literature review and considering the high wind potential of the island.

In Step 3, the areas that are considered appropriate from the previous steps are compared with the areas that are proposed for wind farm siting in different licensing stages. In Step 4, the existing wind farm applications as well as the regions with surface less than 0.3 km^2 are excluded as unprofitable to install wind turbines and the energy carrying capacity for the remaining areas from the previous steps is finally estimated as well as the percentage of energy demands of Andros that are covered.

Figure 2 depicts the methodology followed in this paper.

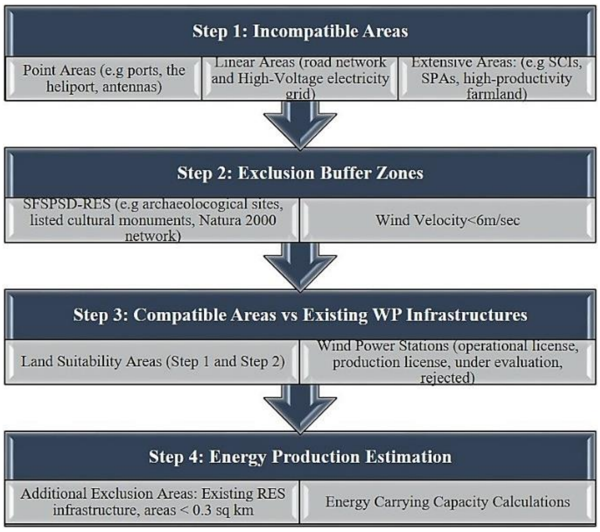

Figure 2. Methodological Framework

4. Results and discussion

4.1. Land suitability areas

At first the areas that don't comply with the restrictions of the national legislation are excluded. According to Article 6 of the Special Framework for SFSPSD-RES and the existing infrastructure and land uses in Andros, the areas considered incompatible as regards the installation of wind farms, which are excluded from the outset, are the following and are shown at Figure 3:

Point areas: ports, the heliport, bathing waters, archaeological sites, listed cultural monuments, monasteries, antennae

Linear areas: the road network and High-Voltage electricity grid

Extensive areas: Sites of Community Importance (SCIs) and Special Protection Areas (SPAs) of the Natura 2000 network, Areas of Outstanding Natural Beauty (AONBs), settlements, high-productivity farmland, quarries and mines

In addition, the relevant planning also excludes rivers and lakes, i.e. surface water bodies, since it is not possible to site an onshore wind farm within them, (e.g. Bennui *et al.*, 2007; Nguyen 2007; Aydin *et al.*, 2010; Szkliniarz και

Vogt, 2011; Phuangpornpitak and Tia, 2011; Zhou *et al*., 2011). According to the literature review, the planning process also excludes Wildlife Refuges (e.g Aydin *et al*., 2010; Watson and Hudson, 2015), which are not included in the Special Framework, but are nevertheless considered to be very important for preserving the biodiversity of a region, since it is thought that if wind turbines are installed therein, then this will potentially disrupt the relevant ecosystem.

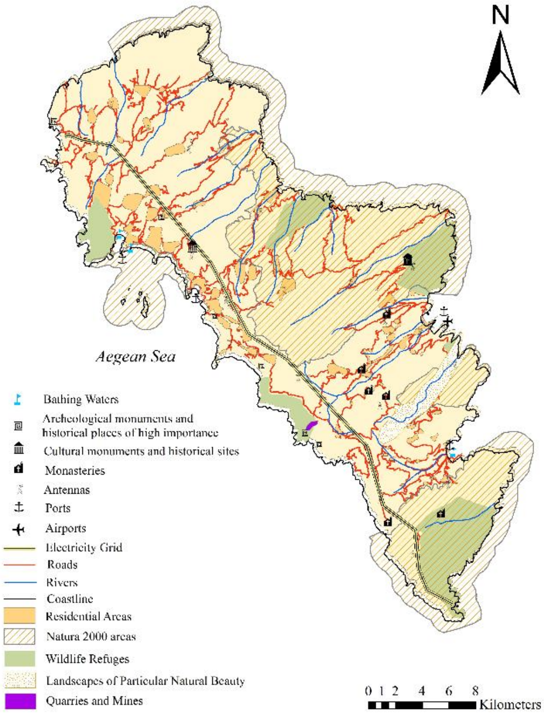

Figure 3. Incompatibility areas and zones

In order to specify the minimun distances of windfarm siting areas from excluded regions and incompatible zones the restrictions proposed in the SFSPSD-RES are considered. According to the SFSPSD-RES (Appendix II), the windfarms should be installed in a distance that exceeds 1500m from bathing waters; 3000m from archaeological monuments and historical places of high importance; 7d[1] which is equal to 600m from cultural monuments and historical sites; 500m from monasteries; 1000m from settlements; 1500m from traditional settlements; 1,5d which is equal to 130m from roads; 1,5d which is equal to 130m from electricity grid; 1,5d which is equal to 130m from high-productivity farmland, 500m from quarries and mines and 1000m from tourism-related facilities.

Moreover, a high wind velocity is the primary criterion which an area has to fulfill in order to be considered suitable for the installation of a wind park, since it is the key factor for the production of energy from a wind turbine. Although this specific criterion is not taken into account by the Special Framework, it is nevertheless deemed essential in this paper to exclude areas with a low wind velocity from subsequent stages of the study. After all, it is an exclusion criterion for a high percentage of scientific papers in the relevant literature (e.g Gorsevski *et al*., 2013; Noorollahi *et al*., 2016), with the most common exclusion wind velocity value reaching 6m/sec. This limit is also selected as the exclusion limit in the case of Andros, since it is an island with very high wind velocities, which even exceed 10m/sec in certain areas.

Thus, after the exclusion of incompatible areas and the buffer zones as well as areas with wind velocity lower than 6m/sec, appropriate areas for windfarm installation are defined. Figure 4 presents the land suitability areas after the application of Step 1 and 2 with a calculated area of 52.1 km^2, percentage equal to 13.74% of the total area of the island.

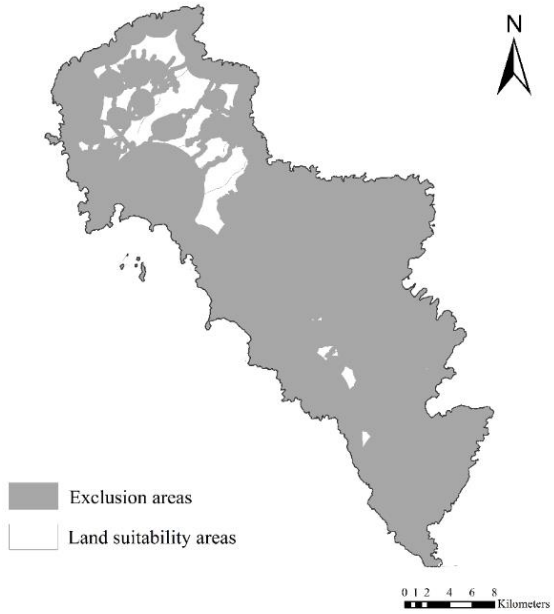

Figure 4. Land suitability areas

4.2. Comparison of land suitability areas with existing wind farm infrastuctures

The areas that are considered compatible from Steps 1 and 2 for wind farm siting are further compared with the areas where wind farms either exist or have been proposed as suitable for siting. The overlap of these two elements is shown in Figure 5.

From the areas that are considered appropriate for wind farm siting according to the Greek legislation, a small percentage is occupied from wind farms under operational licence (0.03%), or are in some stage of licensing or rejected (21%), as shown in Table 2.

Table 2. Surface percentage inside the compatibility zones

Wind farms	Area inside the compatible zones (km^2)	Percentage
Operational license	0.01	0.03%
Production	2.69	5.20%

[1] where d is the rotor's diameter and is equal to 85m according to Article 1 of SFSPSD-RES

license		
Under evaluation	1.97	3.80%
Rejected	10.85	21.00%

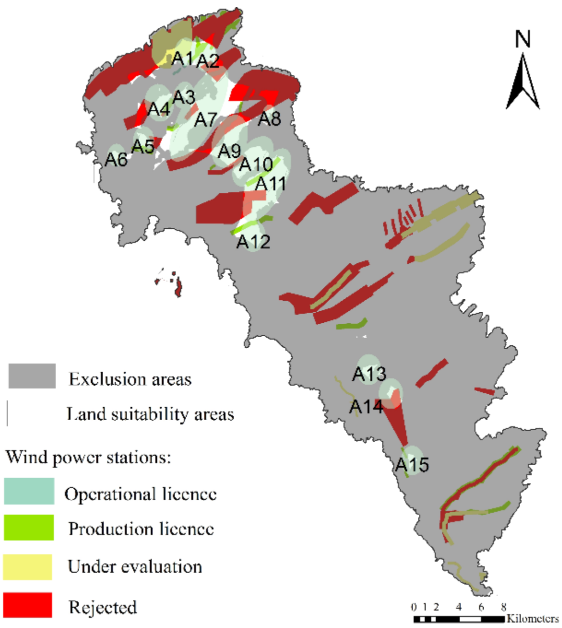

Figure 5. Proposed areas versus existing wind farm applications

Regarding the proportion of areas occupied by wind farms in all licensing stages in consideration with the limitations of the SFSPSD (Table 3), it is observed that wind farms with operational license have the highest percentage (13%).

Table 3. Percentage of compatibility area in current wind farm applications

Wind farms	Area (km^2)	Area inside the compatible zones (km^2)	Percentage
Operational license	0.1107	0.01	13.00%
Production license	22.33	2.70	12.00%
Under evaluation	21.93	1.97	8.80%
Rejected	113.25	10.85	9.60%

4.3. Calculation of energy carrying capacity

The energy production for the appropriate areas is estimated after the exclusion of areas with existing RES infrastructure and regions with area less than 0.3 km^2. The restriction of 0.3km^2 is set due to the fact that regions with that area are considered to be unprofitable for wind farm siting. The areas resulting after the additional exclusions are fifteen (15) and they are depicted in Figure 5. For the calculation of energy production the insular nature of Andros and the strong opposition of the community regarding wind farm siting projects such as project at the area of Kalivari is taken into consideration. As a result medium sized turbines of Enecron type with rotor diameter 44m and installed power 900KW are selected. According to the SFSPSD- RES, the minimum safety distance between the wind turbines is 2,5*d=2,5*44= 110 meters. Thus, a grid with cell size 110*110 is created for every one of the fifteen areas and at each apex of which a wind turbine is located.

It is important, at this point, to clarify that with the use of this technique the number of wind turbines that can be sited in an area based on spatial, environmental and economic constraints is estimated. According to Article 8 of SFSPSD- RES the maximum soil coverage can not exceed 4% per specific administrative level which means 0.53 wind turbines / 1000 acres.

After the calculation of energy carrying capacity the annual energy production of each area is calculated. So the number of wind turbines of each area with the power of each wind turbine and the capacity factor of 0.25 (due to association with the network, etc.) for one year (24 hours and 360 days) are multiplied (Number of wind turbines x 0,9MW x 24 x 360 x 0,25).
Table 4 presents compatible areas for wind farm siting (A1, A2, A3….A15), along with their surface coverage, number of wind turbines that should be placed as well as their contribution in energy production.

Table 4. Energy carrying capacity

Areas	Surface coverage (%)	Number of wind turbines	Energy production contribution
A1	0.207	52	285.2%
A2	0.462	137	751.5%
A3	0.120	34	186.5%
A4	0.389	112	614.4%
A5	0.233	66	362%
A6	0.099	28	153.6%
A7	2.935	325	1782.7%
A8	0.092	27	148.1%
A9	0.876	222	1217.7%
A10	0.903	265	1453.6%
A11	1.690	163	894.1%
A12	0.548	160	877.6%
A13	0.178	53	290.7%
A14	0.084	23	126.2%
A15	0.125	35	192%

Conclusions

The present study forms a four-stage methodology application of the Greek legislation for the siting of onshore wind parks. It is applied to the island of Andros, which belongs to the Region of the South Aegean, where there is a rich wind capacity, and is based on the use of Geographic Information Systems (GIS) for the depiction of the data.

The proposed methodology consists of four stages, according to which the incompatible areas of SFSPSD-RES are firstly excluded. At Step 2 the proposed buffer zones from exclusion areas as well as the areas with wind velocity lower than 6m/sec are also excepted from further examination. At Step 3 the land suitability areas are compared with existing wind farm infrastuctures in order to verify their relevance rate. Finally, at Step 4 the carrying capacity of the final land suitability areas is calculated.

The results from the application of the methodology on Andros island show great interest since the compatible areas for wind farm siting are gathered in mainly in the northern part of the island where the majority of existing wind farm applications are located. The comparison of land suitability areas with existing wind farm infrastuctures also presents particular interest, as it is observed that wind farms with operational license have the highest percentage (13%) of the areas considered as appropriate according to the Greek legislation.

Moreover, the calculation of the energy carrying capacity and its contribution to the final annual energy consumption on the island of all areas considered as suitable for wind farm siting, shows that the compatible areas may outweigh the energy needs of the island, leading to the conclusion that Andros may in the future become an energy-independent island.

The present study helps to promote the vision of a sustainable energy production region, which makes use of the comparative advantages of certain areas, while also supporting the energy policies recommended by the European Union which aim at sustainability.

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