Renewable Energy 75 (2015) 474–480

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Sustainable siting process in large wind farms case study in Crete

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ARTICLE INFO

Article history:
Received 1 February 2014
Accepted 8 October 2014
Available online

Keywords:
Wind energy
Sustainable siting
Carrying capacity

ABSTRACT

The growing energy demand, as well as the European policy framework supporting the sustainable development, has strengthened the global interest in wind power installations during the last two decades. The interest is higher in areas with promising natural terrain, such as the Greek islands. The region of the island of Crete encourages the siting of wind farms due to the strong wind potential and the insular rough terrain.

The aim of this research study is to develop and to implement a methodology of comprehensive evaluation and prioritization of areas for site selection of sustainable wind farms at a regional level, useful to support the strategic spatial planning of the island.

The basic tool used to achieve the study's goals is the Specific Plan for Spatial Planning and Sustainable Development for Renewable Energy applied on Geographic Information Systems and the parallel integration of a systematic and flexible method of multicriteria analysis.

The main output of this study is the provision of an objective and realistic overview of wind farm siting issue and the reinforcement of the regional and national policy/decision makers based on a sustainable regional development strategy avoiding fragmented decisions.

1. Introduction

Renewable energy sources (RES) are amongst the critical parameters of strategic planning for sustainable development. They contribute in the reduction of energy imports and thus enhance energy autonomy ensuring sufficient security of supply. Additionally RES can strengthen the regional competitiveness in long-term, and support the regional development and employability.

Obviously the integrated management of RES interacts with all dimensions related to the sustainable development (economy, environment, technology, society) and thus requires careful planning and social consensus [1,2].

The growing priority for the energy independence of Europe supported by EU policies, has put special emphasis on wind power installations during the last two decades. The interest is higher in areas with promising potential and natural terrain, such as the Greek islands.

Almost all islands have common typical characteristics, such as [3,4]:

- the distance from the mainland
- the lack of endogenous conventional energy resources
- the sea supply of liquid or liquefied fuels
- the small markets, so negative scale economies
- their sensitive natural ecosystems.

The current operation of autonomous power stations is particularly problematic, both because of the use of conventional fuels, and because of their location in or near urban centres (in Xylokamara, Chania and in Linoperamata, Heraklion) [5]. The Cretan power system, based on officially available data, is depicted in Table 1.

Moreover, conventional power stations are not capable to meet the very high seasonal peak due to tourism and - in general – their expansion or relocation to new suitable locations is extremely limited.

Besides, Crete has a very high – unexploited in most sites – RES potential and considerable potential for energy savings. The development and implementation of sustainable energy projects should be a key priority, as it presents important advantages, contributing:

- to the security of energy supply of the islands
- to the reduction of parallel imports of fossil fuels
- to the saving of energy and resources
- to the environmental protection

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http://dx.doi.org/10.1016/j.renene.2014.10.020
0960-1481/

Table 1
Power generation units in Crete: nominal power and power generation (2011 data) [6].

	Nominal power (MW)	%	Power generation (GWh) 2011	%
Linoperamata, Heraklion	278.84	26.4	861.8	29.4
Xylokamara, Chania	349.19	33.0	507.0	17.3
Atherinolakkos, Lassithi	195.04	18.5	991.5	33.8
Wind Park	174.20	16.5	486.5	16.6
P/V	57.80	5.5	83.8	2.9
Hydros	0.60	0.1	0.8	0
Total	1.05567	100	2931.4	100

- to the achievement of national targets and commitments
- to the development of sustainable forms of tourism
- to the increase of employment and retention of people

The aim of this study is to develop and to implement a realistic methodology of comprehensive evaluation and prioritization of candidate areas for site selection of sustainable wind farms at a regional level, proper for the policy makers to support strategic spatial planning. The results of this study were discussed in public with the local society in various places on the island and have been integrated into the regional sustainable planning of the island of Crete.

2. State-of-the-art

In the international literature exist several tools to analyse the sustainable siting of wind parks (WPs) taking into account land or the capacity constraints [7]. They have put emphasis on the potential effects of size, turbine separation and perimeter.

Aydin et al. [8] suggest a spatial decision support system (SDSS) for WP siting using the tools of ArcGIS for western Turkey, using, as siting criteria, the existing wind potential and the environmental suitability (based on the laws of Turkey and other studies). The studied area was divided into grids and thus defined the fuzzy environmental objectives for the characteristics of the selected site taking into account noise, bird habitat, safety and aesthetics. Then, per grid was calculated a satisfaction degree per each environmental criteria. Finally, the produced map was combined with the wind potential map in order to identify the feasible WP sites.

An alternative selection method of WP siting show Haaren and Fthenakis [9], based on a methodology of spatial optimization cost - revenue applied in New York. The GIS algorithm consists of three steps: (i) excludes areas where it is impossible to site a WP due to land uses or geological constraints (criteria: visual impact, noise and safety, ecological criteria, physical constraints); (ii) realize a feasibility analysis based on the expected net present value; (iii) evaluates the environmental impacts on birds and their habitats.

Another study evaluating areas in terms of their suitability for WP siting, combining multi-criteria analysis with GIS, is applied in Lesvos [10]. A set of environmental, economic, social and technical constraints, legally, determine possible locations for WP installation. In addition, the study area is evaluated by a variety of criteria, such as wind resource, land cover, electricity demand, visual impact, land value and distance from the power grid. Then was applied the method of comparing pairs (pair-wise method) within the analytic hierarchy process – AHP-, to calculate the weights of different criteria to determine the relative importance of the evaluation areas.

Using the same methodology Bennui et al. [11] in Thailand and Al-Yahyai et al. [12] in Oman for efficient siting of WPs, integrated GIS and multi-criteria analysis. The selection criteria included various parameters such as topographic (distance to road, terrain slope), urbanism, environmental (historical locations and nature) and technical (wind power, energy demand).

Voivontas et al. [13] developed a decision-making system to assess different areas for the development of renewable energy applications. They created a database for wind potential, topography, urban and special activities and consequently they applied restrictions on the availability of individual regions and technological constraints to evaluate the economic performance taking into account the expected energy production and installation costs.

Finally, Baban and Parry [14], to determine the criteria for WP location using questionnaires directed at relevant public and private sectors. These criteria were applied using two different methods of correlation information in Lancashire, UK. In the first method is considered that all criteria are equally important and have equal weight. The second is the hierarchy of criteria according to their importance.

The current methodology exploits most of the advantages of the previous methods, but also integrates the following important issues:

(i) it has been tested in public consultation in the region of Crete
(ii) the recent revised Spatial Plan of Crete utilizes the main outputs and concept to identify the proper siting for RES plants on the island
(iii) it includes also a uniform digital background of the island in the form of dynamic data, easily to be updated
(iv) it puts emphasis on the bird protection taking into account the most recent findings of the Hellenic Ornithological Society
(v) the selected software is widely spread in the public and private sector facilitating the use of the created database.

3. Methodology

In this work the basic institutional instrument used to achieve the study's goals is the Specific Framework for the Spatial Planning and Sustainable Development for the Renewable Energy Sources" (SFSPSD-RES).[1] The application was performed using the digital platform of *ArcGIS v.10.1*, a geographic information system (GIS) and the parallel integration of a systematic and flexible method of multicriteria analysis.

The developed methodological tool considers the island as a single totality. This provides the possibility to optimize the distribution of wind power minimizing the environmental impacts in the natural landscape and microclimate. Additionally, this application will make it easier to control and monitor the installed wind farms all over Crete.

The next steps describe thee adopted process (Fig. 1):

3.1. Analysis of the current status

The adopted methodology, initially, analyses the current status tracing all data affecting the siting of wind farms, such as areas of

[1] The SFSPSD-RES was coordinated by the Hellenic Ministry for the Environment Physical Planning and Public Works; it has identified criteria and guidelines for the siting of RES projects, putting emphasis on wind systems; it has facilitated authorities and potential investors by defining land uses; it integrated the relevant spatial and urban plans; in included an Action Plan containing a range of necessary practical measures and actions for the effective implementation of the SFSPSD-RES [15].

Fig. 1. Methodology.

environmental interest, areas and elements of cultural heritage, areas of residential activities, networks of technical structure and zones or facilities of productive activities (settlements, traditional settlements, airports, archaeological places and monuments, camping, mobile telephony antennas, monasteries and churches, road network, hydrographic network, areas of Natura 2000, mines, national forests, beaches, ports and marines, electricity grids, ground inclinations, wind potential).

3.2. Definition of the legally available areas

The Specific Plan for Spatial Planning and Sustainable Development for Renewable Energy (SFSPSD-RES) [15,16] defines the exclusion areas of any type of energy generation plant. It is *it is not permitted* the WP siting inside:

- World Heritage areas, archaeological monuments and historical places of high importance, as well as in archaeological sites of zone A
- Areas of absolute protection of the nature
- Wetlands RAMSAR
- Centre of national forests, nature monuments, aesthetic forests,
- Sites of Community Importance of Natura 2000
- Inside urban plans and settlement boundaries
- Areas of integrated touristic development and organized productive activities of the tertiary sector, thematic parks, touristic ports and beaches
- Mining zones and activities

SFSPSD-RES defines the minimum allowed distances of WPs from areas of environmental interest, cultural heritage, etc (Table 2).

As a next step is applied a series of criteria set by SFSPSD-RES and related to the implementation of minimum distances from neighbouring uses or activities, and technical infrastructure networks. After the selection of the available (legally) areas, follows their evaluation using a multicriteria analysis based on group criteria either by the current legislation or from literature [17–21].

Table 2
Minimum allowed distances according to SFSPSD-RES (*Official Government Gazette* 2464/08).

	Minimum distances
From areas of environmental interest	
Areas of absolute protection of the nature	According to the approved specific environmental study or the relevant Presidential Decree
Centre of national forests, nature monuments, aesthetic forests, wetlands RAMSAR	Within the frame of the approval of *environmental terms* and conditions
Sites of *Community* Importance of Natura 2000	
beaches	1500 m
Special Protection Areas of bird habitat	Within the frame of the *environmental terms* and conditions after special, after a special bird study
From areas of cultural heritage	
World Heritage, archeological monuments and historical places of high importance	3000 m
no take *zone* (zone A) of the rest archeological sites	At least 500 m
Cultural monuments, historical sites	At least 500 m
From urban activities	
Towns and settlements with population >2000 inhabitants	1000 m from the ettlement boundaries
Traditional settlements	1500 m from the settlement boundaries
Rest settlements	500 m from the settlement boundaries
Monasteries	500 from the boundaries of the monastery
From grids, networks and special uses	
Main roads, transport network	Safety distance −120 m
High voltage lines	Safety distance −120 m
antennas, radars	Per case after the approval of the relevant public body
Aviation facilities or activities	Per case after the approval of the relevant public body
From zones or production plants	
Rural land of high productivity, land consolidation areas, irrigated areas	120 m
aquaculture	120 m
Livestock plants	120 m
Mining zones and activities	500 m
Areas of integrated touristic development and organized productive activities of the tertiary sector, thematic parks, touristic ports and institutionalized tourist areas, tourist accommodation and special tourist infrastructures	1000 m from the boundaries of the zone/area

3.3. Assessment of available areas

These criteria concern distances from specific elements or structures such as distances from:

- National Parks
- Aesthetic Forests
- Sites of Community Importance of Natura 2000 Network
- Rivers and Lakes
- Archaeological Sites
- Antennas and radar
- Airports
- National Defence Installations
- High Voltage Lines
- Main Roads and
- Land Inclination

The list of data sources is presented in Table 3.

Table 3
Data sources gathered for this study.

Data type	Description	Source
Coasts	Bathing beaches included in the monitoring program of water quality, coordinated by the Ministry of Environment	Ministry of Environment, Energy and Climate Change
Electricity Distribution Lines	Lines of high voltage	Administrator of Greek electricity transmission system
National Park	Core of Samaria National Park	Prefectural Administration of Chania, Government Gazette 200/A/1962
SCIs	Sites of Community Importance (SCI) from Natura 2000 network	Ministry of Environment, Energy and Climate Change
Important places for bird's priority species	Breeding areas, colonies and feeding areas of priority species and areas of special environmental studies	Natural History Museum of Crete
Specific Management Plans and Special Environmental Studies		Natural History Museum of Crete
Monuments	Declared cultural monuments and historical sites	Catalogue of the declared sites and monuments of Greece, Ministry of Culture and Tourism
Archaeological Sites	Absolute Protection Zone (Zone A) of archaeological sites	Catalogue of the declared sites and monuments of Greece, Ministry of Culture and Tourism
Traditional Settlements	Declared Traditional Settlements	Ministry of Environment, Energy and Climate Change
Monasteries	Declared Monasteries	Maps of the Military Geographical Service
Road Network	National, Provincial and Community Roads	Ministry of Environment, Energy and Climate Change and verification from Urban Plans and orthophotos,
Antennas	Antennas with installation permit	National Telecommunications and Post Commission
Radar		Government Gazette 2099/2009 for Protection of Aviation Facilities
Airports	Airports International and Interregional range	Regional Framework for Spatial Planning and Sustainable Development of the Region of Crete (Government Gazette 35207/2008), Government Gazette 2099/2009 for Protection of Aviation Facilities (Government Gazette 2099/2009)
National Defence Installations	Sites of military facilities	National Cadastre
Quarries	Operating mining zones	Ministry of Environment, Energy and Climate Change
Ports	Ports' position	Regional Framework for Spatial Planning and Sustainable Development of the Region of Crete (Government Gazette 35207/2008),
Camps	Organized camps' sites	Regional Authority of Crete
Settlements	Approved settlements' boundaries with database for the respective actual population database	Regional Authority of Crete, Urban Plans, National Statistical Service
Aesthetic Forest	forest of palms "Vai" at Lasithi	Government Gazette 170/A/1973
Wind Power	Average annual wind speed in m/s	Renewable and Sustainable Energy Systems Laboratory
Wind farms	Wind farms that have gotten permission of production, installation or operation	Regulatory Authority for Energy
Rivers and lakes	Streaming Rivers	National Environmental Information Network of Ministry of Environment, Energy and Climate Change

For minimum distances not defined in the SFSPSD-RES were selected data from the global experience – best practice, as well as scientific and technical studies. From these sources formulated the proper criteria, making a ranking of the appropriateness of WP siting and define the priority areas.

Every criterion has given five scales of priority and at every scale has a rate from 0 to 4:

- Particularly suitable (0)
- Suitable (1)
- Moderate Suitable (2)
- Less suitable and (3)
- Not Suitable (4)

After the synthesis of all the criteria every point of the available areas has a value between 0 and 56, which is the sum of the value of the area at all the criteria. Considering therefore the value of 0 equal to 100% priority, and the price equal to the 56% priority 0, the ranking of appropriateness of WP siting is formulated.

3.4. Sustainable siting areas

Then, the results are taken into account, along with the criterion of wind potential. This comparative approach shows the Areas for Sustainable Siting, which offers maximum environmental

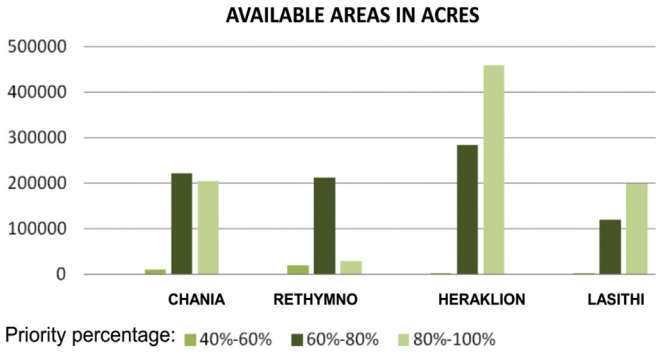

Fig. 2. Ranking of priority areas per regional unit.

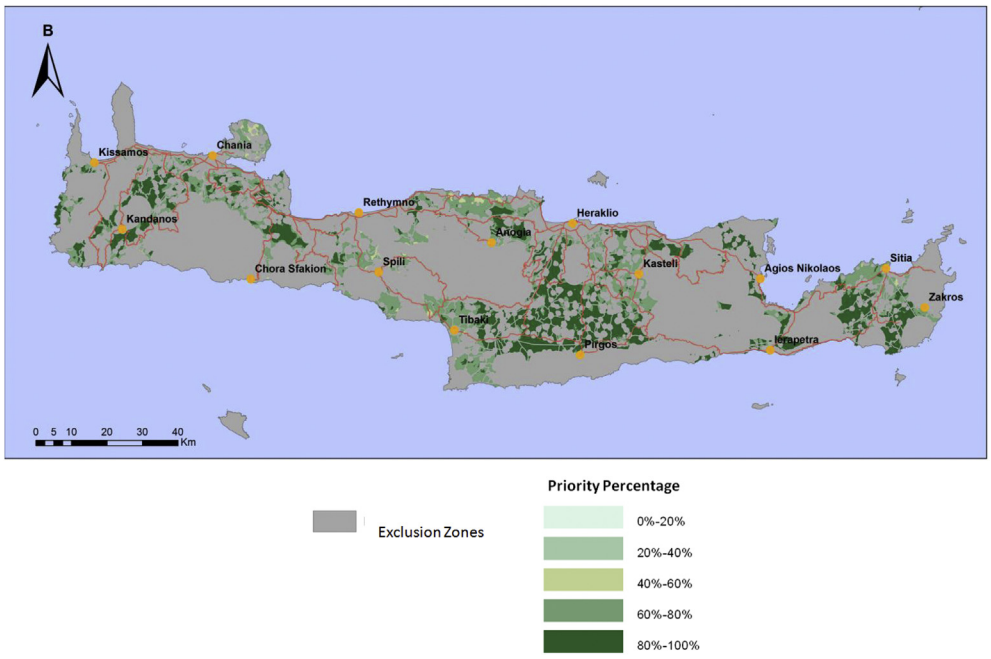

Fig. 3. Priority areas' priority percentage.

protection, minimum land use conflicts, maximum safety, and satisfactory performance.

Finally, only areas meeting the above criteria, will be further analysed so as to determine their maximum capacity of wind turbine installations, in order to guarantee the sustainable development.

3.5. Estimation of the carrying capacity of sustainable siting areas

The carrying capacity of WPs is estimated by the maximum allowed number of wind turbines without major changes in their basic natural and morphological characteristics. According to the SFSPSD-RES the maximum land coverage from wind farms in the inhabited islands of the Aegean Sea, Ionian Sea and Crete cannot exceed 4% of the municipality area. For all calculations the *standard wind turbine had a rotor diameter of* about 85 m and an average power of 2 MW (SFSPSD-RES, Article 1); the necessary surface to determine the maximum wind power (MW) is 75.86 acres/MW (SFSPSD-RES, Article 2) [16].

3.6. Grid-related criteria

The existing installed capacity of WPs on the island is very close to the theoretical *maximum in the* Aegean islands (~20%) [22]; the existing power factor is low (about 55%) and the daily fluctuations often are higher than 200%.

Today, RES penetration is above 50% during high insolation and wind periods. Additionally the Cretan grid is linear, old and need to be improved by modern infrastructure such as smart grids.

Obviously the future connection of the island with continental Greece and Europe will allow the installation of much higher power RES generation stations.

So, for the scope of this study, the criterion of the grid saturation was not taken into account.

4. Results

The areas permitted after applying the legal criteria are very wide covering 1/4 of the total area of the island, necessitating further evaluation of these areas based on the selected criteria.

Initially, all the criteria, except the wind potential were taken into account; the created hierarchy of available areas is shown in Figs. 2 and 3. Based on the criteria, the higher the priority rate an area displays the smaller the effects that would cause a potential siting of a WP in it.

Then, to take into account the "sustainability" of the siting areas, the wind potential and the results of the previous priority evaluation are compared.

Summing, in this report regions of sustainable siting for WPs are considered the areas that are not SCIs of the Natura 2000 network, which meet the criteria of the legislation, collect a priority percentage of at least 60% on the evaluation based on further scientific and bibliographic criteria (Fig. 3) and, also, have wind resources over 8 m/s.

Table 4 provides a brief estimation per regional unit of the total extent of sustainable siting areas and Fig. 4 shows the location of those areas. It is observed that many of the available areas can be characterized as sustainable. However, there is a concentration of the major part of these sustainable areas in the regional units of Chania and Lasithi.

Table 4
Calculation of carrying capacity per regional unit.

Regional units	Maximum coverage 4% (acres)	Sustainable siting areas (acres)	Final coverage (acres)	Maximum wind power from standard wind turbines (MW)
Chania	93,590	171,953	83,707	1103
Rethymno	59,776	80,035	45,798	604
Heraklion	105,658	135,592	84,529	1114
Lasithi	73,107	234,421	67,914	895
Crete region	**332,131**	**622,001**	**281,948**	**3716**

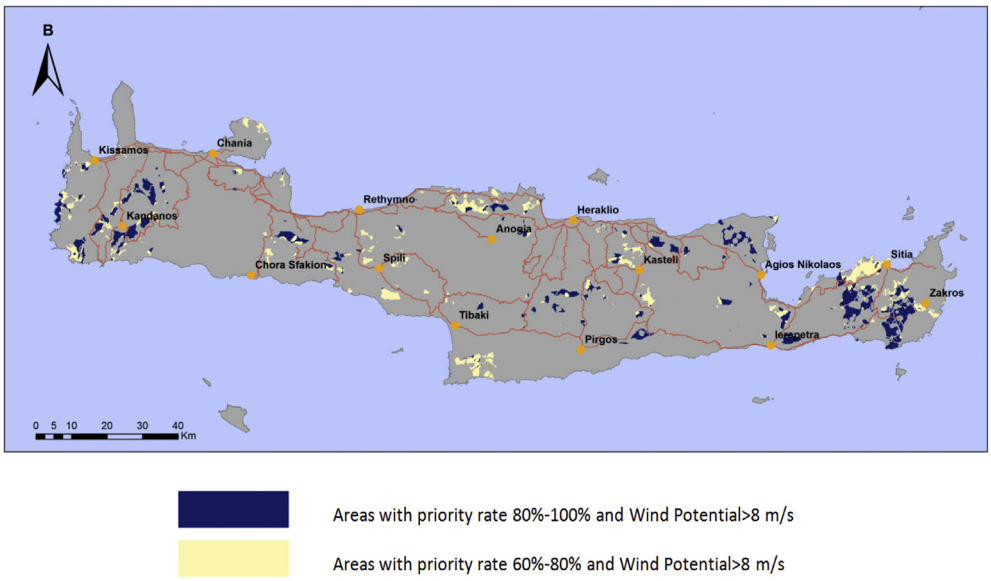

Fig. 4. Sustainable WP siting areas.

Finally, it was estimated the carrying capacity[2] of the sustainable areas for WP siting, based on the method specified in SFSPSD-RES.

An additional constraint is that the maximum land cover percentage of the municipality cannot exceed 4% per municipality (SFSPSD-RES, Article 8). Table 3 refers to the analysis of the carrying capacity done separately for each municipality; the results are presented at a regional unity level.

The results showed that, in most municipalities, the sustainable siting areas are much larger than the 4% of their land. This practically means that in the majority of the municipalities, it is possible to cover the maximum 4% of their land with WPs in areas completely clean in any aspect as these areas are much more than allowed. It can be also observed that even with the use of standard wind turbines with an average power of 2 MW, which are relatively small, a significant power amount can be produced by WPs.

5. Conclusions

The main output of this study is to provide an objective and realistic overview of wind farm siting issue and to reinforce the regional and national policy/decision makers exploiting a sustainable regional development strategy avoiding fragmented decisions. In this way it is feasible to support the policy makers to take into account clear guidelines and rules.

In order to achieve this goal, a versatile tool for decision-making regarding the siting of wind farms on Crete was created and an accurate recording and classification-hierarchy of places available for the development of wind farms was implemented. The methodology used enhances the objectivity, since with the publication of the data; the mapping material is a decision support system essential for the local community, either as a means to overcome any reservations or to argue if it disagrees with some plant decision.

The calculation of the carrying capacity and the assessment of the development prospects, apart from the decisions concerning the insular energy policy, is exploitable in order to take the most critical decisions of national level such as the connection to the mainland grid.

Additionally, the creation of dynamic maps of spatial data analysis which enable various scenarios and the visualization of maps of their impact (Eco-Script, Script enhanced development of wind farms, etc.) is very important. These maps can only be seen as an effort to control the renewable development and to optimize the void between the natural landscape and the overgrowing energy demand and not as a mean of overexploitation of the large RES potential of the islands.

Besides, within the framework of the current method, the development of scenario is a simple and relatively quick process, as well as the potential updating with recent and more accurate data in the future. A medium capacity PC infrastructure is necessary, which is common in the public administration and engineering offices.

The described methodology being dynamic and transparent supports the decision makers to check quickly the appropriateness of the candidate sites, but also to monitor the allocation of the WPs on the island and their connection to the high voltage and medium voltage grid. Also the candidate investors can prioritize their activities with minimum environmental and social constraints.

[2] It is notable that the “carrying capacity” is a dynamic concept, which indicates a limit varying time, based on the fact that the natural and human ecosystems are characterized by intense evolutionary dynamics with perpetual changes and adjustments. Therefore the levels of “carrying capacity” can:

- be real or determined in accordance with existing social, cultural and psychological perceptions.
- be dynamic through adjustments of the human and natural ecosystems.
- be modified through interventions and taking institutional, organizational and technological measures, mainly for reasons of public utility.

Acknowledgements

This study was supported by the project “Siting study for the sustainable establishment of wind parks in the region of Crete” which was commissioned by the Decentralized Administration of Crete to the Laboratory of Sustainable and Renewable Energy Systems, Technical University of Crete, in collaboration with the Museum of Natural History, University of Crete.

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