Offshore Windfarm Siting in Greece using GIS and TOPSIS

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Abstract
The deployment of offshore wind power technologies is becoming increasingly important towards the sustainable development of regions. In Greece, wind energy is provided at the time being, only by onshore plants and the interest in investigating the top choices for offshore wind applications in terms of environmental, economic, social and technical criteria is rapidly growing. The aim of this paper is to investigate the most appropriate sites for offshore windfarm siting in swallow waters (water depth ≤50m), where it is economically or/and technologically feasible to have structures resting directly on the seabed to support the turbine structure, taking advantage the existing knowledge as well as the technical experience of such applications. The proposed methodology includes two distinct stages (exclusion and evaluation) and integrates Geographical Information System (GIS) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method for solving spatial and policy planning problems. Thirteen exclusion criteria (e.g. wind velocity, distance from electricity grid, distance from residential network) and six assessment criteria (e.g. electricity energy production, distance from marine protected areas) are considered in the analysis. The results reveal five sites in swallow waters for offshore windfarm siting that could contribute to the energy interdependency of many areas.
Keywords: offshore wind farm siting; swallow waters; GIS; TOPSIS

1. Introduction

In Europe, offshore wind energy reached the record figure of 3,148 MW of total installed capacity in 2017 (Wind Europe Business Intelligence et al., 2018). This extensive spatial diffusion of offshore wind farms (OWFs) sites is accompanied with many important environmental, social, economic and technical issues. Geographic Information Systems (GIS) in combination with Multi-Criteria Decision-Making Methods (MCDM) have been applied within a large number of case studies in renewable energy systems siting (e.g. Höfer et al., 2016; Sánchez-Lozano et al., 2013). In the present paper, a methodology for the suitability assessment of marine sites suitability for OWF development in swallow waters in Greece is proposed based on a combination of the above techniques and considering social and environmental constraints as well as technical and economic criteria.

2. Methodology

The study area includes the Exclusive Economic Zone (EEZ) of Greece. The methodological framework is presented in Fig. 1 and consists of two distinct stages.

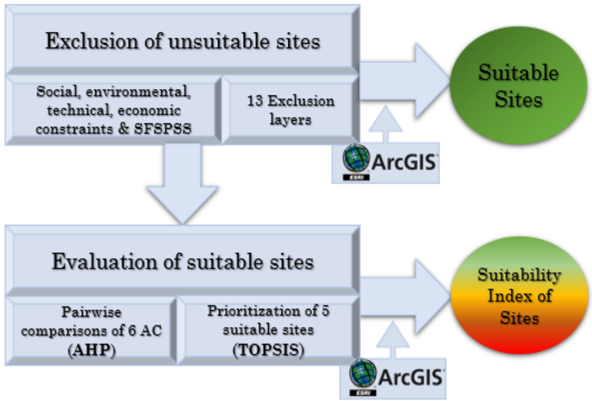

Figure 1. Schematic of the proposed methodology.

In the first stage, sites are excluded, based on planning constraints related to the special characteristics of the study area as well as the Greek Special Framework of Spatial Planning and Development for Renewable Energy Resources (SFSPSD-RES, 2008). Thirteen Exclusion Criteria (EC), shown in Table 1, are used in the analysis.

EC9 refers to the distance of an OWF from the coast and is used to ensure landscape protection, avoid visual and acoustic disturbances and ensure the social acceptance of an OWF. The minimum limit is set to 5 km as it ensures a distance of approximately 35 times of the height of the selected offshore wind turbine in this study (Generic 5MW turbine model developed by the National Renewable Energy Laboratory) (Jonkman et al., 2009).

Table 1. Exclusion criteria

Exclusion Criterion	Unsuitable Areas
EEZ (EC1)	Outside the boundaries
Wind Velocity (EC2)	< 6 m/sec
Water Depth (EC3)	> 50 m
Military Zones (EC4)	All
Seismic Hazard Zones (EC5)	Zone III (0.36g)
Underwater Cables (EC6)	All
Distance from Ports (EC7)	> 80 km
Distance from High Voltage	> 80 km

Electricity Grid (EC8)	
Landscape Protection/Visual and Acoustic Disturbance (EC9)	≤ 5 km
Distance from Shipping Routes (EC10)	≤ 3 miles
Distance from Marine Protected Areas (EC11)	≤ 2 km
Distance from Wildlife Refugees and Migration Corridors (EC12)	≤ 3 km
Distance from Residential Network (EC13)	≤ 1 km (non-traditional settlements) ≤ 1.5 km (traditional settlements)

In the second stage, the remaining suitable sites are evaluated based on six Assessment Criteria (AC): wind velocity (80m) (AC1), project capacity (AC2), distance from ports in where water depth is >10m (AC3), proximity to national electricity grid (high voltage) (AC4), distance from marine protected areas (AC5) and water depth (AC6) and the Suitability Index (SI) of each site is calculated.

It should be noted that the project capacity of each suitable site is calculated by mapping all wind turbines of the sites in ArcGIS software and selecting dx and dy values for the wind turbines' layout. For this study, the dx and dy values are $8D_{rotor}$ and $8D_{rotor}$ respectively.

A synthetic application of two multicriteria decision making methods, Analytical Hierarchy Process (AHP) and TOPSIS, is applied to compare AC and hierarchical rank the alternative OWF sites respectively.

3. Results And Discussion

Five suitable marine sites with a total surface area of 237 km^2 result from the application of exclusion criteria. Thus, only 0.048% of the total surface area of the EEZ of Greece can be used for OWF development in swallow waters.

AC1 and AC2 present the highest relative importance (weight) and therefore, the strategic policy orientation of the current siting analysis focuses on technical and economic criteria.

A marine site suitability index is developed to demonstrate the suitability distribution of the potential sites and to visualize their spatial allocation on the final suitability map (Fig.2) through the implementation of AHP and TOPSIS method and integration of the results in ArcGIS software. The suitability map includes three scales: low suitability (0.00-3.00), moderate suitability (3.00-7.00) and high suitability (7.00-10.00). The majority of the potential surface area (62.95%) can be considered as 'high suitability' sites for OWF development in Greece.

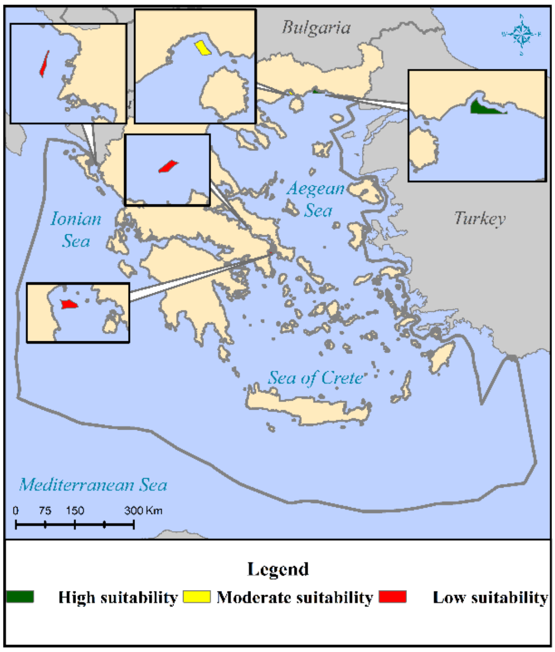

Figure 2. Suitability index of the marine feasible sites.

4. Conclusions

The GIS-MCDM integration is a powerful tool for solving spatial energy planning issues, such as the appropriate siting of OWFs in swallow waters. The present paper aims at the development of OWFs in swallow waters in Greece covering several economic, socio-political, technical and environmental issues that are related to such installations. The proposed decision-making tool could be applied to regional, regional unit and local level, by adapting the special characteristics of each location as well as the special needs and policies. It should be mentioned that the implementation of this spatial guide for the development of OWFs in swallow waters in Greece could contribute to the energy interdependency of many areas.

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