Offshore solar farm siting in the Aegean Sea

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Abstract Climate change and its environmental effects have raised the need to use mild forms of energy. Solar photovoltaic panels and wind turbines are by far the biggest drivers of the rapid increase in renewable energy electricity generation. There are several technologies of photovoltaic systems such as ground systems, photovoltaic installed on roofs, floating systems, etc.

The aim of this paper is to identify and prioritize the appropriate sites for offshore solar farm (OSF) siting in the Aegean Sea (Greece), considering various restrictions and several evaluation criteria. The methodology includes: i) definition of the study area, ii) selection of exclusion criteria iii) geospatial depiction of incompatible sites, iv) selection of assessment criteria and v) application of entropy weight method and TOPSIS to hierarchically rank the sustainable sites for offshore solar farm deployment.

Nine (9) eligible Greek marine sites in the Aegean Sea (of total surface area that equals to 17.25km^2) have been identified and are candidates for further evaluation. The three first most appropriate sites for the OSF siting in the Aegean Sea correspond to marine areas located close to, Thasos, Samothrace and Crete. The exploitation of offshore solar energy could be the way to make many coastal regions, islands and remote locations sustainable.

Keywords: Solar farm siting, entropy weight, TOPSIS

1. Introduction

The scarcity of habitable land combined with the growing energy consumption as well as the environmental effects of fossil fuels are imposing the development of offshore renewable energy projects (López eat al., 2020). Intensive research is devoted to developing technologies in offshore wind, wave and tidal energy as the main forms of renewable energy in the marine environment (Taveira-Pinto et al., 2015). However, there is an alternative that has been little explored in the marine environment: solar energy (Kumar et al., 2015). To exploit and harvest this resource in the oceans and seas, floating photovoltaic (FPV) systems are required. Although the deployment of this technology in the marine environment is new, several applications of FPV farms have appeared worldwide in lakes and reservoirs (Santafé et al., 2014).

Photovoltaic technology utilizes solar radiation and converts it into electricity, without emitting pollutants and causing environmental impacts. In addition, offshore solar power plants presents two main technical advantages: i) sun-tracking around a vertical axis simplifying the requirements for the concentrator systems and avoiding shading between collector rows, ii) unlimited cooling water availability, which can increase the efficiency of the thermodynamic cycle (Diendofer et al., 2014).

The aim of this paper is to investigate the suitability of the Aegean Sea (Greece) to deploy offshore solar farm (OSF) projects and to identify and prioritize the most appropriate sites, considering various constraints and several evaluation criteria. The remainder of this paper is organized as follows. Section 2 describes the methodological framework of OSF sitting assessment applied in this study, presenting both the exclusion and the evaluation criteria. In Section 3, the results are presented and discussed, while, in Section 5, the main conclusions are drawn.

2. Materials and Methods

The first goal of the present study is to obtain the suitable locations for OSF deployment in the Aegean Sea - Greece (Phase I). This is achieved using Geographical Information System (GIS) to create thematic maps related to exclusion criteria. Subsequently a multi-criteria decision model is adopted to evaluate these sites (Phase II). In the present study, an entropy-based objective weighting procedure and the technique for order preference by similarity to ideal solution (TOPSIS) method are combined to prioritize the potential alternatives. The entropy weight method (EWM) is an important information weight model that avoids the interference of human factors on the weight of indicators, enhancing the objectivity of the comprehensive evaluation results (Zhu et al., 2020). TOPSIS is a simple and computationally efficient MCDM technique that selects the best solution from a pool of solutions. It follows a number of steps that are clearly described in in Chen and Hwang (1992), with reference to Hwang and Yoon (1981). The primary concept of the method is that the chosen solution should be the closest to the positive ideal solution and the farthest from the negative ideal solution (Jahanshahloo et al., 2006).

GIS also supports the implementation of the above-mentioned multi-criteria decision analysis methods. The methodological framework of the proposed approach is depicted in Figure 1.

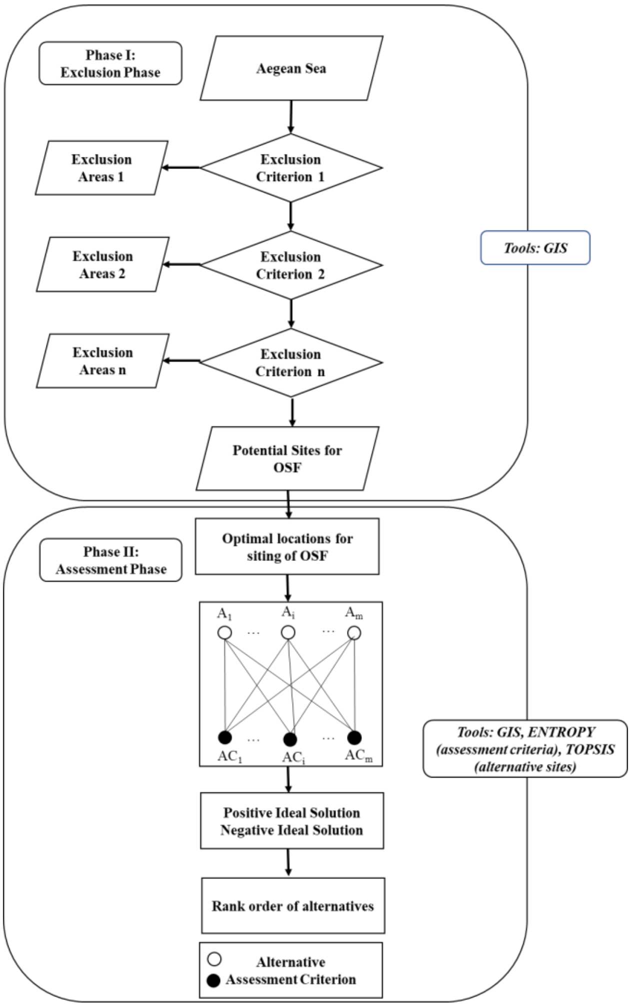

Figure 1. Methodological framework for site selection of OSF in the Aegean Sea

2.1. Restriction layers and feasible locations

GIS contributes to the implementation of the first part of the methodological framework (Phase I). Thematic layers that represent and define the study area, as well as areas where it is impossible to implement OSF are introduced (exclusion criteria). Table 1 presents the exclusion criteria and their restrictions. The values come from either the Greek Specific Framework for Spatial Planning and Sustainable Development for Renewable Energy Sources (SFSPSD/RES) or literature review on various renewable energy sources (e.g. offshore wind, onshore solar).

Table 1. Exclusion criteria

Exclusion Criteria	Unsuitable Areas
Areas to be licensed for Exploration and Exploitation of Hydrocarbons (AEEH)	Occupied areas (Vasileiou et al., 2017)
Military Exercise Areas (MEA)	Occupied areas (e.g. Schillings et al., 2012; Kim et al., 2016)
Ports and Shipping Routes (PSR)	<1 km buffer from sea route (Kim et al., 2016) >100 km from deep water ports and >50km from small piers (Murphy et al., 2011)
Marine Protected Areas (MPA)	<1km (e.g. Mekonnen and Gorsevski, 2015; Vagiona and Kamilakis, 2018)
Aquaculture Zones (AZ)	Occupied areas (e.g. Jay, 2010; Schillings et al., 2012)
Distance from Shore (DS)	<10km (MEECC, 2008)
Areas where Offshore Renewable Energy Projects (AOREP) that have been already installed or planned to be installed	Occupied areas (Vasileiou et al., 2017)
Water Depth (WD)	> 100m
Site Area Limitations (SAL)	<0.3km^2, >7km^2

2.2. Assessment criteria

The eligible OSF areas from Phase I are evaluated and ranked combining entropy weight method with TOPSIS method. For the evaluation, seven (7) assessment criteria are considered. The assessment criteria are defined, as in the case of the exclusion criteria, through literature review (e.g. Mekonnen and Gorsevski, 2015; Cradden et al., 2016; Vagiona and Kamilakis, 2018; Díazet al., 2019; Spyridonidou et al., 2021) on various renewable energy sources (e.g. offshore wind, onshore solar). The assessment criteria include: water depth (AC1), distance from shore (AC2), main voltage at a maximum distance of 100 kilometers from the site area (AC3), distance from ports (AC4), serving population (AC5), solar radiation (AC6) and installation site area (AC7). Entropy weight method (EWM) is the weighting method used to measure value dispersion in decision-making. The results are shown in Figure 2.

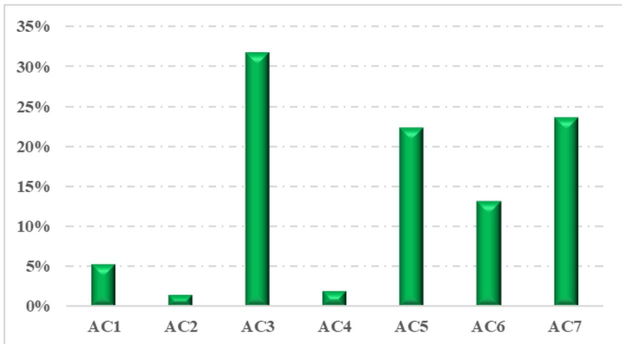

Figure 2. Entropy weights of assessment criteria

It can be seen that the entropy weights of AC3 and AC7 have the highest values, indicating that the main voltage at a maximum distance of 100 kilometers from the site area and the installation site area present the two most important assessment criteria for determining the preference order of the OSF siting in the Aegean Sea.

3. Results and Discussion

The unsuitable marine areas for the deployment of OSF are identified together with the potential marine areas, which are candidates for further evaluation (Figure 3). Based on the results, nine (9) eligible Marine Areas (MA1-MA9) in the Aegean Sea are candidates for further evaluation (Figure 3).

The assessment criteria in OSF site selection are scored using entropy method and the potential marine areas are prioritized by using TOPSIS as an MCDM approach.

The basic thought of TOPSIS is to define the ideal solution and negative ideal solution for decision making problem firstly, then find a feasible solution and rank the OSF sites according to the closeness between the feasible solution and the ideal solution, which is made the nearest from the ideal solution and farthest from the negative ideal solution.

The weighted decision matrix V, the ideal value V^+ and the negative ideal value V^-, are shown as follows:

$$V=\begin{bmatrix} 0.0205 & 0.0053 & 0.0750 & 0.0074 & 0.1835 & 0.0638 & 0.0331 \\ 0.0205 & 0.0053 & 0.0750 & 0.0074 & 0.0320 & 0.0638 & 0.0364 \\ 0.0205 & 0.0053 & 0.0750 & 0.0074 & 0.0471 & 0.0425 & 0.0378 \\ 0.0205 & 0.0053 & 0.0330 & 0.0049 & 0.0471 & 0.0638 & 0.0449 \\ 0.0205 & 0.0035 & 0.0330 & 0.0074 & 0.0471 & 0.0425 & 0.1660 \\ 0.0205 & 0.0035 & 0.0330 & 0.0049 & 0.0471 & 0.0213 & 0.0567 \\ 0.0103 & 0.0053 & 0.0330 & 0.0049 & 0.0471 & 0.0213 & 0.0331 \\ 0.0103 & 0.0053 & 0.2000 & 0.0074 & 0.0471 & 0.0213 & 0.0549 \\ 0.0103 & 0.0053 & 0.2000 & 0.0074 & 0.0471 & 0.0213 & 0.1233 \end{bmatrix}$$

V^+= (0.0103, 0.0035, 0.2000, 0.0039, 0.1835, 0.0638, 0.1660)

V^-= (0.0205, 0.0053, 0.0330, 0.0077, 0.0320, 0.0213, 0.0331)

The distance of every feasible solution (MA1-MA9) from the ideal solution and the negative ideal solution is obtained and each MA is ranked by the relative degree of approximation and shown in the Table 2.

Table 2. Distance of each MA from the ideal and the negative ideal solution

	Si+	**Si-**	**Pi**	**Ranking**
MA1	0.1829	0.1629	0.4711	3
MA2	0.2356	0.0599	0.2026	5
MA3	0.2264	0.0497	0.1799	6
MA4	0.2476	0.0467	0.1588	7
MA5	0.2170	0.1355	0.3844	4
MA6	0.2457	0.0282	0.1031	8
MA7	0.2569	0.0184	0.0670	9
MA8	0.1811	0.1694	0.4834	2
MA9	0.1492	0.1907	0.5611	1

The MA9, corresponding to the marine area near to Thasos presents the most adequate area for the sitting of OSF in the Aegaen Sea. This is mainly due to the fact that this area is located close to local grids of high voltage capacity (AC3), as well as due to the high value of installation site area (AC7) compared to the rest eligible areas. Due to the high values of the aforementioned assessment criteria (AC3 and AC7), the second top choice corresponds to the MA8 near to Samothrace. The MA1 presents the third top choice, as the deployment of OSF in MA1 enables the coverage of the energy needs of the largest part of population (AC5) among the rest alternatives.

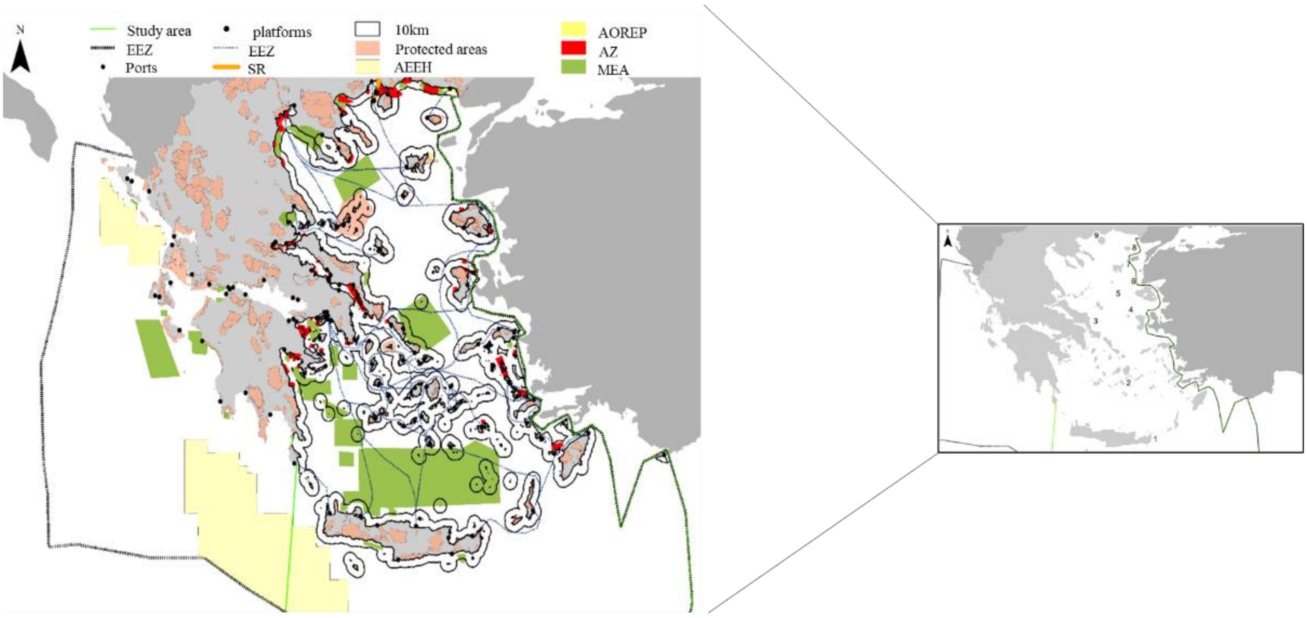

Figure 3. Unsuitable and eligible areas for the siting of SWF in the Aegean Sea

4. Conclusions

Considering the world's growing interest in sustainable energy development and the great potential of solar power as a vast and clean source of energy available for sustainable exploitation, this paper examines the suitability of multiple marine sites in the Aegean Sea for the construction of an OSF. More specifically, nine (9) eligible MAs for the siting of OSF in the Aegean Sea have been identified, through the application of certain exclusion criteria with the use of GIS. Entropy weight method is used for the evaluation of the assessment criteria, avoiding effectively the subjectivity using other scoring methods, and leading to more objective results. The ideal solution, the negative ideal solution and the relative degree of approximation are determined, and the suitability of the nine MAs has been evaluated according to the value of the relative degree of approximation used by TOPSIS. This application provides a rational scientific methodological approach and could be applied to rank the site suitability of various renewable energy sources projects.

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