Brodogradnja Volume 75, Number 2 (2024) 75204

journal homepage: www.brodogradnja.fsb.hr

Brodogradnja

An International Journal of Naval Architecture and Ocean Engineering for Research and Development

University of Zagreb Faculty of Mechanical Engineering and Naval Architecture

GIS-based floating offshore wind turbine installation site selection using fuzzy analytic hierarchy process in northeast Aegean Sea

Selahattin Alp Erkurtulmus[1], Emre Pesman[2]*

Yalova University, Altinova Vocational School, Naval Architecture Program, Yalova, Turkey
Karadeniz Technical University, Surmene Faculty of Marine Sciences, Naval Architecture and Marine Engineering, Trabzon, Turkey

ARTICLE INFO

Editor-in-Chief: Prof. Nastia Degiuli
Associate Editor: PhD Ivana Martić

Keywords:
Floating offshore wind turbine
Fuzzy Analytic Hierarchy Process (F-AHP)
Geographic Information System (GIS)
Gökçeada
North Aegean Sea

ABSTRACT

The ever-increasing consumption of electrical energy due to increasing requirements arising in parallel with the developing technology forces manufactures and users to seek new and environmentally compatible energy resources. Due to it endless energy potential and continuity, wind energy, which has been used by humanity for various purposes for centuries, continues its journey, which started with windmills that transform one form of mechanical energy into another, with offshore wind energy turbines. In this study, installation site selection, which is the first step for floating offshore wind turbine installation, is carried out. First, a Fuzzy Analytic Hierarchy Process (F-AHP) is applied to obtain the weights of criteria. Transformed alternatives and criteria in a fuzzy decision matrix through triangular fuzzy numbers are used to obtain a database via a Geographic Information System (GIS). Finally, the installation site and study area are determined. This area is located in the Northeast Aegean Sea, between Çanakkale and Gökçeada, 12 km to the northeast of Gökçeada, and 12 square kilometers. The minimum distance of the area to ship routes is 3000 m, and its minimum distance to fault lines is 2000 m. The average sea depth is 110 m, and the average wind speed is 9.26 m/s (18 knots). With this potential, enough energy can be generated for settlements on Gökçeada and the coastlines.

1. Introduction

The ever-increasing consumption of electrical energy due to the increasing requirements arising in parallel with the developing technology forces manufactures and users to seek new and environmentally compatible energy resources. Considering the current problem of global warming, the environmental harms and exhaustibility of fossil fuels and increasing energy demands encourage a shift towards renewable resources for electricity generation [1, 2]. Forms of renewable energy, which can be listed as solar, hydro, wind, current, tide, and wave energy, not only help protect employment but also contribute to increasing it [3]. Due to its endless energy potential and continuity, wind energy is frequently preferred worldwide as a renewable energy resource for electricity generation.

[*] Corresponding author.

E-mail address: alp.erkurtulmus@yalova.edu.tr

http://dx.doi.org/10.21278/brod75204

Submitted 03 October 2023; Accepted 30 January 2024;
ISSN 0007-215X; eISSN 1845-5859

While electricity generation with wind power used to be realized with the utilization of only 12 kW Brush turbines in the 1800s, today, it has been developed further and become a key element [4]. According to the Global Wind Energy Council (GWEC),the global installed wind power value was 23900 MW in 2001, while this number increased 20 times in 15 years and reached 486000 MW in 2016 [5]. With 51.3 GW of new installations, the total installed power amount increased to 591 GW in 2019, and it is projected to conduct 55 GW of onshore and offshore installations each year until at the end of 2023 [6].

Offshore wind conditions have several major differences from onshore wind conditions, and this is an important issue considering site selection, installation operations, and developments [7]. There are also offshore sites with a continuous large area suitable for large wind farm projects, as opposed to congested onshore sites [7]. Additionally, offshore developments significantly reduce noise and aesthetic concerns and prevent land use disputes [7].

Offshore wind turbines provide several advantages over onshore power plants [8]. Due to climate effects, the number and scale of offshore wind farms are increasing day by day. Because pressure differences in the seas are higher than those on land, and more open areas are available in the seas, the potential of wind energy in the seas is greater and more stable. For these reasons, the establishment of wind farms in the open seas and the generation of energy from these are becoming increasingly common. However, financial difficulties and some hydrodynamic complexities arise in this process [8]. The total implementation cost of offshore wind farms is higher than those of onshore projects [9]. For example, Wind Europe reported that onshore projects have a total of 10,923 MW capacity costing 9.3 billion euros, and an offshore wind energy project with a capacity of 1,567 MW cost 18.2 billion euros in 2016 [9]. It seems that offshore wind turbine installations are financially costlier than onshore wind turbine installations.

The advancement of offshore wind power also resembles the early days of the oil-gas industry. At the beginning of the 20th century, the first search for oil at sea took place in shallow waters using stationary structures [10]. Over the years, the development of floating platforms has made it possible to work in deeper waters. The first offshore wind farm, Vindeby in Denmark, opened in 1991, and it was decommissioned in 2017. The electricity generation capacity of the installation, which was 4,500 kW in its early stages, reached 10-15 MW in recent years [10].

In the case of offshore installations, many wind power plants are located in Europe, China, and North America, and they are established away from shores into deep waters [11]. The average water depth around which active plants were established was 16 m in 2013, and their average distance to coasts was 29 km in the same year, while at the end of 2016, there was a significant increase in these numbers, reaching an average water depth of 29.2 m and an average distance to shore of 43.5 km [12]. As the distance to the shore gradually increases, fixed platforms will be insufficient, and they will need be replaced by floating platforms. The selection of a suitable installation site is a difficult and complicated process because of various technical/mechanical, environmental, and socio-economic parameters, as well as relevant national legislations concerning marine spatial planning [13].

Kim et al. [14] stated that the most important factors for suitable site selection are the availability of wind resources and wind speed. Other important factors are marine environment criteria such as sea depth, seabed conditions, and the length of transmission lines. Among these factors, sea depth plays a role in determining the type of platform to be used for turbine installation. Moreover, wind speed plays a role in the choice of turbine capacity. Seabed conditions also have an impact on platform type and mooring systems. Transmission line length also effects the cost of power generation. Table 1 presents some advantages and disadvantages of offshore wind energy plants [14].

Table 1 Advantages and disadvantages of offshore wind energy [14].

Advantages	Disadvantages
Available area	Cost
Wind speed and wind potential	Knowledge
Smooth surface area	
Non-turbulent flow	
Lack of visual impact	
Lack of noise concerns	

Large areas are required for the installation of large-scale offshore wind farms. There is virtually no restriction of available areas on the sea compared to land. More space in this regard is one of the primary advantages of offshore projects. The transition of European countries to offshore wind power plants has started for reasons such as the fact that wind-efficient sites on land are located in areas that are difficult to reach, and therefore, maintenance and repair difficulties, as well as costs, arise [15].

The power generated by a turbine is directly proportional to cube of wind speed as given in Equation (1). Here, P is the generated power (watt), A is the area covered by the turbine blades (m^2), v is the wind speed, and ρ is the air density (kg/m^3). Wind speed and potential are substantially greater offshore. This is because pressure differences in the seas are much greater than those on land. Acher and Jacobson [16] showed that the wind speeds in offshore installations are 90% higher than those in onshore installations:

$$P = \frac{1}{2}\, \rho\, v^3\, A \quad (1)$$

Wind speed, which increases in direct proportion to hub height, has a variable profile due to environmental effects. Friction forces and obstacles on the surface on which a wind power plant is established affect this situation. Compared to the roughness that causes friction on the surface and therefore turbulence in the wind on land, the sea surface is almost perfectly smooth. For this reason, the turbulence effect that will occur due to the installation surface in the sea is smaller than that on land. This contributes to a lower degree of mechanical fatigue in the structure and a longer lifespan of the structure:

$$V = V_0 \left(\frac{h}{h_0}\right)^{z_0} \quad (2)$$

In Equation (2), V is the wind speed at a height h from the ground (m/s), V_0 is the wind speed at a 10 m height from the ground (m/s), and z_0 is the roughness height of the ground (mm). The approximate roughness heights of some surfaces are shown in Table 2.

Table 2 Roughness heights of some surfaces

Definition	Roughness heights (z_0) (in mm)
Sea surface	0.20
Grass	8.00
Flat land with sparse vegetation	30.00
Sparsely wooded areas	100.00
Wooded or sparsely populated area	250.00
Forest area	500.00
City centers with tall buildings	300,000

Offshore wind farms are located away from settlement areas and therefore have a low visual impact. Due to the long distance of turbines from living areas, people are not affected as much by issues such as noise and eye strain [15].

The feasibility testing of setting up an offshore wind farm includes many parameters. Many of these may be missing in terms of data. This also creates a disadvantage. Each region includes different conditions such as depth, current, sea conditions, and wave heights. It is therefore not possible to generalize the design of a platform or mooring system.

For the selection of onshore and offshore wind farm installation sites, the geographic information system (GIS) method has become an important tool [17]. In several countries, such as China [18], Denmark [19], Greece [20, 21], South Korea [22], Taiwan [23] and Türkiye [1, 24]. The GIS methos has been used for onshore and offshore wind projects. Yue and Yang [23] evaluated wind energy resources with the help of the GIS method based on real local conditions. They included various factors such as wind speed, water depth, land use, and ecological environments as local constraints. Hong and Möller [18] investigated offshore wind potential in China by using the GIS method with a combination of wind resources, technical forecasts of wind turbines, cost, and spatial constraints [7]. Möller [19] constructed a spatially continuous resource economic assessment model of an offshore windfarm based on the GIS method. For all Greek coastal areas, GIS-based technical and environmental constraints were applied to identify potential offshore windfarm sites and developments [20]. For Crete, the GIS method was also used [21] to identify sustainable offshore windfarm siting with respect to ecological and economical resources. The Aegean Sea coast was studied [3] using a GIS-based Fuzzy Analytic Hierarchy Process (F-AHP) for the Gökçeada and Bozcaada Regions for suitable fixed offshore wind farms. Erkurtulmus [24] conducted GIS based site selection for floating offshore wind turbines and examined their effects on motion outcomes and performance on the Aegean Sea coast.

Furthermore, multi-criteria decision-making (MCDM) methods are also used frequently in offshore windfarm site selection. In terms of decision-making criteria, it is seen that the degrees of importance and rankings of the same criteria vary from researcher to researcher [25]. In this case, a joint decision is needed to interpret different views. One of the MCDM methods is an Analytic Hierarchy Process (AHP), proposed by Thomas L. Saaty in 1977 [26]. In this method, weighted criteria are determined, and “pairwise comparisons” and matrix algebra are used according to these criteria. The decision to be made is determined by the weights derived from the evaluation criteria. Objective criteria are not the only criteria used in decision-making. Instead, people’s opinions should be included in the analysis to consider subjective criteria. In this case, the proposition of “Fuzzy decision-making” comes to the fore. In the study performed by Zadeh [27], the “fuzzy set theory” was proposed to prevent qualitative, imprecise information, and ill-advised decisions. The fuzzy set theory is a modeling tool proposed for complex systems that can be controlled by humans but cannot be defined precisely. In this context, a fuzzy analytic network process was modeled to reduce the risk associated with offshore wind farms by Shafiee [28]. An AHP was used in another study [20] aiming to apply a systematic methodology for the evaluation of offshore wind farms around Greece, combining multi-criteria approaches, MCDM, and GIS tools. In a study conducted in Iran, a new MCDM method was developed by considering the Fuzzy Analytic Network Process (F-ANP), Fuzzy DEMATEL, and Fuzzy ELECTRE methods to select the best site among four offshore wind farm sites [29]. A hybrid multi-criteria decision support method for the selection of an offshore outsourcing region was studied for selecting the best alternative [30]. For this purpose, the AHP and PROMETHEE methods, which are MCDM techniques, were used. For the coast of the Murcia Region in the southeast of Spain, a F-AHP was applied to obtain the weights of criteria, and the Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method was used to evaluate the alternatives [31].

Recently, there has been increasing interest in site selection in Türkiye, and some studies have focused on economic analyses for offshore wind power plant site selection. Some others have been carried out based on wind speed. For the establishment of offshore wind power plants in the Aegean Sea, Çanakkale, Gökçeada, and Bozcaada were comparatively categorized by using the F-AHP and GIS methods together [3]. In another study [32], an AHP method was applied for Northwest Türkiye. Local criteria were not used in the aforementioned study, and important areas such as Kiyikoy and Karabiga were excluded due to lack of wind data. Another GIS method in combination with MCDM was applied for the coastal areas of Turkey [33]. For suitable site selection, 3 main criteria, namely Technical (C1), Environmental (C2), and Social (C3) criteria, and 13 sub-criteria were chosen. As a result, 13 regions including Bandırma, Gemlik coastline, Saros Bay, Gökçeada, Istanbul, Samandağ, Kastamonu, Tekirdag coastline, Çanakkale Bay, Ayvalık coastline, and İzmir Bay, were determined for suitable site selection based on the constraint criteria that were used. Both sides of the Aegean Sea were examined in another study [34] for selecting suitable sites for offshore wind energy power plants using a GIS-based MCDM model. Their methodology aimed to assess sites for bottom-fixed offshore wind farms implemented in Cyclades (Greece) and İzmir coastline (Turkey). Their results showed that the Turkish side of the examined region had a suitable area of 519 km^2 (10.23%), while the Greek side had a suitable area of 289 km^2 (3.22%). In other studies, Yerci [35], Özdilim [36], Emeksiz and Demirci [37], and Argin et al. [38] used onshore wind speed measurements from the Turkish Meteorological Service [32]. There are no wind speed measurements for offshore installations in Türkiye yet. Additionally, all available studies have been performed at water depths usable for fixed-bottom platforms.

In this study, as opposed to others, a methodology is developed and presented to select a site for **floating offshore wind turbines in the Northeast Aegean Sea Shores of** Türkiye. To propose a methodological framework for floating offshore wind turbine installation site selection, "GIS" and "F-AHP" are integrated as two MCDM methods. Primarily, a floating offshore wind turbine installation and operation site is determined. The study area was determined as the Northeast Aegean Sea Shores of Türkiye based on the Turkish Wind Energy Potential Atlas (REPA) [39].

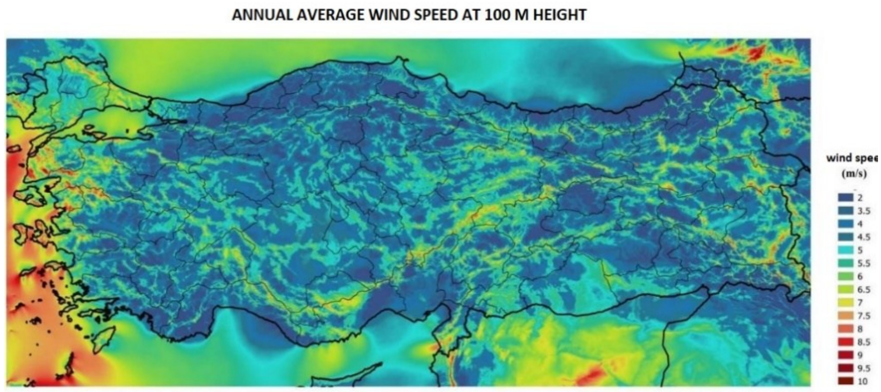


Fig. 1 Turkish Wind Energy Atlas [39].

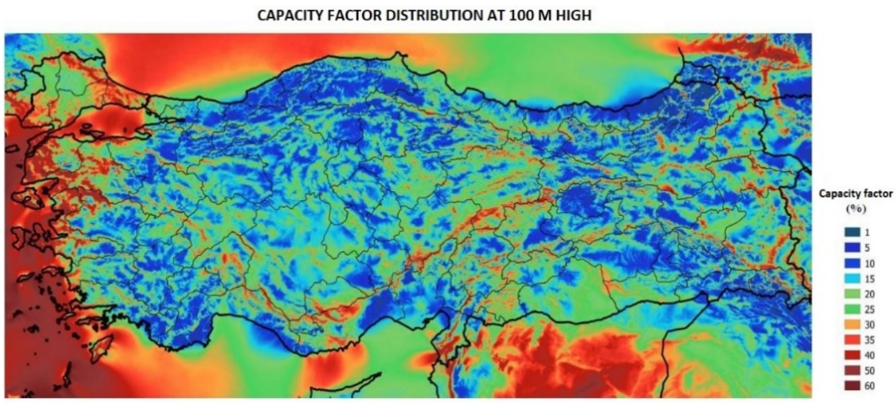


Fig. 2 Turkish wind capacity factor distribution [39].

2. Methodology

Decision criteria were determined based on the review of the relevant literature and by considering the assessments, knowledge, and experience of expert academic staff. Later, these criteria were converted to vector data format and raster data format in the GIS software named ArcGIS. This process was carried out separately for each criterion, and these were combined into a single layer in the ArcGIS software. At the stage of integrating the criterion data, the weights were determined by the F-AHP method.

2.1 Geographic information system

A GIS is a computer system designed to collect geographical data about people, places, and locations in a database together with their real references on earth, to conduct various analyses on them according to the purpose of the practitioner and show the results using maps, tables, and graphics [40]. Since wind speed is the most important factor in wind energy generation, firstly, wind potential areas for the installation of floating offshore wind turbines along the Turkish coasts were determined. For this purpose, unlike previous studies, satellite data [24, 40] were used instead of land-based wind data. Then, existing GIS-based software was used by adding physical factors including wind speed, sea depth, fault lines, and distances to network substations, marine traffic routes, military areas, fishing zones, and fish and bird migration routes [24, 41]. Additionally, for the wave height criterion, significant wave heights between 5 and 10 m should be considered in the installation of offshore wind farms [24, 42].

However, since there are no high waves in the north of the Aegean Sea as in the oceans, significant wave heights were not considered in the selection of alternative sites for the installation in line with the opinions that were received. Here, the priority weight values of the digitized layers combined with the "weighted overlay" method were obtained by using the F-AHP method. With the methodology used in this study, the selection of the most suitable installation site for floating offshore wind turbines was carried out in the environmental conditions of the Northeast Aegean Sea.

2.2 Multi-criteria decision-making methods

People must constantly make decisions at every moment in their lives. Evaluating multiple criteria among these decisions and determining the appropriate choice among the alternatives according to the priority of the criteria is called decision-making. In some cases, decision-making is easy, while in other cases, it can become very complex. Thus, different methods have been developed for the solution of situations that are especially difficult to decide [43]. Within the scope of this study, an F-AHP model was used for the selection of an installation site for floating offshore wind turbines.

2.2.1 Fuzzy analytic hierarchy process

The AHP method is a decision-making method based on the operation of a decision mechanism to assign relative importance values to decision alternatives and decision criteria in complex problems [44, 45]. Ozgormus et al. [46] stated that the AHP approach is not fully suitable for decision-making in uncertain situations. The use of real numbers, especially in the comparison of qualitative factors, is an important challenge for decision-makers. Additionally, decision-makers make evaluations using real values. The F-AHP approach, on the other hand, can evaluate options more easily by using fuzzy numbers or verbal variables. For this reason, F-AHP was proposed by Laarhoven and Pedrycz [47] for the first time by intertwining AHP with fuzzy logic.

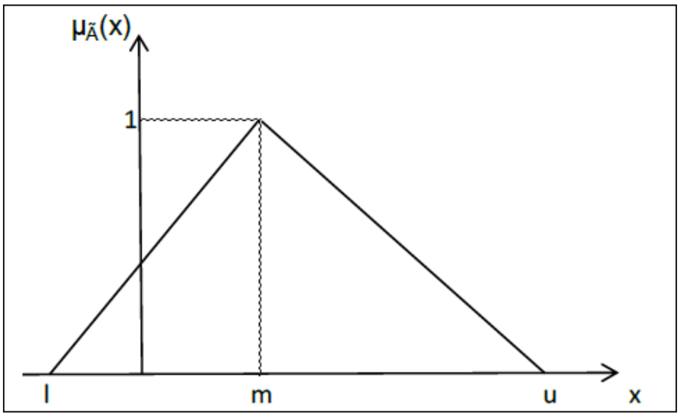


Fig. 3 Triangular fuzzy numbers

In this study, Triangular Fuzzy Numbers (TFN) were calculated using the Fuzzy Mean Squares Method (Logarithmic Least Squares Method) developed by Laarhoven and Pedrycz [47], where:

$$\mu_{\tilde{A}}(X) = \begin{cases} \frac{(x-1)}{(m-1)}, & 1 \le x \le m \\ \frac{(u-x)}{(u-m)}, & m \le x \le u \\ 0, & x > u \; or \; x < 1 \end{cases} \tag{3}$$

After this, the α-cut method was used for the defuzzification of fuzzy weights, and exact values were obtained. For this study, the degree of optimism λ was taken as 0.5.

2.2.1.1 Fuzzy mean squares method

Laarhoven et al. [47] expressed verbal variables using TFNs in the form of a_{ij}. Thus, their rates on the pair of similar alternatives are separately indicated. On the other hand, Önüt et al. [48] proposed Equation (3) and Equation (4) for calculating fuzzy weights and values:

$$\widetilde{W}_k = \left(W_k^l, W_k^u, W_k^m\right), k = 1, 2, 3, \ldots, n \tag{4}$$

$$W_k^s = \frac{\left(\prod_{j=1}^{n} a_{kj}^s\right)^{1/n}}{\sum_{l=1}^{n}\left(\prod_{j=1}^{n} a_{lj}^m\right)^{1/n}} \tag{5}$$

2.2.1.2 α-cut method

In this method, fuzzy numbers calculated using the comparison matrix are subjected to α-cut values. This way, the degree of matching the fuzzy number of the defuzzified value is increased. The optimism degrees of the decision makers are $0 \le \lambda \le 1$. The closer λ is to 1, the more optimistic the decision is, and the closer it is to 0, the more pessimistic the decision is [49]. In the application of the method, firstly, lower-upper limit priority values are determined as below.

For the lower limit:

$$L = \alpha \times (m - l) + l \tag{6}$$

For the upper limit:

$$R = u - \alpha \times (u - m), \; \alpha = 1, 2, 3, \ldots, T \tag{7}$$

where, *l, m,* and *u* are the fuzzy priority values for the "*k*" factor. The lower and upper limit values obtained later are as follows:

W_{kL}: The lower priority value for k factor.

W_{kR}: The upper priority value for k factor.

W_{dk}: The defuzzified value for k factor.

λ: Degree of optimism.

Then, the defuzzified values are found by combining them with the following Equations:

$$W_{kL} = \frac{\sum_{l=1}^{T} \alpha_l L_l}{\sum_{l=1}^{T} \alpha_l} \tag{8}$$

$$W_{kR} = \frac{\sum_{l=1}^{T} \alpha_l R_l}{\sum_{l=1}^{T} \alpha_l} \tag{9}$$

$$W_{dk} = \lambda \, W_{kR} + (1 - \lambda) \, W_{kL} \;, \; \lambda \in [0, 1] \tag{10}$$

A decision model was created for the alternative region by using the values obtained using the GIS and F-AHP methods explained in the next section. There are a few scale types used in the F-AHP method, and the scale types used in this study are shown in Table 3.

Table 3 Triangular fuzzy conversation scale

Triangular fuzzy numbers	Linguistic values	Reciprocal triangular fuzzy scale
(1, 1, 1)	Equal importance	(1, 1, 1)
(2, 3, 4)	Weak importance (of one over the other)	(1/4, 1/3, 1/2)
(4, 5, 6)	Strong importance	(1/6, 1/5, 1/4)
(6, 7, 8)	Demonstrated importance over the other	(1/8, 1/7, 1/6)
(8, 9, 10)	Absolute importance	(1/10, 1/9, 1/8)

3. Implementation

In this study, the decision-making process of alternative site selection for floating offshore wind turbine installation was carried out in 2 steps as "exclusion" and "evaluation". Since wind speed is a factor in wind energy generation, firstly, a wind potential map was created, and priority areas for site selection were determined. Then, existing GIS-based software was used by adding physical factors including wind speed, sea depth, fault lines, and distances to network substations, marine traffic routes, military areas, fishing zones, and fish and bird migration routes.

3.1 Identification of buffer zones by GIS tools

For the selection of floating offshore wind turbine installation sites, the most important criterion is wind speed. According to the World Bank Report "Going Global: Expanding Offshore Wind to Emerging Markets", a 7 m/s wind speed at a 100 m hub height is feasible [50]. Additionally, wind speed usually needs to be higher than 6 m/s to achieve an efficient and cost-effective investment [7, 51–53]. For installations examined in Europe, the annual average wind speed was reported to be approximately 8-9 m/s in these sites [32].

Another important criterion is water depth, which directly affects costs. Greater depths bring about greater costs of mooring, cables, and foundations. Information in previous studies [54, 55] was take into account, and a water depth of **50 m was selected as a threshold** for floating and fixed-bottom applications. Sites which were **deeper** than the determined threshold were considered in this study.

Additionally, areas such as commercial fishing areas, archaeological sites, fish and bird migration routes, and military zones are not suitable for the installation of wind turbines.

In this study, considering the points above, 3 excluded areas were determined using GIS and excluded from the decision-making process. These areas are listed below:

- Regions where the wind speed is less than 6.5 m/s,
- Regions where the sea depth is less than 50 m,
- Protected areas such as military areas and fish and bird migration routes.

3.2 Evaluation stage

The feasibility analyses of the site selection objective of this study were performed with GIS tools. For this purpose, bathymetry, wind speed, distance to the nearest grid and marine protection area, sea traffic routes, and distance to fault lines were determined as basic parameters. These parameters were determined based on the review of the relevant literature and the opinions of academic staff working on this subject. The hierarchical structure of the site selection process is shown in Fig. 5.

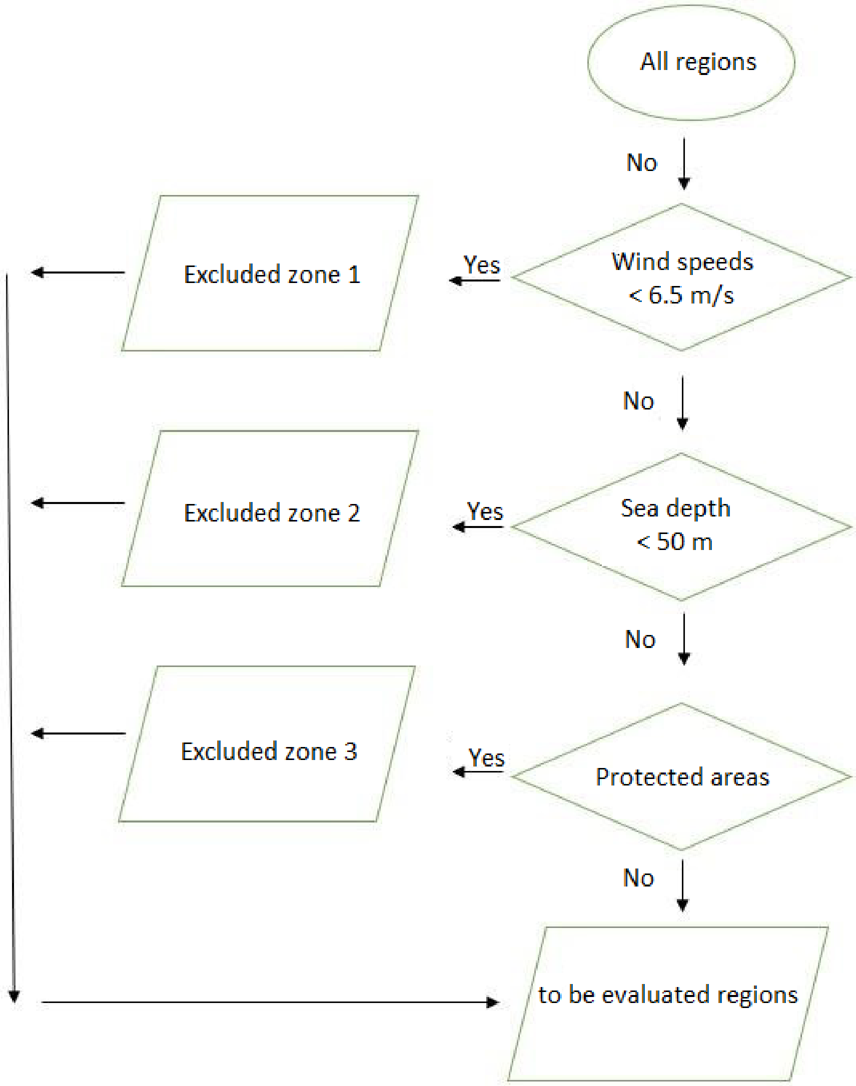


Fig. 4 Region selection flow chart

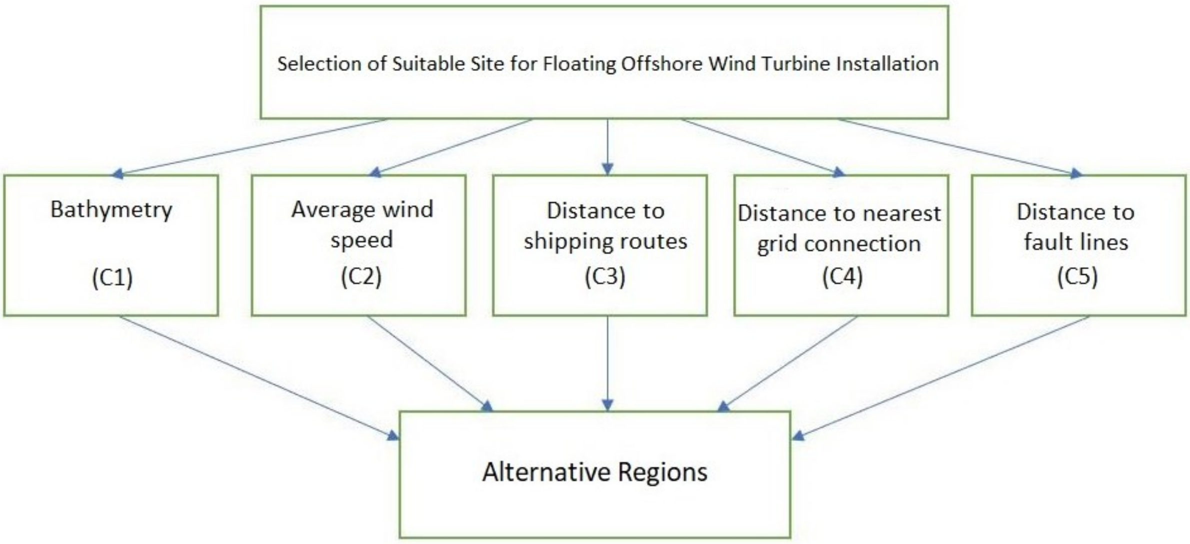


Fig. 5 Hierarchical structure of site selection process

The parameters to be used in the feasibility assessments of installation were digitized using GIS-based software. With the program, data layers were created, these layers were put on top of each other, and an alternative region was determined for the installation of floating offshore wind turbines. The Çanakkale region, which is shown in Fig. 6, was chosen as the study area due to its high wind speeds and wind potential, sea traffic characteristics, and location.

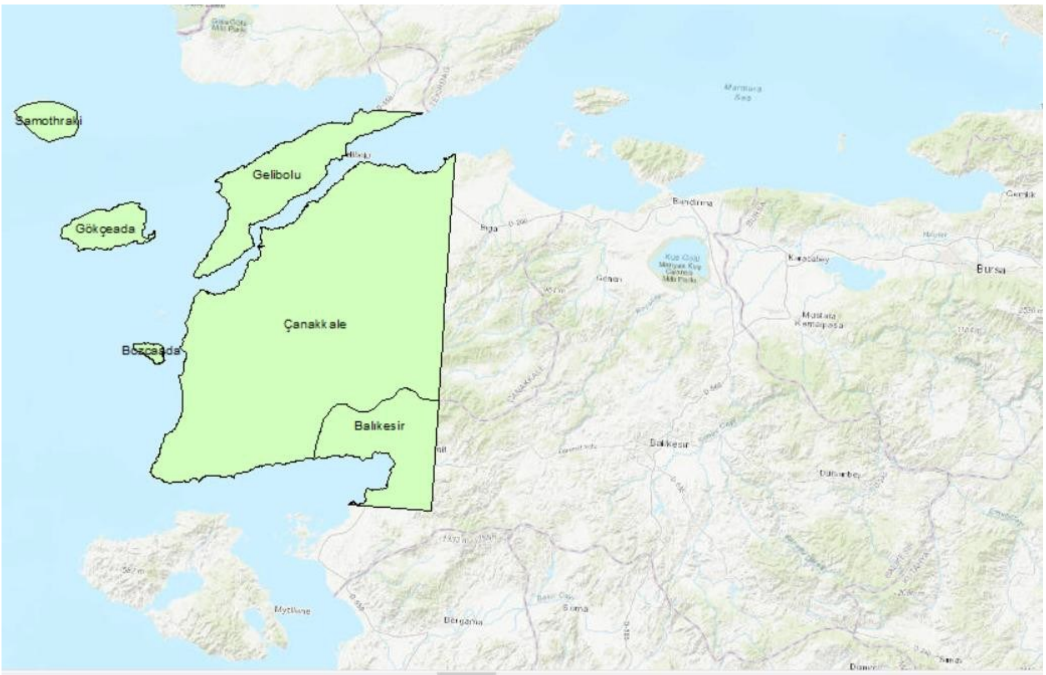
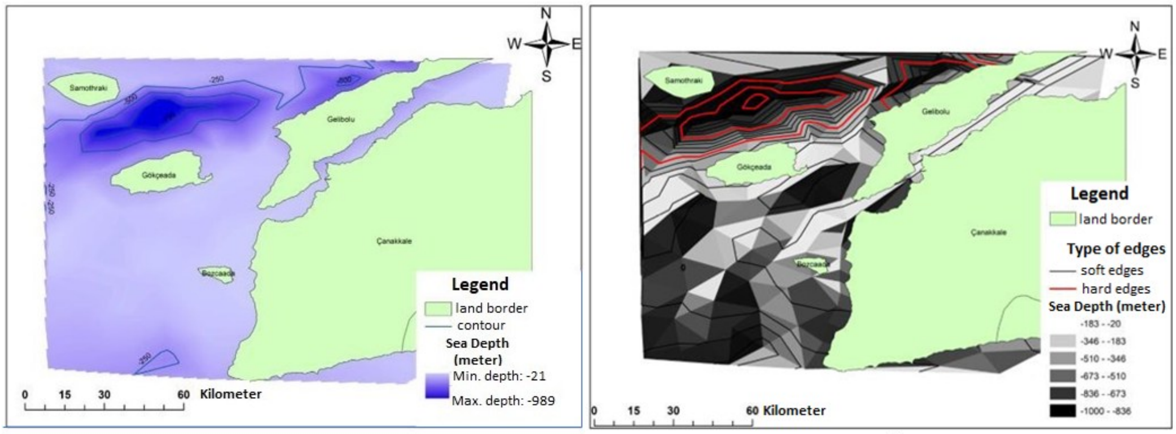


Fig. 6 The digitized study area on map

3.2.1 Bathymetry (C1)

Sea depth is an important criterion that determines the type and nature of the platform on which the tower will be mounted, and therefore, its cost. As depth increases, it is not possible to establish fixed pile foundations. This is because increasing depths are associated with an increase in cost. In the literature and practice, the ideal depth for turbine installation has been determined to be 15-75 m [56]. After this depth threshold, the use of floating platforms will be more appropriate. Floating offshore wind turbines can be used after a depth of 100 m. Considering the cost increase along with depth, 50-300 m was accepted in this study, and other depths were not considered in the selection of sites as excluded regions. In this part of the study, the digitization process was carried out using the online maps of the National Centers for Environmental Information [24]. The maps in question are shown in Fig. 7.

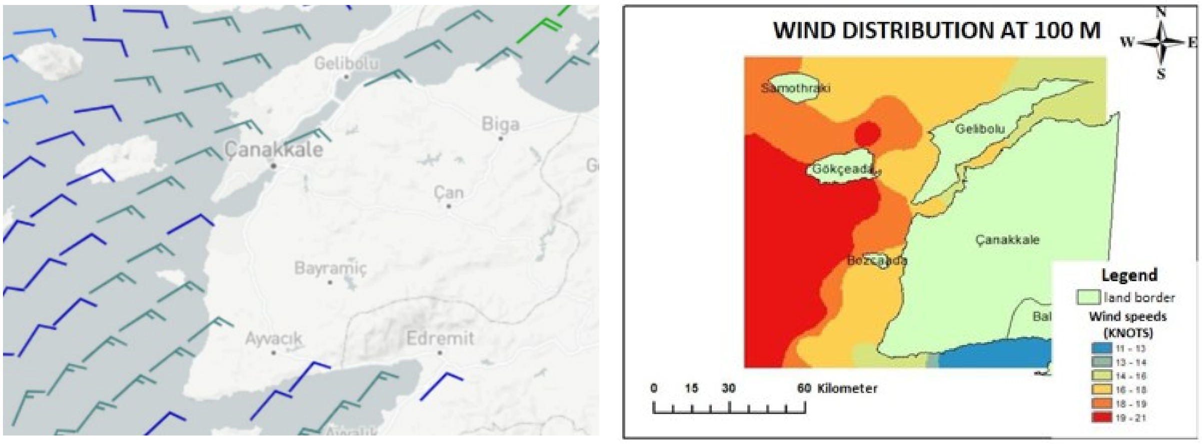


a) b)

Fig. 7 Bathymetry maps of study area: (a) sea depth contour lines at 100 m intervals, (b) relief map of bathymetry

3.2.2 Average wind speed (C2)

In this study, average wind speeds greater than 6.5 m/s at 100 m above ground level were considered. For this reason, wind speeds of 13 knots and above were used in the study. In the digitization process, the wind speed data of the Marine Traffic Online map [41] was used. The wind values were entered into the GIS-based software as vector data. In the last stage, digitization was performed using the inverse distance weighting (IDW) method, and the average wind distribution map for study area was obtained.



a) b)

Fig. 8 A wind speeds: (a) Marine Traffic Online map [41], (b) digitized wind distribution map

3.2.3 Distance to shipping routes (C3)

As seen in Fig. 9 [57], maritime traffic is quite crowded in Türkiye. Turbines do not have any personnel during their normal operating hours. However, a possible collision during new installation or repair-maintenance activities may cause injury or loss of personnel. For these reasons, the systems to be installed should be located at a point away from sea traffic.

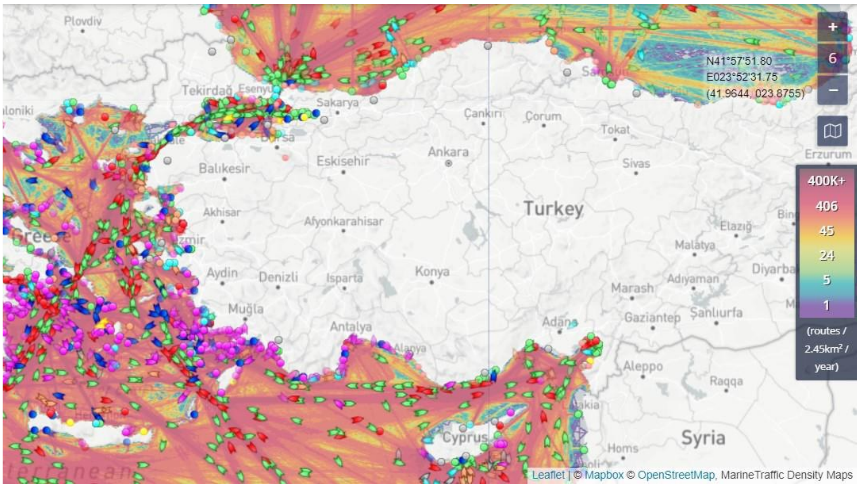


Fig. 9 Türkiye maritime traffic density [57]

In other studies in the literature, the distance to ship routes is considered as an average of 1000 m [58]. However, in this study, the distance to ship routes was chosen as an average of 2000 m in accordance with the expert opinions of academicians in terms of safety. In other words, distance values around an average of 2000 m from shipping routes were determined to be safe for installation. The pink areas seen on the route show distances up to 2000 m in Fig. 10.

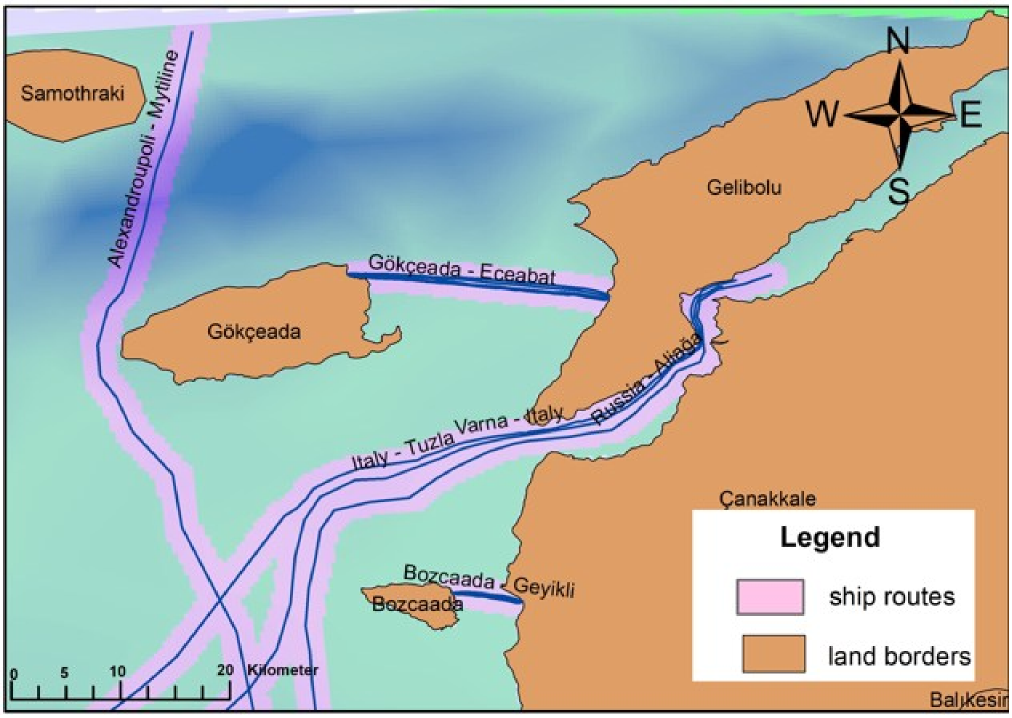


Fig. 10 Ship routes map

3.2.4 Distance to nearest grid connection (C4)

Power distribution unit (PDU) centers were created by entering data for PDUs and transmission lines obtained from REPA [59] into the GIS-based software as data points. Distance to the grid will affect the length of the transmission lines to be installed and will significantly affect cable costs. For this reason, the energy that is generated should be given to the grid from the closest possible point.

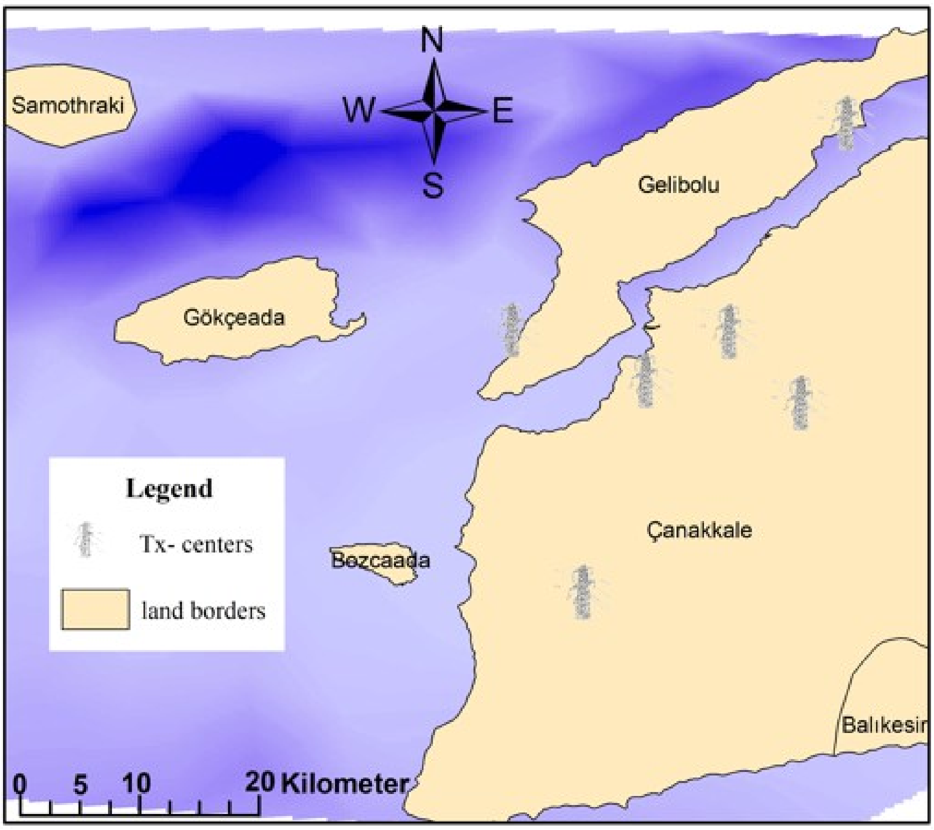


Fig. 11 Map of PDU centers

3.2.5 Distance to fault lines (C5)

In this study, distance to fault lines was evaluated based on data obtained from Kandilli Observatory [60]. In different studies in the literature, it has been argued that the distance of similar installations to fault lines should be at least 2,000 m [3]. In this study, areas 3,000 m distant from fault lines were chosen as the most suitable ones. Fault lines (Linear Seismogenic Sources, Spatial Seismogenic Sources) created with the GIS-based software as polyline data points are shown in Fig. 12. Boundaries drawn in red indicate distances up to 3,000 m from fault lines.

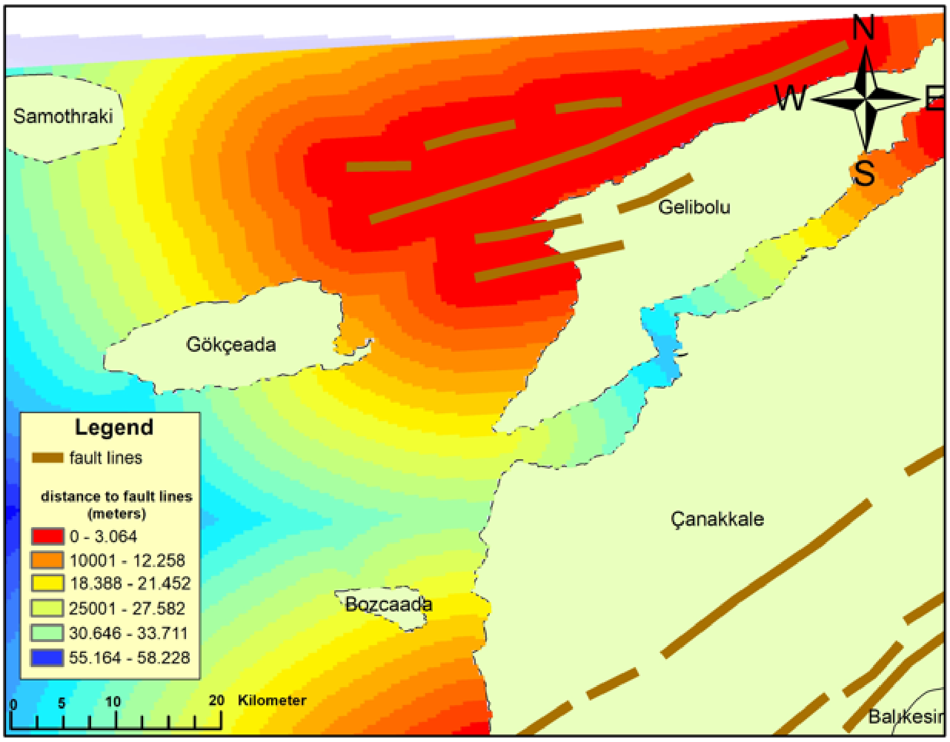


Fig. 12 Map of fault lines

3.2.6 Protected areas (C6)

As described in the previous section, areas such as commercial fishing areas, archaeological sites, fish and bird migration routes, and military areas are not appropriate to for the installation of offshore wind power plants.

Fig. 13 Marine protected areas [61]. (Red lines show borders of study area)

As seen in Fig. 13, protected areas were not used as a criterion in the site selection process in this study, since no protected area was found in the selected study area.

4. Results and discussion

4.1 Scenario I: Optimal site selection by combining equally weighted layers

In this stage, priority weight values were assigned equally to the digitized layers combined with the weighted overlay method. The most suitable sites for floating offshore wind turbine installation created by this method are shown in Fig. 14.

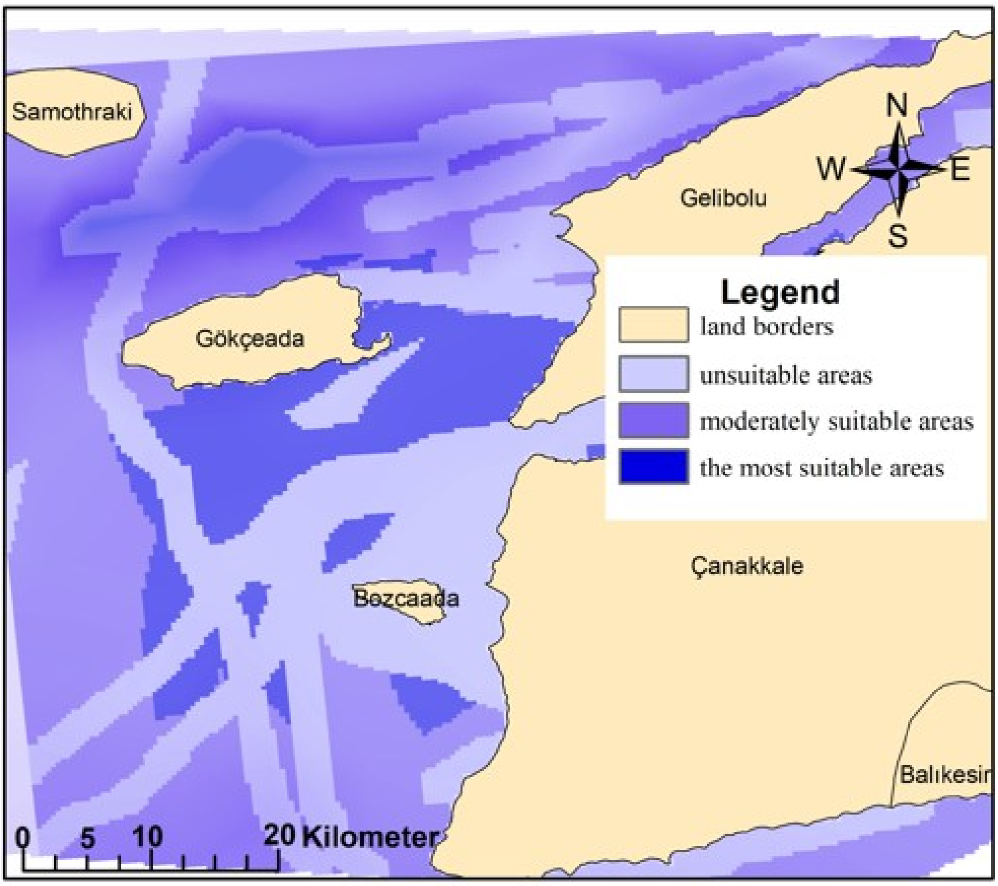


Fig. 14 Site selection according to equally weighted criteria

Here, areas with an average wind speed higher than 7 m/s (13 knots), sea depths of 50-300 m, with the nearest centers of PDUs, ship routes, and areas not on fault lines are seen. By reclassification, the most suitable, somewhat suitable, and unsuitable areas were determined.

4.2 Scenario II: Optimal site selection with layers created by determining priority weight values using the F-AHP method

In this stage, the priority weight values of digitized layers combined with the weighted overlay method were obtained using F-AHP. Considering the importance scale shown in Table 3, while evaluating the criteria among each other, the opinions of experts on the examined problem were consulted in line with their experiences. By using expert opinions, pairwise comparison matrices were obtained by forming fuzzy triangles with the fuzzy criterion comparison degrees in Table 3. Finally, fuzzy weights were determined using the fuzzy geometric mean method developed by Laarhoven and Pedrycz [47]. Calculations were carried out using Equation (3) and Equation (4).

For the C1 (bathymetry) criterion, the fuzzy geometric mean was calculated as follows Equation (11):

$$(1 \times 0.25 \times 5 \times 2 \times 2)^{1/5}, (1 \times 0.33 \times 6 \times 3 \times 3)^{1/5}, (1 \times 0.50 \times 7 \times 4 \times 4)^{1/5} = (0.2, 0.26, 0.32) \quad (11)$$

Calculations for other criteria were carried out in the same way, and "m" geometric fuzzy numbers were obtained. The sum of the geometric fuzzy numbers was in Equation (12) as below:

$$(1.78 + 3.25 + 0.90 + 0.62 + 0.34) = 6.89 \quad (12)$$

Then, the fuzzy weights (Wk) of the criteria were calculated. For the C1 criterion, the fuzzy weight was as follows in Equation (13):

$$[(1.38 \div 6.89), (1.78 \div 6.89), (2.24 \div 6.89)] = (0.20, 0.26, 0.32) \quad (13)$$

The fuzzy weights of the other criteria were calculated the same way, and all results are shown in Table.

Table 4 Pairwise comparison matrices of fuzzy weights

C	C1			C2			C3			C4			C5			Geometric mean values			Fuzzy weights		
	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u
C1	1.00	1.00	1.00	0.25	0.33	0.50	5.00	6.00	7.00	2.00	3.00	4.00	2.00	3.00	4.00	1.38	1.78	2.24	0.20	0.26	0.32
C2	2.00	3.00	4.00	1.00	1.00	1.00	4.00	5.00	6.00	3.00	4.00	5.00	5.00	6.00	7.00	2.61	3.25	3.84	0.38	0.47	0.56
C3	0.25	0.33	0.50	0.17	0.20	0.25	1.00	1.00	1.00	2.00	3.00	4.00	2.00	3.00	4.00	0.70	0.90	1.15	0.10	0.13	0.17
C4	0.20	0.25	0.33	0.20	0.25	0.33	0.33	0.50	1.00	1.00	1.00	1.00	2.00	3.00	4.00	0.48	0.62	0.85	0.07	0.09	0.12
C5	0.20	0.25	0.33	0.14	0.17	0.20	0.20	0.33	0.50	0.33	0.33	0.50	1.00	1.00	1.00	0.26	0.34	0.44	0.04	0.05	0.06
TOTAL																	6.89				

After these processes, defuzzified values for the criteria were obtained by using the α-cut method with Equation (7), Equation (8), and Equation (9). The obtained defuzzified values are shown in Table 5.

Table 5 Defuzzified criteria priority values

Criteria	Fuzzy weights (Wk)	Defuzzified values
C1 (bathymetry)	(0.20; 0.26; 0.32)	0.26
C2 (average wind speed)	(0.38; 0.47; 0.56)	0.47
C3 (distance to ship routes)	(0.10; 0.16; 0.17)	0.13
C4 (nearest grid connection)	(0.07; 0.09; 0.12)	0.09
C5 (distance to fault lines)	(0.04; 0.05; 0.06)	0.05
Total		1.00

These defuzzified values were normalized, and priority weights used to determine the most suitable alternative site were obtained for each criterion as shown in Table 6.

Table 6 Normalized priority values

Criteria	Normalized priority values
C1 (bathymetry)	0.26
C2 (average wind speed	0.47
C3 (distance to ship routes)	0.13
C4 (nearest grid connection)	0.09
C5 (distance to fault lines)	0.05

Considering the normalized priority values in Table 6, it is seen that the criterion with the highest priority was C2. This criterion was followed by C1, C3, C4, and C5.

Lastly, the weighted overlay method was used by considering the priority weights of the criteria. Thus, the most suitable sites were determined as in Fig.15.

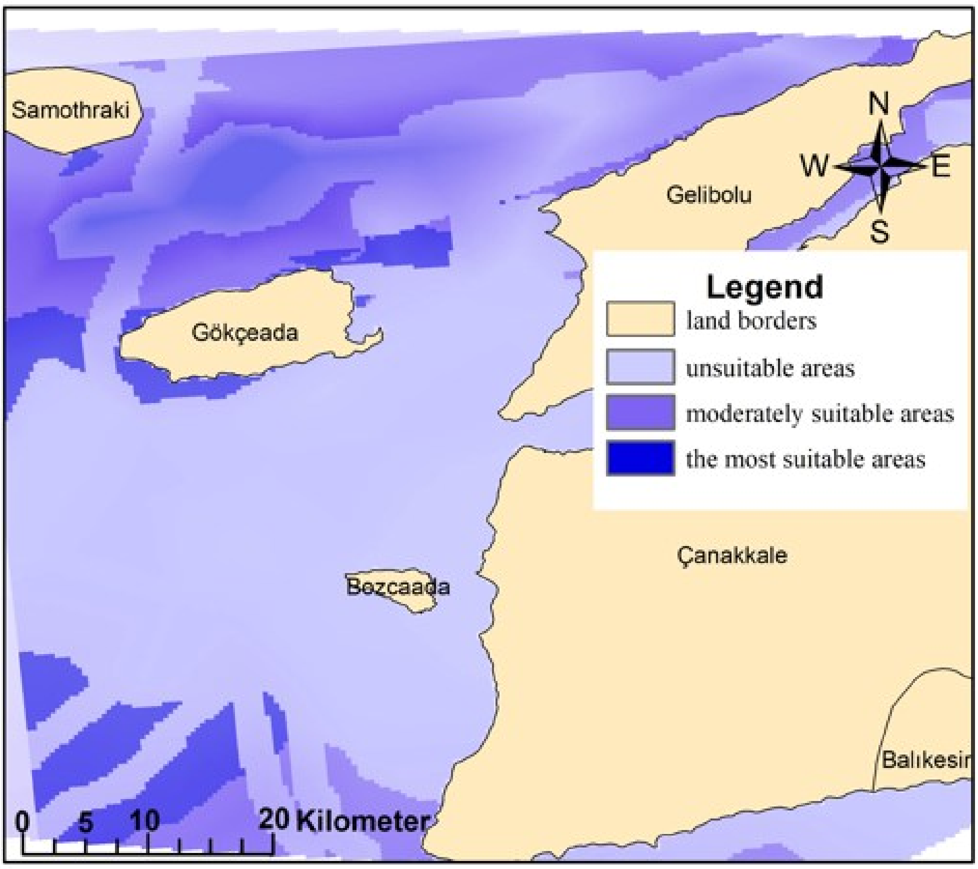


Fig. 15 Site selection according to criteria weight priorities

Contrary to the analysis in Scenario 1, in this part, sea depth values were chosen to be in the range of 100-300 m with an average wind speed of 7 m/s (13 knots) and above. This was because, according to a previous study [56], after a sea depth of 100 m, the use of floating offshore wind turbines will be more appropriate. For other criteria, the nearest center of PDUs, ship routes, and areas not on fault lines are seen. By reclassification, the most suitable, somewhat suitable, and unsuitable areas were determined.

In Fig. 15, it is seen that the areas around Samothraki and Gökceada and those between Babakale offshore and the northwest of Lesbos were suitable areas for the installation of floating offshore wind turbines.

4.3 Scenario III: Fuzzy weighted alternative site selection according to minimized values

In this stage, the priority weight values found in the previous section for Scenario II were used. However, here, especially by keeping the distances as short as possible, the closest sites to the mainland were determined. Thus, it was aimed to achieve an economic improvement in the cable cost part, which is an important item for the installation of floating offshore wind turbines. The alternative sites are shown in Fig. 16.

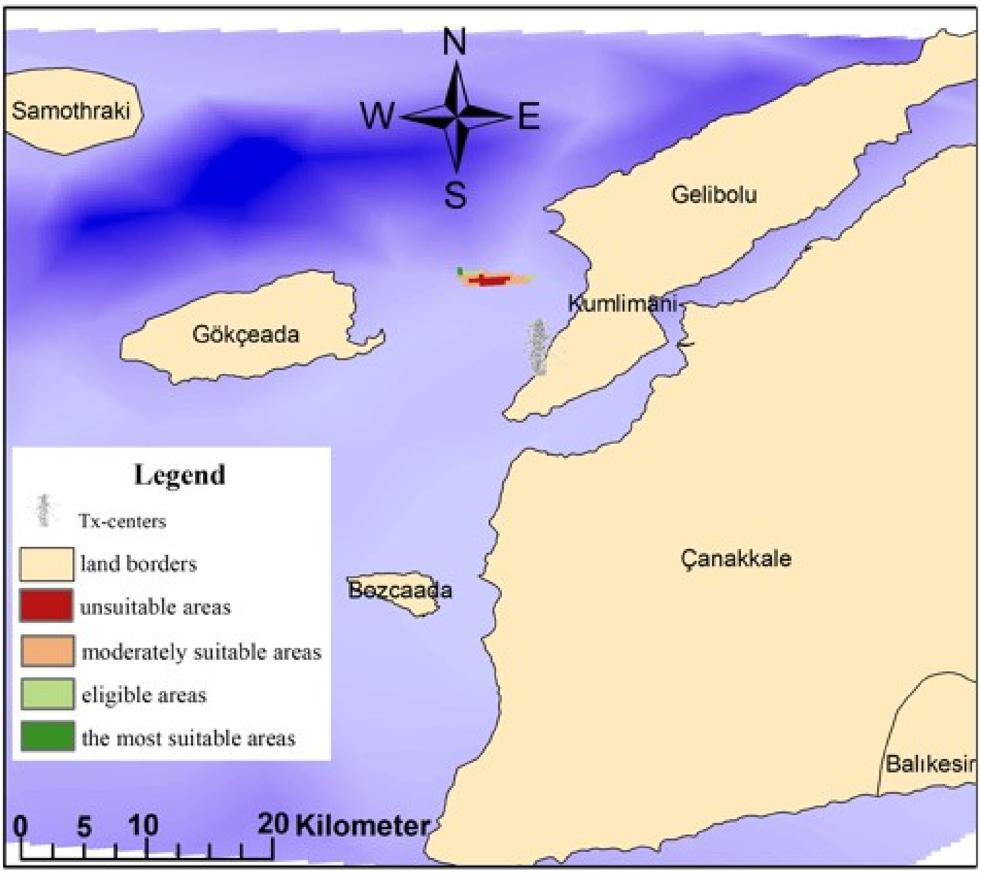


Fig. 16 Alternative site selection according to minimized values

As seen on the map in Fig. 16, the most suitable areas were between Gökçeada and Gelibolu, approximately 12 km from both coasts. It was observed that the average depth in the area was 110 m, and the average wind speed was 18 knots (9.26 m/s).

5. Conclusion and remarks

In this study, the most suitable installation site for floating offshore wind turbines in the Northeast Aegean Sea shores was selected using a GIS-based F-AHP method. For this purpose, the opinions of 9 national and international experts were obtained with a questionnaire. Decision criteria and exclusion criteria including buffer zones were defined considering 9 parameters, which was average wind speed, ship routes, grid connections, sea depth, fault lines, military zones, commercial fishing zones, bird and fish migration routes, and archaeological sites. According to the questionnaire results, among the decision criteria, the most important criterion was the average wind speed (36%), followed by sea depth (28.2%), ship routes (19.3%), grid connections (12.2%), and fault lines (4.3%).

Considering the parameters above that could affect the selection criteria, decision criteria including buffer zones and exclusion criteria were defined. Here, the areas where the average wind speed was less than 6.5 m/s and those where the sea depth was less than 50 m were selected as the exclusion area, while military zones, commercial fishing zones, bird and fish migration routes, and archaeological sites were determined as buffer zones. Then, the fuzzy weights of the decision criteria were calculated using the F-AHP method, and the exclusion stage was completed. Finally, scenario analyses were carried out, and the results are presented below.

The digitization of the selected criteria for distance to ship routes, distance to PDU centers, and distance to faut lines was carried out using the Euclidean distance method in the GIS-based software. Wind speed and bathymetry vectors were digitized using the IDW and TIN methods, respectively, and raster data were obtained. the obtained raster data were reclassified and finalized. With this reclassification process, data points with the same characteristics were classified among each other.

In the reclassification of the raster data created for ship routes, areas 3000 m away from the routes were included. For fault lines, areas 2000 m distant were included in the reclassification. In the reclassification of the bathymetry raster data, high values were assigned to areas between 100 and 300 m of water depth, and low values were assigned to areas with other depth values. The classification process of the substation raster data was carried out in such a way that the regions close to the substations had high values, and other regions had low values. These values used in all reclassification operations were selected from 1 (lowest) to 6 (highest).

The digitized raster data layers reclassified by being overlapped on the same coordinate system (Geographic Coordinate Systems WGS1984 was used as the coordinate system) in this study were superimposed with different criterion weights obtained via F-AHP using the weighted overlay method, and the most suitable floating offshore wind turbine installation site was selected.

In Scenario I, the weighted overlay method was used for the equal assignment of priority weight values to the digitized layers. According to this method, a total of 9 most suitable installation sites were determined, with large areas on the south-southeast offshore of Gökçeada. In these determined sites, the sea depth is 50-85 meters, and wind speeds are in the range of 9-11 m/s (18-21 knots). To make the installation sites more feasible, the weights calculated in line with the opinions of experts were assigned to the determined criteria, and Scenario II was created accordingly. Additionally, an exclusion was made here again for areas with less than 100 meters of sea depth which were accepted as excluded areas in accordance with the literature [56]. Thus, while the number of applicable sites decreased to 7, it was seen that there was also a decrease in the number of suitable installation sites as in Figure 15. The sea depth values varied between 100 and 200 meters with wind speeds varying in the range of 9-11 m/s (18-21 knots).

The results of this study showed that almost all parts of the examined areas were suitable as installation sites. However, Scenario III was created to bring the results to a more feasible and economical level. For this purpose, sites were selected by minimizing the criteria in the most appropriate way, and to reduce cable cost, which is one of the important factors of overall cost, the installation site was selected as close to the grid connection as possible. Located between Çanakkale and Gökçeada, 12 km to the northeast of Gökçeada, this site has an area of 12 square kilometers. The average sea depth is 110 m, and the average wind speed is 9.26 m/s (18 knots). With this potential, enough energy can be generated for settlements on Gökçeada and around the coastlines. The minimum distance of the site is 3000 m to ship routes and 2000 m to fault lines.

This study is believed to be novel and contribute to the literature in that it is the first study to apply the F-AHP method for floating offshore wind turbine installation site selection. Additionally, the study also included distance to fault lines as one of the selection criteria, considering earthquake hazards due to the active faults in the region. It is also thought that this study will directly contribute to further feasibility and cost analysis studies.

It should be known that environmental and ecological studies are needed to take this study further by including criteria such as commercial fisheries, fish and bird migration routes, fish breeding areas, and protected areas in the seas. Additionally, the seabed structure of the region, which was not used as a selection criterion in this study, should be known as it will directly affect the mooring systems of structures.

Consequently, with on-site measurements, the long-term met-ocean characteristics of the region such as waves, currents, and wind speed can be determined, and thus, the factors that will directly affect the design and cost of projects can be considered.

Acknowledgments

This study was produced from the corresponding author's doctoral thesis, titled "Floating Offshore Wind Turbines Motion Analysis and Its Effect of Performance".

REFERENCES

[1] Zhang, Y., Li, D., Hong, S., Zhang, M., 2023. Design of a new oscillating-buoy type wave energy converter and numerical study on its hydrodynamic performance. *Brodogradnja*, 74(1), 145–168. https://doi.org/10.21278/brod74108

[2] Legaz, M. J. Soares, C. G., 2022. Evaluation of various wave energy converters in the bay of Cádiz. *Brodogradnja*, 73(1), 57–88. https://doi.org/10.21278/brod73104

[3] Akalın, S., 2018. Açık Deniz Rüzgar Enerjisi Türbinlerinin Kurulum Yeri Seçimi İçin Bir Model Önerisi. Gazi Üniversitesi.

[4] Kaldellis, J. K., Zafirakis, D., 2011. The wind energy (r)evolution: A short review of a long history. *Renewable Energy*, 36(7), 1887–1901. https://doi.org/10.1016/j.renene.2011.01.002

[5] Global Wind Energy Council, 2017. GWEC Global Wind Report 2017.

[6] Global Wind Energy Council, 2019. GWEC Global Wind Report 2019.

[7] Vagiona, D. G., Kamilakis, M., 2018. Sustainable site selection for offshore wind farms in the South Aegean-Greece. *Sustainability*, 10(3), 749. https://doi.org/10.3390/su10030749

[8] Uzunoglu, E., Karmakar, D. Soares, C. G., 2016. Floating offshore wind platforms. *Floating Offshore Wind Farms*, Springer, 53–76. https://doi.org/10.1007/978-3-319-27972-5_4

[9] Fraile, D., Mbistrova, A., 2016. WindEurope Business Intelligence, *Wind power*.

[10] Uzunoglu, E., 2019. A System for the Hydrodynamic Design of Floating Wind Turbine Platforms. PhD thesis, Instituto Superior Tecnico, Lisbon, Portugal.

[11] Fowai, I., Zhang, J., Sun, K., Wang, B., 2021. Structural analysis of jacket foundations for offshore wind turbines in transitional water. *Brodogradnja*, 72(1), 109–124. https://doi.org/10.21278/brod72106

[12] WindEurope, 2017. The European offshore wind industry–Key trends and statistics 2016, Vol. 20.

[13] Soukissian, T., Papadopoulos, A., Skrimizeas, P., Karathanasi, F., Axaopoulos, P., Avgoustoglou, E., Kyriakidou, H., Tsalis, C., Voudouri, A., Gofa, F., Katsafados, P., 2017. Assessment of offshore wind power potential in the Aegean and Ionian Seas based on high-resolution hindcast model results. *Aims Energy*, 5(2) 268-289. https://doi.org/10.3934/energy.2017.2.268

[14] Kim, J. Y., Oh, K. Y., Kang, K. S., Lee, J. S., 2013. Site selection of offshore wind farms around the Korean Peninsula through economic evaluation. *Renewable Energy*, 54, 189–195. https://doi.org/10.1016/j.renene.2012.08.026

[15] AWS Truewind, 2009. Offshore wind technology overview. Report for the Long Island - New York City Offshore Wind Collaborative, 21.

[16] Archer, C. Jacobson, M., 2003. Spatial and Temporal Distributions of U.S. Winds and Wind power at 80 m Derived from Measurements. *Journal of geophysical research: Atmospheres*, 108(D9). https://doi.org/10.1029/2002JD002076

[17] Christidis, T. Law, J., 2012. The use of geographic information systems in wind turbine and wind energy research. *Journal of Renewable and Sustainable Energy*, 4(1), 12701. https://doi.org/10.1063/1.3673565

[18] Hong, L., Möller, B., 2011. Offshore wind energy potential in China: Under technical, spatial and economic constraints. *Energy*, 36(7), 4482–4491. https://doi.org/10.1016/j.energy.2011.03.071

[19] B. Möller, 2011. Continuous spatial modelling to analyse planning and economic consequences of offshore wind energy, *Energy Policy*, 39(2), 511–517. https://doi.org/10.1016/j.enpol.2010.10.031

[20] Vagiona, D. G., Karanikolas, N. M., 2012. A multicriteria approach to evaluate offshore wind farms siting in Greece, *Global NEST Journal*, 14(2), 235–243. https://doi.org/10.30955/gnj.000868

[21] Christoforaki, M., Tsoutsos, T., 2017. Sustainable siting of an offshore wind park a case in Chania, Crete. *Renewable Energy*, 109, 624–633. https://doi.org/10.1016/j.renene.2017.03.063

[22] Kim, T., Park, J.-I., Maeng, J., 2016. Offshore wind farm site selection study around Jeju Island, South Korea. *Renewable energy*, 94, 619–628. https://doi.org/10.1016/j.renene.2016.03.083

[23] Yue, C.-D., Yang, M.-H., 2009. Exploring the potential of wind energy for a coastal state. *Energy Policy*, 37(10), 3925–3940. https://doi.org/10.1016/j.enpol.2009.04.055

[24] Erkurtulmus, S. A., 2022. Floating offshore wind turbines motion analysis and its effect on performance. Karadeniz Technical University, 2022.

[25] Adigüzel, O., 2009. Personel seçiminin analitik hiyerarşisi prosesi yöntemiyle gerçekleştirilmesi. *Dumlupınar Üniversitesi Sosyal Bilimler* Dergisi, 24, 2009.

[26] Saaty, R. W., 1978. The analytic hierarchy process—what it is and how it is used. *Mathematical modelling*, 9(3–5), 161–176. https://doi.org/10.1016/0270-0255(87)90473-8

[27] Zadeh, L. A., 1996. Fuzzy sets. *Fuzzy sets, fuzzy logic, and fuzzy systems: selected papers by Lotfi A Zadeh*, World Scientific, 394–432. https://doi.org/10.1142/9789814261302_0021

[28] Shafiee, M., 2015. A fuzzy analytic network process model to mitigate the risks associated with offshore wind farms, *Expert Systems with Applications*, 42(4), 2143–2152. https://doi.org/10.1016/j.eswa.2014.10.019

[29] Fetanat, A., Khorasaninejad, E., 2015. A novel hybrid MCDM approach for offshore wind farm site selection: A case study of Iran. *Ocean & Coastal Management*, 109, 17–28. https://doi.org/10.1016/j.ocecoaman.2015.02.005

[30] Li, H., Wang, J., Yang, D., 2006. Where to outsource: Using a hybrid multi-criteria decision aid method for selecting an offshore outsourcing location, *12th Americas Conference on Information Systems (AMCIS 2006)*, 4-6 August, Acapulco, Mexico, 380.

[31] Sánchez-Lozano, J. M., García-Cascales, M. S., Lamata, M. T., 2016. GIS-based onshore wind farm site selection using Fuzzy Multi-Criteria Decision Making methods. Evaluating the case of Southeastern Spain. *Applied Energy*, 171, 86–102. https://doi.org/10.1016/j.apenergy.2016.03.030

[32] Caceoğlu, E., Yildiz, H. K., Oğuz, E., Huvaj, N., Guerrero, J. M., 2022. Offshore wind power plant site selection using Analytical Hierarchy Process for Northwest Turkey. *Ocean Engineering*, 252, 111178. https://doi.org/10.1016/j.oceaneng.2022.111178

[33] Genç, M. S., Karipoğlu, F., Koca, K., Azgın, Ş. T., 2021. Suitable site selection for offshore wind farms in Turkey's seas: GIS-MCDM based approach. *Earth Science Informatics*, 14(3), 1213–1225. https://doi.org/10.1007/s12145-021-00632-3

[34] Tercan, E., Tapkın, S., Latinopoulos, D., Dereli, M. A., Tsiropoulos, A., Ak, M. F., 2020. A GIS-based multi-criteria model for offshore wind energy power plants site selection in both sides of the Aegean Sea. *Environmental Monitoring and Assessment*, 192(10), 652. https://doi.org/10.1007/s10661-020-08603-9

[35] Yerci, V., 2015. Türkiye denizlerindeki rüzgâr enerjisi potansiyeli ve deniz üstü rüzgâr santralleri kurulabilecek bölgelerin belirlenmesi, Fen Bilimleri Enstitüsü.

[36] Özdilim, A. M., 2017. Türkiye'de Kurulabilecek Deniz Üstü Rüzgâr Santralinin Teknik ve Ekonomik Analizi. *13. Ulusal Tesisat Mühendisliği Kongresi Sonuç Bildirisi*, 15.

[37] Emeksiz, C., Demirci, B., 2019. The determination of offshore wind energy potential of Turkey by using novelty hybrid site selection method. *Sustainable Energy Technologies and Assessments*, 36, 100562. https://doi.org/10.1016/j.seta.2019.100562

[38] Argin, M., Yerci, V., Erdogan, N., Kucuksari, S., Cali, U., 2019. Exploring the offshore wind energy potential of Turkey based on multi-criteria site selection, *Energy Strategy Reviews*, 23, 33–46. https://doi.org/10.1016/j.esr.2018.12.005

[39] T.C. Enerji ve Tabii Kaynaklar Bakanlığı, 2021. Yillik Ortalama Rüzgar Hizi Dağilimi – 100 Metre. *Repa*. https://repa.enerji.gov.tr/REPA/bolgeler/TURKIYE-GENELI.pdf

[40] Fitzpatrick, C., Maguire, D. J., 2000. GIS in schools: Infrastructure, methodology and role, *GIS: A sourcebook for schools*, 62–73.

[41] Marine Traffic. Çanakkele Rüzgâr Haritası. https://www.marinetraffic.com/en/ais/home/centerx:25.9/centery:39.5/zoom:9

[42] Sulaiman, O. O., Magee, A., Bahrain, Z., Kader, A. S. A., Maimun, A., Pauzi, A. G., Wan Nick, W.B., Othman, K., 2013. Mooring analysis for very large offshore aquaculture ocean plantation floating structure. *Ocean & Coastal Management*, 80, 80–88. https://doi.org/10.1016/j.ocecoaman.2013.02.010

[43] Karakaşoğlu, N., 2008. Bulanık çok kriterli karar verme yöntemleri ve uygulama.

[44] Timor, M., 2011. *Analitik hiyerarşi prosesi*. Türkmen Kitabevi.

[45] Timor, M., 2022. Kolayda ürünler için perakende satış yeri seçimi: Bir Analitik Hiyerarşi Prosesi uygulaması, *Yönetim Dergisi İstanbul Üniversitesi İşletme Fakültesi İşletme İktisadı Enstitüsü*, 13(41), 23–36.

[46] Özgörmüş, E., Mutlu, Ö., Güner, H., 2005. Bulanık AHP ile personel seçimi. V. Ulusal Üretim

[47] Van Laarhoven, P. J. M., Pedrycz, W., 1983. A fuzzy extension of Saaty's priority theory. *Fuzzy Sets and Systems*, 11(1–3), 229–241. https://doi.org/10.1016/S0165-0114(83)80082-7

[48] Önüt, S., Kara, S. S., Işik, E., 2009. Long term supplier selection using a combined fuzzy MCDM approach: A case study for a telecommunication company. *Expert Systems with Applications*, 36(2), 3887–3895. https://doi.org/10.1016/j.eswa.2008.02.045

[49] Özçelik, S., 2011. Çok yönlü personellerin değerlendirilmesi ve üretim hattı personel atama problemi için bir optimizasyon modeli. *Gazi Üniversitesi Fen Bilim. Enstitüsü*, Ankara.

[50] World Bank, Energy Sector Management Assistance Program, 2019. *Going Global: Expanding Offshore Wind To Emerging Markets*.

[51] Cradden, L., Kalogeri, C., Barrios, I. M., Galanis, G., Ingram, D. Kallos, and G., 2016. Multi-criteria site selection for offshore renewable energy platforms. *Renewable energy*, 87, 791–806. https://doi.org/10.1016/j.renene.2015.10.035

[52] Vasileiou, M., Loukogeorgaki, E., Vagiona, D. G., 2017. GIS-based multi-criteria decision analysis for site selection of hybrid offshore wind and wave energy systems in Greece. *Renewable and Sustainable Energy* Reviews, 73, 745–757. https://doi.org/10.1016/j.rser.2017.01.161

[53] Sourianos, E., Kyriakou, K., Hatiris, G. A., 2017. GIS-based spatial decision support system for the optimum siting of offshore windfarms. *European Water*, 58, 337–343.

[54] Díaz, H., Soares, C. G., 2020. An integrated GIS approach for site selection of floating offshore wind farms in the Atlantic

continental European coastline. *Renewable and Sustainable Energy Reviews*, 134, 110328. https://doi.org/10.1016/j.rser.2020.110328

[55] Kim, C. K., Jang, S., Kim, T. Y., 2018. Site selection for offshore wind farms in the southwest coast of South Korea. *Renewable energy*, 120, 151–162. https://doi.org/10.1016/j.renene.2017.12.081

[56] Malhotra, S., 2011. Selection, Design and Construction of Offshore Wind Turbine Foundations. https://doi.org/10.5772/15461

[57] Marine Traffic. Türkiye Deniz Trafiği Yoğunluğu. https://www.marinetraffic.com/en/ais/home/centerx:29.2/centery:38.6/zoom:6

[58] Rawson, A., Rogers, E., 2015. Assessing the impacts to vessel traffic from offshore wind farms in the Thames Estuary. *Zeszyty Naukowe Akademii Morskiej w Szczecinie*, 43(115), 99–107.

[59] REPA, 2018. Çanakkale ili rüzgar kaynak bilgileri.

[60] Rasathanesi, K., 2021. Kandilli-çanakkale-deprem. http://www.koeri.boun.edu.tr/sismo/2/son-depremler/harita-uzerinde/.

[61] Meola, B., Webster, C., 2019. MedPAN and SPA/RAC, 2019. The 2016 status of Marine Protected Areas in the Mediterranean. November, 222. http://rac-spa.org/sites/default/files/doc_medmpanet2/statut_amp_en.pdf