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Research Article

Site Selection and Capacity Determination of Potential Offshore Wind Farm in Western Black Sea Region of Turkiye

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Abstract

In this study, the site selection and capacity determination of a potential offshore wind farm in the western Black Sea region of Turkey is carried out by applying technical, environmental, and social criteria in full details for a suitable location along a coastline segment of 600 km-length. The region selected for the wind farm is located off the Kıyıköy shores which covers approximately 75-80 km^2 area. According to an intended target for the size and capacity of the planned wind farm, 99 wind turbines of V174-9.5 MW with rotor diameter 174 m and hub height 110 m are suggested for the possible area use. The nominal power capacity of the entire farm is calculated by the use of wind data for the region and technical data of the selected turbine. The calculations give an estimated total annual energy yield of 3300 GW·h/year, corresponding to a supply of energy for nearly one million people. Being a first detailed work carried out for this particular region the study is expected to provide an incentive for further more comprehensive works which may eventually lead to an actual installation of a wind farm.

Keywords: Wind energy, Offshore wind farms (OWF), Selection criteria for OWF, Capacity determination of OWF

Introduction

Use of fossil fuels such as oil, gas, and coal, still remains the dominant way of fulfilling the energy needs hence increase in emissions of carbon dioxide and other greenhouse gases continues, contributing the global climate change appreciably. Non-renewable energy currently supplies around 80% of the world’s total energy need. The Intergovernmental Panel on Climate Change (IPCC) has found that emissions from fossil fuels are the dominant cause of global warming. In 2018, 89% of global CO2 emissions came from fossil fuels and industry.

According to the United States EIA, the world energy consumption is expected to increase approximately 50% between 2020 and 2050 [URL1]. In order to reduce the amount of carbon dioxide in the air, especially developed countries should accelerate the transition from the fossil-based systems to energy supplies with low carbon dioxide production. To achieve this aim, there are basically two options: nuclear energy and renewable energies (wind, bioenergy, solar, marine, hydropower, and geothermal energy). Among renewable energies the wind energy stands out as the most promising choice. Today, wind turbines are increasing rapidly in almost every part of the world; according to the latest data published by IRENA, electricity generated from wind energy in 2016 accounted for 6% of the energy produced from all renewable sources [URL2, URL3]. Within the period between 2001-2019 the worldwide energy production from the wind reached 651 GW [URL4]. The appreciable increase in wind energy production can be observed by comparing the energy production of 539 GW by the end of 2017 [URL5-URL7] to 591 GW in 2018 [URL6, URL7], denoting an increase of 9.6%. In highly populated countries such as India and China the wind energy trend began around the early 2010’s and subsequently overtook those of traditional markets in North America and Europe, reaching to a level more than half the worldwide production. China's wind power generation reached 145 GW in 2015, claiming almost half the wind energy produced in the world [URL5]. According to the data of 2018, nearly half of the world's countries use wind energy and some countries have managed to raise this indicator to higher levels. For example, 41% of electricity production in Denmark is provided by the wind energy, this is 28% in Ireland, 21% in Germany, and 19% in Spain [URL7].

Wind farms are built as onshore and offshore wind farms. These choices have their own advantages and disadvantages. For instance, compared to offshore the onshore locations have the disadvantage of relatively reduced and non-uniform wind speeds due to the presence of natural and/or artificial obstacles. Furthermore, there is the work of leveling of land and hills, hence harming the forests, which are habitats of birds, and other living species. On the other hand, offshore wind farms do not pose as many threats to living species in comparison with those of onshore farms but the initial investment and maintenance of the offshore wind farms are considerably costlier and difficult to accomplish. Nevertheless, the annual reports of WindEurope reveal that, in 2019 the capacity of onshore wind turbine farms in Europe was accounting for 24% of the renewable energy on the average, while this indicator was 38% for offshore wind farms [URL8]. Taking these points into account, for countries with coastal regions it is plausible to prefer offshore wind farms. As a result, the offshore wind energy market is growing rapidly and offshore wind energy has great significance in terms of energy security of developing countries such as Turkey. According to the research conducted in 2020, in meeting Turkey's electricity needs the coal is still the first source by 35%, the hydro-power plants is in the second place by 26%, and the third place is occupied by the electricity generated from wind, solar and geothermal power plants which accounts for 15% [URL9].

Fig. 1. Region of interest for offshore wind farm.

Although presently no offshore wind farms exist in Turkish waters, preliminary studies concerning potential offshore wind farms are conducted within the last decade. Due to relatively higher wind speeds, the Aegean Sea shores, Bozcaada and Gökçeada receive particular attention in these studies (Satır et al., 2017; Turhanlar, 2018). Naturally, this attention was not restricted to the Turkish waters; Konstantinidis et al. (2014) studied the possibility of offshore wind farm construction for North Aegean Sea. In the same vein, a study covering both sides of the Aegean Sea was carried out by Tercan et al. (2020). Relatively less noticed regions such as Antakya Bay (Öksel at al., 2016) and Bandırma Bay (Karipoğlu et al., 2021) were also studied in terms of their potential to accommodate offshore wind farms. Küçükali and Dinçkal (2014) considered the West Black Sea region while İlkılıç and Aydın (2015) surveyed the entire coastal regions of Turkey and relatively recently Genç et al. (2021) did a similar broad search for suitable offshore wind farm locations in Turkish waters (Öztürk and Serkendiz, 2018).

The present work attempts to determine a suitable location for a relatively large offshore wind farm in the western Black Sea region of Turkish waters, determines the layout and foundation types, and finally estimates the production capacity of the suggested wind farm. The study should be viewed as an initiative for supplying a framework for selecting a more suitable part in this particular region, where realization of an actual wind farm is desirable due to relatively high energy demand in the area. Thus, with the ultimate aim of an actual installation of a wind farm, other more comprehensive works comprising the estimation of environmental and installation costs together with feasibility analysis may follow this attempt.

Methodology

The initial selection of the west part of Black Sea rests on four main reasons: first, being in close proximity to Istanbul, there is a big demand for energy in the region; second, grid connection problem is relatively easier to solve; third, this area has considerably higher wind speeds compared to the eastern Black Sea; fourth, international territorial problems are minimum. Once this broad regional selection is done the detailed work here narrows down the choices to two particular locations by employing virtually standard screening steps which examine technical, environmental, and social aspects. Following the tentative determination of a definite region gives access to bathymetric conditions hence comes the choice of foundation type. Further, depending on the actual mean wind speeds of the region the turbine type with a definite hub height is selected so that the wind speeds at the hub height satisfy at least the required minimum wind speed for a commercially feasible farm. Finally, with all the technical data available and the number of turbines decided, a good estimate for the energy production capacity of the wind farm is computed.

Applications of Criteria for Location Selection of Wind Farm

In this work, location selection, layout, foundation type, annual energy production capacity of a potential offshore wind farm in the western Black Sea region of Turkey are carried out.

Location selection is done first by considering technical, environmental, and social aspects. These three aspects are further divided into sub-items as follows (Genç et al., 2021).

- Technical: Wind speed, water depth.
- Environmental: Bird migrations, ship traffic density, fault lines, underwater cables and pipelines, civil aviation, military regions, territorial waters.
- Social: Tourism, fishery.

The potential region considered in this study is an approximately 600 km shoreline in the western part of the Black Sea shown in a Google Earth map covering the region of interest between Beğendik and Zonguldak (Fig. 1). This region basically corresponds to the northern part of the Marmara Region which includes the cities of Kırklareli, Tekirdağ, İstanbul, Kocaeli, Sakarya besides the provinces of Düzce and Zonguldak.

Technical Criteria

Wind speed: The average wind speeds measured across the Black Sea vary in the range 6.70 to 7.44 m/s in the west and 1.60 to 1.85 m/s in the east (İşlek et al., 2020). Typically, wind speeds 7.00 m/s and higher at 50 m height are considered feasible for wind farms as indicated in (Genç et al., 2021). The wind speeds in some parts of the present region of interest are slightly below (6.7 m/s) the expected average of 7.00 m/s but can be compensated by higher turbine towers as done in Sections 4 and 5 for commercially feasible operation. From the web page "globalwindatlas.info" the measured average wind speeds are determined to be 5.55 m/s at 10 m height and 6.59 m/s at 50 m height above the sea level as seen in Fig. 2 [URL10].

Water depth: The relevant bathymetric maps, which could not be included here due to space limitations, reveal that the nearshore water depths in the entire region of interest are typically less than 50 m, hence suitable for the installations of monopile foundations. On the other hand, the average wind speeds from Istanbul (Asian side) to Zonguldak remain below 6.25 m/s even for 100 m above sea level. These relatively low wind speeds necessitate the location of potential wind farm be selected in a region farther west where higher wind speeds are observed.

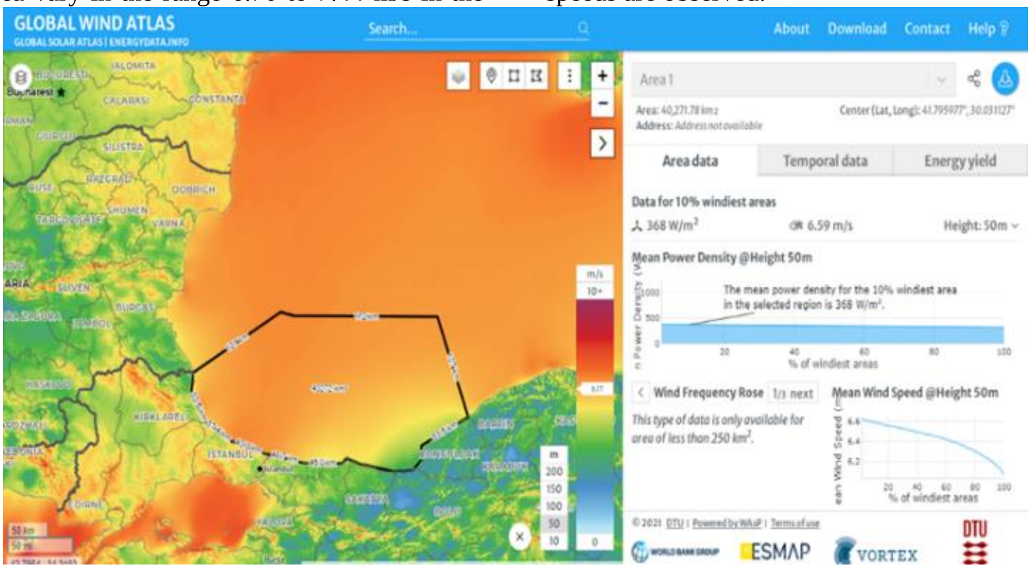

Fig. 2. Data chart for average wind speeds at 50 m height (lower) above the sea level in area of interest.

Fig. 3. Main migration routes of birds across Turkey as given in [URL11].

Environmental Criteria

Typically, environmental considerations imply the effects related to nature itself or natural life forms, but when choosing a location for a wind farm, it also is necessary to consider the interactions with human activities and man-made constructions. Potential conflicts due to land uses, environmentally sensitive regions, and the overall profile of the area must all be accounted for and a "buffer zone" must be placed between the wind farm and such environmentally sensitive areas (Vagiona and Kamilakis, 2018). Buffer zone lengths for various areas can be found in (Genç et al., 2021; Vagiona and Kamilakis, 2018). Accordingly,

- Historical places – 3000 m.
- • Other protected areas/natural protection areas – 3000 m
- Ship wrecks – 1000 m
- Bird protection areas – 500 m
- Military areas – 3000 m
- Airports – 3000 m
- Beaches (Only Blue Flag beaches) – 1000-1500 m
- Shipping lane – 2-5 nm (1 nm=1.852 km)
- Small ships – 350 m

Migration routes of birds: Some main migration routes of birds (Black Sea–Mediterranean Flyway) pass across Turkey as sketched in Fig. 3 [URL11].

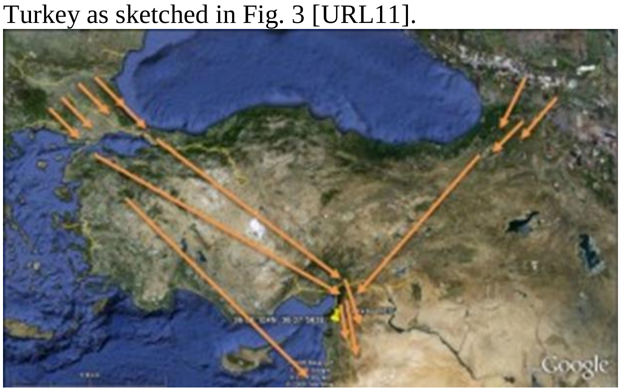

Fig. 3. Main migration routes of birds across Turkey as given in [URL11].

The region under consideration is somewhat near the one of these main routes but not in it; therefore, the threat to the birds is relatively low. However, there are some important "bird areas" in the study region that must be avoided: Iğneada Floodplain Forests National Park, Çamlıköy Nature park, Çilingoz Nature park, Lake Durusu [URL12]. The buffer zones for Iğneada and Çilingöz Natural Parks are 3000 m, as these regions are both natural parks and bird habitats. On the other hand, being a bird protection area the buffer zone for the Lake Durusu is 500 m. Fig. 4 shows a sketch of buffer zones for these areas as indicated on a Google map.

Earthquakes: Earthquakes are one of the biggest natural disasters that can cause loss of life and money. Turkey is among the seismically most active regions in the world and the North Anatolian fault line passes near the study area. According to the data from the Kandilli Observatory and Earthquake Research Institute [URL13], the largest earthquake that has occurred in the region since the beginning of 2020 has a magnitude of 4. While this earthquake is relatively near the considered region, it is an isolated earthquake outside the North Anatolian Fault Line hence we may assume that earthquakes with greater magnitudes are unlikely to occur in this particular area. This assumption is supported by the past records of earthquakes that occurred in the region of interest.

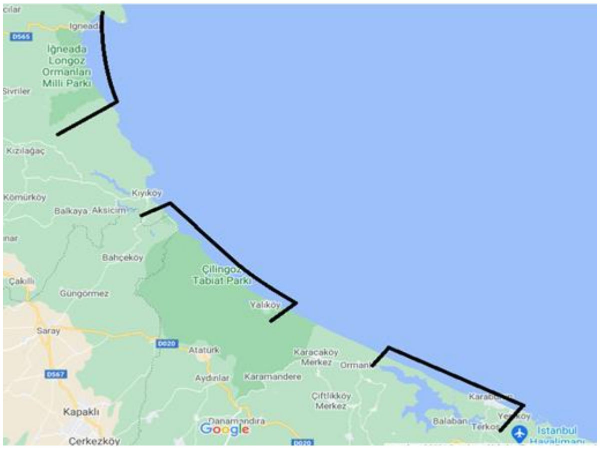

Fig. 4. Sketch of buffer zones for Iğneada, Çamlıköy, Çilingöz Natural Parks and Lake Durusu.

Civil and military airports and military areas: Wind turbines can have some negative effects on aviation. These are divided into two parts: direct and indirect impacts [URL14].

- Direct impacts – Physical, technical and operational
- Indirect impact – Economical and environmental

Direct impacts

Physical: The most important physical impact wind turbines pose is physical threat to the flight's safety. This would mostly occur when airplanes are closest to the land; namely, when taking off and landing to airports, or while participating in low-altitude flying operations, typically for military purposes.

Technical: Any wind turbine (or other obstruction) within line of sight of aviation disrupts the flow (transmission and reception) of radio signals, potentially causing the equipment to malfunction. Generally speaking, wind turbines can disrupt radar networks used for civil or military aviation.

Operational: A flight safety issue may occur if a controller sees anything that is inaccurate or unclear. Hence, obstacles arising from technical and physical problems can cause flight intensity, which can distract the controller and cause accidents [URL14].

Indirect impacts

Economic and environmental: If a flight route changes, fuel used by the aircraft increases, thus affecting the flight costs. Also, from an ecological point of view, staying in the air longer means more fuel, which means more CO_2 emissions into the air [URL14].

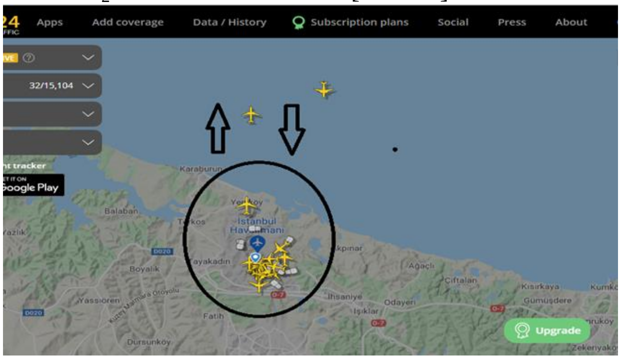

Fig. 5. Buffer zone (black circle) for Istanbul Airport and take-off/landing directions.

When all such drawbacks are considered, a buffer zone must be applied for airports as well. The buffer zone for the airports are applied as 3 km when choosing a potential location for an offshore wind turbine. Fig. 5 shows the largest airport in the area (Istanbul Airport) and the black circle delineates the buffer zone of 3 km.

Military areas: It was determined that at present there is no military air base on the land in the region, but according to the information published in the official newspaper on May 27, 2020, the area located on the Black Sea coast of Kırklareli, about 5 kilometers from the Bulgarian border, is declared a second-degree military forbidden zone. The military forbidden zone in the north of Iğneada covers an area of approximately 20 square kilometers (T.R. Official Gazette, 2020). To avoid hindering military radars and activities in the region, again a buffer zone of 3 km is applied.

Shipping traffic density: Between the outside borders of an offshore wind farm and the shipping lane, a proper safety barrier of 2 nm (nautical miles) must be kept. At the entry and departure of a traffic separation scheme, the safety zones among shipping lanes and an offshore wind farm should be a minimum of 5 nm, and a minimum distance of 4 nm should be observed from an anchorage (Konstantinidis et al., 2014). Fig. 6 shows the shipping traffic density outside the Strait of Istanbul in the Black Sea [URL15].

Territorial waters: In 1982 United Nations Convention on the Law of the Sea defined that, coastal waters for a country should not exceed 12 nautical miles from the coastline country's shoreline [URL16]. In terms of territorial waters, no problems are identified as the region can accommodate the potential wind farm considered without any conflict with the territorial waters of Bulgaria, which is the closest country to the region.

Underwater cables and pipelines: Turkey harbors many global energy and communication lines, either as a transit country due to its geographical location or for its own needs. KAFOS (The Black Sea Fiber Optic System) is a subsea line that connects Romania, Bulgaria, and Turkey to the current network across the Black Sea. The first leg coming from Bulgaria is in the Iğneada region within the scope of the military forbidden zone while the second leg passes far from the coast and does not pose any problem for a wind farm [URL17].

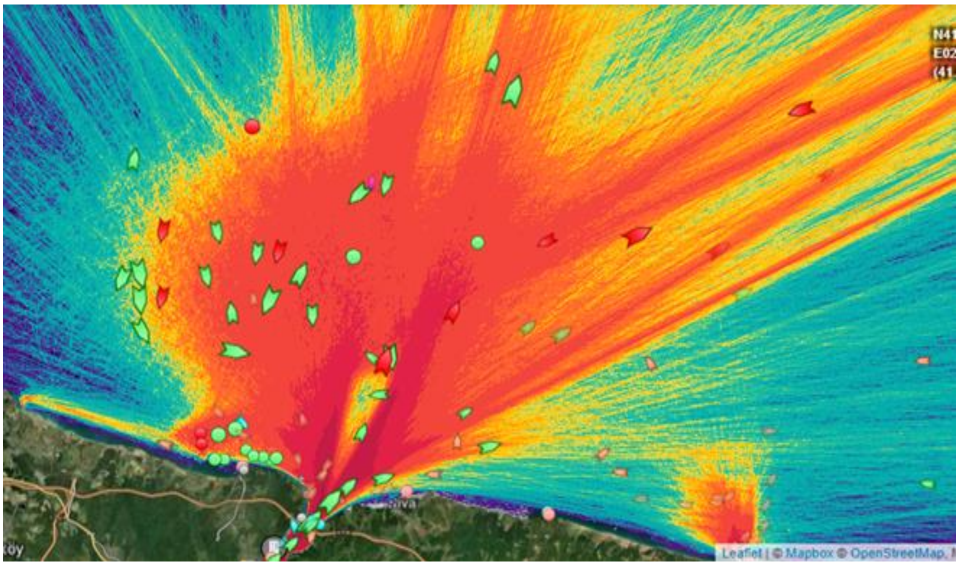

Fig. 6. Shipping traffic density outside of the Strait of Istanbul in the Black Sea.

The other project is the TurkStream, which is an important project for Turkey and other countries in the region. The relevant public body has given their clearance for a 420 m (210 m on either side of the pipeline) wide operating safety zone along the pipeline route. This safety zone denotes an operational safety zone that restricts third-party seabed-related activities (anchorage, trawling, other construction).

Social Criteria

Tourism: There is just one Blue-Flag beach in Iğneada, which is already restricted by a buffer zone. Outside the buffer zones there are three more beaches: Poliçe (South side of Iğneada Natural Park), Evcik, and Ormanlı beaches (between Çilingoz Natural Park and Lake Durusu). Due to their relatively small sizes these beaches are not preferred by tourists and generally used by local people. For instance, the Poliçe beach is located in a bay with a length of 200 m. Normally, beaches with special status (e.g. Blue-Flag beaches) are taken under protection. Despite this permission, in this work a 1000 m security circle is defined for these beaches in order to ensure the safety of the local people and their right to use the sea.

Fishery: Fishery is an important factor that must be considered for this region as the Black Sea provides 76% of Turkey's total fish production. As a result of live observations made in the web page [URL15], it was determined that there are two major ports used by fishing boats in the region: Iğneada and Kıyıköy. Since the Iğneada port is located near the Iğneada Natural Park and this area is already in the buffer zone, no construction can be done in this area. Considering the east of Iğneada, besides the presence of fishing boats, the water depths are typically more than 70 meters hence these parts are not suitable for a wind farm either. The Kıyıköy Port is located outside the safe zone of the TurkStream project but due to the fishing traffic on the east part of the port this region would not be a good choice. Finally, leaving a distance of 350 m (Turhanlar, 2018) between the concentration area of fishing boats and the potential wind farm, the remaining area between Iğneada and Kıyıköy Ports for the offshore wind farm would be as sketched in Fig. 7. This potential region is termed as the first region hereafter. Considering the other possible region between Çingöz Natural Park and Lake Durusu; fishery activities are not observed here hence a potential area for a wind farm is possible as sketched in Fig. 8. This potential region is termed as the second region hereafter.

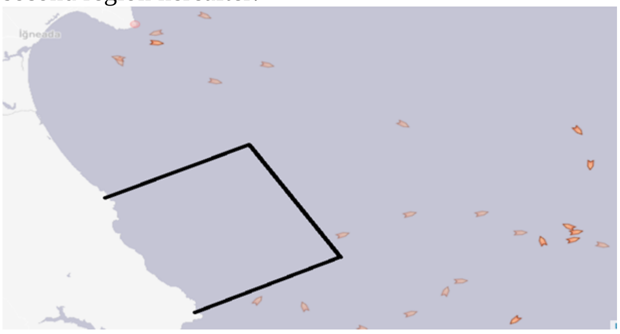

Fig. 7. The first potential region for an offshore wind farm between Iğneada Natural Park and TurkStream project.

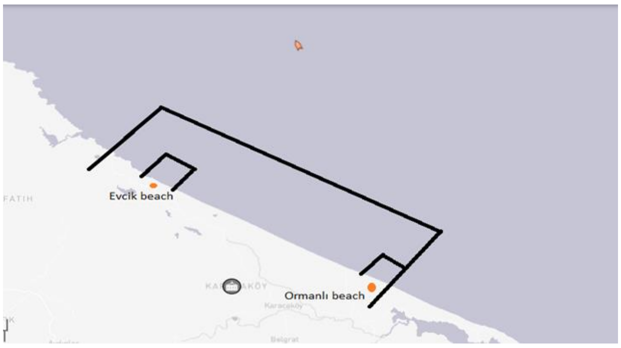

Fig. 8. The second potential region for an offshore wind farm between Çilingoz Natural Park and Lake Durusu.

Bathymetric Comparisons

The preceding detailed analyses reveal that due to various restrictions considered only two regions are suitable for a possible wind farm construction. To make the final selection, bathymetry, wind conditions, and suitability of grid connections are to be compared. Bathymetric maps of these regions, which could not be included due to space limitations, show that in principle both regions are appropriate. However, the second region is relatively narrower and for a given number of turbines it is necessary to install more turbines in the deeper regions hence the first region has a slight advantage over the first one in terms of bathymetric conditions.

Wind Speed Comparisons

The measured data shows that the mean wind speed at 50 m height is 6.38 m/s for the first region and 6.53 m/s for the second region. Contrary to the bathymetric considerations, in terms of the wind speeds, the second region is obviously advantageous and this point should be viewed with importance for the final selection.

Grid Connections

Wind turbine cables are linked to an offshore substation and then connected to an onshore transmission line. The power grid on land is the place where the wires from the offshore wind farm substation are linked. Grid connection site must be verified since these connection cables are costly and must be placed as short as feasible. This is a crucial consideration in the location selection for the wind farm. A wind power plant on land is presently located in Kıyıköy, close to the first region. This makes it easier to connect the energy from a future wind farm to the grid, thus making the first region preferable in this aspect compared to the second region.

Results

Overall, both regions are acceptable choices for a potential wind farm. Nevertheless, in terms of logistics and grid connections, the first region has advantages over the second one. Thus, out of four main factors; namely, logistics, grid connections, wind speeds, and water depths, the first region is better for the first two factors, slightly inferior concerning the wind speeds, and nearly equal in bathymetric aspects when compared with the second region. With these nearly balanced considerations we tentatively select the first region shown in Fig. 9 as a candidate for a potential wind farm.

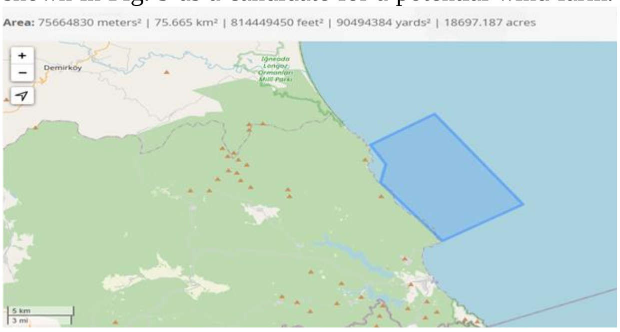

Fig. 9. Selected location of Iğneada and Kıyıköy (the first region) for a potential wind farm.

However, it must be emphasized that the second region has very similar qualities and in case some other favorable aspects arise, this region may be preferred as well, especially when the relatively higher average wind speeds hence higher energy production capacity is considered.

Turbine Selection

Considering the average wind speeds of the selected region, the V174-9.5 MW™ wind turbine produced by Vestas appears to be a good choice in terms of its energy production capacity and relatively high hub height, which is quite necessary for the present project to reach mean wind speeds of 7.00 m/s. The technical data of the turbines are given as [URL18]:

- Cut-in wind speed: 3 m/s
- Cut-out wind speed: 25 m/s
- Standard operating temperature range: From -15°C to +25°C with a de-rating interval from +25°C to +35°C
- Rotor diameter: 174 m
- Swept area: 23779 m^2 ($A=\pi r^2$)
- Approximate hub height: 110 m
- Approximate tip height: 197 m
- Rated power: 9.5 MW with an optimal rotor to generator ratio
- Ratio power: 9500/9600 kW

Logistic reasons also support the choice of Vestas. The company installed the first wind turbines in Turkey in 1984 and later opened an office in Istanbul in 2008. Presently, Vestas supplies more than 600 MW of wind energy capacity to the region with three warehouses and service stations in the nation [URL18].

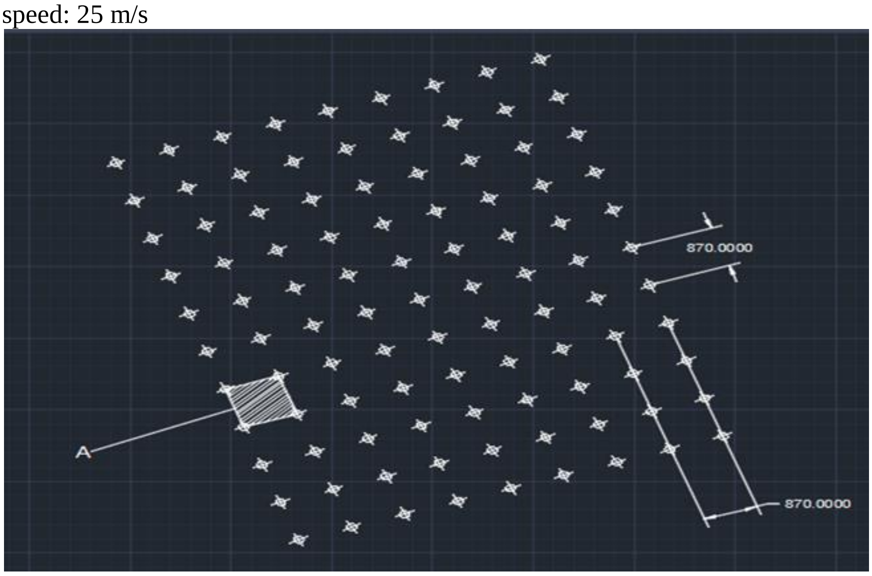

Fig. 10. Layout sketch of wind farm. Distances indicated are in meters.

Layout of Wind Farm

The area of the selected region is approximately 75-80 km^2 with a length and width nearly 10 km and 7.5 to 8 km. Taking an optimal distance of 5 rotor diameters to reduce the wake effects between any two wind turbines results in 5·174 m = 870 m intervals. In view of the available area a big wind farm consisting of 99 turbines (11 by 9 rows) with a total nominal power capacity 940 MW is proposed. This farm requires approximately 60 km^2 area, considering A=0.87·0.87=0.7569 km^2 denotes the area cornered by four turbines the area of the entire wind farm is 10·8·A=60.55 km^2, which is well within the limits of 75-80 km^2 available area. Various types of layout forms are used in design of offshore wind farms but three of them are preferred much more than others: square layout, hexagonal layout, octagonal layout. For the current project the square layout is preferred as depicted in Fig. 10. Finally, although water depths reach to 65 m in deeper parts of the proposed farm, the foundations are decided to be monopile as monopile foundations are currently the proven technology.

Production Capacity of Wind Farm

In order to determine the actual power production capacity of a turbine the wind speed at the hub height must be estimated first. For the selected turbine type the hub height is specified as 110 m, while the available measured wind data are given at 100 m and 150 m heights. Using the logarithmic wind profile assumption (Beji and Lützen, 2021),

$$V_h = V_{href} \frac{ln(h/z_0)}{ln(h_{ref}/z_0)} \tag{1}$$

the wind speeds at 100 m are determined from the data at 100 m and 150 m heights, separately. In eqn. (1) z_0 denotes the roughness length and it can be taken as 0.0002 for winds blowing over the sea surface.

The measured mean wind speed ranges are given as 6.74-6.96 m/s at 100 m altitude and 6.94-7.43 m/s at 150 m altitude. Using eqn. (1) with $z_0 = 0.0002$ for the measured ranges gives;

$$V(110) = 6.74 \frac{ln(110/0.0002)}{ln(100/0.0002)} = 6.79 \text{ m/s}$$

$$V(110) = 6.96 \frac{ln(110/0.0002)}{ln(100/0.0002)} = 7.01 \text{ m/s}$$

for the data taken at 100 m height, and

$$V(110) = 6.94 \frac{ln(110/0.0002)}{ln(150/0.0002)} = 6.78 \text{ m/s}$$
$$V(110) = 7.43 \frac{ln(110/0.0002)}{ln(150/0.0002)} = 7.26 \text{ m/s}$$

for the data taken at 150 m height. Thus, according to the above estimates, the measured wind speed at the hub height of 110 m varies between 6.78 m/s to 7.26 m/s. The average wind speed is 7.02 m/s, which can be rounded off to 7 m/s. Then, to a very good approximation the annual energy yield calculations can be done for the mean wind speed 7 m/s. The annual energy production of a single turbine can be estimated from the following formula (Beji and Lützen, 2021)

$$E_{Trb} = P_{rated} \cdot T_{equivalent} = P_{rated} \cdot cf \cdot T_{year} \quad (2)$$

Where P_{rated} is the rated power of the turbine, cf is the capacity factor determined according to the probability density function of the wind speeds, and $T_{year} = 8760$ hours is the total hours in a year. For the present purposes, instead of carrying out lengthy calculations, assuming a capacity factor $cf = 0.4$ is quite acceptable to get a good estimate.

$$E_{Trb} = 9.5 \text{ MW} \cdot 0.4 \cdot 8760 \text{ hours}$$
$$E_{Trb} = 33288 \text{ MWh/year} \approx 33.3 \text{ GWh/year} \quad (3)$$

The estimated annual energy output is then approximately $E_{Trb} = 33.3$ GWh/year per turbine. For the entire wind farm of 99 turbines the estimated total energy yield is $99 \cdot 33.3 \text{ GWh/year} \approx 3300 \text{ GWh/year}$.

The estimated energy production of the proposed wind farm can be used to calculate the number of people who can benefit from such a farm. The data from BP's (British Petroleum) statistical analysis of world energy for 2020 shows that the annual average electricity consumption per capita in Turkey is approximately 3500 kWh [URL19].

Dividing the estimated energy yield by the annual average energy consumption of 3500 kWh/year gives the number of people the wind farm can serve: $3300 \cdot 10^6 \text{ kWh/year} 3500 \text{ kWh/year} \approx 940000 \text{ persons}$.
Thus, the proposed wind farm, being quite large for today's standards can serve nearly one million people.

Discussion and Conclusion

Location selection and preliminary calculations of a relatively large wind farm in the western Black Sea region of Turkey are presented. The location selection is carried out by considering three main criteria: technical, environmental, and social. Each main criterium contains subitems which must be satisfied to ensure the selection of an acceptable region. After searching along a shoreline of approximately 600 km, only two regions; namely, the strip between Iğneada and Kıyıköy and the strip between Çilingoz Natural Park and Lake Durusu are found to satisfy the requirements. Although the first region is tentatively selected as the suitable one, the second region too may be considered as a possible choice since both regions are quite balanced against each other. A slight drawback of the proposed project lays on the mean wind speed at the hub height, which is 7.00 m/s. This speed, as indicated, is the minimum wind speed required for a commercially feasible wind farm. It must also be indicated that this speed could be achieved for the selected turbine at 110 m hub height. Nevertheless, for the Black Sea this wind speed is the maximum that could be achieved and accordingly the proposed wind farm is calculated to produce an estimated total annual energy of 33.3 GWh/year, capable of serving the electric energy needs of nearly one million people.

Acknowledgement

This work was compiled from the master's thesis of the first author at Faculty of Naval Architecture and Ocean Engineering, Istanbul Technical University.

References

Beji, S., Lützen, U. (2021). Offshore Wind Farm Design Lecture Notes. Faculty of Naval Architecture and Ocean Engineering, Istanbul Technical University.

Genc, M.S., Karipoglu, F., Koca, K., Azgin, S.T. (2021). Suitable site selection for offshore wind farms in Turkey's seas: GIS‑MCDM based approach. *Earth Science Informatics*, *14*, 1213-1225.

İlkılıç, C., Aydın, H. (2015). Wind power potential and usage in the coastal regions of Turkey. *Renew. Sustain. Energy Rev.*, *44*, 78-86.

İslek, F., Yüksel, Y., Şahin, C. (2020). Spatiotemporal long-term trends of extreme windcharacteristics over the Black Sea. *Dynamics of Atmospheres and Oceans*, *90*, 101132.

Karipoğlu, F., Öztürk, S., Genç, M.S. (2021). Determining suitable regions for potential offshore wind farms in Bandırma Bay using multi-criteria-decision-making method. *Journal of Engineering Science and Researches*, *3-1*, 123–132.

Konstantinidis, E.I., Kompolias, D.G., Botsaris, P.N. (2014). Viability analysis of an offshore wind farm in North Aegean Sea, Greece. *J. Renewable Sustainable Energy*, *6-2*, 023116, 2014.

Küçükali, S., Dinçkal, Ç. (2014). Wind energy resource assessment of Izmit in the West Black Sea coastal region of Turkey. *Renew. Sustain. Energy Rev.*, *30*, 790-795.

Öksel, C., Koç, A., Koç, Y., Yağlı, H. (2016). Off-shore Wind Energy Potential Research for Antakya Bay. *Selçuk University Journal of Engineering, Science & Technology*, *4-1*, 18–29.

Öztürk, B., Serkendiz, H. (2018). Location Selection forWind Turbines in Balıkesir, NW Turkey, Using GIS. *International Journal of Environment and Geoinformatics*, 5(3), 284-295, doi.10.30897/ijegeo.400025

Satır, M., Murphy, F., McDonnell, K. (2017). Feasibility study of an offshore wind farm in the Aegean Sea, Turkey. *Renew. Sustain Energy Rev.*, *81-2*, 2552-2562.

T.R. Official Gazette, Presidential Decree No. 2574. 31137, 26 May 2020.

Tercan, E., Tapkın, S., Latinopoulos, D., Dereli, M.A., Tsiropoulos, A., Ak, M.F. (2020). A GIS-based multi-criteria model for offshore wind power plants site selection in both sides of the Aegean Sea. *Environ. Monit. Assess.*, *192-652*, 2–20.

Turhanlar, O. (2018). *A Potential Offshore Wind Farm Arrangement off the Bozcaada Shores* (MSc thesis). Istanbul Technical University, Istanbul, Turkey.

URL1. ClientEarth (2023). Fossil fuels and climate change: the facts. Retrieved 23 Jan. 2023 from https://www.clientearth.org/latest/latest-updates/stories/fossil-fuels-and-climate-change-the-facts/

URL2. Nalley, S. LaRose, A., Boedecker, E., Namovicz, C., Farber-DeAnda, M., Bergman, A., Majkut, J. (2021). U.S. EIA's International Energy Outlook 2021. Retrieved 23 Jan. 2023 from https://www.csis.org/analysis/us-eias-international-energy-outlook-2021

URL3. International Renewable Energy Agency: Wind energy. Retrieved 23 January 2023 from https://www.irena.org/

URL4. Wikipedia, Wind power. Retrieved 23 Jan. 2023 from https://en.wikipedia.org/wiki/Wind_power

URL5. Sun and Wind Energy. Retrieved 23 Jan. 2023 from https://www.energie.de/sonne-wind-waerme/international/sun-wind-energy

URL6. Global Wind Market (2018). Retrieved 23 Jan. 2023 from https://www.evwind.es/

URL7. Wikipedia, Wind power by country. Retrieved 23 Jan. 2023 from https://en.wikipedia.org/wiki/Wind_power_by_country

URL8. Komusanac, I. (2020). Wind energy in Europe in 2019: Trends and statistics. Retrieved 23 Jan. 2023 from https://www.researchgate.net/publication/339301911_Wind_energy_in_Europe_in_2019_Trends_and_statistics

URL9. Wikipedia, Electricity sector in Turkey. Retrieved 23 Jan. 2023 from https://en.wikipedia.org/wiki/Electricity_sector_in_Turkey#:~:text=Each%20year%2C%20about%20300%20terawatt-hours,increase%20exports%20during%20the%202020s

URL10. Globalwindatlas (2021). Wind atlas. Retrieved 22 Oct. 2021 from https://globalwindatlas.info/

URL11. T.C. Turizm ve Kültür Bakanlığı ve Akdeniz Üniversitesi PHASELIS Araştırmaları. (2013). Retrieved 23 Jan. 2023 from http://www.phaselis.org/phaselis-arastirmalari/ekolojik-arastirmalar/2013-raporu

URL12. Wikipedia, Important Bird Areas of Turkey. Retrieved 23 Jan. 2023 from https://en.wikipedia.org/wiki/Bird_Areas

URL13. Kandilli Observatory and Earthquake Research Institute, Earthquake information. Retrieved 23 Jan. 2023 from http://www.koeri.boun.edu.tr/sismo/2/en/

URL14. The Airspace & Safety Initiative Windfarm Working Group in consultation with DCLG, RTPI and Planning Officers Managing, The Impact of Wind Turbines on Aviation. (2013). Retrieved 23 Jan. 2023 from https://docplayer.net/28246568-Managing-the-impact-of-wind-turbines-on-aviation.html

URL15. Marine Traffic, Information about density of ships. (2023). Retrieved 23 Jan. 2023 from https://www.marinetraffic.com/

URL16. Marine Regions, Territorial waters. (2023). Retrieved 23 Jan. 2023 from https://www.marineregions.org/

URL17. Submarine Cables Map. Submarine Cables. (2023). Retrieved 23 Jan. 2023 from https://www.submarinecablemap.com/

URL18. Vestas. V174-9.5 MW™ wind turbine. Retrieved 23 Jan. 2023 from https://www.vestas.com/en

URL19. Our World in Data, BP Statistical Review of World Energy, Ember Global Electricity Review & Ember European Electricity Review (2021). Retrieved 23 Jan. 2023 from https://ourworldindata.org/

Vagiona, D.G., Kamilakis, M. (2018). Sustainable Site Selection for Offshore Wind Farms in the South Aegean-Greece. *Sustainability*, *10*, 749.