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# Dikili Açıklarında Bir Açık Deniz Rüzgâr Çiftliğinin Kavramsal Tasarımı

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## ÖZET

Bu çalışmada, Türkiye için açık deniz rüzgâr enerji potansiyelinin önemi vurgulanarak bir açık deniz rüzgâr çiftliğinin teknik açıdan kavramsal tasarımı sunulmaktadır. 640,000 m2 büyüklüğünde bir alanı kapsayacak şekilde önerilen açık deniz rüzgâr çiftliği için seçilen yer Türkiye'nin Ege Denizi bölgesinde bir sahil kasabası olan Dikili'nin güneybatı kıyılarıdır. Rüzgâr türbini modeli, göbek yüksekliği 78 m olan Vestas V80-2.0 Offshore (IEC IIA sınıfı) tipi olarak tavsiye edilmekte olup, önerilen açık deniz rüzgâr çiftliğinin kurulu gücü 20 MW olacaktır. Şebeke bağlantı noktası, önerilen açık deniz rüzgâr çiftliğine en yakın ve en uygun yer olan Narlıdere Limanı olarak belirlenmiştir. Temel tipi ise su derinliği ve deniz tabanı koşulları dikkate alınarak tek kazıklı (mono-pile) temel olarak seçilmiştir. Önerilen açık deniz rüzgâr çiftliğinin yıllık tahmini ortalama enerji üretimi 72 GW olacaktır.

**Anahtar kelimeler:** Açık deniz rüzgâr enerjisi, açık deniz rüzgâr çiftlikleri, açık deniz rüzgâr çiftliği tasarımı

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Research Article

# A Conceptual Design of an Offshore Wind Farm off the Dikili Shores

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## ABSTRACT

In this study, importance of the offshore wind energy potential for Turkey is emphasized by working out a technical conceptual design of an offshore wind farm (OWF). The site selected for the proposed OWF with an area of 640,000 m2 is located in the southwestern shores of Dikili, a coastal town in the Aegean Sea region of Turkey. The wind turbine model recommended is Vestas V80 - 2.0 Offshore (IEC IIA class) type with a hub height of 78 m, hence the installed power of the OWF composed of ten units is 20 MW. The grid connection point is determined as the Port of Narlıdere, which is the nearest convenient place to the proposed OWF. The foundation type is selected as mono-pile foundation according to the water depth and seabed conditions. The proposed OWF is estimated to yield average annual energy of 72 GW.

**Keywords:** Offshore wind energy, offshore wind farms, design of an offshore wind farm

**Article history:** Received 29/12/2021 – Accepted 23/03/2022

## 1. Introduction

Presently, an appreciable number of onshore wind farms is realized in Turkey but as yet no offshore wind farm (OWF) is installed (Argin and Yerci, 2015). Conceptual design suggestions and feasibility studies on potential OWFs are also lacking. The purpose of this study is to emphasize the importance of offshore wind potential of Turkey and suggest a conceptual design case for the use of this potential. Accordingly, without considering environmental and financial aspects, a conceptual technical design of a potential OWF off the Dikili shores is presented by making exemplary use of the *Horns Rev I Wind Farm*, which is the first large-scale offshore wind farm in the world, located on the west coast of Denmark.

Turkey has a significant wind energy potential due to her available high power densities, especially in coastal areas. Compared to European countries, Turkey has the highest technical wind energy potential with 83 GW over the wind class 3 (Satir et al., 2017). The use of technical wind energy is considered economically viable up to wind class 3 (annual average wind speed of 6.4 - 7.0 m/s at 50 m height) (Hau, 2013). As can be observed from Figure 1 the Aegean Sea has wind speed profiles similar to the North Sea (above 8 m/s at 50 m height), where approximately 70% of offshore wind projects are located today. Despite the significant offshore wind capacity indicated by the European Environment Agency, Turkey is one of the countries that has not yet started to exploit this capacity. To pave the way, feasibility studies and possible conceptual design suggestions should be done first (Satir et al., 2017).

Figure 1 shows an overview of the annual average wind speed at 50 m height with a coverage area up to 50 km. Offshore wind projects are potentially feasible at wind speeds above 7 m/s; these areas are marked with orange and red. Offshore wind potential of Turkey is summarized below (World Bank Group, 2020):

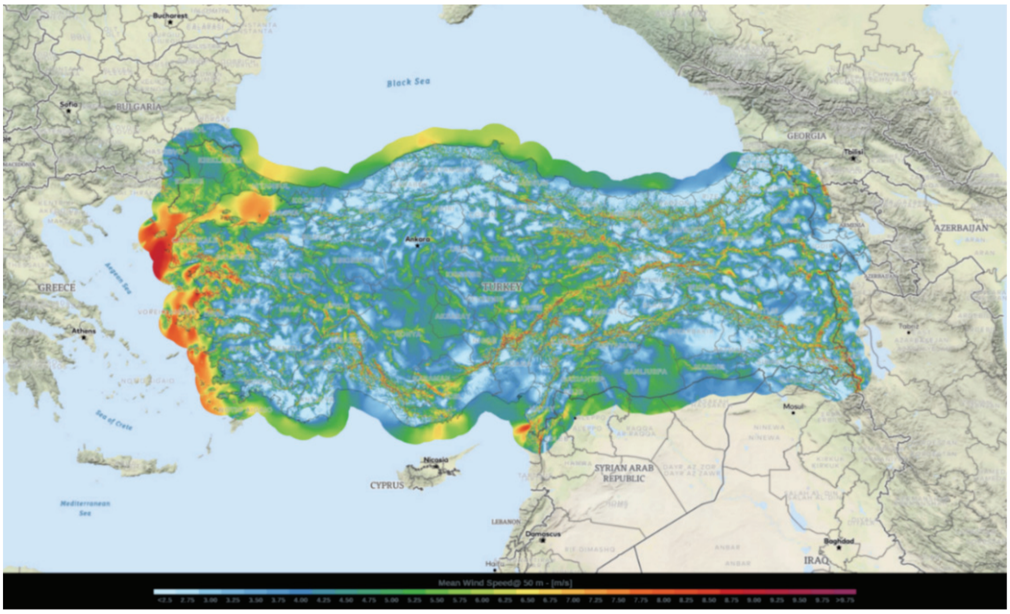

**Figure 1.** Annual average wind speed map of Turkey (Global Wind Atlas, 2020).

- The most suitable areas for offshore wind are in the northwest of the Aegean Sea where wind speeds reach up to 9 m/s.
- The Marmara Sea and the Black Sea have good wind speeds of 7 - 8 m/s.

- There are many opportunities on the west coast.
- The regions with water depth of less than 50 m have an offshore wind energy potential of 12 GW for bottom-fixed foundations.

## 2. Design Parameters for an Offshore Wind Farm

The lifecycle (estimated 25 years) of a typical OWF project consists of four stages (Aquaret, 2018):

- Design and planning,
- Construction and installation,
- Operation and maintenance,
- Decommissioning.

The design of an OWF process begins with a detailed assessment of the internal (size of wind farm, financing of project, potential locations) and the external (water depth, marine life, shipping routes, borders, grid connection, soil, restrictions) design conditions at the site of interest (Beji and Lützen, 2017). The following points must be decided for the design of an OWF:

1. A location for the wind farm,
2. The size and layout of wind farm,
3. The type, model and hub height of wind turbine,
4. The type of foundation.

We will be following this order in the technical design approach of the OWF off the Dikili shores.

### 2.1. Location

First, a suitable location must be determined (Aquaret, 2018). The site selected for the proposed OWF is the southwestern shores of Dikili, located in the Aegean region of Turkey, is a district of Izmir province. The location of the proposed OWF is opposite the Island of Karaada in the Bay of Narlıdere, the Gulf of Çandarlı as shown in Figure 2.

**Figure 2.** Location of the proposed offshore wind farm.

The minimum distance from the Dikili shores to the northwest corner of the proposed OWF is 1.16 km and the coordinates defining the boundaries of the proposed OWF as obtained from the Google Earth Pro are indicated in Figure 3.

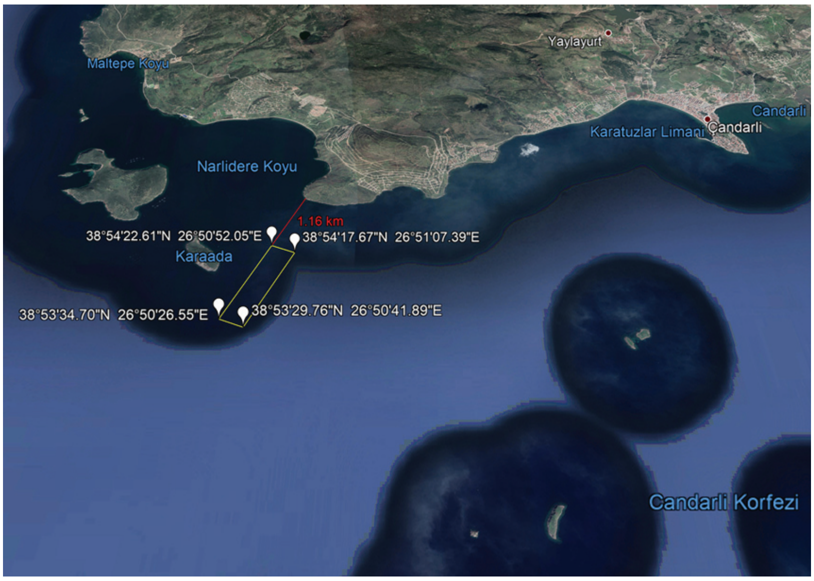

**Figure 3.** Coordinates of the proposed offshore wind farm.

Northwest corner: 38°54'22.61"N 26°50'52.05"E
Northeast corner: 38°54'17.67"N 26°51'07.39"E
Southwest corner: 38°53'34.70"N 26°50'26.55"E
Southeast corner: 38°53'29.76"N 26°50'41.89"E

### 2.1.1. Criteria for selecting location

#### 2.1.1.1. Wind potential

The wind speed at the selected location for an OWF must be within an acceptable range. Accurate and reliable wind data are required for a better assessment of the selected location. The wind data should include wind speed, wind direction, temperature and humidity information (Argin and Yerci, 2015).

Turkish State Meteorological Service is the governmental agency that provides wind data information only for onshore locations. There is no meteorological observation station in the seas of Turkey. The nearest meteorological observation station to the location of the proposed OWF is Dikili Automatic Weather Station, whose coordinates are 39°04'25.3"N 26°53'16.8"E (39.07°N 26.88°E) as indicated in Figure 1. Dikili Automatic Weather Station is 19.7 km from the center of the proposed OWF, whose coordinates are 38°53'56.18"N 26°50'46.97"E (38.89°N 26.84°E). On the other hand, Karaada with coordinates 38°54'00"N 26°50'24"E (38.90°N 26.84°E) is the nearest location to the proposed OWF; therefore, the wind data of Karaada, which could be obtained from the Meteoblue weather archive, is used for the proposed OWF. The Meteoblue provides high-quality local weather information for any location in the world, whether on land or at sea. The Meteoblue climate diagrams are based on hourly weather model simulations (Meteoblue, 2020).

The dominant wind direction in Karaada is North-North-East (NNE), as shown in Figure 4. The wind rose for Karaada is obtained from the Meteoblue climate diagrams. It indicates the hours per year the wind (at 10 m height from the sea) blows from the indicated direction. NNE: Wind blows from NNE to South-South-West (SSW).

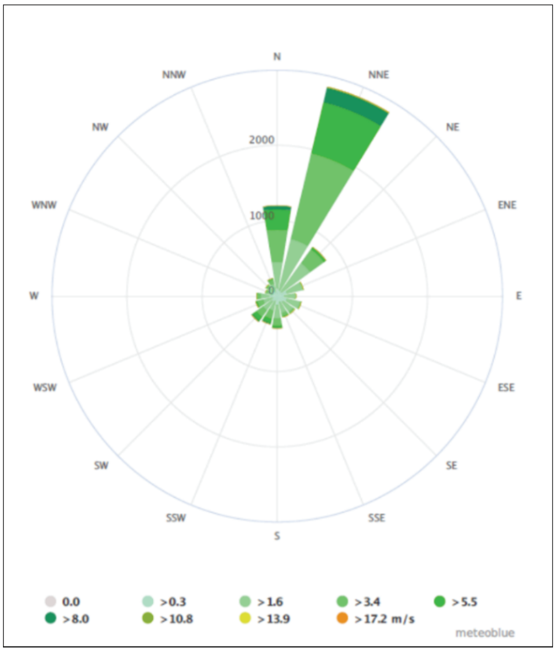

**Figure 4.** Wind rose for Karaada at 10 m height (Meteoblue, 2020).

The annual average wind speed is 8.75 m/s (at 50 m height) at the center of the proposed OWF, as shown in Figure 5. The annual average wind speed map of the southern shores of Dikili is obtained from the GWA. This wind data information gives the best possible estimate for the wind energy potential of the proposed OWF (GWA, 2020).

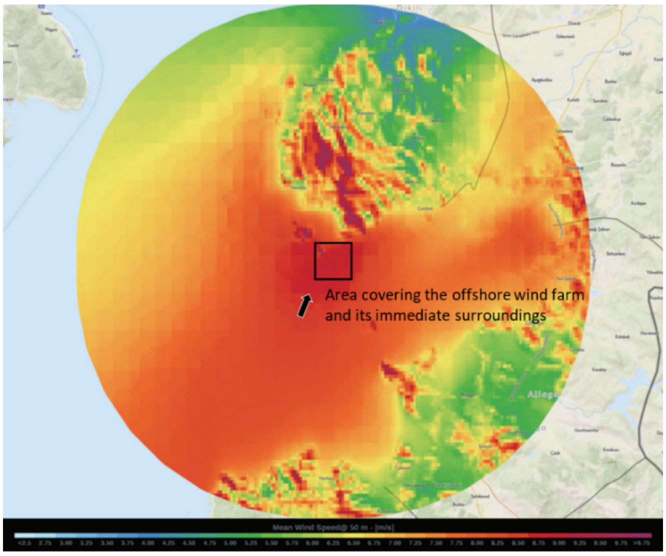

**Figure 5.** Annual average wind speed map of the southern shores of Dikili (GWA, 2020).

### 2.1.1.2. Territorial waters

In the Aegean Sea there are many Greek islands quite close to Turkey as can be observed in the map (Argin and Yerci, 2015) in Figure 6. The location of the proposed OWF is therefore determined to be in the territorial waters of Turkey to avoid problems concerning national borders.

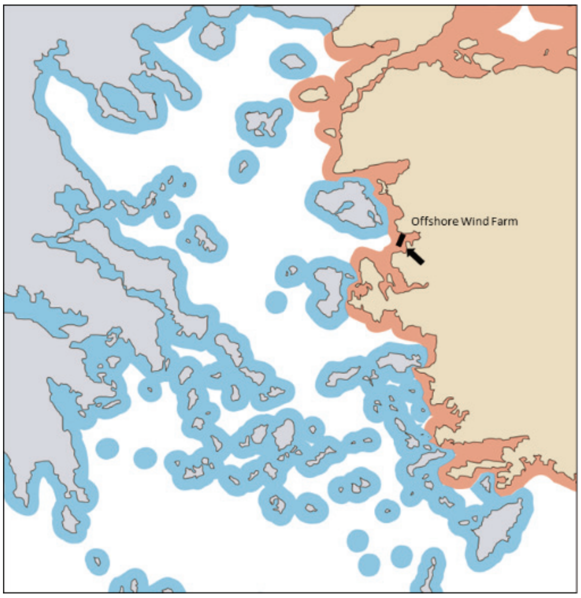

**Figure 6.** Territorial waters of Turkey (red) and Greece (blue) in the Aegean Sea based on 6 nm and the location of the proposed OWF.

### 2.1.1.3. Civil aviation

The selected location for an OWF should not be in the vicinity of airports (Argin and Yerci, 2015). According to the Regulation on Communication, Navigation and Surveillance Systems Obstacle Criteria of the Directorate General of Civil Aviation; wind farms are required to be installed at least 2 km away from airports air/ground communication stations and at least 15 km away from navigation aid systems. The location of the proposed OWF fulfills this requirement comfortably as the nearest airport, Midilli International Airport, is approximately 25 km away.

### 2.1.1.4. Marine traffic

The selected location for an OWF should be away from heavy marine traffic (Argin and Yerci, 2015). According to the free maps showing marine transport routes in the Aegean Sea, the major maritime routes in the Aegean Sea are not close to the proposed OWF. Local maritime traffic and the mooring areas should be carefully checked with information to be obtained from the Office of Navigation, Hydrography and Oceanography before the installation phase. But during the design phase, this requirement is fulfilled as the location of the proposed OWF is off the shipping routes.

#### 2.1.1.5. Submarine pipelines and cable lines

The selected location for an OWF should not be on submarine pipelines and cable lines (Argin and Yerci, 2015). A check, using the Annual Notices to Mariners publication of the Office of Navigation, Hydrography and Oceanography concerning submarine pipelines and cable lines reveals that the proposed OWF is outside such a region.

### 2.2. Wind Farm Layout

The layout of wind turbines in a wind farm requires many considerations like turbine wake effects, ambient wind, available area, environmental restrictions, and visibility (Beji and Lützen, 2017). In an OWF the closer the turbines are placed together, the lower the cost of the power cables is. However, closer spacing increases turbulence and energy losses associated with turbine wakes, which in turn results in less power generation (depending upon topology, wind climate, etc.) and higher maintenance cost. Compared to the land-based turbines the offshore turbines can be larger (an advantage of lower ambient turbulence) and accordingly larger turbine spacing (5 - 8 rotor diameters) is needed (Manwell, 2013; Dalén, 2013). Keeping these points in mind the present wind farm area is planned as ten units offshore wind turbine (OWT) facing the NNE direction in two rows, with five wind turbines per row. The layout of wind turbines in the wind farm area is shown in Figure 7.

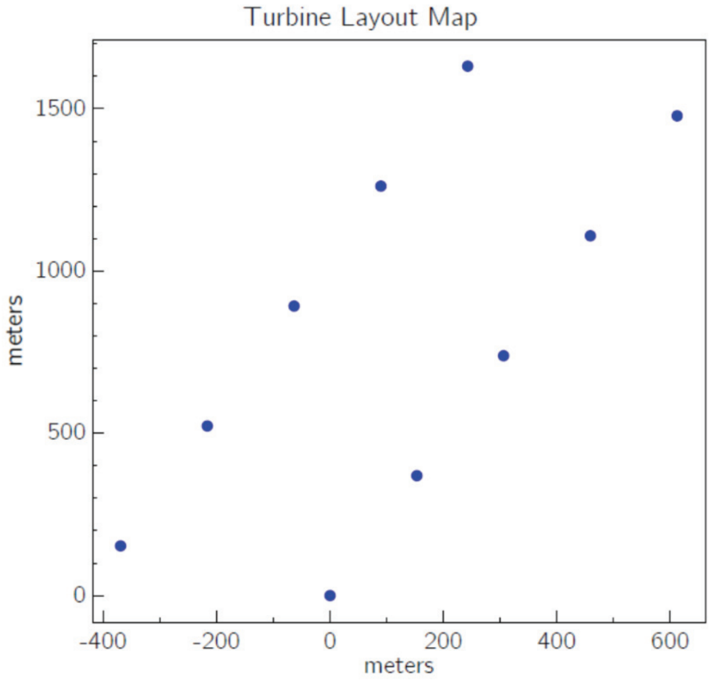

**Figure 7.** Turbine layout map of the proposed offshore wind farm (SAM, 2019).

- Number of rows = 2 (in the NNE-SSW axis)
- Turbines per row = 5 (facing the NNE direction)
- Row spacing = 400 m (5 rotor diameters)
- Turbine spacing = 400 m (5 rotor diameters)
- Size of the wind farm (with 10 turbines) = 400 x 1600 m = 640,000 m$^2$

## 2.3. Wind Turbine

It is crucial to select the appropriate OWT model. Although offshore wind speeds are generally higher than onshore, this factor have prevented land-based turbines from being used offshore in the past. There are many differences between offshore turbines and land-based turbines. (Aquaret, 2018).

Several OWT manufacturers are on the market. Siemens Gamesa Renewable Energy is the current market leader with 69% of the total installed OWTs. MHI Vestas Offshore Wind is the second turbine manufacturer with 24%, followed by Senvion with 5%. These three manufacturers represent 98% of all OWTs installed in Europe at the end of 2018 (Wind Europe, 2019).

The selected wind turbine for the proposed OWF is *Vestas V80 - 2.0 Offshore* (78 m hub height). Figure 8 is a photograph of these turbines (Hau, 2013) while Figure 9 is the power curve of this particular turbine (SAM, 2019). Main parameters of the turbine are listed in Table 1. The wind turbine V80-2.0 Offshore is a production of Vestas Wind Systems A/S, a Danish manufacturer operating since 1979 (Wind-turbine-models, 2019).

**Figure 8.** Vestas V80 - 2.0 offshore wind turbines of the North Hoyle wind farm (Hau, 2013).

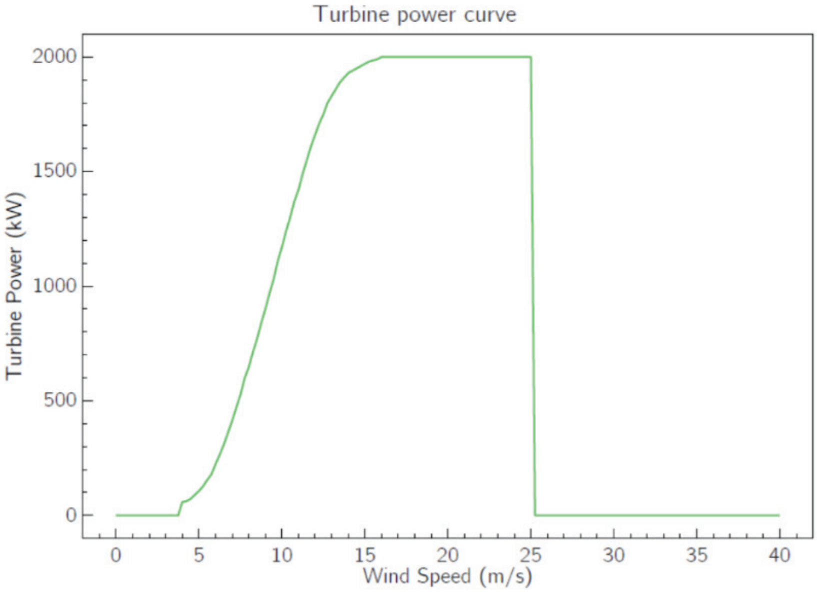

**Figure 9.** Power curve for Vestas V80 - 2.0 offshore turbine (SAM, 2019).

**Table 1.** Vestas V80 - 2.0 offshore wind turbine parameters (Wind-turbine-models, 2019).

| | | |
|---|---|---|
| Rotor | Diameter: | 80 m |
| | Area swept: | 5027 m$^2$ |
| | Nominal revolutions: | 16.7 rpm |
| | Operational interval: | 9 - 19 rpm |
| | Number of blades: | 3 |
| | Power regulation: | Pitch |
| | Air brake: | 3 separate hydraulic pitch cylinders |
| Tower | Hub height: | 78 m |
| Operational data | Cut-in wind speed: | 4 m/s |
| | Nominal wind speed: | 15 m/s |
| | Cut-out wind speed: | 25 m/s |
| Generator | Type: | Asynchronous doubly fed |
| | Nominal output: | 2000 kW |
| | Operational data: | 50 Hz / 60 Hz, 690 V |
| Gearbox | Type: | Planet/parallel axles |
| Control | Type: | Remote monitoring |
| Weight | Nacelle: | 67 t |
| | Rotor: | 37 t |
| | Tower (IEC IIA): | 190 t |

### 2.3.1. Estimated annual average wind speed at hub height

For power calculations it is necessary to estimate the wind speed at the hub height. For such estimations basically two different wind profile formulations are used: the logarithmic profile and the 1/7-power-law profile (Beji and Lützen, 2017). Basically, these two profiles give similar results, the choice of one over the other is merely a matter of preference; the logarithmic profile is used here,

$$U(h) = U(h_{ref}) \left[ \frac{ln\left(\frac{h}{z_0}\right)}{ln\left(\frac{h_{ref}}{z_0}\right)} \right] \tag{1}$$

where $U(h)$ is the wind speed at the height $h$, $U(h_{ref})$ is the wind speed available for a definite reference height $h_{ref}$, and $z_0$ is the roughness length determined according to the surface properties over which the wind blows. For the present case $h_{ref} = 50$ m and $U(h_{ref}) = 8.75$ m/s are the available reference height and corresponding wind speed. Taking $z_0 = 0.0002$ m as the roughness length suggested for a choppy sea surface, the wind speed at the hub height $h = 78$ m is estimated as

$$U(78) = 8.75 \left[ \frac{ln\left(\frac{78}{0.0002}\right)}{ln\left(\frac{50}{0.0002}\right)} \right] = 9.063\, m/s \cong 9.0\, m/s$$

which is used in the subsequent relevant calculations.

### 2.3.2. Wind turbine IEC class

The selected wind turbine IEC (International Electrotechnical Commission) class is IIA, according to the annual average wind speed $U_{avg}$ at the hub height of the proposed OWF. The wind speed parameters of the selected wind turbine class are taken from the Wind Turbine Generator System (WTGS) classes to IEC 61400-1 and listed in below (Hau, 2013):

WTGS Class: II - Medium wind

Turbulence Intensity Category: A - Higher turbulence

$I_{15} = 18\%,$ $\alpha = 2,$ $U_{avg} = U(78) = 9.0\ m/s$

The turbulence intensity can be calculated by using the formula

$$I_u = \frac{I_{15}\left(\alpha + \frac{15}{U_{avg}}\right)}{(\alpha + 1)} \tag{2}$$

$$I_u = \frac{0.18\left(2 + \frac{15}{9.0}\right)}{(2 + 1)} = 0.22 = 22.0\%$$

which indicates Category A-Higher turbulence.

### 2.3.3. Estimated energy production

The total rated power of the proposed OWF (10 turbines) is $P_{rated} = 10 \cdot 2.0\ \text{MW} = 20\ \text{MW}$. On the other hand, the capacity factor is defined as

$$cf = T_{equivalent}/T_{year} \tag{3}$$

where $T_{equivalent}$ is the equivalent hours of operation at nominal wind speed and $T_{year} = 365 \cdot 24 = 8760\ hours$ is the total hours in a year. Typically, $cf \approx 0.35 - 0.45$ but a much more accurate estimate is possible by the use of the Weibull or Rayleigh distribution. The Weibull probability density function (pdf) (Strach-Sonsalla et al., 2016) is given by

$$f_W(k, a, U) = (k/a)(U/a)e^{-(U/a)^k} \tag{4}$$

where $k$ is the shape factor ranging between $k = 1 - 4$ but typically taken as $k = 2$, $U$ the wind speed and $a$ the Weibull scale parameter given by

$$a = \frac{U_{avg}}{\Gamma\left(1 + \frac{1}{k}\right)} \tag{5}$$

where $U_{avg}$ is the annual average wind speed and $\Gamma(z) = \int_0^\infty t^{z-1}e^{-t}dt$ is the Gamma function. For the typically used value of $k = 2$ the exact value of the Gamma function is

$$\Gamma\left(1 + \frac{1}{2}\right) = \frac{1}{2}\pi^{1/2} = 0.8862269254$$

Annual yield of a turbine is calculated by the following integral:

$$E_{Turbine} = T_{year} \int_{U_{ci}}^{U_{co}} P(U) f(U)\, dU \tag{6}$$

where $P(U)$ is the power according to the given power-curve of the turbine for the wind speed $U$, $f(U)$ the pdf, $U_{ci} = 4\ \mathrm{m/s}$ the cut-in and $U_{co} = 25\ \mathrm{m/s}$ the cut-out wind speeds for the turbine as specified by the manufacturer (see Table 1). Considering the following equation

$$E_{Turbine} = P_{rated} \cdot T_{equivalent} = P_{rated} \cdot cf \cdot T_{year} = T_{year} \int_{U_{ci}}^{U_{co}} P(U) f(U)\, dU \tag{7}$$

The capacity factor $cf$ can be written as

$$cf = \frac{1}{P_{rated}} \int_{U_{ci}}^{U_{co}} P(U) f(U)\, dU \tag{8}$$

Using the manufacturer-supplied power-curve of the turbine given in Figure 9 and the Weibull pdf defined above by $f_W(k, a, U)$ with the scale parameter $a = 10.155\ \mathrm{m/s}$ determined according to the chosen $k = 2$ value and the mean wind speed $U_{mean} = 9.0\ \mathrm{m/s}$ at the hub height, a numerical integration yields the capacity factor for the present problem as $cf = 0.4117$. Since

$$T_{equivalent} = cf \cdot T_{year} = 0.4117 \cdot T_{year}$$

the yearly energy production estimate for a single turbine is then

$$E_{Turbine} = P_{rated} \cdot cf \cdot T_{year} = 2.0 \cdot 0.4117 \cdot 8760 \cong 7213\ MW \cdot hours \cong 7.2\ GW \cdot h/year$$

The proposed OWF with 10 turbines is then expected to generate an estimated energy of

$$E = 10 \cdot 7.2\ GW \cdot h/year \cong 72\ GW \cdot h/year$$

### 2.3.4. Grid connection

The selected grid connection point is the Port of Narlıdere, which is the nearest suitable location to the proposed OWF. Since power cables and their laying are costly, a minimum distance to the grid on the land is aimed; accordingly, from the proposed OWF to the Bay of Narlıdere shores is only $4.83\ \mathrm{km}$. As the distance to shore is quite short (< 8 km) there is no need to connect the OWTs output to an offshore substation. Substations are costly and subjected to failure risks. The electricity generated by the OWTs can be transmitted directly to the shore and then integrated into the public grid (Dalén, 2013). A schematic description of the grid connection, which is a string topology type, is given in Figure 10. Compared to the looped topology the string topology is a fairly simple and reliable power connection. Generally, power cables in wind farms are relatively low voltage (24 to 33 kV) (Manwell, 2013); therefore, power collection and transmission voltages can be taken as 30 kV on the average for the proposed OWF. The electrical system of the proposed OWF is briefly listed in Table 2.

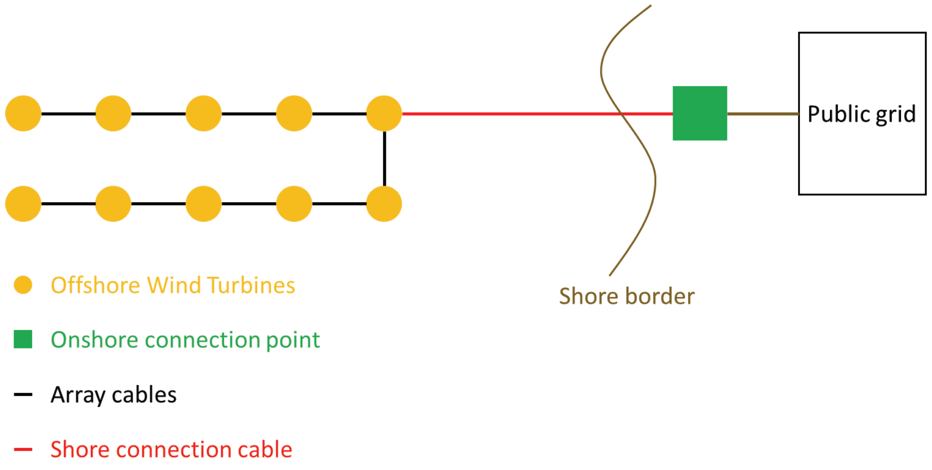

**Figure 10.** Grid connection topology for the proposed offshore wind turbines.

**Table 2.** Electrical system of the proposed offshore wind farm.

| | |
|---|---|
| Installed power: | 10 x 2 MW = 20 MW |
| Power collection voltage: | 30 kV |
| Power transmission voltage: | 30 kV |
| Distance to shore: | 1.16 km |
| Shore connection: | AC connection on shore, wind farm voltage level |
| Network topology: | 2 strings of 5 turbines |

### 2.4. Substructure and Foundation

The selected foundation type for the proposed OWF is mono-pile foundation. Temporary design parameters of the mono-pile foundation system are given in Table 3. Selection of the foundation type depends on the water depth and seabed conditions; e. g., soil type, extent of scouring. The maximum water depth at the location of the proposed OWF is 25 m as shown in the bathymetry map (Openseamap, 2019) given in Figure 11. The type of soil in the location of the proposed OWF is gravelly mud as described in the seabed substrate map (Europe-geology, 2020) given in Figure 12, which is obtained from the EMODnet-Geology project powered by the EuroGeoSurveys' European Geological Data Infrastructure.

Mono-pile foundations are proven technology, quite commonly used in shallow waters. They represent 81.5% of all installed substructures in Europe at the end of 2018 (Wind Europe, 2019). Mono-piles are usually economic and technically feasible for water depths less than 30 m (Strach-Sonsalla et al., 2016). Suitable soil conditions for mono-piles are sand and silt layers, as they do not require pre-drilling (Dalén, 2013).

**Figure 11.** Bathymetry map of the southern shores of Dikili (Openseamap, 2019).

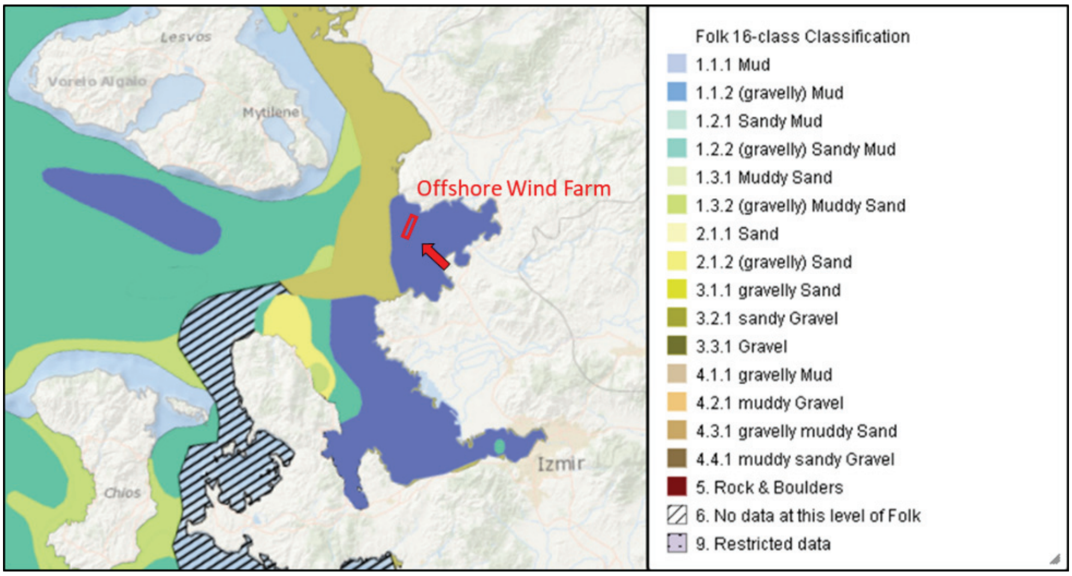

**Figure 12.** Seabed substrate map of the Dikili shores (Europe-geology, 2020).

A mono-pile consists of two main parts; a pile and a transition piece made of high-quality steel. The pile is a cylindrical tube driven into the ground using a hydraulic hammer. The transition piece is connected to the pile by a grouting system. The transition piece is equipped with work platform, intermediate platform, boat landing, navigation lights, etc., and the tower is bolted on the top of the transition piece (Dalén, 2013). A schematic diagram of a mono-pile foundation system (Mott MacDonald, 2010) is shown in Figure 13.

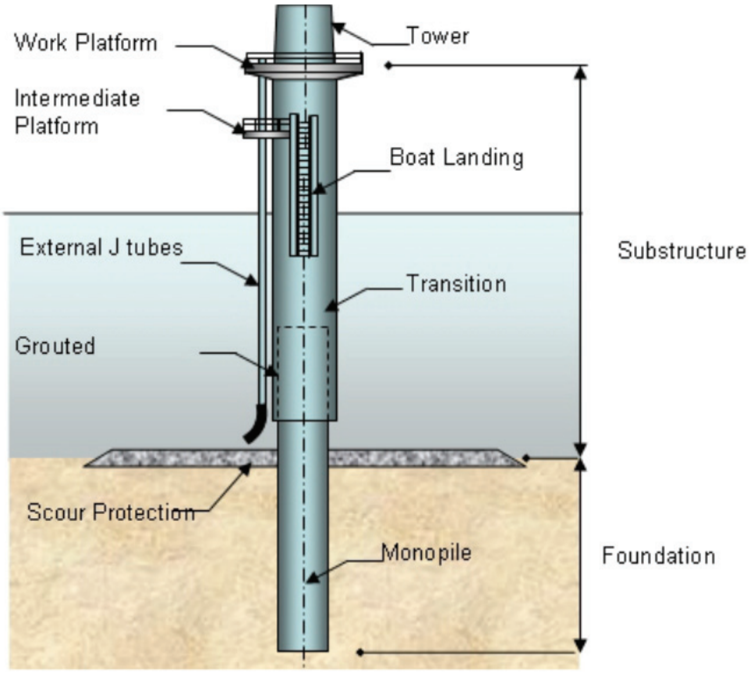

**Figure 13.** Schematic diagram of a mono-pile foundation system (Mott MacDonald, 2010).

**Table 3.** Temporary design parameters of the mono-pile foundation system.

| |
|---|
| The pile diameter (*D*) is 4 m and the wall thickness is 50 mm. |
| The effective fixity length (6*D* for general calculations) is 24 m (seabed penetration). |
| The transition piece diameter is 4.6 m and the grout is 6 m. |
| The working platform is 9 m above the sea level. |
| Two layers of stones (gravel) are used for the scour protection. |

## 3. Conclusions and Recommendations

Offshore winds are stronger, more stable, and less turbulent than onshore winds. All these aspects positively contribute to the service life of an offshore turbine. From the technical and environmental points of view, offshore wind projects are considered more advantageous. On the other hand, initial installation, operation and maintenance costs of an offshore wind farm are unquestionably higher compared to those of an onshore wind farm. Decision on the choice must be made by a careful consideration and weighting of all these aspects.

Turkey has a rapidly growing economy with a corresponding increase in energy demand. A large portion of Turkey's energy demand is met by imported fossil fuels. Potential OWFs together with onshore wind farms can help to meet Turkey's increasing energy demand and reduce her dependency on energy imports. Further, OWFs can also help to reduce greenhouse gas emissions.

In this study, a potential OWF with size of 640,000 m$^2$ (400 x 1600 m) project is designed technically as a case study. The proposed OWF is located opposite the Island of Karaada in the Bay of Narlıdere, 1.16 km distance from the southwestern shores of Dikili. The annual average wind speed is 8.75 m/s (at 50 m height) at the center of the proposed OWF. With strong and steady winds, this site is suitable location for the wind power generation. At the same time, there is the possibility that the proposed OWF and its infrastructure will affect the ecosystem in the area. Always various impacts are observed on the immediate environment where an OWF is installed (Aquaret, 2018). However, with careful planning and research, these environmental disturbances can be prevented. In any OWF project to be realized, the following issues should be explored (Manwell, 2013; Dalén, 2013):

- Noise impact,
- Barriers of water flow,
- Visual impact,
- Impacts on radio signals,
- Impacts on birds,
- Impacts on marine life,
- Impacts on benthic fauna and flora,
- Possibility of ship collisions.

Installed power of the proposed OWF is 20 MW. The ten units *Vestas V80 - 2.0 Offshore* model wind turbine with 78 m hub height and 80 m rotor diameter (in two rows with five turbines each facing the NNE direction) are proposed to be installed in mud (gravelly) type soil at a maximum water depth of 25 m using the mono-pile foundation system. As of 2020, according to the United States Energy Information Administration (EIA), electricity net consumption of Turkey is 263,952 GWh/year (population of Turkey is 84,428,280) and total consumption per capita is around 3126 kWh/year (EIA, 2022). The proposed OWF will generate an estimated 72 GWh/year of electricity energy. This clean and sustainable electricity, which can be transmitted directly into the public grid from the Port of Narlıdere connection point, can meet the annual electricity needs of approximately 23,000 households (as of 2020, Dikili has a total population of 45,217). This is more than half of Dikili's population and 23,000 households would definitely accommodate more than the total population of Dikili.

Finally, it should be emphasized that an OWF project must be analyzed economically during the development phase. Accordingly, a feasibility study should be done before the proposed OWF project is realized and the following costs should be calculated for the financing of the project (Barutçu, 2010):

- Project and license costs,
- Turbine costs,
- Electrical infrastructure costs,
- Installation costs,
- Transportation costs,
- Construction costs,
- Operation and maintenance costs.

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