

The Assessment of Offshore Wind Power Potential of Turkey

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Abstract

In this paper, the offshore wind power potential assessment of Turkey is presented. Due to the increased amounts of energy needs, the need for energy supply from renewable energy sources has increased in the world. Turkey with its growing industry, economy, and population has high energy demands thus investments on all renewable energy resources primarily on wind power has shown increase in the last decade. However there is still dependence on foreign energy resources. This paper examines the suitability of 54 coastal regions for offshore wind power installation. The study reveals that among 54 regions 10 of them are suitable for plant installation but initially Bozcaada, Amasra, Samandagi, Gokceada and Inebolu coastal regions should be considered for offshore wind power generation due to higher wind speeds but further analysis should be carried out before making the final decision.

1. Introduction

Energy is one of the most important elements in today's world. Demand for energy has shown increase with the emerging technology in the world. Fossil fuels have been the main source of energy for many decades however there has been a drawback on the use of fossil fuels due to their harmful impact on the environment [1-3]. In addition to environmental impact, limited fossil fuel resources also cause increased effort to search for alternative and renewable energy resources to address these concerns.

Particularly, wind power has shown the fastest growth in the last decade. Worldwide wind power capacity has reached over 336 GW by mid-2014 and 360 GW is expected by the end of the year. Global installed wind capacity has shown 13,5 % increase only from mid-2013 to mid-2014 with 51 GW addition and the overall capacity has increased almost eight times in the last decade [4,5]. Economic advantages of wind power and its competitiveness with respect to other electricity sources make wind power investment appealing worldwide.

Many of the investments on wind power is for onshore installations, but offshore wind power has a potential of meeting Europe's energy demand seven times over and United States Energy demand four times over. There has been limited number of development with offshore wind power up until 2008 because of mainly high costs, and technical complexities. Initial offshore wind power installations were made in Europe primarily in Denmark and Holland with turbine capacities below 1 MW. Today, over 90% of wind power installation is located in Northern Europe and the UK is leading the world with 4,494 MW cumulative power as seen in Fig. 1. There is a growing demand for offshore wind power in Northern America and Asia.

Both China and the United States have a target of 30 GW and 54 GW of offshore wind power capacity by 2030 respectively [6, 7].

With higher wind speeds and lower roughness classifications, offshore locations enable to harness more wind energy thus generating higher electrical energy. Besides, installation of offshore wind power by the coastline near larger loads avoids needs for long transmission lines. Most importantly, due to expensive property values and public opposition to onshore wind power plants, offshore wind power plants become the painless alternative. Although offshore wind power plants are costly and hard to finance, it is much more beneficial in the long run due to its higher generation capacity with respect to onshore wind power plants [8, 9].

Total installed capacity of the electrical energy in Turkey is 69,1 MW. Total electrical energy generation is 251,9 Million kWh and only 3,4% comes from wind energy. Most importantly 47,9% of total generation is from natural gas which solely depends on foreign energy resources [10]. Thus there is a very high need to search for any alternative energy sources. While developed countries have been investigating on offshore wind power generation and installing plants, there isn't any attempt for offshore wind power plant installation in Turkey. In this study, offshore wind power potential assessment of Turkey will be presented. The paper is organized as follows; Section II gives information about overall wind energy potential in Turkey while Section III presents the criteria for selecting offshore wind power plant locations. Results and discussion are presented in Section IV with the paper concluded in Section V.

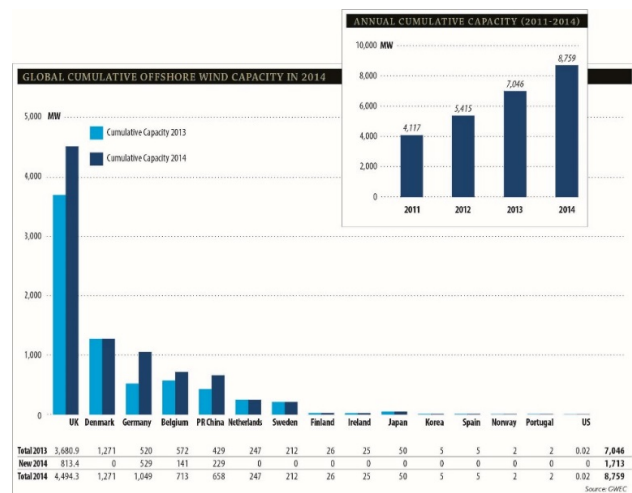


Fig. 1. Global cumulative offshore wind power capacity in 2014 [6].

2. Wind energy potential in Turkey

Turkey has the 19th best economy in the world and is one of the developing countries. The need for electrical energy has continuously increased because of increasing population and growing economy. Turkey's energy consumption has increased 4,4% from 2013 to 2014. Based on 2014 data, coal, natural gas, and hydropower have been the major energy resources and they almost comprise of 94% of the total energy resources. Geothermal, wind, solar, liquid fuels and others have about only 4% share on the energy resource [10]. The first wind power plant was established in 1998 with an installed capacity of 7,2 MW [11]. Significant progress in wind power plant installation has not been seen until the Renewable Energy Law was passed in 2005. Since then cumulative installed wind capacity has increased from 51 MW in 2006 to 3,762.1 MW in 2014. Majority of the wind power plants are located in Ege, Marmara, and Akdeniz regions. 21,75% of the wind power plants are in Balıkesir. İzmir and Manisa follow Balıkesir with 18,20% and 12,89% installed capacity respectively [12].

Although three sides of Turkey are surrounded with seas, there is no offshore wind power generation. Studies about offshore wind power generation is very new in Turkey. Assessment of wind power potential for turbine installation in 12 coastal regions was investigated based on wind speed and wind energy [13]. Study showed that Balıkesir and Çanakkale have higher wind energy potential. Köroğlu studied offshore wind power plant design criteria and types of grid connectivity issues. Technical and economic comparison of grid connection methods were analyzed and superiorities to each other were presented [14]. Güzel presented the feasibility guidelines for offshore wind power plant installations and conducted a case study for Gökçeada and Bozcaada [15]. In a recent study, potential of wind power in the coastal areas of Turkey have been investigated based on wind speed and wind energy [11]. The study revealed that Turkey's best wind energy potential areas are Marmara and Aegean region's coasts, and coasts of northern and southern Anatolia. These studies also reveal the fact that Turkey is not using its wind energy potential efficiently.

3. Criteria for selecting offshore wind power plant location

The two main factors affecting offshore wind power plant costs are distance to the land and cost of foundations. Foundation costs increase with sea depth and sea basement structure. Underground cable and transportation costs increase with distance from the land. An additional transformer station may even be required on the sea if the plant is too far from the land. Thus sea depth, sea basement structure, distance to the land and the nearest transformer station play great role on the cost of offshore wind power plant. Before making the cost analysis based on the above factors, following criteria must be met to decide about the suitability of offshore wind power plant location. These criteria for Turkey are; wind potential, territorial waters, military zones, civil aviation, maritime traffic, pipelines and underground cables [14, 15].

3.1. Wind potential

First and foremost, wind speed at the possible wind power plant location should be in an acceptable range. Locations with a wind speed of 3 m/s are very appropriate for wind power plant

installation [13]. Accurate and reliable wind speed data is required for better assessment of the location. In Turkey Renewable Energy General Administration (EİE) and Turkish State Meteorological Service (DMI) are the two major government agencies that provide wind data information only for onshore locations. The source of EİE's wind maps that are created based on air flow models in 2006 is not provided [15]. DMI provides hourly wind speed information based on measurements made at 10 meter but there are sustainability issues with these measurements. The ideal wind speed data should consist of hourly measurements for 10 years made at a minimum of 30 meters. In addition to wind speed, the data should include information about wind direction, ambient temperature and humidity. If the measurement stations are not at the desired height, either extrapolations should be made or computer programs like WaSP, WindPRO or WindFarmer should be used for calculation at the desired height.

3.2. Territorial waters

In international law, territorial waters is defined as the area of the sea immediately adjacent to the shores of a state and subject to the territorial jurisdiction of that state [16]. The standard width of territorial waters has gradually increased from initially 3 nautical miles (5.6 km), to 6 nautical miles (11 km), and currently 12 nautical miles (22 km). The current value has been protected in treaty law by the United Nations Convention on the Law of the Sea of 1982 (Art.3). [17]. The suitability of shores for offshore wind generation in terms of territorial waters of Turkey is not an issue at Black Sea and Mediterranean Sea, but it could be an issue at Aegean Sea due to close proximity to Greek islands.

3.3. Military zones

Some shores and lands are used by military for training purposes thus these zones become restricted for use by government and private entities. Location of the offshore wind power plants should be away from these military zones.

3.4. Civil aviation

Offshore wind power plant locations should be away from aircrafts' take-off and landing points. Hence suitability of a location should also be checked in terms of civil aviation.

3.5. Maritime traffic

Three sides of Turkey is surrounded with seas and there are many peninsulas and islands around it. Transportation to these peninsulas, islands and neighbor countries which are located by the seas are carried out by maritime vessels thus maritime traffic increases. In addition, there are local maritime traffic at bays and shores. Thus offshore wind power plant locations should be away from these maritime routes.

3.6. Pipelines and underground cables

Turkey has limited number of pipelines and underground cables crossing its seas. Thus offshore wind power plant locations should be chosen away from these cable routes.

4. Results and discussion

Wind data from 54 coastal regions were obtained from DMI's 8th Meteorological Agency in Konya. As there is no measurement station on the sea in Turkey, these measurements give the best possible estimation for wind power potential of the related regions. Wind speed data consists of hourly measurements from 2005 to 2015 made at 10 meters. Average wind speed for these places is provided in Table I. Table I reveals that only offshore locations at İnebolu, Çanakkale, Datça, Amasra, Karasu, Gemlik, Aliğa, Samandağ, Gökçeada, and Bozcaada are considerable for wind power plant installation due to high wind speeds.

Table 1. Average wind speeds at coastal regions in Turkey

Average wind speed (m/s)					
Akçakoca	1,90	Didim	2,90	Ünye	1,48
Zonguldak	2,36	Bodrum	2,60	Çatalzeytin	2,09
İnebolu	4,03	Fethiye	1,32	Akçaabat	1,92
Sinop	2,95	Datça	3,63	Pazar(Rize)	2,09
Samsun	1,83	Marmaris	1,79	Karasu	3,02
Ordu	1,35	Antalya	2,17	Gemlik	3,67
Giresun	1,31	Alanya	1,53	Fatsa	2,49
Trabzon	2,02	Anamur	2,19	Aliğa	3,18
Rize	0,98	Silifke	1,61	Seferihisar	2,16
Hopa	2,67	Mersin	1,76	Kemer	1,68
Tekirdağ	2,63	İskenderun	2,12	Alata-Erdemli	1,51
Çanakkale	3,93	Finike	1,59	Dört Yol	0,95
Yalova	1,52	Kaş	2,58	Kale-Demre	1,55
Ayvalık	2,28	Amasra	4,57	Yumurtalık	2,04
Dikili	2,60	Cide	2,98	Karataş	2,58
İzmir	2,88	Bozkurt	2,24	Samandağ	4,24
Çeşme	2,57	Ereğli	2,05	Gökçeada	4,12
Kuşadası	2,31	Alaçam	2,20	Bozcaada	5,60

These locations are also shown in Fig. 2.



Fig. 2. Locations suitable for offshore wind power generation based on wind speeds.

The suitability of 10 regions for offshore wind power generation in terms of territorial waters is analyzed. Regions on the Black Sea and the Mediterranean Sea do not have territorial water problems thus Samandağ, Gemlik, Amasra, Karasu, and İnebolu can be considered for offshore wind power generation. Other regions are by the Aegean Sea thus suitability of shores for wind power generation should be checked in those territorial waters carefully. Fig. 3. shows the territorial waters between Greece and Turkey based on 6 nautical miles.



Fig. 3. Territorial waters between Greece and Turkey in the Aegean Sea [18]

Based on the careful analysis of shores of Datça, Çanakkale, Aliğa, Gökçeada and Bozcaada in Fig. 3, it appears that offshore wind power installation only at Datça bay is relatively difficult due to close proximity between Datça lands and Greek islands.



Fig. 4. Military Training Zones at Aegean Sea [18]

Fig. 4 shows military training zones by the coastal regions at Aegean Sea. Regions labeled with numbers from 061 to 078 are

military training zones. Based on the map, there are military training zones around Çanakkale and Aliğa. More restrictions exist for Çanakkale region thus it seems difficult to consider an offshore wind power plant installation except the area surrounding Gökçeada. There isn't any military training data available for Mediterranean and Black Sea coastal regions, but suitability of these regions for a potential offshore wind power installation must be checked with Defense Ministry before making the final decision.

Major maritime routes in Turkey are shown in Fig. 5. The figure shows that maritime routes are not very close to proposed coastal regions therefore there isn't any problem for offshore wind power installation. İstanbul and Çanakkale dardanelles are only used for maritime traffic therefore they are not suitable for offshore wind power plant installation. When considering the location of the offshore wind power plant, local maritime traffic routes must be checked carefully for each of these regions for the suitability of the plant installation.



Fig. 5. Major maritime routes in Turkey

When considering offshore wind power plant locations in terms of civil aviation, the most important criteria that should be analyzed is aircrafts' take-off and landing points. Civil Aviation Administration in Turkey provides information about aircrafts take-off and landing points [19]. Based on this information, there is no airport in any of these 10 locations, but there are helicopter and small aircraft landing points on or by the sea at Gemlik, and Datça. With multiple landing points on the sea, Datça appears to have more obstacles in terms of offshore wind power installation.

Fig 6 shows Gemlik bay. Due to local maritime traffic because of a port at a very narrow bay in the region, Gemlik is not a suitable place for offshore wind power generation.



Fig. 6. Gemlik bay

Fig. 7 shows natural gas and petroleum pipelines in Turkey. As seen from the figure, there isn't any pipeline around the

proposed coastal regions except the Dardanelles which is already a restricted zone due to maritime traffic.



Fig. 7. Natural gas and petroleum pipelines in Turkey[20]

Analysis of the selection criteria shows that although there is high wind speeds, Çanakkale, Datça, and Gemlik are not suitable for offshore wind power plant installation. For possible offshore wind power installation, sea depth, sea basement structure, distance to the land and to the nearest transformer station of a location in the remaining regions must be analyzed. Considering the high costs of offshore wind power plants, initially Bozcaada, Amasra, Samandagi, Gökçeada and İnebolu coastal regions should be considered for offshore wind power generation due to higher wind speeds.

5. Conclusions

This study investigates the offshore wind power potential assessment of Turkey. Wind data from 54 coastal regions were obtained from DMI's 8th Meteorological Agency in Konya. Regions with average wind speed of 3 m/s and over are selected for the analysis. The assessments are conducted based on several criteria including wind potential, territorial waters, military zones, civil aviation, maritime traffic, pipelines and underground cables for the selected regions including İnebolu, Çanakkale, Datça, Amasra, Karasu, Gemlik, Aliğa, Samandağ, Gökçeada, and Bozcaada. Based on the analysis, the following conclusions can be drawn:

- Due to limits on territorial waters at Aegean Sea and space limitations because of civil aviation, Datça is not suitable for offshore wind generation.
- Çanakkale is not appropriate for offshore wind generation due to military training zones in the shores on Aegean Sea and maritime traffic routes at the Dardanelles.
- Due to local maritime traffic because of a port at a very narrow bay in Gemlik, offshore wind power plant installation is not possible.
- Considering the high costs of offshore wind power plants, initially Gökçeada, Bozcaada, Samandağ, Amasra, and İnebolu regions should be considered for offshore wind power plant installation. However sea depth, sea basement structure, distance to the land and to the nearest transformer station of a possible plant location in these regions must be analyzed carefully. Most importantly long term wind speed and wind energy potential at higher altitudes on the sea must be obtained before making the final decision.

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