



## An Overview of Turkey's Offshore Wind Energy Potential Evaluations

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### Abstract

This paper deals the existing condition of wind energy in Turkey and mainly focuses on the development of the offshore wind power. Wind energy potential and its feasibility in terms of techno-economic aspect, industrial progress and environmental concerns are studied. By 2015, the total installed offshore wind power capacity of the World has reached 12 GW of capacity. Unfortunately, this is not the case in Turkey because sufficient concerns are not given to the offshore technology and investments, although high potential of wind power density is available on the shores of Turkey. Annual and cumulative comparisons of wind energy throughout the years are also discussed in the context of this study. Territorial distribution of wind energy installations of Turkey is demonstrated that indicated offshore installations of wind power plants are also appropriate for power generation. Comparisons of wind energy potential of Turkey with Europe indicate that Turkey has more wind power potential both on land and sea; however, presently, installed wind power is less with respect to European countries. Potential of wind energy for Turkey was estimated to be 48,000 MW approximately, but current installed power capacity is only 4,718 MW until 2015. It is already planned in 2023 vision to attain 20,000 MW of wind power installments in Turkey where the share of wind power among the cumulative increases with high percentage. Offshore wind power capacity of Turkey is predicted to be 11 MW. Land of Turkey is surrounded by seas on having convenient opportunity in generating energy from available offshore wind power. But, there is no attempt regarding offshore wind power plant installations, yet. Studies on this issue in Turkey are recent attempts and thus this study presents the assessment of available status of offshore wind potential in Turkey.

**Keywords:** Renewable energy, Wind energy, Offshore wind

### INTRODUCTION

In recent years, global energy demand has shown an increase with the emerging technology and population growth. Total demand for energy is expected to increase around 21% by 2030 [1]. Additionally, CO<sub>2</sub> emissions are expected to increase from 35.9 Gt in 2014 to 42 Gt by 2030. For this reason, renewable energy is playing an expanding and significantly important role in this regard. Inside of renewable energies, wind energy is attractive as a renewable non-polluting, being a resource of having large reserves, and a wide distribution. Wind power currently satisfies 3.1% of global electricity generation. By 2050, wind power will have the potential to contribute up to 18% of the world's total electricity supply, saving up to 4.8 Gt of CO<sub>2</sub> emissions per year. On the other hand, today, offshore wind power technology has only been actually developed only in a few European countries. Nevertheless, offshore wind generation technology is rapidly expanding.

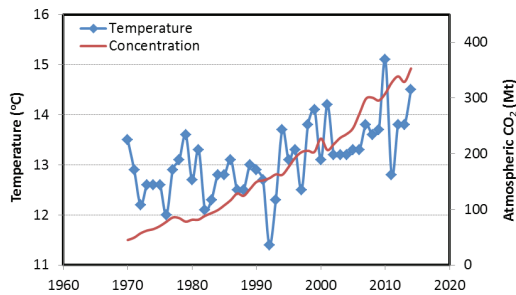
Wind power generation technologies by means of onshore have been established globally [2]. On the other hand, the recent development of large onshore wind farms has decreased the amount of remaining sites with good wind resource potential; this is mainly the case in more densely populated areas of Europe. Consequently, some European countries rapidly develop offshore wind power using the advantage of the relatively shallow seabed adjoining the continent [3]. Recently, particularly in Europe, offshore wind power plants have gained higher market shares as a result of supportive government policies [3]. As long as conditions of higher wind speeds and lower roughness classifications are satisfied, offshore locations permit to harness more wind energy thus generating surplus electrical energy [4]. The advantages of offshore wind energy have

made it become extremely attractive as a potential resource. These advantages include that it is a safe, non-polluting, renewable resource, having plenty of reserves, across a wide distribution, and that its development will not take up land resources [2].

While developed countries have been investigating on offshore wind power generation and installing offshore plants, no attempt for offshore wind power plant installation in Turkey is unfortunately observed [4]. Studies about offshore wind power generation in Turkey are a new concept. In this study, detailed discussions of the existing status and recent developments of offshore wind power in Turkey are explained.

### TURKEY'S INSTALLED ELECTRIC POWER PLANT CAPACITY

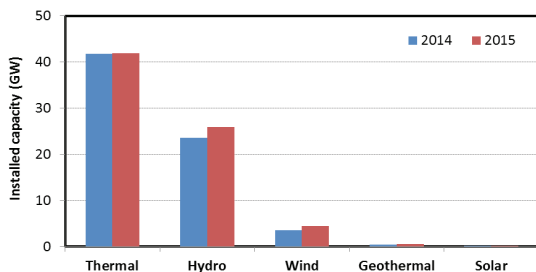
Turkey is located in middle of Europe and Asia. It is located in Anatolia and southeastern Europe, where it is bordered by Black Sea, the Aegean Sea, and the Mediterranean Sea [5]. Turkey being the 19<sup>th</sup> best economy in the world is accounted as a developing country. Electrical energy demand in Turkey has been continuously increased parallel to the continuous growth of the population and the economy. In parallel to such developments, CO<sub>2</sub> emissions originating from fossil fuels in Turkey for electricity generation have rapidly increased. Figure 1 indicates the CO<sub>2</sub> concentration increasing from 44.85 Mt in 1970 to 353.19 Mt in 2014. Turkey's average atmospheric temperature finally increased from 13.5 °C to 14.5 °C during this time range, although fluctuations of temperature were observed between 1970 and 2014. Thus, 1 °C rise of average atmospheric temperature in Turkey since 1970 has been observed.



**Figure 1.** Turkey’s average atmospheric temperature and its CO<sub>2</sub> concentration between 1970 and 2014

Figure 2 presents the installed power capacity of electric generating plants in Turkey. This figure gives the comparison of 2014 and 2015 in terms of the electricity generated from power plants including thermal, hydro, wind, geothermal and solar sources. However, there is no application of nuclear power in electric production, yet. It is clear from Figure 2 that thermal and hydro power plant applications are the most rapid growing installed capacities in Turkey. Besides, geothermal, solar and wind power installations are unfortunately small. Considering foundation of Turkey in 1923, installed capacity of electricity production and the cumulative electricity production were merely 33 MW and 45 GWh, respectively [5]. However, Turkey’s installed power capacity reached 73,146.7 MW by 2015. When the installed capacity is taken into account, thermal power plant share is 57.29% corresponding to 41,903 MW by 2015. Hydro and wind installations are reported as 35.36% and 6.16% matching to 25,868 MW and 4,718 MW of power, respectively.

Large pipeline of projects are currently available in the Turkish market. According to the Turkish Wind Power Association, a total installed capacity of 10 GW is estimated to be reached in ten years considering the current regulatory outline. However, this could be even exceeded to reach 20 GW as long as the correct amendments to the regulatory framework are applied. Turkey is among the leading players in European wind market and has become the 10<sup>th</sup> largest annual market by 2015 [6]. Turkey is rapidly shifting its direction to renewable sources to improve the energy security. Also, it is searching ways to obtain 30% of total electricity from renewable sources by 2023, because oil and gas reserves are limited. On the other hand, more renewable energy investments are rapidly required to meet the growing energy demand [6].

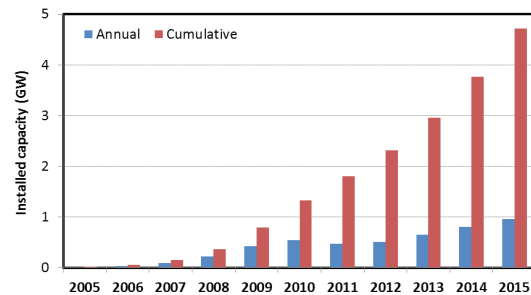


**Figure 2.** The comparison of Turkey’s installed electric power plant capacity for 2014 and 2015

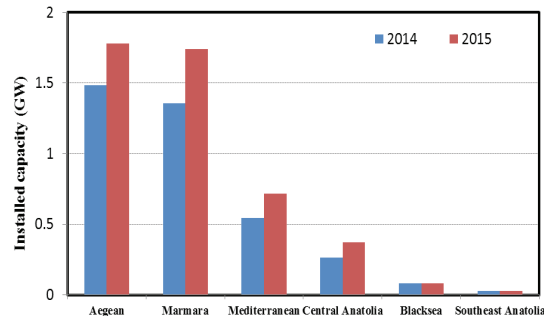
### WIND POWER CAPACITY of TURKEY

Turkey’s total installed capacity for wind power is shown in Figure 3 covering the years between 2005 and 2015.

Rapid increasing trend in wind energy capacity installations in this range of years is observed. In Turkey, while total installed capacity of wind power in 2005 is 20 MW, in 2012 it reaches 2,312 MW, indicating this rapid increase. In 2013 and 2014, this is followed by, 2,958 MW and 3,762 MW, respectively. The total wind energy installations reaches to 4,718 MW through the end of 2015, and 1,868 MW of new capacity will soon be introduced from continued wind power plant installations [7]. Especially Çanakkale, İzmir, Balıkesir and Hatay regions are highly available regions in terms of wind resources to be initially considered in wind power installations. Thus, Figure 4 shows the Aegean, Mediterranean and Marmara regions of Turkey to be more concentrated according to the wind turbine distributions. By the end of 2015; 1,780 MW, 1,743 MW and 717 MW installed wind capacities were reported for Aegean, Marmara, and Mediterranean regions, respectively [6].



**Figure 3.** The cumulative wind power installed capacity in Turkey between years of 2005 and 2015



**Figure 4.** Installed wind power capacity by provinces in Turkey

### TURKEY’S OFFSHORE WIND POWER POTENTIAL

The offshore wind energy advantages have made this technology to become extremely attractive, thus it is considered as a potential resource [2]. Turkey is surrounded with seashore by three sides, named Anatolian peninsula, including the Mediterranean Sea in the south, the Aegean Sea in the west and the Black Sea in the North. Accordingly, Turkey can appreciate good wind potential of the windy shores [8]. On the other hand, offshore wind power technology has yet not gone in action [4]. As of 2015, the installed wind power capacity of Turkey is 4,718 MW; by the end of 2023, it is scheduled to approach 20,000 MW. In this respect, smart wind resource plan evaluation is vital to make a great deal of profit by optimization of land use and other related effects. Thus, offshore wind farm investments would be unavoidable when the case that Turkey is a peninsula surrounded by sea on three sides is considered [9].

In determining the characteristics and the distribution of the wind resources of Turkey, the Wind Energy Potential

Atlas of Turkey (REPA) was developed by the General Directorate of Electrical Power Resources (EIE) in 2006 [8]. Figure 5 shows Turkey's wind speed map according to the yearly average at 50 m height. As clear from the map that the high wind potential shores generally lay along the Aegean Sea shore, followed by central Black Sea and eastern Mediterranean Sea [8]. Table 1 gives the wind power capacity in Turkey defined with respect to the different degrees of wind resources, wind classes, power densities and wind speeds [8]. According to the reports of REPA presents that Turkey's total technical wind power potential at 50 m altitude is estimated to exceed 47 GW. Moreover, Turkey's offshore wind power potential exceeds 10 GW, i.e. 22% of the cumulative wind power capacity. Turkey's offshore wind power potential defined with respect to the different wind classes is demonstrated in Table 2 [8].

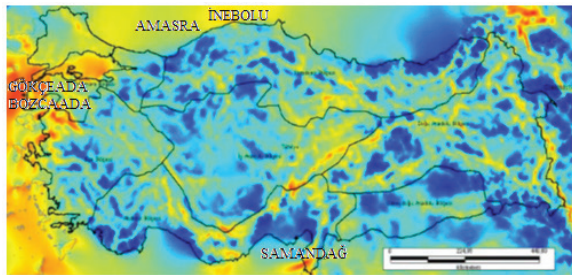


Figure 5. Wind distribution of Turkey at 50 m altitude

Table 1. Turkey's cumulative wind power capacity

Yearly average wind speed (m/s)	Power density (W/m <sup>2</sup> )	Power Potential (MW)
7.0 – 7.5	400 – 500	29,259.36
7.5 – 8.0	500 – 600	12,994.32
8.0 – 9.0	600 – 800	5,399.92
> 9.0	> 800	195.84
	<b>Total</b>	<b>47,849</b>

Table 2. Turkey's offshore wind power potential

Wind resource degree	Wind class	Yearly average wind speed (m/s)	Power density (W/m <sup>2</sup> )	Power Potential (MW)
Good	4	7.0 - 7.5	400 – 500	5,133
High	5	7.5 – 8.0	500 – 600	3,444
Excellent	6	8.0 – 9.0	600 – 800	1,742
Extraordinary	7	> 9.0	> 800	142
			<b>Total</b>	<b>10,463</b>

Although other developed countries investigate on offshore wind power production and install wind power plants, no attempt in offshore wind power plant installations in Turkey has yet started. Even studies regarding offshore wind power are very new in Turkey. In this context, Argin and Yerci [4] studied on the offshore wind power potential

evaluation of Turkey. They showed the related assessments based on criteria such as wind potential, territorial waters, military zones, civil aviation, maritime traffic, pipelines and underground cables according to the selected regions. High costs of offshore wind power plants result Gökçeada, Bozcaada, Samandığ, Amasra, and İnebolu regions to be considered initially in offshore wind power plant installations, as shown in Figure 5. Inclusive factors such as sea depth, sea basement structure, distance to the land and to the nearest transformer station of a possible plant location in these regions must also be tackled, carefully. Long term wind speed and wind power potential coinciding higher altitudes on the sea must be especially obtained before giving the final decision [4].

## CONCLUSIONS

Large potential of renewable energy sources are available in Turkey. 2023 target of Turkey covers to reach 30% share in renewable energy generations among the total energy generation methods. However, Turkey must increase its interest and need to support clean renewable energy technologies. Reduction of the dependency on fossil fuels is needed to be applied as soon as possible. In this respect; solar, hydro, geothermal and wind energy potentials are so impressive. Turkey's wind resources are estimated to be greater than 48 GW at the locations having wind speeds exceeding 7 m/s considering 50 meters of altitude. Additionally, Turkey needs to use large shores for off-shore wind farm installations. Also, offshore wind power potential of Turkey is greater than 10 GW that corresponding to 22% of the cumulative wind power capacity. No offshore wind power generation has been applied in Turkey although enough wind power potential along sea shores of Turkey is available. Since, seas surround Turkey along the three sides, offshore wind turbine feasibility for the seas should be explored in detail. In Turkey; initially, Gökçeada, Bozcaada, Samandığ, Amasra, and İnebolu locations can be considered for the installations of offshore wind power plants. The other factors including sea depth, sea basement structure, and distance to the land and to the nearest transformer station of a possible plant location in these locations should also be carefully examined.

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## REFERENCES

- [1] IEA, International Energy Agency. Carbon capture and storage: The solution for deep emissions reductions, 2015. Available from <https://www.iea.org>
- [2] Zheng C.W., Li C.Y., Pan J., Liu M.Y., Xia L.L., 2016. An overview of global ocean wind energy resource evaluations. *Renewable and Sustainable Energy Reviews*.53:1240-51.
- [3] IRENA, The International Renewable Energy Agency. Wind power technology brief, 2016. Available from <http://www.irena.org>
- [4] Argin M., Yerci V., 26-28 November, 2015, Bursa, Turkey. The assessment of offshore wind power potential of Turkey. 9<sup>th</sup> International Conference on Electrical and Electronics Engineering (ELECO). 966-70.
- [5] Bilgili M., Sahin B., 2010. *Electric Power Plants and*

Electricity Generation in Turkey. Energy Sources, Part B: Economics, Planning, and Policy. 5:81-92.

[6] GWEC, Global Wind Energy Council. Global wind report, 2015. Available from <http://www.gwec.net>

[7] TWEA, Turkish Wind Energy Association, 2016. Available from <http://www.tureb.com.tr/bilgi-bankasi/turkiye-res-durumu>

[8] Unlu M.A., 2012. Offshore wind power economics, analysis on the economic utilization of Turkey's offshore wind power potential under the current support mechanisms. Master's Thesis in Energy, Natural Resources and the Environment.

[9] Tan E., 02 March 2015, Istanbul, Turkey. Offshore wind energy potential of Turkey. 5<sup>th</sup> International Conference on Meteorology and Climatology of the Mediterranean.