Pre-Feasibility Study on the Offshore Wind Energy Capacity Assessment of Turkish Seas

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1. INTRODUCTION

Following preliminary studies carried out by the Turkish General Directorate for Renewable Energies (YEGM) over the past ten years and a claim that Turkey's offshore wind potential is around 40 GW, in Q3/2018 the Turkish government invited bidders to partake in an offshore tender for three project sites with a total capacity of 1,2 GW. No company applied for participation in this tender, most likely due to a lack of available on-site wind data, an expected relatively low wind potential (in comparison to international offshore sites) and due to a low ceiling price of 0,08 US$/kWh.

In this study, we aim to conduct a detailed analysis on Turkey's offshore wind energy potential, based on available meso-scale wind datasets, available development constraints and their influences on the annual energy production of the "DTU 10MW" wind turbine, used for reference purposes herein. Based on our findings, we propose a total number of 9 project sites for either fixed bottom and/or floating based wind farm layouts in order to assess the real offshore wind energy potential of Turkey.

2. METHODOLOGY AND EVALUATION CRITERIAS

2.1. Site development strategies

In order to define potential project sites for offshore wind farms, we used a step-by-step approach. We first defined all coastal areas of Turkey that are in between -30m and -800m in depth. Then we overlaid EMD-WRF data over the bathymetry maps and excluded all areas with wind speed indications of less than 7,5 m/s in 100m above the sea level. Finally we overlaid maps showing obvious development constraints and excluded these areas. Once the remaining areas were determined, we performed micro-siting with the "DTU 10 MW" wind turbines while considering wake effects and other environmental constraints.

2.1.1. Bathymetry

Based on the EmodNET bathymetry maps for Turkey, we assessed the entire Turkish coastline. We filtered the bathymetry data for two ranges in order to define areas that are suitable for either fixed-bottom or alternatively for floating candidate sites. We generously defined the acceptable range for fixed-bottom sites as in between -30m to -70m for gravity based, suction bucket, mono-pile, tripod or jacket foundation types. As a range for floating wind farms we defined a depth in between -80m and -800m to be suitable for spar-buoy, spar submersible and tension leg platform foundation types. The analysis of Turkish coast can be seen in below Figures 1 and 2.

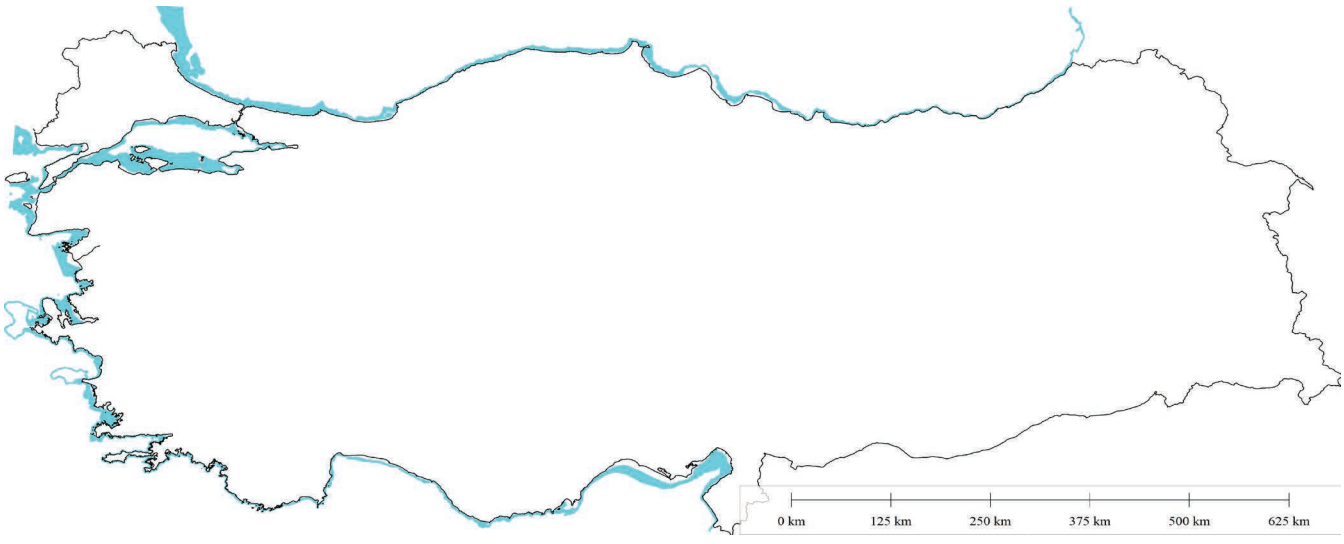

Figure 1: *Shallow waters (pale blue) of the entire Turkish coast. The depth range varies between -30m to -70m*

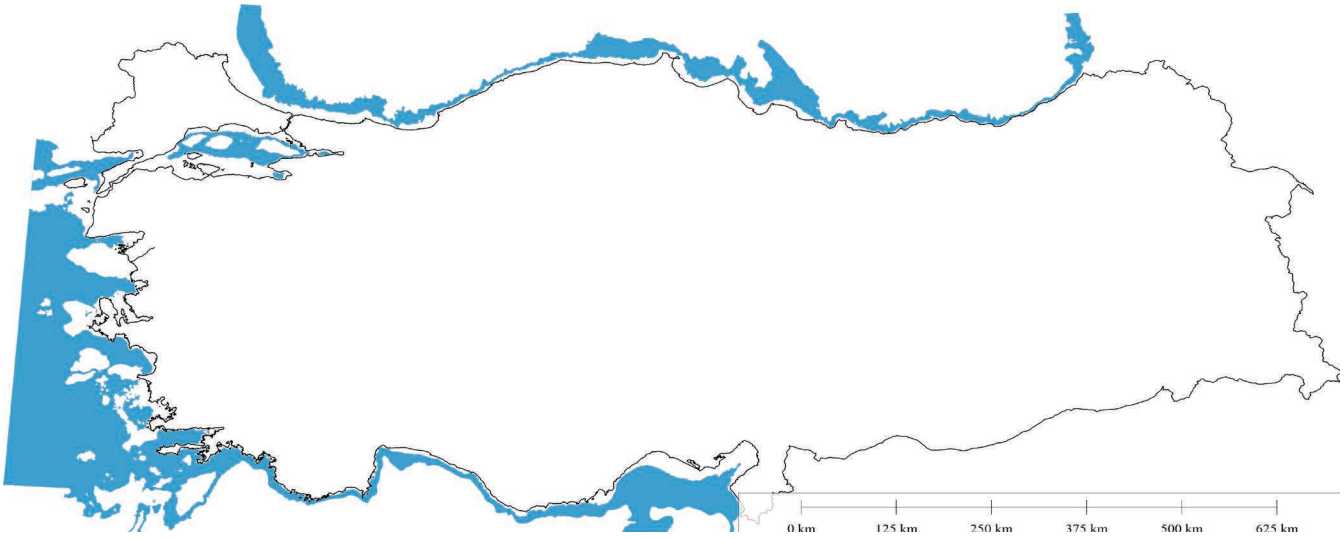

Figure 2: *Filtered bathymetry map of the Turkish coast (dark blue). The depth range varies between -80m to -800m*

2.1.2. Wind atlas

EMD International offers "EMD-WRF" datasets that cover most middle-east countries and include Turkey. Their model is run at a spatial resolution of 0.0290 x0.0290 and approximately 3x3km with hourly temporal resolution. ERA Interim data of these simulations were taken from ECMWF which was simulated via it Integrated Forecasting System (IFS) that accounts for dynamics of the atmosphere, physical processes like atmospheric composition, marine environment and land processes. In addition the simulations are based on probabilistic forecasting due to impossibility of certain forecasting by not knowing the exact initial state of the atmospheric dynamics. Such approach provides the results with error 'of the day'.

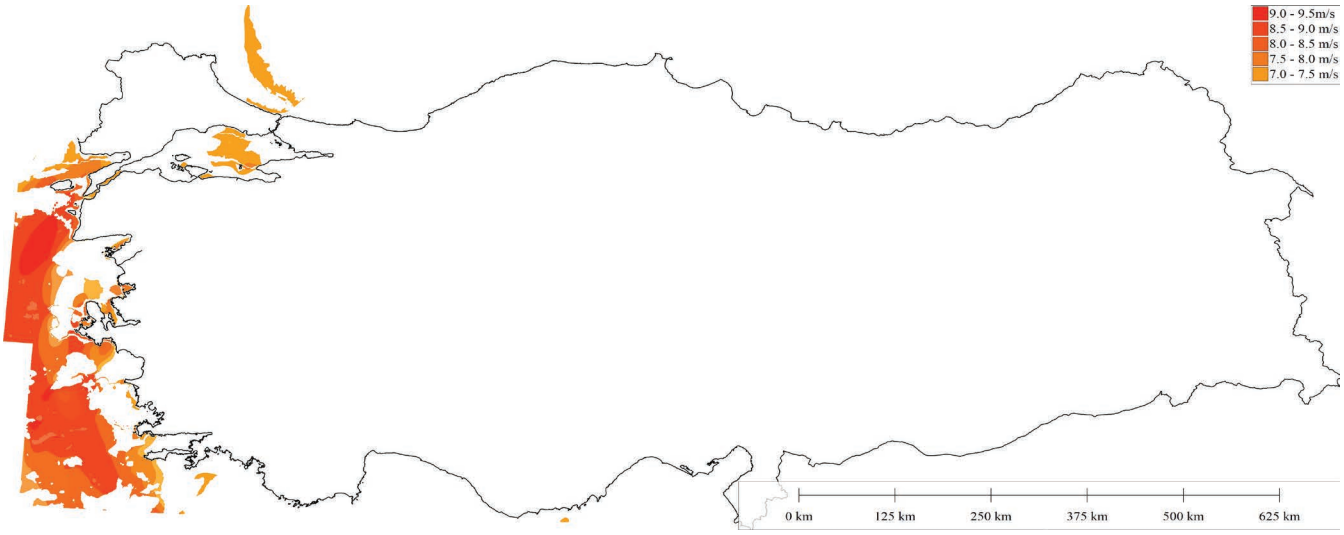

Figure 3: *Overlaid EMD wind atlas on both bathymetry ranges; wind speeds > 7,0 m/s*

Figure 3 shows the areas where wind speeds exceed 7 m/s in 100m height a.sl., overlaid to the filtered bathymetry map of the Turkish coast.

2.1.3. International Sea borders

Since the sea borders in the Aegean Sea are partly disputed, for this study we used the Global Maritime Boundaries indications as given by Google-Earth.

2.1.4. Shipping routes

The Bosphorus and Çanakkale straights are densely frequented international shipping routes, used by maritime vessels in order to reach sea ports of not only Turkey, but also Bulgaria, Romania, the Ukraine, Russia and Georgia. For this study we used the combined route plots of cargo and tanker vessels as published by "IDV Solutions".

2.1.5. Military training areas

Within Turkey's territorial waters there are a variety of offshore areas declared either as "training areas" for the Turkish navy or "forbidden zones" as per Turkish Law. For this study we used all restricted offshore areas that were published in Turkey's Official Gazette as well as the indications in a nautical map, published by "Navionics" on the internet.

2.1.6. Pipelines

We obtained the route of several undersea pipelines from Botaş, Turkey's state-owned crude oil and natural gas pipelines and trading company.

2.1.7. Environmental constraints

There is yet no national regulation, describing above-sea or undersea constraints in Turkey. However, based on international experiences and regulations in other countries, we addressed major constraints for offshore wind projects in Turkey that are likely to be risky for both developers and local settlements. In particular we addressed the following issues:

2.1.7.1. Fishing, Flora and Fauna

Protecting the undersea ecosystem is a very crucial issue in Turkey. Yet there is no sufficient regulation on protecting spawning grounds for fish, breeding grounds for sea turtles, dolphins, seals, etc. There are some academic researches (e.g. TUDAV – 2017, showing that Turkey's undersea ecosystem is highly fragile and needs to be protected against all sorts of disturbance, both below and above sea, especially in Aegean waters. The construction of pile foundations for offshore wind turbines creates significant noise (<200dB) which noise sensitive fish and especially the Mediterranean Monk Seal need to be protected against in the Aegean and the Marmara Seas. Most of our proposed offshore project sites are likely to overlap with undersea habitats, hence detailed data collection and thorough Environmental Impact Assessments need to be carried out prior to any investment.

2.1.7.2 Tourism

Turkey's economy is highly dependent on income from the tourism industry. Sailing and diving are among the major activities that make Turkey attractive to tourists. Some data on diving areas is available under "Navionics" on the internet as well as Turkey's Official Gazette. Our proposed potential offshore project areas in Seferihisar, Karaburun, Bozcaada and Çandarlı are prime touristic areas with attractions for tourists and local inhabitants along the shoreline. In addition, most of our proposed project sites are just 5km off the shoreline and hence have a significant visual impact that may not necessarily be of desire for tourists and local inhabitants.

2.1.7.3. Archeology and old ammunition from WW1 and 2

Several areas around the Turkish coast are already marked as "diving restricted zones", both in the Official Gazette and the "Navionics" map. Some of these are protected due to expected archeological findings, some of them due to the suspicion of unexploded ordnance. Especially the latter may overlap with our proposed sites in Bozcaada and Enez.

2.1.7.4. Bird migration routes

The Aegean and Marmara Seas are crossed and surrounded by major bird migration routes; an issue that needs to be carefully addressed when planning offshore wind farm projects.

During the course of data collection for this article we asked for a variety of written opinions from several Turkish state institutions. However, due to the lack of available data, the answers we received summed up mainly as "we do not know, further studies are needed". Nevertheless, we succeeded to define the rough locations of some major development constraints; however it was not possible to define the exact borders for archeological sites and undersea flora and fauna areas. In terms of detailed project development for any of our suggested potential offshore wind project areas, detailed undersea analyses will need to be performed.

2.1.7 Geological settings and constraints

Tectonically active areas are associated with high extensional stress zones such as the North Anatolian Fault Zone and the Western Anatolia Extensional Systems in the West of Turkey. Many destructive earthquakes were recorded in Western Anatolia; some of them are listed as the M: 6.9 Alaşehir (Manisa;1969), Md: 7.1 Gediz (Kütahya;1970), M:7.4 (İzmit; 1999) and M:7.2 (Düzce; 1999) in the 20th century. The most damaging earthquakes were observed along the strike-slip of the North Anatolian Fault Zone. The fault zone consists of 3 branches with the northern branch passing the Marmara Sea, the middle branch passing Bursa and stretching right into the Aegean Sea and the southern branch passing south of Bursa. Tectonic activities continue allover Western Anatolia.

Among the proposed project sites in this article, the sites "Bandırma", "Bozcaada", "Enez" and "Silivri" are located directly within the impact area of the North Anatolian Fault Zone, whereas the sites "Çandarlı", "Foça" and "Karaburun" show different geological characterizations. "Foça" and "Karaburun" are located within the NW-SE trending graben. The region is affected by both Neogen aged volcanism and Aegean Extension tectonics. Further south, the basement around the "Seferihisar" project site consists of Paleozoic aged Menderes Metamorphites and the region is also affected from Pliocene aged young volcanism. The entire region is tectonically active and the fault zone can produce more than M:6 earthquakes. The basement of the area around the "Çeşme" project

consists of sedimentary and volcanic rocks. Among the tectonically zones in the Aegean Sea, the Çeşme-Chios line is tectonically highly active and can produce more than M:6 earthquakes.

Although the regional geology is among the important criteria for the foundation design of wind turbines, the tectonical and volcanological activities also have a great importance in the proposed project sites. Western Turkey is highly tectonically active and the Turkish coast is affected by tectonical activities and tsunamis that can occur along the coast of the Sea of Marmara and the Aegean Sea. A tsunami may happen after M:6-6.5 earthquakes and it is recorded that at least 30 tsunami events have occurred along the Sea of Marmara in the past 200 years. The most affected areas are listed as the Istanbul coasts, the Gemlik (Bursa) Bay, the İzmit Bay as well as Kapıdağ and the Gelibolu Peninsula. If a tsunami occurs in the Sea of Marmara, it is likely to exceed a 3 m wave height and to reach the coast within five minutes. It is noted that tsunami waves are also possible on the Aegean costs due to the Aegean Arc system. Researchers state that more than 50 tsunami events occurred in past; the last event in June 2017. The M: 6.2 Karaburun (İzmir) earthquake rose the water level at least 15 cm at the coast.

All suggested project areas are located along the Turkish coasts and if an earthquake higher than M: 6.5 occurs in Sea of Marmara or the Aegean Sea, specifically the proposed Bozcaada, Çeşme and Karaburun projects are likely to be affected by a tsunami.

2.2. Resource assessment strategies

2.2.1. Microscale modeling

The WindPro 3.1.633 software and its 'Resource' module are used in wind resource simulations over the WAsP 11.06 software. In order to perform full energy yield simulations, the orography, roughness data and meteorological data are required for generating wind resource maps. The datasets used in the simulations are SRTM (for topography), EMODnet Digital (for Bathymetry), CORINE (for roughness) and EMD-WRF (for local meteorological data).

After having selected available areas to develop offshore wind farms, the most representative meteorological data for each site was downloaded from WindPro. EMD WRF data was taken as reference data. Thereafter, the MCP module of WindPro software was used to convert EMD WRF data into long term corrected datasets and was applied in the microscale modeling. Finally, the long term corrected dataset was coupled with the DTU 10MW reference wind turbine and used in the final resource assessment. The layouts were designed after several simulation iterations in order to achieve lowest level of wake effects.

3. RESULTS

3.1. Potential project sites

We were able to define a total of nine potential offshore wind farm sites within Turkey's territorial waters. Six of these sites with a total capacity of **3.060 MW** appear to be constructible with **bottom-fixed** foundations and three sites with a total capacity of **2.760 MW** are suitable only for **floating** turbines. Among the six sites, suitable for bottom-fixed foundations, three sites with a total capacity of **770 MW** should be defined as "not-executable" and **"hardly-financeable"**, since they are located just 1,5 km off the coast and would have a major visual impact on the population (and in summer partly on tourism), living nearby. Among the remaining six project sites, the capacity factors vary in between 46,5% (Bozcaada project) and 35% (Bandırma project); summary to be seen in the tables below:

Results of evaluated sites

Sites suitable for bottom-fixed turbines, but hardly executable:

Project name	Province	Location	Turbines	Total MW	Capacity factor (%)	Comments
Çandarlı	İzmir	Dikili	30	300	42.50%	Closest distance of a turbine to shore: 1,5 km / Danger of flicker effect /
Karaburun	İzmir	SE of Karaburun	27	270	33.90%	Closest distance of a turbine to shore: 1,5 km / Danger of flicker effect. Military training area would needed to be cancelled
Seferihisar	İzmir	W of Seferihisar	20	200	43.20%	Closest distance of a turbine to shore: 1,5 km / Danger of flicker effect - Major tourism area / Suspected breeding are of monk seal

Sites suitable for bottom-fixed turbines:

Project name	Province	Location	Turbines	Total MW	Capacity factor (%)	Comments
Enez	Edirne	West and SW of Enez	64	640	38.00%	Military training area needs to be partly cancelled
Bandırma	Balıkesır	Between Marmara island, Erdek and İmralı island	115	1.150	35.00%	
Bozcaada	Çanakkale	South of Bozcaada	50	500	46.50%	Military training area needs to be partly cancelled

Sites suitable only for floating turbines:

Project name	Province	Location	Turbines	Total MW	Capacity factor (%)	Comments
Foça	İzmir	West of Dikili & Aliağa	43	430	39.50%	
Çeşme	İzmir	South of Urla / West of Seferihisar	143	1.430	44.10%	
Silivri	İstanbul	South of Silivri	90	900	42.40%	

The proposed locations of the mentioned sites are shown in Figure 4.

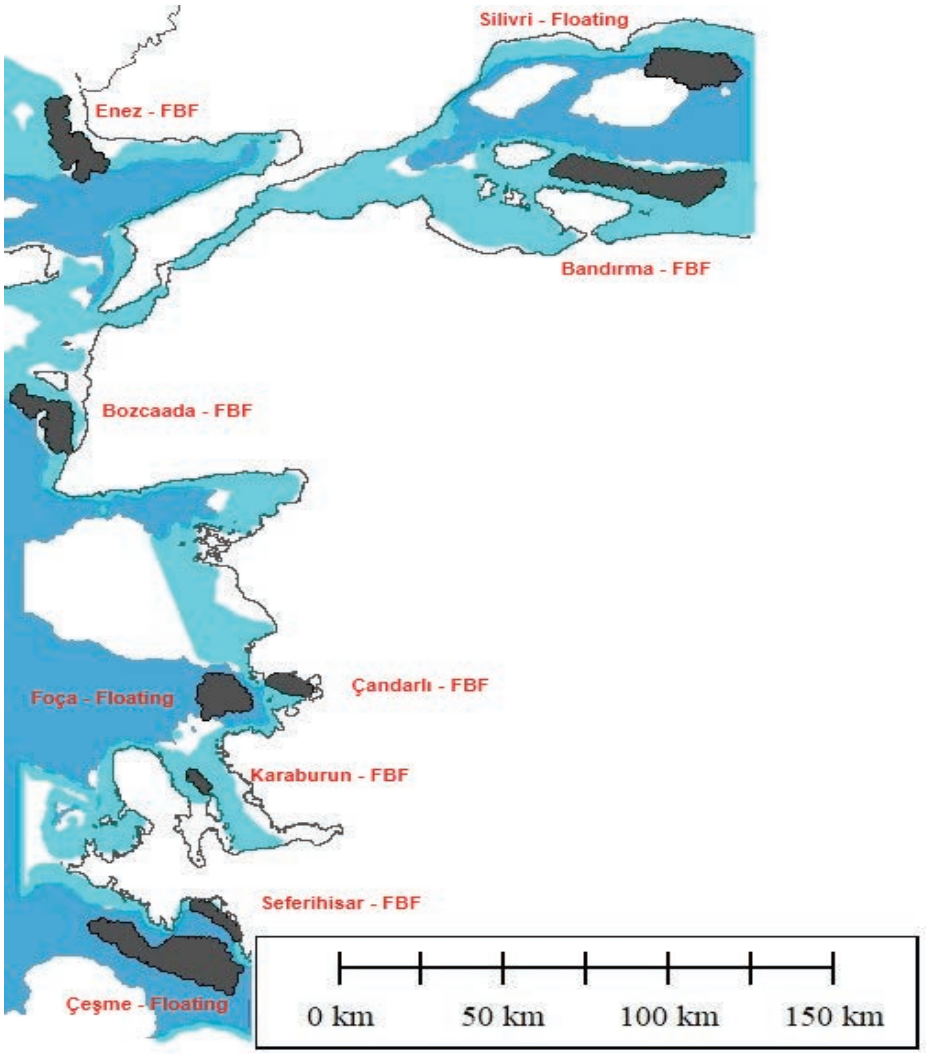

Figure 4: *Rough locations of all proposed sites*

4. CONCLUSION & DISCUSSIONS

As per our study, Turkey's environmentally and technically executable offshore wind energy potential is roughly **5 GW**. With capacity factors of in between 35% and 46% however, the energy to be yielded from these projects is not significantly higher in comparison to already operating onshore wind farms in Western Turkey. Capacity factors of around 45% can already be achieved in the provinces of Çanakkale, Balıkesır, partly İzmir and partly in Thrace.

This article does not cover studies on the necessary on-shore infrastructure (mainly port facilities), needed for the handling of large offshore wind turbines, nor does it cover the availability of vessels to transport the wind turbines to their final project sites.

Whether or not offshore wind energy is a financially feasible option for Turkey (which tries to lower the feed-in price for wind farms to significantly below 7,3 USDcents/kWh) should be discussed separately.