

IMPORTANCE OF OFFSHORE WIND FARMS MARMARA SEA FOR TURKEY'S RENEWABLE ENERGY TARGETS: A CASE STUDY MARMARA SEA

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Abstract

In Turkey, current energy generations are not sufficient for the existing energy needs and besides, energy demand is expected to increase by 4-6% percent annually until 2023. Therefore, the government aims to increase the ratio of renewable energy sources in total installed capacity to 30 percent by 2023. Turkey has three quarter seas around itself. So, Turkey has a high level offshore wind potential for energy generations. But there are not any offshore wind farms in Turkey seas. In this study, we aimed at assessing the viability of establishing offshore wind farms of Marmara Sea and to identify favorable sites for such farms using Geographical Information System (GIS) procedures and algorithms. GIS layers were created and a weighted overlay GIS model based on the above mentioned criteria was built to identify suitable sites for hosting a new offshore wind farm. Furthermore, EMODnet (the European Marine Observation and Data Network) and GWA (Global Wind Atlas) were employed for data acquisition to unlock fragmented and hidden marine data resources and to facilitate investment in sustainable coastal and offshore activities. Received technical, social and environmental data from different sources were processed in the GIS and we created the GIS-based model. Results showed that most of Marmara Sea offshore areas were unsuitable. There are only two suitable areas. It is apparent that the growth of offshore wind farms in Turkey will increase provided that the supporting mechanism and the necessary legislation are ensured.

Keywords: GIS-based Model; Suitable Site Selection; Offshore Wind Farm; GIS

1. INTRODUCTION

The growing world population, the fast depletion of fossil fuel reserves and the document climatic effects of fossil fuel burning have prompted world governments to pursue renewable energy sources [1]. Wind, solar, biomass, hydraulic, geothermal and wave energy named as renewable energy [2]. Because of overconsumption of fossil resources and the concern about reduction of greenhouse gas emission, the renewable clean energies such as wind energy plays a vital role in the electricity generation. Particularly, wind power has shown the fastest growth in the last decade. Offshore wind energy is a fastest growing renewable energy this has recently drawn more worldwide attention. 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 [3,4].

The air movement formed by the pressure difference due to the fact that the sun does not heat the earth homogeneously is called wind. This wind energy is considered as kinetic energy due to the speed of the air. Wind power has been used throughout to help accomplish mechanical tasks such as water pump. Having wind machines with 15-20 years lifespan that can be implemented at sufficient wind sites, makes wind energy competitive with other renewable energy systems for electricity energy generation [5]. Furthermore, wind has become one of the fastest growing renewable sources for power generation and has become more competitive with conventional energy sources in recent years [6].

Turkey is extremely dependent on natural gas imports especially for electric power generation. The total imported natural gas amount in 2014 was 1.7 billion cubic feet [7]. The most amounts of Turkey energy need are supplied from coal, natural gas and hydropower. They almost comprise of 94% of the total energy resources. Geothermal, wind, liquids fuels, solar and others have about only 6% share on the resources [8]. So, Turkey must generate the energy demands from renewable sources. If Turkey in the wind energy potential in general are facing, Turkey onshore and offshore wind potential have been identified 48000 MW, 17393.2 MW, respectively [9]. Turkey has a lot of onshore wind farms, but there is no any offshore wind farms in Turkey. In this study, we aimed the suitable site selection for offshore wind farms in Marmara Sea.

The most important factor in selecting a new site for offshore wind farms is the availability of adequate wind resources. Water depth and soil conditions determine the type of wind turbine foundation and have a significant impact on its economic feasibility [10]. Generally, suitable water depth for offshore wind turbine suggests between 20-50 meters. Beyond that depth, floating foundations are needed and therefore the cost of wind farm is increased. The objective of the present study is to analyze with Geographical Information System (GIS) of Marmara coastal regions of Turkey for offshore wind power assessment in detail. Investigated topics will consist of environmental, social and technical issues in which are documented as an obstacle in terms of installation.

2. THE STUDY AREA

2.1. Location:

The sea of Marmara, also known as the Sea of Marmora or the Marmara Sea, is the inland sea, entirely within the borders of Turkey, that connects the Black Sea to the Aegean Sea, thus separating Turkey's Asian and European parts. The Bosphorus strait connects it to the Black Sea and the Dardanelles strait to the Aegean Sea. The former also separates Istanbul into its Asian and European sides. The Sea of Marmara is a small sea with an area of 11,350 km² (4,380 sq mi), and dimensions 280 km × 80 km (174 mi × 50 mi). Its greatest depth is 1,370 m (4,490 ft) [11]. The study area is shown figure 1. The Marmara sea has a high level of ship density. In Tekirdağ and Balıkesir coasts, the water depth level is lower than other regions.



Figure 1. Study Area from Google Maps.

2.2. Wind Potential in Marmara Sea:

Wind speed in Marmara Sea is usually below the 10 m/sec for most of the year [12]. Channel effect occurs due to the geographical location of Marmara Sea. Thanks to the channel effect, the wind speed can reach up to 20 m/sec. Terrestrial wind turbine plants are in front row in terms of installed power. Therefore, it has high wind potential both land and at sea. As seen in figure 2. Marmara Sea's mean wind speed is 8 m/sec at 100 m elevation. This high wind speed is very important for electricity generation. Databases seen in figure 2 was obtained from Global Wind Atlas (GWA) [13]. And then, this data is processed in GIS.

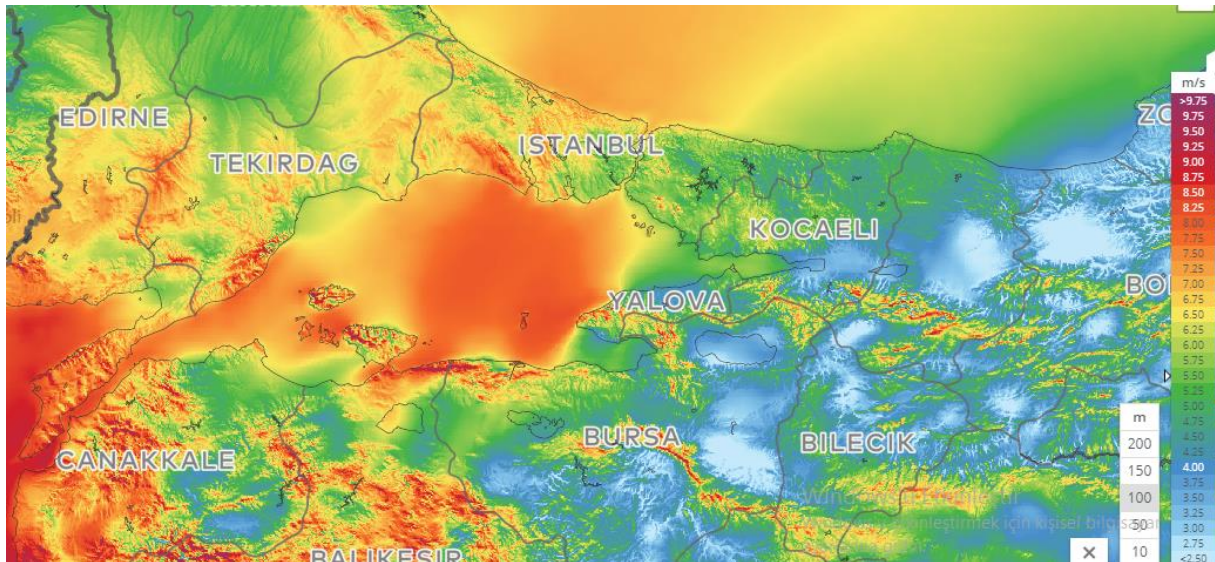


Figure 2. Mean Wind Speed at 100 m over Marmara from GWA.

2.3. Environmental and Social Impacts:

Environmental and social impacts is very important in offshore wind power assessment [14]. Environmental and social impacts have a lot of restrictions for wind power installation. Considering of the environmental and social conditions in Marmara Sea, several criteria are taken into consideration to assess the suitability of location for installing an offshore wind farm. It was found that an offshore wind farm location must be suitable primarily in terms of military areas, shipping routes and ports, tourism facilities, national parks, designated regions and the presence of infrastructures such as pipelines and underground cables. In this paper the majority of environmental and social data's received from Emodnet (Human Activity). Emodnet (the European Marine Observation and Data Network) was employed for data acquisition to unlock fragmented and hidden marine data resources and to facilitate investment in sustainable coastal and offshore activities [15].

2.3.1. Military Regions:

There are 21 military regions in Turkey [15]. This military regions have a important value for Turkey government. So, Wind farm cannot installed in this military regions. There are 7 military regions in Marmara coasts. 6 military zones take place onshore, only of them is situated nearly of Marmara Sea. The military zone takes place in Tekirdağ southeast borders. In seen figure 3. Military regions at all coastal zones of Turkey.



Figure 3. Military regions at all coastal zones of Turkey.

2.3.2. Ship Routes, Density and Ports:

Due to geographical location Turkey, its acts as a bridge between Asia and Europe. So, the load, military, passenger ships use to Turkey’s seas. The Marmara Sea has heavy ship traffics. Offshore wind farm cannot installed in use ship routes and heavy traffic regions. As seen in figure 4. Sea routes and ports of Turkey. As received data from Emodnet, we analyzed in GIS program. Heavy traffic routes appear in figure 5 [15]. This heavy traffic routes, the offshore power plant is not true. Only 3 regions are suitable for installation offshore wind farms.

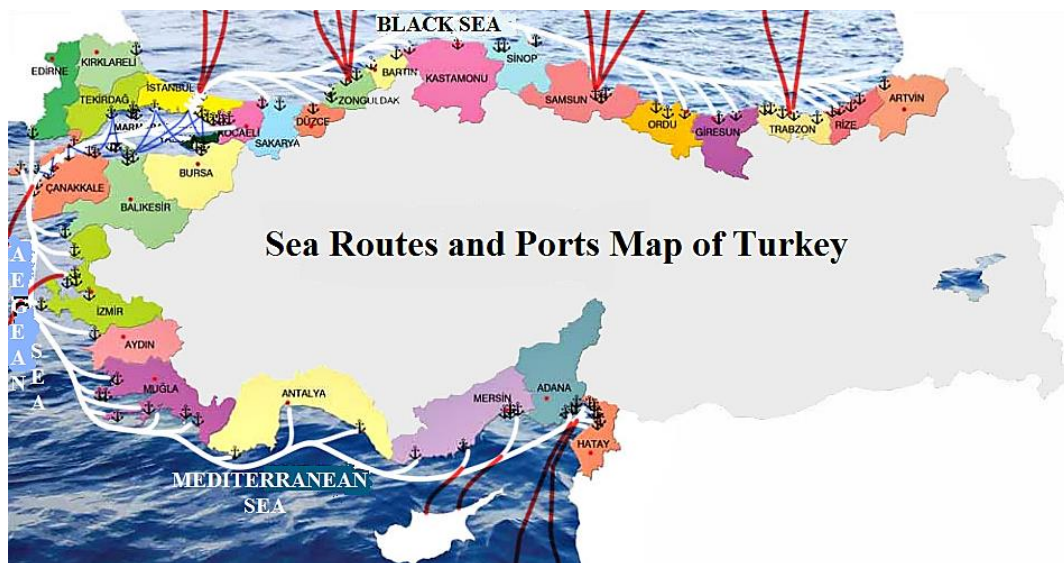


Figure 4. Sea Routes and Ports Map of Turkey.

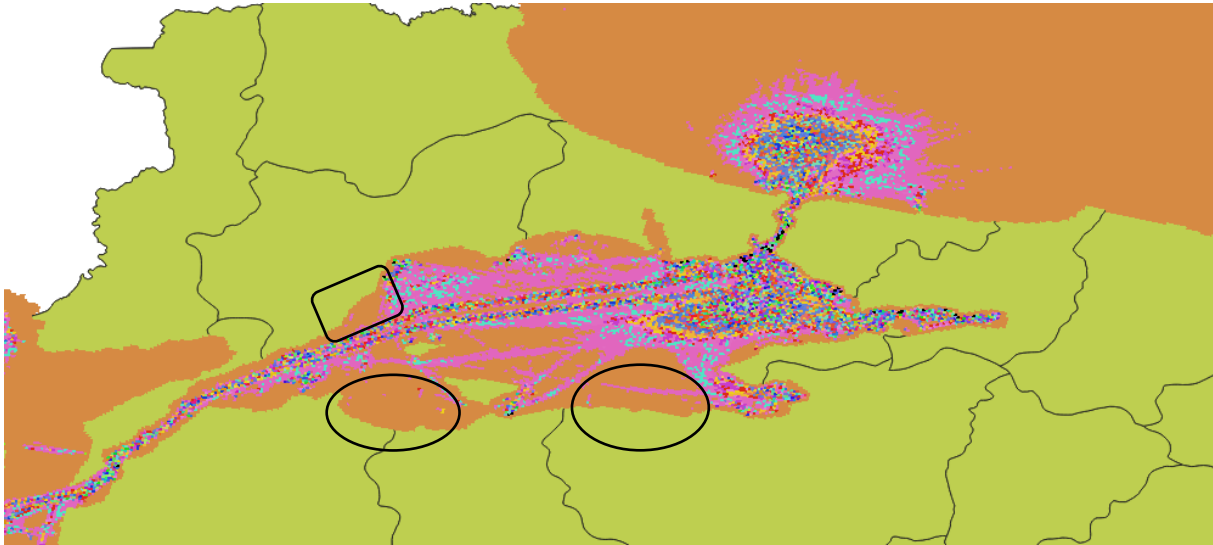


Figure 5. Heavy Traffic Routes Analysis in GIS

2.3.3. Tourism Sector:

Turkey has 4 quarter seas. Therefore, sea tourism sector is very developed. In selected of suitable offshore wind farms areas, it is necessary to give importance to the tourism sports and activities areas. Wind turbines to be installed must be at least 5 km from the shore [16]. In seen Figure 6, Beach areas used extensively shown to in Turkey. Tourism activities in the Aegean region have improved a lot. Offshore wind farms, which should not be close to the shore, cannot be installed in the Aegean region. Because of outside tourism activities, it does not belong to Turkey border. Tourism activities of the Erdek region have also developed in the Marmara Sea. Therefore, Offshore wind turbines cannot be installed in this region in order to not to restrict tourism activity areas.

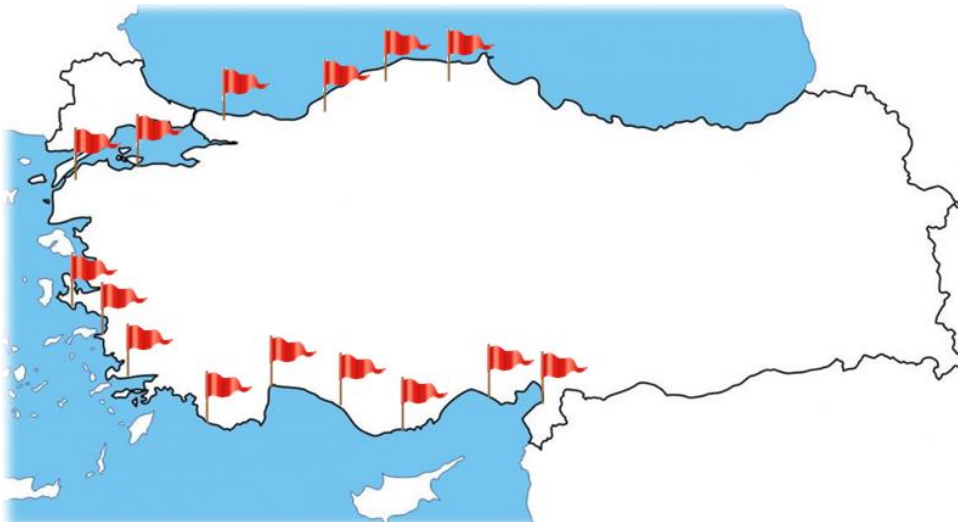


Figure 6. Tourism Activities Regions in Turkey

2.3.4. National Parks and Designated Regions:

Worldwide, important parks and regions are protected by international commissions. These zones cannot be used without permission [17]. Therefore, offshore wind farm cannot be established in the

protected areas. It was processed in the GIS program given from Emodnet and figure 7 was obtained [15]. According to figure 7, Turkey has two protected areas in the region. These regions are; Aegean and west of the Black Sea. Offshore wind power plant cannot be established in these regions. There is no protected area in the Marmara Sea.



Figure 7. National Parks and Designated Regions adopted by GIS.

3. METHODOLOGY

This study adopts a GIS-based methodology to identify areas suitable for installation offshore wind farms. The selection process is performed in two stages: an area exclusion stage and an area ranking stage. Firstly, unsuitable regions is excluded for offshore wind farm. Secondly, remaining regions is ranking based on wind speed and water depth. So, suitable, moderately-suitable and unsuitable regions is determine in Marmara Sea.

3.1. Selection Criteria:

The criteria used to determine suitable locations for wind farms are divided into two categories according to their role. The first category yields a binary decision and is used in determining the excluded area mask. The second category is used to compute a suitability score to determine different area suitability level. The set of criteria first category is summarized in table 1 [18]. These criteria consist of environmental-social parameters to exclude areas listed.

Table 1. Criteria used to exclude areas from the selection process.

Parameters	Unsuitability Condition
Water/Land Mask	Land
Military Regions	Within 5000 m
Oil and Gas Pipelines	Within 250 m
Ship Routes and Ports	Within 500 m
Tourism Region	Within 5000 m
National Park	Inside
Protected Areas	Inside

The set of criteria for the second category is summarized in table 2. It includes wind speed and water depth. The suitability conditions adopted in the study are based on published literature. Areas where wind speed are below 4.5 m/sec are not favorable for wind energy and deemed unsuitable [19]. Areas where wind speeds are above 5.4 m/sec can be considered suitable [20]. The water depth has an economic implementation on the choice wind farm site as it affects its installation cost [21].

Table 2. Criteria used to rank non-excluded areas.

Parameter	Suitability Condition
Wind Speed	< 4.5 m/s : unsuitable
	4.5-5.4 m/s: moderately-suitable
	5.4 m/s < : suitable
Water Depth	0-20 m: moderately-suitable
	20-50 m: suitable
	>50 m: unsuitable

3.2. Data Sets:

Data needed for this study are collected from different sources in different formats and characteristics. They are pre-processed into the same spatial reference system and stored in a geodatabase for use in GIS. Table 3. Summarizes the data sets collected and main characterizes.

Table 3. Data sets used in the study.

PARAMETER	LAYER	TYPE	DATE
WATER DEPTH	Bathmetry	Raster	2019
WIND SPEED AT 50 M	Wind_speed	Raster	2020
PIPELINES	HA_Pipelines	Lines	2015
DESIGNATED REGIONS	Environment_Design	Polygon	2015
VESSEL DENSITY	HA_Vessel	Raster	2018
MAIN PORTS	HA_Main_Ports	Polygon	2018
MILITARY REGIONS	Military_Areas	Polygon	2014

3.3. Creation of Suitable Maps:

Regions that are not excluded by the first stage of the model are candidates for wind farms. Their criteria listed in the table 2 [1]. The approach adopted in this study is based on a weighted sum overlay whose inputs are derived from the wind speed and water depth layers. For suitable selected region, according to water depth and wind speed, we ranking between 1-3.

Table 4. Ranking of according to wind speed and water depth

wind speed	water depth	ranking
$v < 4.5$ m/sec	$d < 50$ m	1
$4.5 \leq v \leq 5.4$ m/sec	$0 < d < 20$ m	2
5.4 m/sec $< v$	$20 \leq d \leq 50$ m	3

After ranking, parameter is required to calculated the suitability of the regions. For the literature, the suitability of regions is expressed ‘S’.

$$S = W_{\text{wind}} * \text{ranked wind speed} + W_{\text{depth}} * \text{ranked water depth} \quad (1)$$

where W_{wind} is the weight given to the wind speed criterion and W_{depth} is that given to the water depth criterion. In this study, we assign a value of 2 to W_{wind} and 1 to W_{depth} . The calculated suitability can take values between 3-9 in table 5. The suitability is reclassified and ranked between 1-9 as per table 6.

Table 5. Suitability Values (S)

v	d	S	v	d	S	v	d	S
1	1	3	2	1	5	3	1	7
1	2	4	2	2	6	3	2	8
1	3	5	2	3	7	3	3	9

Table 6. Ranking of the Suitability Results

Suitability (S)	Ranking	Condition
3 - 5	1	Unsuitable
6 - 7	2	Moderately suitable
8 - 9	3	Suitable

4. RESULT AND DISCUSSION

According to the information and data described in the section 3, a suitable region for offshore wind farms assessment study was carried out for the Marmara Sea. The information and data received from

different sources were processed in the GIS program. The results will be evaluated according to the GIS-based methodology.

4.1. Exclusion Regions in the Study Area:

The impact of the social and environmental impacts mentioned in section 2 on the study area (seen in figure 8) was evaluated. The necessary data were obtained from Emodnet and GWA. And then, this data was processed in the GIS program. The results obtained were shown on the image appearing in figure 9, the sections that were excluded.

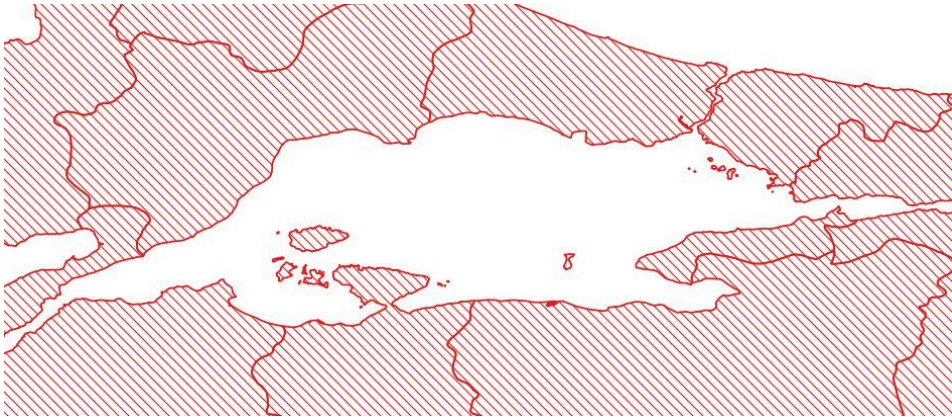


Figure 8. Study Area

As a result of the data received and evaluations, three parameters that are effective in the Marmara Sea are: Ship density and routes, telecommunication cables and tourism activities. Figure 9 shows the areas that have a negative impact on the Marmara Sea. So, this areas not suitable for offshore wind farms.

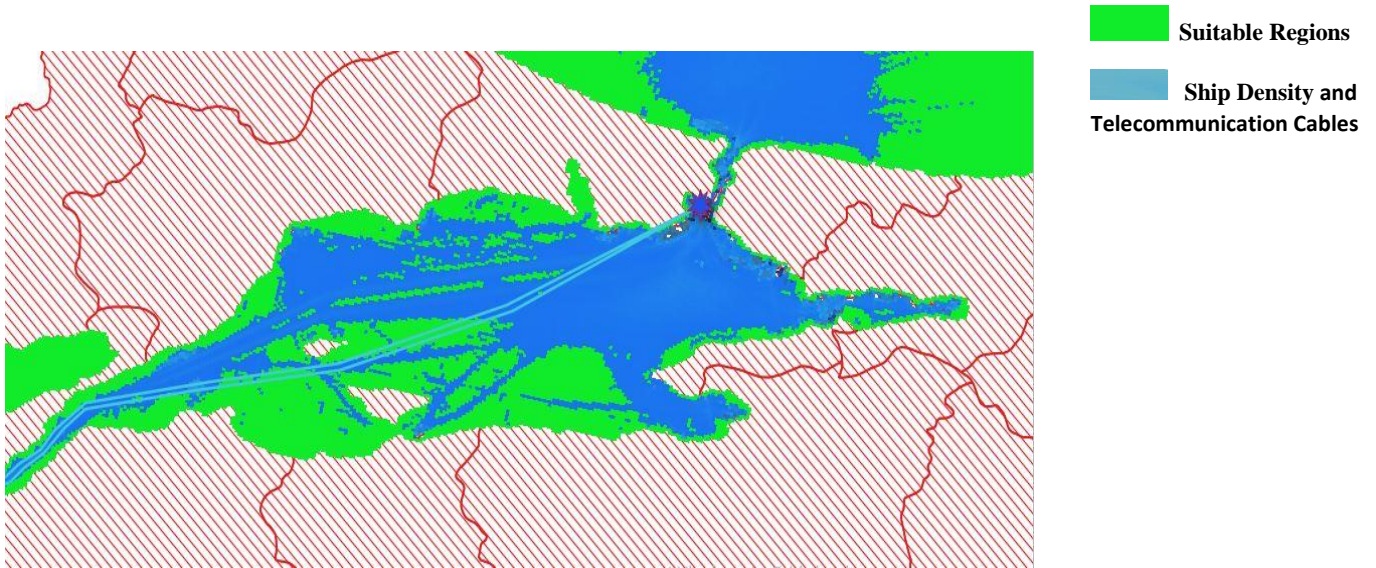


Figure 9. Suitable Areas in the Study Area

4.2. Wind Speed Distribution Map:

In order to establish a wind farm in any region, the wind speed and potential must be sufficient. The wind speed and potential analysis of the selected region should be made correctly.

We received the required data at elevated 100 m from Global Wind Atlas for the wind speed assessment of Marmara Sea. We classified these data according to the information in section 3 and we obtained 3 different wind speed zones as seen in figure 10.

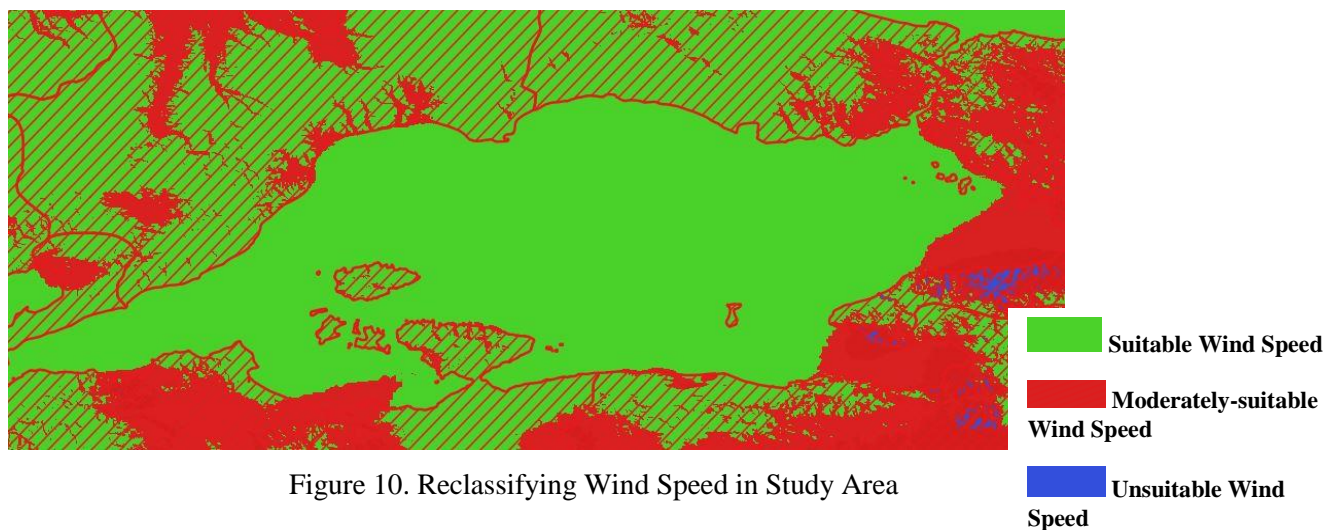


Figure 10. Reclassifying Wind Speed in Study Area

4.3. Water Depth Assessment Map:

The most important factor of offshore wind farm cost is the foundations. So, Offshore wind power farms to be built in shallow areas. In this study, we choose the appropriate water depth level between 20-50 meters. Because there are tourism activity regions around the Marmara Sea, regions close to the

shore cannot be chosen. Received data from Emodnet-Bathymetry, we processed in GIS program. We can see in figure 11. that the sea depth level classified in table 2.

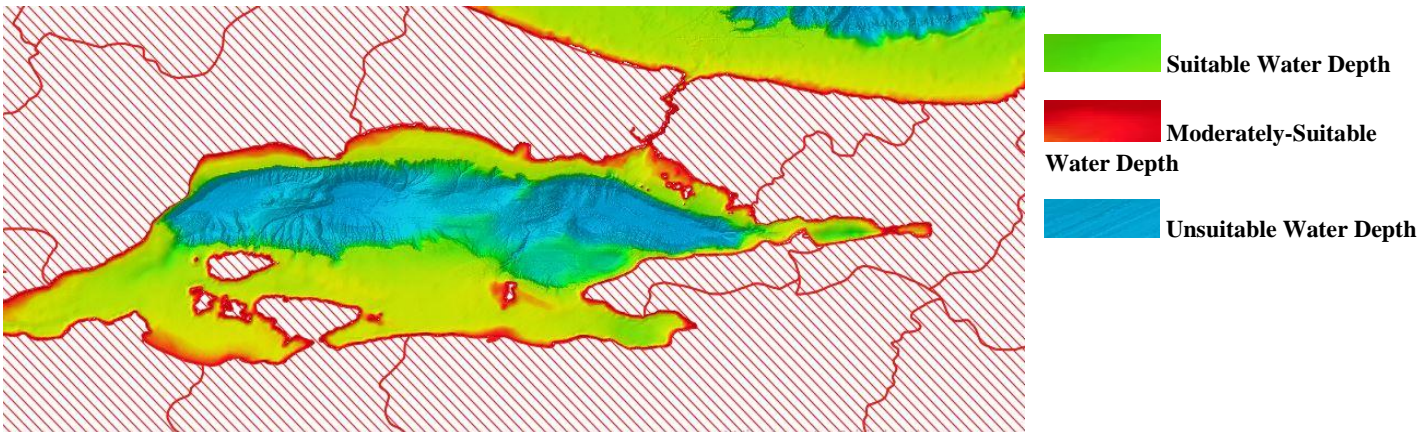
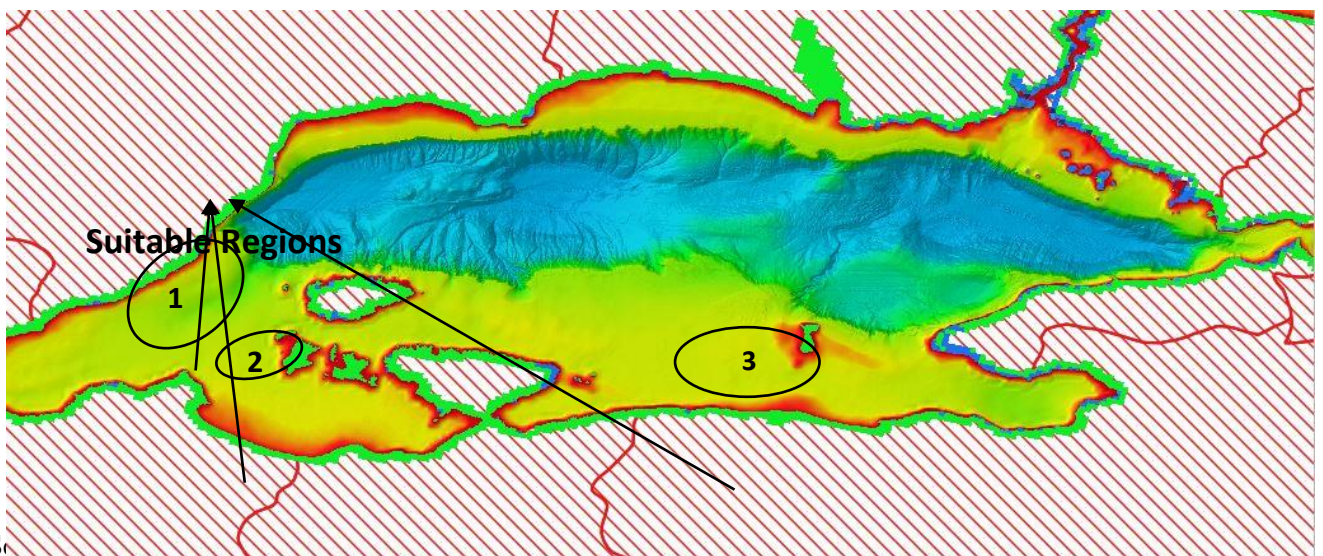


Figure 11. Water Depth Classified Regions

4.4. Candidate Regions of Suitable for Offshore Wind Farm:

The suitability model described in section 3.3. is run using the classified wind speed and bathymetry inputs to create the suitability map shown in figure 12. It candidates that only three small fraction of offshore Marmara Sea is suitable for offshore wind farms.



So, offshore wind power plant. Finally, we examined these three small regions socially and environmentally. Seen in figure 12, Region 1 and 3 are also suitable socially and environmentally. But region 2 is not suitable where is intensive tourism activity regions. As a result of the arrangements to be made by the local people and administrations, region 2 can be made suitable for offshore wind farms.

4. CONCLUSION

The objectives of this study were to assess the viability of establishing offshore wind farms in Marmara Sea. We obtained the necessary data for suitable offshore wind farm selection region from different sources. These data would be processed in GIS program and the rest of analysis in this study completed to GIS-based methodology. GIS was efficient in assembling and evaluating layers of the spatial variables that were incorporated into a multi-criteria model. The model consisted of two stages: an area exclusion stage and an area suitability ranking stage. According to the model, we designated suitable areas in the study for offshore wind farms.

Finally, the GIS-based model was very successful in identifying potential sites for eventual offshore wind farms. With this model, we examined the Marmara Sea for offshore wind potential. As a result of our analysis studies, we obtained one suitable region for offshore wind farm. This suitable area is region 1 and region 3 shown in figure 12.

Consequently, Turkey, where its huge quantity (three quarters) is surrounded by seas, should be disposed to offshore renewable energy sources if dependency on other countries wants to be decreased. Therefore, this comprehensive study will be the first step of the Marmara Sea and a useful guide of offshore wind power development in Turkey.

References

- [1]. Saleous N., Issa S., Mazrouei J., "GIS-Based Wind Farm Site Selection Model Offshore ABU DUBAI Emirate", Remote Sensing and Spatial Information Sciences, XXIII ISPRS Congress, 2016, Czech Republic.
- [2]. Abbasi T., Premalatha M., Abbasi S.A., "Wind Energy; Increasing deployment, rising environmental concerns.", Renewable and Sustainable Energy Reviews, 270-288, 2014.
- [3]. UK Offshore Wind: Opportunity, Costs & Financing. Climate Change Investment Research. 2011.
- [4]. Renewable Energy Technologies, Cost Analysis Series. International Renewable Energy Agency Working Paper. 2012.
- [5]. Ammari H., Al-Rwashdeh S., Al-Najideen M., "Evaluation of wind energy potential and electricity generation at five locations in Jordan.", Sustainable Cities and Society, 135-143, 2015.
- [6]. Chandel S., Ramasamy P., Murthy K., "Wind power potential assessment of 12 locations Himalayan region of India.", Renewable and Sustainable Energy Reviews, 530-545, 2014.
- [7]. International Energy Agency (IEA), Energy supply security emergency response of IEA countries, www.iea.org, 2014.
- [8]. Turkish Electricity Transmission Company 2014 Report.
<https://www.teias.gov.tr/FaaliyetRaporlari/faaliyetrap2014/2014jn.pdf>.

- [9]. Altuntaşoğlu, Z. T. 2012. “Türkiye’de Rüzgâr Enerjisi, Mevcut Durum, Sorunlar,”
Mühendis ve Makine Dergisi, cilt 52, sayı 617, s. 56-63.
- [10]. Kim J., Oh K., Lee J., “Site selection of offshore wind farms around the Korean Peninsula through economic evaluation.”, *Renewable Energy*, 189-195, 2013.
- [11]. Wikipedia, https://tr.wikipedia.org/wiki/Marmara_Denizi.
- [12]. Turkish Meteorological Directorate General (DMI) Wind Report.
a. <https://www.mgm.gov.tr/deniz/ww3-ruzgar.aspx>.
- [13]. Global Wind Atlas, Wind Speed and Wind Density Map, Download GIS Files.
a. <https://globalwindatlas.info/downloads/gis-files>
- [14]. Akpınar A., “Evaluation of wind energy potentiality at coastal locations along the North eastern coasts of Turkey.”, *Energy*, 395-405, 2012.
- [15]. The European Marine Observation and Data Network/ Human Activity/Download Data Files. <https://www.humanactivities.eu/download-data.php>
- [16]. Waewsak, J., Landry, M., Gagnon, Y. Offshore wind power potential of the Gulf of Thailand. *Renewable Energy*, 81: 609-626, 2015.
- [17]. Mann H., Teilmann J., “Environmental impact of wind energy”, *Environmental Research Letters* 8 (3):035001, 2013.
- [18]. Argin M., Yerci V., “Offshore wind power potential od the Black Sea region in Turkey”, *International Journal of Green Energy*, 811-818, 2017.
- [19]. LAtinopoulos D., Kechagia K., “A GIS-Based Multi-Criteria Evaluation for Wind Farm Site Selection: A Regional Scale Application in Greece.”, *Renewable Energy*, 550-560, 2015.
- [20]. Baban S., Parry T., “Developing and applying a GIS assisted approach to locating wind farms in the UK.”, *Renewable Energy*, 59-71, 2001.
- [21]. Higgins P., Folley A., “The key technology and development of offshore wind farm in China.”, *Renewable and Sustainable Energy Reviews*, 453-462, 2014.