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RESEARCH ARTICLE

Suitable site selection for offshore wind farms in Turkey's seas: GIS-MCDM based approach

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Abstract

Offshore wind energy resources are not fully exploited renewable energy resources until now and could play a crucial role in mitigating the impacts of climate change by the generation of renewable electricity. Planning processes such as technical, social, environmental, various agents, and political concerns are necessary for the development of offshore wind energy projects. The objective of this study was to assess the comprehensive feasibility of a desired offshore wind power plant applying Geographical Information Systems (GIS) and Multi-Criteria Decision-Making (MCDM) guidance for the coastal area of Turkey. Furthermore, 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. For the determination of potential site with Multi-Criteria Decision Maker Method, 3 main criteria Technical (C1), Environmental (C2), and Social (C3), and 13 sub-criteria were determined. Based on these criteria, the suitability map was created by using all criteria map layers with their buffer zones. The final map indicated that %1.38 (3294.8 km^2) of Turkey Seas was suitable for offshore wind farms. The most suitable region was determined in the Marmara Sea with 1194 km^2. The Aegean Sea, the Black Sea, and the Mediterranean Sea were following the Marmara Sea in terms of the huge suitable regions respectively. It was apparent that the growth of offshore wind farms in Turkey would increase if the supporting mechanism and the necessary legislation were ensured.

Keywords Renewable energy · Feasible site selection · Offshore wind farm · Geographic information system (GIS) · EMODnet

Introduction

Because of abrupt industrialization and pollution issues all over the world such as energy requisition and fossil fuel consumption, countries research ways to improve their renewable energy capacities. As a pioneering renewable energy source since the 1980s, wind energy has been utilized for electricity production (Kaldellis and Zafirakis 2011). After that, Europe has become the leader in the wind energy market (Hansen and Hansen 2007). On behalf of increasing the usage of renewable energy to 20%, the 2020 aims defined by the European Union (EU), have swiftly broadened the economy of Turkey in conjunction with its Gross Domestic Product (GDP) (World Bank 2017). This ensures Turkey to be a crucial territorial power in terms of energy systems. The Turkish government has already planned very ambitious objectives and strategies for 2023 regarding electricity generation based on the high availability of RES-hydro, wind, solar, geothermal, etc. It is planned to increase the use of renewable energy in electricity generation capacity to at least 27GW by 2023 (World Bank 2017). Furthermore, it is estimated that Turkey's electricity demand will be 530,000 GWh in 2023, and 160,000 GWh of this requisition will

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be planning to obtain from renewable energy resources (Melikoglu 2013a, b).

The total coastline distance of Turkey is 7200 km and its mean elevation of 1132 m. These measures make Turkey have a crucial wind energy potential (Kucukali and Dinçkal 2014). Turkey's wind energy capacity was calculated about 48,000 MW based on wind energy potential atlas (REPA). A majority amount of wind energy potential (more than 98%) belongs to East-Mediterranean, Marmara, and Aegean Regions (Hepbasli and Ozgener 2004). It is estimated that wind farms, which have 5 MW capacities, can be built at 50 m above the ground level. Moreover, Table 1 illustrates that Turkey's wind energy potential data based on annual mean wind speed when annual average wind speed is more than 7.0 m/s at 50 m above the ground level (Çeliktaş and Koçar 2010; Melikoglu 2013a; YEGM 2014; TWEA 2017).

Based on the study performed by Dursun and Gokcol (2014), Turkey depends on imported fossil energy sources for electricity generation. Having 37.9% of total electricity generation by means of imported natural gas causes Turkey enormously dependent on foreign countries. Based on the data by the Turkish Government Electricity Transmission Company (TEIAS 2015), 4.5% of the total electricity generation is obtained by onshore wind power. Turkey started to generate electricity by means of wind power in the late 1990s with an installed capacity of 7.2 MW (Ilkiliç and Aydin 2015). Moreover, by the end of 2017, Turkey has 207 wind power plants in conjunction with a total installed capacity of 6,516 MW. This is equivalent to 7.6% of the total capacity. In 2017, 17,909 GWh, which means 6.06% of Turkey's electricity production, was obtained from wind energy (MENR 2017).

Having a lower roughness coefficient and higher wind speeds on sea surface enable offshore wind energy to be taken into consideration for electricity production. Concordantly, feasibility investigations of offshore wind installation have abruptly gained momentum in the last decade. As the pros of offshore power plants, the requirement for transmitting power from a further distance is avoided. In addition, it does not have public resistance and expensive land values as being in onshore wind farms. Having a higher generation capacity more than onshore wind farms makes the offshore wind farms to be charming even though it is more expensive (Waewsak et al. 2015; Noori et al. 2015). Regarding the earliest offshore wind power in Europe, it was implemented in Netherland and Denmark in conjunction with its generation capacities not more than 1 MW due to technical difficulties and higher cost. As the precursors of offshore wind power, Northern European Countries and the UK take part in their current generation of 7 GW. China and the USA, where play an important role at the top of rank with regards to electricity generation from Renewable Energy, aim to achieve 30 GW and 54 GW of power generation from offshore wind energy by 2030 (Zhao and Ren 2015; GWEC 2015). However, it looks like the European continent will keep leading versus the Asian and American continents because offshore wind energy provides 0.85% of the electricity demand of European Unions (EU) (GWEC 2016). Furthermore, higher maintenance and installation costs of offshore wind turbines may be decreased by 40–50% in terms of the installation of new offshore wind farms by 2021 (GE 2016). Currently, Europe has 84 offshore wind installations. The installed capacities of the North Sea, Irish Sea, Baltic Sea, and the Atlantic Ocean are 9,099 MW (corresponds to 72% of all installed offshore wind energy in Europe), 2,689 MW (16.4%), 1,457 MW (11.5%), and 5 MW (4%), respectively (WE 2017).

Table 1 Turkey's wind energy potential data based on annual mean wind speed (according to more than 7.0 m/s at 50 m above the ground level)

Annual Average Wind Speed (m/s)	Power Density (W/m^2)	Capacity (MW)
7.0–7.5	400–500	29,259
7.5–8.0	500–600	12,994
8.0–9.0	600–800	5400
> 9	> 800	196
Total - Onshore	–	37,836
Total - Offshore	–	10,013
Total	–	47,849

Concerning the studies performed by researchers for various feasible offshore wind installations, an offshore wind farm in the Greek Sea region (Northeast of the Limnos Island) was studied by Konstantinidis et al. (2014) in terms of viability analysis. The feasibility analysis of offshore wind farms for the Puglia Region was conducted by Pantaleo et al. (2005). Four various locations in this region were investigated in terms of the cost of energy, cost estimation, and profit analyses. Szurek et al. (2014) carried out studies to determine the location of wind farms by using GIS and MCDM in Poland. Rodrigez and Montesdeoca (2018) studied spatial planning to estimate the offshore wind potential method for the Canary Islands based on the GIS-MCDM method. GIS-based multi-criteria decision analysis (MCDA) was determined as the most effective method for spatial siting of offshore wind farms by Mahdy and Bahaj (2018). Both Effiom et al. (2016) and Kim et al. (2013) carried out studies to economically underline the evaluation of offshore wind turbines and suitable site selection in Kenya and the Korean Peninsula by using the GIS-MCDM approach, respectively.

Turkey does not have any offshore wind farms (TWEA 2017). Thus, studies and investigations related to the offshore wind power of Turkey are quite new. Concordantly, studies on offshore wind power potential of Turkey in literature are insufficient to understand potential. Based on the study carried out by Köroğlu (2011), the design criteria of offshore wind farms and their grid connectivity problems were studied. 12 coastal areas with regards to their wind power potential were investigated by Ucar and Balo (2010). They concluded that especially Çanakkale and Balıkesir (Northwest of Turkey) areas had a crucial wind power potential. Ilkiliç and Aydin (2015) performed a study with regards to wind power potential of all coastal regions including Marmara, Aegean, Northern and Southern Anatolia. Their study showed that these coastal regions had the highest wind power potential. To understand the design criteria of the offshore wind farm for Bozcaada and Gökçeada regions on the Aegean Sea, a case study was conducted by Güzel (2012). Also, Tercan et al. (2020) carried out studies to obtain the site selection method for offshore wind farms by using a GIS-based multi-criteria model on both sides of the Aegean Sea. Argın and Yerci (2015) assessed 54 coastal areas whether these coastal areas were suitable in terms of offshore wind farm development. Karipoglu et al. (2021a) studied to determine the suitable regions for offshore wind power in Bandırma Bay by using the GIS-MCDM approach. The authorities preferred to use Global Wind Atlas (GWA) and Emodnet to obtain necessary data. Their assessment indicated that the criterion of location selection was quite important. That is, obstacles such as geographical, environmental, and social properties with regards to an offshore location can become a problem for installation.

The assessment of wind potential, determination of distribution for wind speed data is the most important step in assessing wind energy potential of a region. In Turkey, a lot of studies such as in Refs. (Şen et al. 2016; Genç and Gökçek 2009; Gökçek and Genç 2009; Genç 2010a, b; Genç et al. 2012a, b; Karipoglu et al. 2021b) were made about the determination of probability distribution for wind speed data for onshore applications. The objective of the present study was to analyze the multi principles of all coastal regions of Turkey for offshore wind power assessment in detail. The novelty of this study was to determine the optimum site location of an offshore wind farm in Turkey by using EMODnet, Global Wind Atlas, and GIS approach. Investigated topics consisted of environmental, social and geographical issues in which were documented as an obstacle in terms of installation. Besides these principles, the current legislation with regards to wind energy would be discussed as well. This study also aims to help policymakers and renewable energy investors in evaluating suitable locations for offshore wind power plants and other RES technology in Turkey.

Material and method

Overview of methodology

The methodology steps for the determination of a suitable site for offshore wind farms were indicated in Fig. 1. The methodology was summarized under four stages: (*i*) defining offshore wind farms criteria, (*ii*) data collection and processing was defined based upon few criteria including the study of literature and legislation, dataset collection and data convert for the necessary format, (*iii*) determine restrictions which are important for suitable site selection and defining buffer zones of restrictions, (*iv*) in the last stage to indicate suitable sites and locations for offshore wind power installation.

Study area

This study has been performed in the coastal part of Turkey (Fig. 2) with an area of 240.000 km^2, located between 36°–42° North latitude and 26°–45° East longitude. Turkey occupies a unique geographic position, lying partly in Asia and partly in Europe. Turkey, surrounded by water on three sides and one inner region were named as follows: the Mediterranean Sea, the Aegean Sea, the Black Sea, and the Marmara Sea, respectively.

Multi-criteria decision making with GIS

This method is very important for suitable site selection for energy plants. The application of Multi-Criteria Decision-Making (MCDM) techniques is gaining more reputation and importance in renewable energy management (Pohekar and Ramachandran 2004). MCDM methods are tools that allow the best choice to be made from multiple and concurrent criteria. As the energy management problems are getting more complex, economic considerations are complemented with environmental and social considerations, leading to multiple-criteria decision-making being used to deal with conflicting decision problems (Değirmenci et al. 2018). The international studies in the field of solar energy evaluating the criteria effective in the installation of solar PV power plants using GIS have often preferred MCDM to determine the weights of the parameters (Szurek et al. 2014; Siyal et al. 2015; Vasileiou et al. 2017). GIS ensures visually to classical computing in conjunction with its unique features and it allows to make several geographical analyses on maps. Unique and visual analysis of the decision-making method should be made to solve the suitable site selection problems with clear and correct decisions. In this study, it was used as a decision-making method for suitable site selection. It

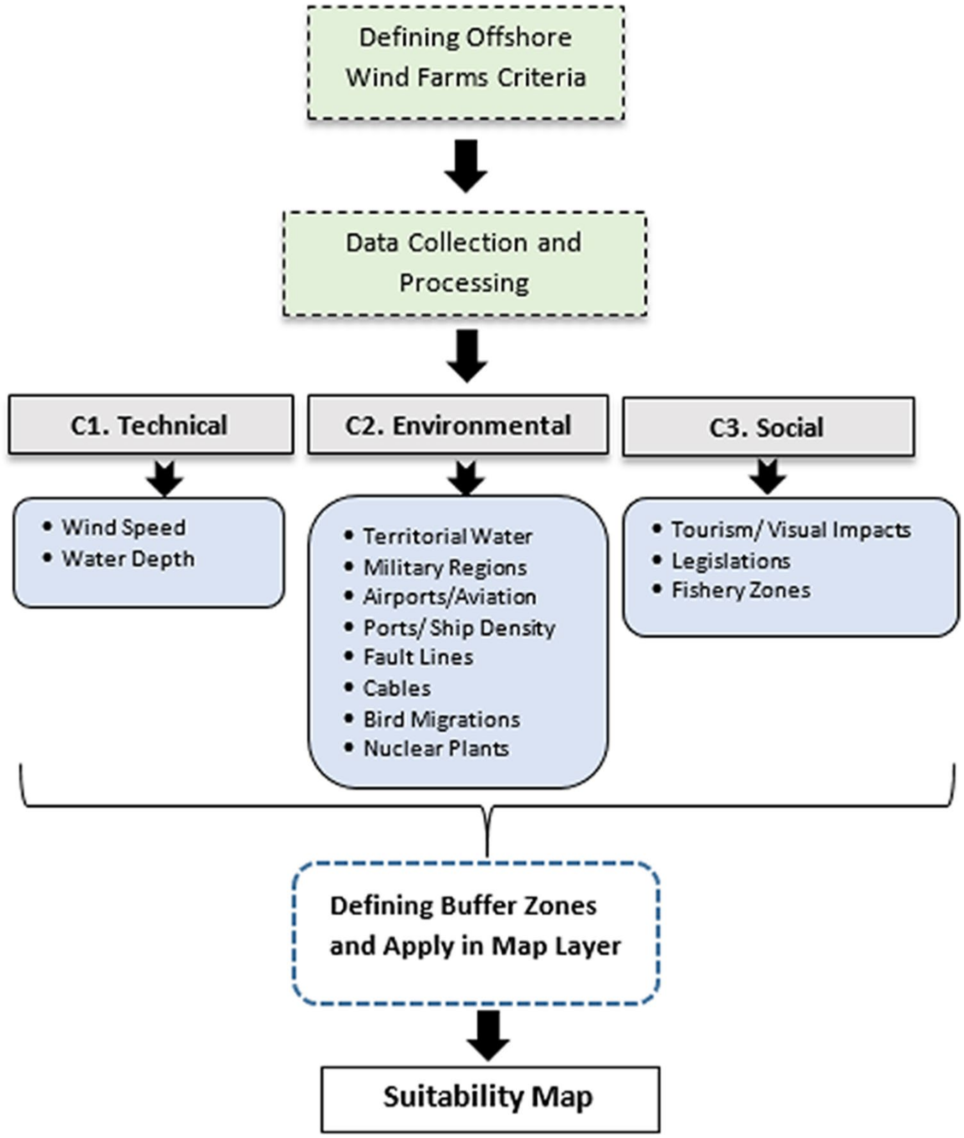

Fig. 1 Methodology diagram

was examined in two steps. Firstly, technical impacts were examined, and then, environmental and social impacts were examined carefully. In this study, all weights for criteria were accepted equal to 1 because of the lack of offshore wind power plant applications in Turkey. With determined all impacts, a general method by using GIS and MCDM combination was obtained for assessment selecting regions of energy power plants. All data sources and buffer zones of restrictions were given in Table 2 with details. Also, Fig. 3 shows all map layers of each criterion based on buffer zones.

Wind energy potential

The values of onshore wind data which are measured at the closest onshore meteorology station have been taken into consideration for the desired offshore site. For onshore wind farms in Turkey, long term wind speed measurements were performed by some researchers (Şen et al. 2016; Genç and Gökçek 2009; Gökçek and Genç 2009; Genç, 2010a, b; Genç et al., 2012a, b; Karipoglu et al. 2021b). Sea surface state data of 54 coastal regions were provided by the 8th Meteorological Agency of the Turkish State Meteorological Service (DMI) (2015). The measurements were hourly performed from 2005 to 2015 at 10 m above ground level. But the measured wind data should be extrapolated for a presumed average turbine hub height by using Eq. 1 as suggested in Ref. (Genç, 2010a, b). Frictional effects at the surface of the earth may cause the wind speed to change. Therefore, the presumed average turbine hub height was selected as 100 m. In this study, the log law boundary layer profile used by some researchers (Genç, 2010a, b; Genç et al., 2012a, b) was also utilized to determine the average wind speed at presumed turbine hub height:

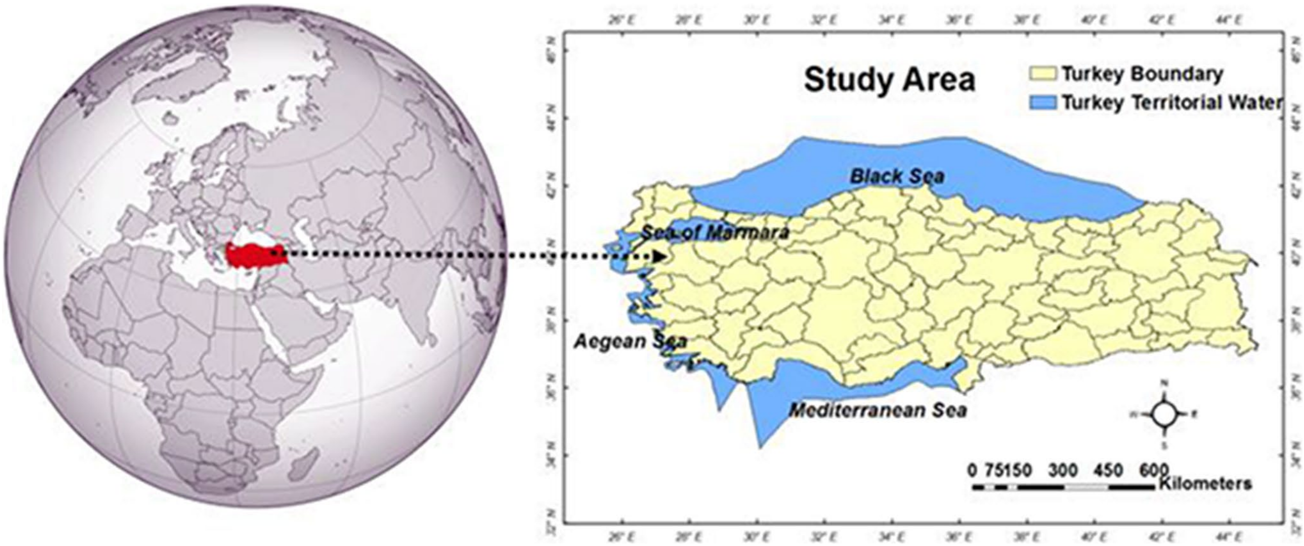

Fig. 2 Study area

$$v/v_0 = \ln(z/z_s)/\ln(z_0/z_s) \quad (1)$$

where v, v_0, z, z_0, and z_s indicate desired average wind speed at presumed turbine hub height, measured wind speed, turbine hub height, measured height, and surface roughness parameter, respectively. Determination of surface roughness parameters was determined by taking into consideration of sea surface states. z_s is determined as 0.11 according to a smooth surface by using equations that belong to physical oceanography (Hersbach 2011; Kim et al. 2018; Edson et al. 2013; Öksel et al. 2016). The remarkable location in this region is the Bozcaada periphery (especially the northern side) as mentioned in the study presented by Satir et al. (2017). Not only the high-speed value of Bozcaada Island enables it to be attractive in terms of an offshore wind farm installation but also having fewer residential areas makes the social barriers to be decreased. Another important criterion is water depths of nearly 20–30 m. It enables feasible offshore wind farm locations to have a shorter infrastructure. Therefore, capital expenses have been lower. For the economic investment in offshore wind power plants, the average wind speed must above 7 m/s (Baban and Parry 2001).

Table 2 The list of used criteria and buffer zones

Criteria/data sources	Sub-Criteria	Buffer Zone	Unit	References
C1. Technical - Global Wind Atlas - General Directorate of State Meteorological Affairs of Turkey - EMODNET Bathymetry	Wind Speed	= > 7	m/s	Baban and Parry 2001
	Water Depth	< = 50	m	Kim et al. 2013
	Sea Surface State	< = 25	%	Kim et al. 2018; Edson et al. 2013
C2. Environmental - Copernicus Land Monitoring Service - European Marine and Observation Data Network -General Directorate of Mineral Research and Exploration -Birdmap5	Territorial Water	inside		United Nations Convention on the Law of the Sea 2016
	Dist. from Military Regions	> 3	km	Turkish Military Forces Law 1976
	Dist. from Airports	> 3	km	Legislation Construction Criteria 2012
	Dist. from Ship Routes	> 3	km	Argin et al. 2019
	Dist. from Cables	> 500	m	Mahdy and Bahaj 2018
	Dist. from Fault Lines	> 150	m	Demirtas 2005
	Dist. from Bird Migration Routes and Nuclear Power	> 3	km	Değirmenci et al. 2018; Baskurt and Cevdet 2018
C3. Social - Copernicus Land Monitoring Service -European Marine and Observation Data Network -Turkish Energy Planning Institution	Dist. from Tourism Regions	> 2	km	Legislation Tourism Sector 2008
	Dist. from Protected Fishery Zones	> 3	km	Watson et al. 2015
	Legislations, Fixed Tariff	-	$	Turkish Ministry of Energy and Natural Resources 2015

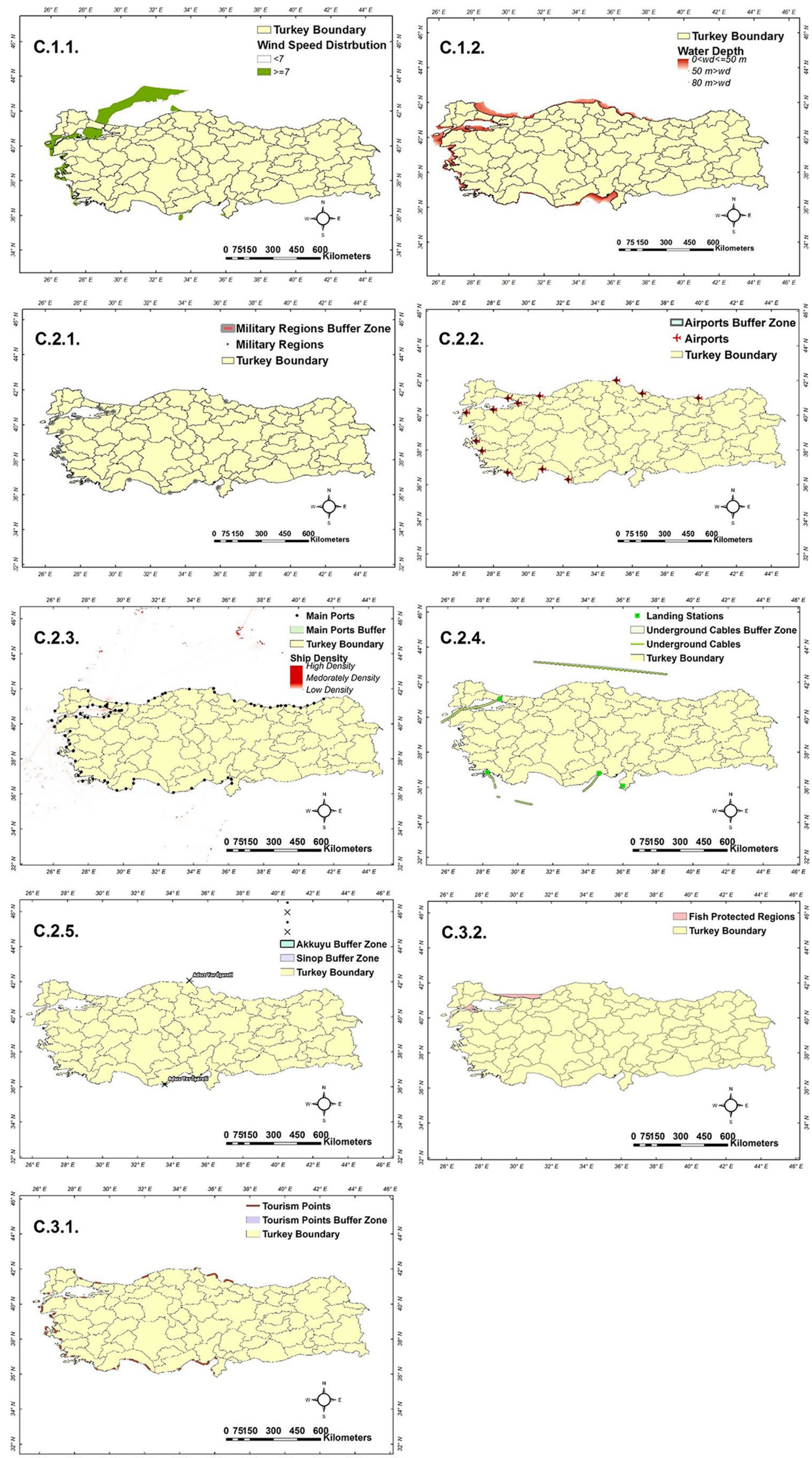

Fig. 3 Reclassification map layers for 9 sub-criteria. * C.1.1. Annual Wind Speed, C.1.2. Water Depth (wd), C.2.1. Military regions and buffer zone, C.2.2. Airports and buffer zones, C.2.3. Main ports and ship density, C.2.4. Underground Cables and buffer zones, C.2.5. Nuclear power plants and buffer zones, C.3.1. Tourism points and buffer zones, C.3.2. Fish protected regions

With the scope of this criteria, the wind speed distribution map layers were prepared based on 7 m/s wind speed. The finally, for the wind potential analysis, data were received from Global Wind Atlas at 100 m elevation. These data proceed in GIS and were obtained from the wind speed distribution map labeled C.1.1 as seen in Fig. 3.

Water depth

Bathymetry is the measurement of the depth of water in oceans, rivers, or lakes. Bathymetric maps look a lot like topographic maps, which use lines to show the shape and elevation of land features. On topographic maps, the lines connect points of equal elevation. On bathymetric maps, they connect points of equal depth. A circular shape with increasingly smaller circles inside of it can indicate an ocean trench. It can also indicate a seamount or underwater mountain.

For offshore wind turbines, marine depth maps are too crucial. Installation and maintenance of wind turbines in a marine region above this depth are very difficult. For suitable regions, water depths must be less than 50 m (Kim et al. 2013). The sea depth data were taken from EMODnet (2020) and the areas were determined according to these data to suitable regions labeled C.1.2. in Fig. 3 by using GIS.

Territorial water and military regions

According to the international law defined by the 2013 United Nations Convention on the Law of the Sea (UNC 2016), the territorial water is a belt of coastal waters broadening at most 12 nautical miles (it equals 22.2 km) from the baseline of a coastal state. That value is still preserved in agreement law these days. In terms of the territorial water of Turkey as illustrated in Fig. 2, the proper shores for offshore wind power are not a problem topic at the Mediterranean Sea and the Black Sea. Unlike those 2 locations, installing the offshore wind farm in the Aegean Sea may be a problem because of its proximity to the Greek Islands including the islands of Rhodes and the insular group of Castellorizo. The disagreements of land use are gradually enlarging by increasing the number of both offshore and onshore wind turbines. Using regions for both wind power industry and military aviation needs to be an open region in conjunction with a low population ratio. Because military services utilize these open regions for training requirements and they can make these areas to be restricted for any other use. Moreover, they can oppose occasionally when a wind farm wants to be installed in their territories because the noise caused by wind turbine blades affects their aviation equipment.

According to assertions of the wind power industry, implemented restrictions cause the installation of feasible both offshore and onshore wind farms to hinder economically. As a result of all these issues, the reason for disagreement on land use can occur for offshore and onshore wind farms (Lindgren et al. 2013). Therefore, estimated and considered the location of offshore wind farms in Turkey must be selected carefully not to encounter any disagreement.

Military training centers at the coastal area in Samsun (located in the North of Turkey), Kumburgaz, Tuzla, Ulaşlı, Gemlik, Erdek, Kumbağ, Gelibolu and Çanakkale (located in the Marmara Region), Akçay, Foça, Ilıksu, Yolluca, Özdere, Bodrum (located in the Aegean Region), Hisarönü, Aksaz, Karpuzkaldıran, Anamur, Mezitli (located in the Mediterranean Region), Uluçınar and Gülcihan (located in the Iskenderun Bay). The military regions and buffer zone of it shown in Fig. 3. with labelled C.2.1.

Civil and military aviation

Another criterion of the optimal location of offshore wind farms is civil aviation. Wind turbines may create noise, which gives a negative effect on human health. In addition, take-off and landing areas of aircraft should be away from offshore wind farms, because these noises created by wind blades may disrupt the communication signals, which are important for aircraft by landing and taking-off duration (Pantaleo et al. 2005). Thus, the offshore wind farms must be 3 km away from airports according to Table 2. The issue of civil aviation should be taken into consideration when an offshore wind farm is installed at the coastline. Shown in Fig. 3, airports located in quite close the coastal regions of Turkey are as follows: Ordu-Giresun Airport, Samsun and Trabzon Airports located in the Black Sea coastal area, Istanbul Atatürk, Sabiha Gökçen and Bursa Yenişehir Airports located in the Marmara Region, Edremit and Milas-Bodrum Airports located in the Aegean Region, Dalaman, Antalya and Alanya-Gazipaşa Airports located in the Mediterranean coastal area.

Ports and ship density

Maritime traffic and shipping routes may play a crucial role in terms of installing offshore wind farms in coastal regions. Developed countries that provide a considerable amount of their energy needs from Renewable Energies should not ignore this issue (Douvere et al. 2007; Jay 2017; Firestone et al. 2015). There are a lot of major sea routes in Turkey shown in Fig. 3 labeled C.2.3. The busiest ports in Turkey in terms of transportation and passenger traffic are Istanbul, Izmit, Izmir, Mersin, Iskenderun, and Samsun. Therefore, local maritime traffic (especially busiest ports in Turkey) must be reviewed meticulously for proper location when the installation of the offshore wind farm is considered.

Underground cables and pipelines

Turkey has a critical position between Europe and Asia continents. This enables Turkey to acquire important advantages such as natural gas and petrol transition. Petrol and petroleum derivate, which are produced in Iraq and Caspian regions, can be transported by the Baku-Tbilisi-Ceyhan and Iraq petrol pipelines to Turkey. Like petroleum transportation, natural gas is carried with natural gas pipelines from Russia, Azerbaijan, and Middle East Countries, where have huge natural gas reserves. But, there is no threat in terms of installation of offshore wind farms in Turkey, because except for the Çanakkale region, pipelines do not pass at the coastal areas of Turkey. Also, there are four main cable landing stations in different locations. Therefore, telecommunication cables pass at the sea of Turkey especially intensively in the Marmara Sea. These landing stations and cable routes were shown with labeled C.2.6. in Fig. 3.

Fault lines

Turkey could be expressed as an earthquake country because of its intensive fault lines. The complex wind turbine systems in Turkey are either very tall or very heavy. Any wind turbine's static balance must calculate carefully for weather conditions and the soil topology. In selecting the location of installation of a wind energy power plant, areas with low earthquake risk should be selected (Çolak et al. 2020). Therefore, another factor for selecting a solar PV power plant site is the presence of earthquake fault lines. For the fault line, spatial data were received from the Kandilli observatory earthquake research institute (2020) and the General Directorate of Mineral Research and Exploration (2020). Fault lines map layers were prepared in GIS based on these two sources' data. There are different ideas relate to buffer zones of fault lines. In this study, the buffer zones were selected based on the destructive effect of active lines in Turkey.

Bird migration routes and nuclear power plants

Generally, people say that wind turbines kill the birds or change their migration paths. In the literature view, the wind turbine and planes are caused the rate 0.003% percent of all the bird death (Değirmenci et al. 2018). Of course, the wind farms are affected by the migration paths. In addition, different issues can also emerge such as loss of physical habitat due to location changes coupled with the breakup in the ecological habitat network (Birdmap 2020). Also, the bird migration pathways received from Bird Map (2020) and analyzed with the buffer zone.

Turkish Governments will install two nuclear power plants until 2023 in Akkuyu and Sinop coastline. There is an important buffer zone of nuclear power plants because of the cooling water region and radioactive swing. Therefore, for maintenance and operation processes, nuclear power must be 3 km away from offshore wind power (Baskurt and Cevdet 2018). The location and buffer zone of nuclear power plants are illustrated in Fig. 3 with C.2.5.

Tourism and visual impacts

Another crucial key is tourism impacts. According to the study performed by Toke (2005), the occurrence of public concern with regards to effects of wind farms may be said as a significant criterion in terms of installation when important tourist facilities and accommodations want to be established close to these wind farms. Furthermore, some troubles may emerge with the offshore wind energy when they cause the essential visual variation of seaside and beaches where much of them are identified as popular locations of mass tourism (Urry 1992). However, offshore wind farms installed at a distance that will not disturb the touristic places may provide the energy needs of these touristic locations. Because, the tourism attractions not only benefit countries' economies but also compensate for their energy demands, which are used for different duties such as accommodation, catering, transportation, etc. (Gössling 2002; Becken and Simmons 2002). As the famous touristic locations and beaches in the coastal area of Turkey, Aegean and Mediterranean Seas are significantly attracted the coastal tourism (Observatiorie Report 2016). The famous beaches in Mediterranean and Aegean Seas are 38 places located in Iskenderun Bay, 28 places located in Mersin, 14 places located in Anamur, 264 places located in Antalya and its neighbor cities, 210 places located in Bodrum and Muğla, 148 places located in Izmir, 87 places located in Ayvalık (TMH 2017). Besides Aegean and Mediterranean Regions, there are 210 beaches in Marmara Region, while there are 231 beaches in the Black Sea coastal. Hence, the coastal region where is suitable for wind speed potential should be determined carefully. Also, the huge size of offshore wind turbines could be affected to tourists or native people negatively in terms of visual impacts. Therefore, the distance from famous beaches of offshore wind turbines must be selected carefully. Maybe, social acceptability studies could be done to analyze negative effects. Electricity demand will be not only ensured enormously but also the country's economy will positively be affected by tourism impact with the suitable installation of offshore wind farms.

Legislations, the fixed tariff of energy and fishing activities

According to actual Turkish legislation on Renewable Energy Resources (RER), there were neither regulations nor was financial aid on RER in the early 2000s even though Turkey had high renewable energy potential. In 2001, the first act was observed by the Electricity Market Law (with Law No. 4628), which was enabled the competitive power generation and distribution to be liberalized. Renewable energy companies had opportunities with this new law. In 2005, the law on the utilization of RER for generating electrical energy was legislated in conjunction with the RER Law (with Law No. 5346). The objective of this law was to increase the usage of renewable energy. Hence, it was explicitly observed that license implementation for the usage of renewable energy increased. The unit capacity of wind turbines, as well as license implementation, was increased during 2005 and an abrupt increase was observed to installed wind power capacity since 2006 (Dursun and Gokcol 2014). Likewise, few additions such as purchase tariff and land allocation were conducted by RER law (Simsek and Simsek 2013). In 2007, processes and principles were determined by Energy Efficiency Law (with Law No. 5627), which was promulgated as a revision of the RER law. Wind power manufacturers had the rights to sell the electricity to appropriate customers or grids at higher warranted costs by means of this revision (Saidur et al. 2010). In 2009, the Ministry of Energy and Natural Resources (MENR) launched a plan, covering the years 2010–2014. This plan aimed at 10 GW of wind power for 2015, whereas it targeted 20 GW of wind power by 2023. In 2010, the RER Law was amended with the new crucial regulation (Law No. 6094). The Renewable Energy Support Mechanism was presented and grid linkage to renewable resources was given priority. Besides, Fixed Feed-in Tariff (FiT), which was eligible for the first 10 years, was legislated following resource type and it was exchanged from EURO (€) to USD ($) (Çeliktaş and Koçar 2010). Renewable energy plants were also exonerated from a license with the emergence of the Renewable Energy Support Mechanism. In 2013, modification of the Electricity Market Law (with Law No. 6446) was carried out. The limit of license exoneration for corporations and individuals was initially raised to 1 MW. Then, licenses are divided into 2 parts named pre-license and full-generating license. In 2014, the National Renewable Energy Plan for between 2014 and 2023, was promulgated by MENR. This plan demonstrated that Turkey had a responsibility to the EU participation and the Aims of the Directive 2009/29/EC. Developments in terms of grid operators were performed with the agreement between the Turkish grid operator (TETC) and the European Network of Transmission Systems Operators (ENTSO-E) in 2015. Henceforth, reliable and purchasable procurement was enabled for users by means of this agreement (ENTSOE 2015). Regarding the pre-license application to wind power, the acceptance of additional applications to wind power was carried out by the Energy Market Regulatory Authority (EMRA 2017) in 2018. There were 1018 applications with 40 GW in 2015. Concordantly, an extra 2 GW was admitted via the announcement of EMRA. So far, the mentioned regulations are concerning actual Turkish legislation on RER. Because there is no offshore wind installation in the coastal areas of Turkey, the legislative framework lacks guidelines or guidance related to the installation, design, and operation of offshore wind farms.

There is a lot of different type of fish habitat in Turkey's seas because of their low salty level. So, fishing activities are an important income area for some people who live in Black Sea Coastline. The vibrations and electromagnetic flows of offshore wind turbines can affect negatively these habitats especially extinct fish. Therefore, determined protected fishery zone by Turkish Governments and UNESCO was determined in Fig. 3.

Results

According to a roadmap of methodology, the necessary criteria for suitable site selection of offshore wind farms were determined based on technical (C1), environmental (C2), and social (C3) impacts. Within the scope of these impacts, the required restrictions have been prepared and have been determined buffer zones of them. Each criteria dataset proceed in GIS and was determined a lot of map layers. These map layers are shown as suitable regions for offshore wind farms. All map layers were combined in a suitability map (Fig. 4) by using GIS tools. The final thematic map shows suitable regions for Turkey's seas according to technical, environmental, social impacts as shown in Fig. 4.

Therefore, this study focused on suitable locations where offshore wind installations might be proposed. According to Table 2, it was observed that 13 sub-criteria except for legislation and Fixed-Tariff were suitable for offshore wind installations. In the scope of these criteria, the reclassification map layers were obtained separately as shown in Fig. 3. These map layers were combined to complete the suitability map. The final map indicated that %1.38 (3294.8 km^2) of Turkey Seas was calculated as suitable for offshore wind farms. The most suitable region was determined in the Marmara Sea with 1194 km^2. The Aegean Sea, the Black Sea, and the Mediterranean Sea were following the Marmara in terms of the huge suitable regions respectively. Samandag Bay has the highest wind power density (1027 W/m^2), whereas Saros Bay has a high wind power density (913 W/

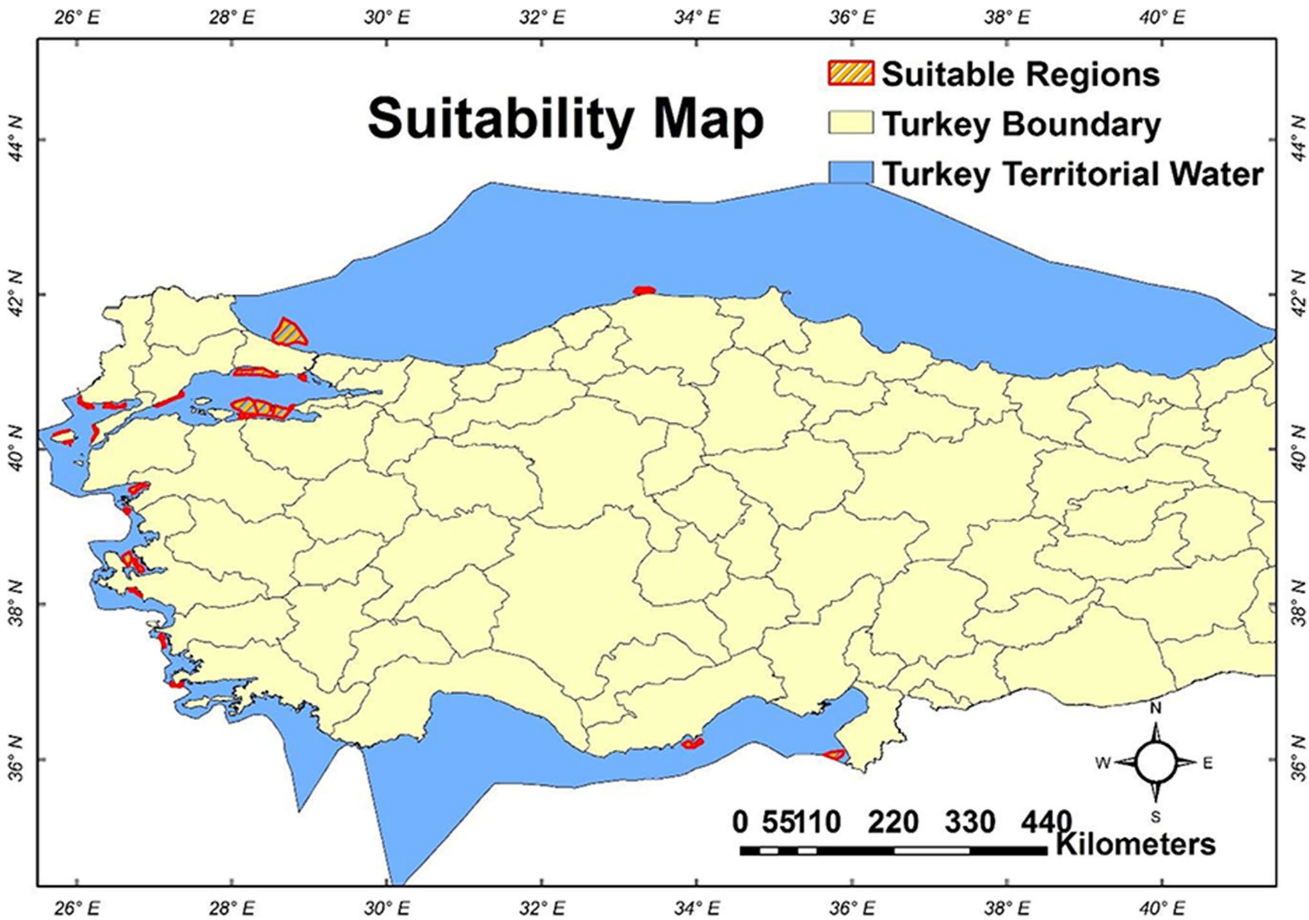

Fig. 4 Suitability map for offshore wind power plant

m^2) because of the existing tunnel effect. However, Istanbul North Coastline has the lowest wind power density (580 W/m^2). The huge amount of study area is non-suitable because of a lot of restrictions. In the future, with some regulations in the sea legislations, this suitability map may expand or contract.

Discussion and conclusions

The studies of offshore wind potential are new in Turkey. Argin et al. (2019) assessed the offshore wind potential of Turkey without using the GIS-MCDM combination method. Therefore, there was a gap to examine and evaluate suitable region's capacity. In the other study, Akdağ and Yeroglu (2020) examined the offshore wind installation on the Black Sea without created a comprehensive analysis method. Also, Emeksiz and Demirci (2019) studied to determine the offshore wind potential of Turkey by using a hybrid site selection method. Although this study (Emeksiz and Demirci 2019) was done by using Analytic Hierarchy Process (AHP), some important restrictions were ignored such as airports, tourism facilities, and fishery zones. In this scope, to determine the offshore wind potential of Turkey was necessary the analysis study consisted of all restrictions. Our comprehensive study filled the information gap and visualized the suitable regions by using GIS.

Offshore wind power plant installations were extensively assessed by means of 13 sub-criteria of different coastal areas of Turkey in this comprehensive survey. According to the most important hallmark for offshore wind energy, wind speed data based on smooth sea surface were calculated with physical oceanography equations. The average wind speeds of 7 m/s and more were taken into consideration for suitable site selection. Moreover, the sea depth of sites was assigned as under 50 m for the shorter infrastructure and fewer installation expenses. The other environmental and social criteria were analyzed carefully and indicated map layers separately in Fig. 3. It was observed the most common excluding region consisted of technical, environmental, and social criteria (C1, C2, C3).

Following critical conclusions based on comprehensive analysis and assessment were obtained as follows:

- All coastal areas of Turkey for site selection were considerable for installation based on the technical, environmental, and social impacts. But, these all of coastal areas were limited to 13 regions including Bandırma-Gemlik Coastline, Saros Bay, Gökçeada, Istanbul Coastline (South and North), Samandag, Kastamonu Coastline, Tekirdag Coastline, Çanakkale Bay, Aydın Coastline, Mugla Coastline, Mersin Bay, Ayvalık Coastline, Izmir Bay because of restrictive criterion mentioned above.
- Samandag Bay has the highest wind power density (1027 W/m^2), whereas Saros Bay has a high wind power density (913 W/m^2) because of the existing tunnel effect. However, Istanbul North Coastline has the lowest wind power density (580 W/m^2).
- The Marmara and the Aegean Sea were very profitable seas because of their high offshore wind speed. But in these regions, there were important restrictions such as high ship density, tourism facilities, military regions. Although the territorial boundary of the Aegean Sea was narrow, the suitability rate was determined higher than the Mediterranean and the Black Sea due to high wind speed and shallow water depth.
- After offshore site selection, the suitable offshore wind turbine can be selected and R&D (Research and Development) can be carried out to extract maximum power generation.
- In addition, the Turkish government should present public finance and fiscal encouragement to promote offshore wind power projects.

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 renewable energy-driven comprehensive study by using EMODnet, GIS, and Multi-Criteria Decision Maker Method will be the first step and a useful guide for offshore wind power development in Turkey. Regarding future works: Acts and legislation should be promulgated because the legislative framework lacks guidelines or guidance related to the installation, design, and operation of offshore wind farms. Furthermore, it is recommended that offshore meteorology stations should be installed to obtain more accurate offshore wind speed data acquisition.

Declarations

Competing interest The authors declare that they have known competing for financial interest or personal relationships that could have appeared to influence the work reported in this paper.

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