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Wind energy potential of Marmara region in Turkey

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Abstract
Turkey is one of the developing countries in the world. According to economical, industrial and population growth, electrical energy demand has valuably increased in the last decade. The continually increase of electrical energy demand and global sensitivity to environmental pollution raise the importance of renewable energy sources. Wind energy has become more popular than other renewable energy sources owing to its advantages such as supplying great power, being sustainable and clean energy resource. In this study, wind energy potential analysis of Marmara region which is one of the Turkey's geographical regions is presented. Due to its high energy demand, crowded population, large industrial areas and attractive wind energy potential, this paper focused on the Marmara region. Installed wind energy conversion system (WECS) power is 923.65 MW and available WECS power is 46,996.28 MW in Marmara region. It is obviously seen that only 1.96 % of the existent capacity is utilized. A valuable increase in installed capacity could provide an attractive opportunity to decrease the import energy resources, transmission losses and greenhouse gas (GHG) emission of Turkey.

Keywords: Wind energy; Marmara region; Renewable energy sources; Turkey.

1. Introduction

Limited reserves of fossil fuels and their negative effects on the environment have led institutions, organizations and governments to look for new technologies. Rise in the prices of fossil fuels, environmental pollution and undesired climate changes began to affect the world [1, 2]. Besides, it is known that renewable electrical energy, which is obtained from natural resources, has negligible contribution to environmental pollution [3, 4]. Therefore, many countries trend to renewable energy sources such as solar, wind, biogas and geothermal. Also, especially at the rural areas, renewable energy has become an economical electrical power resource for most of the countries. When compared with the cost of providing electrical energy from national network by using transmission lines, establishment of renewable energy systems are more economical for these regions. Also, the numbers of renewable energy suppliers are increasing consistently with the developments in this technology.

In the last decade, limited reserves, harmful effects on environment and high costs of fossil fuels have accelerated usage of renewable energy systems [5-8]. Wind energy has become more popular than other renewable energy sources owing to its advantages such as supplying great power, being sustainable and clean energy resource. Developments on wind energy systems bring requirements for solving the fast and accurate project producing problems. Accurate and reliable wind data is very important during the planning and designing of a wind energy system. Development of new wind projects in many countries are adversely affected from lack of accurate wind data and reliability studies. This data is obtained by giving the authority to governments or private institutions [7].

Installed wind turbine capacity in the world is 296.255 GW in the middle of 2013 and installed capacity is aimed to be 318 GW until the end of the year. While China takes the first place in the use of wind energy with 80.824 GW installed wind power, United States of America and Germany are in the second and third, respectively [9].

The installed wind power capacity of European Union (EU) is 106.040 GW by the end of 2012 and 6.3% of the total electrical energy requirement was provided from wind energy in 2011. It is targeted to generate 20% of electricity demand in the Europe from WECSs at 2020. When installed wind power within the borders of the European Union is examined, Germany, Spain and United Kingdom are at the first three places [10].

Social, economic and industrial developments of Turkey increase the electrical energy demand. The primary energy sources for electricity generation in Turkey are coal (28.4%), natural gas (43.6%), hydropower (24.2%), geothermal + wind (2.8%), liquid oil (0.7%) and others (0.3%) in 2012. Total installed power capacity is 64,044.10 MW in Turkey according to 2014 data [11]. Installed power capacity of Turkey according to production type at the end of 2013 is given in Figure 1 [12].

As large oil and natural gas reserves do not exist in the country, most of these requirements are largely met by imports [3, 13]. There are efficient energy resources such as coal, hydraulic, solar, thermal, wind, biomass, etc. in Turkey. Although, national hydro and lignite resources are mainly used for electrical energy production, this production is insufficient to supply electrical energy requirements of the country. Dependence on foreign resources (natural gas and liquid oil) increases due to the growing electrical energy demands [1, 13].

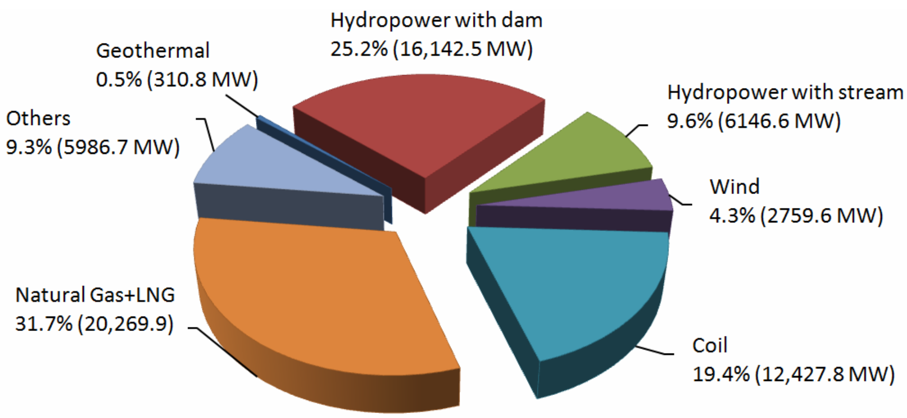

Figure 1. Installed power capacity according to production types

Nowadays, energy status of Turkey has some fundamental problems such as dependence on foreign sources, environmental pollution, inefficient energy usage and low electrical energy production from renewable energy sources [3, 14]. Installation of renewable energy systems is required for obviating dependence on foreign resources and reducing the percentage of fossil fuels at the primary energy consumption of Turkey [3].

Usage of renewable energy sources and technological developments are important for sustainable and environmental economic development of Turkey. Therefore, low utilization percentage of renewable energy sources, especially wind and solar energy is promoted by new regulations.

Besides electrical energy demands, one of the most important problems that affects the humankind is carbon emission. Many cities try to reduce carbon emission, and determine future targets for carbon emission levels as given in Table 1 [15].

Although wind energy conversion systems produce low carbon emission during production and installation, this value can be neglected compared with the fossil fuels [16]. The effects of carbon emission to atmosphere and climate change make governments realize the importance of requirement low carbon emission, thus they started to give economic incentives for this propose [17].

The most crowded and industrialized region in Turkey is Marmara region. Therefore, carbon emission increases in the region, continuously. High wind energy potential is an important advantage to reduce the CO_2 emission for this region.

Table 1. Long-term carbon reduction targets for cities of the world

City	Target year (base year)	Reduction target (%)
Copenhagen	2025 (2005)	Carbon neutral
London	2025 (1990)	-60%
Boston	2050 (1990)	-80%
Melbourne	2020 (1996)	Carbon neutral
Sydney	2050 (1990)	-70%
Toronto	2050 (1990)	-80%
Stockholm	2050	Carbon neutral

Geographical location of Turkey has advantages for the usage of renewable energy sources. The cumulative installed wind power is over 2 GW in 2012 and approximately 3.5% of energy production is obtained from wind energy in Turkey [18]. When the geographical regions of Turkey are taken into consideration, it can be recognized that Marmara region has the highest average wind speed and the largest wind energy potential. Also, this region takes the first place with 923.65 MW in terms of installed wind power capacity. The annual average wind data shows that Marmara, Aegean and Southeast Anatolia Region are suitable for wind energy utilizations [1].

In this study, wind energy potential of Marmara region in Turkey is investigated. The reasons for selection of this region are its high energy demand, crowded population, large industrial areas and attractive wind energy potential.

Additionally, large hydropower plants of Turkey placed at the eastern part of the country. Transferring electrical energy from the hydropower plants to the Marmara Region, which is located at western part and have highest population density and industrialization, brings transmission losses.

Also, remarkable amount of primary electrical energy sources of Turkey are depends on fossil fuels. According to 2011 data, percentages of gas, coal and liquid oil are 43.6%, 28.4% and 0.7%, respectively [11]. Most of these resources are imported and have negative effect on Turkish economical development.

Taking into account all of these factors, it is quite obvious that utilization of wind energy potential of Marmara Region would have favorable effect on decreasing transmission losses and imported primary energy resources. Moreover, generated electricity from an environmental source will have a major contribution on reducing the greenhouse gas (GHG) emission.

2. Wind energy in Turkey

Depending on industrialization and population growth, electrical energy demand is continually increasing in Turkey. As conventional energy resources used for electrical energy generation (hydro, coal, etc.) are insufficient, energy dependence of Turkey to foreign countries is increasing.

Rise of energy demand, dependence to foreign countries for energy resources and environmental pollution problems are cause of rapidly increasing interest in renewable energy at Turkey. The investigations show that Turkey has large renewable energy sources. Therefore, researches and investments at this field are increasing in recent years.

The investments in Turkey show that wind energy is the distinguished renewable energy source. Installation of wind energy conversion systems (WECS) started in 1990s and continues rapidly in Turkey. Having high power potential and fast installation are the main reasons for the popularity of WECSs. The development of WECSs in Turkey is shown in Table 2 [19].

The data given in Table 2 show that power production from wind energy started in the late 1990s and continues without interruption in recent years. The investments are raised particularly after 2006 and the largest investment was made in 2007.

The wind map of Turkey for 10 m height is given in Figure 2. Turkey is divided into seven regions geographically and as seen from the figure, the average wind speed above 3 m/s occurs in four regions. Marmara region is particularly suitable for installation of WECS.

Table 3 shows the annual average wind speed and wind power values for geographical regions of Turkey [6, 18, 19]. It reveals that Marmara region has the highest annual average wind speed, annual average wind density. Marmara, South-eastern Anatolia and Aegean regions are at the first three ranks when compared with other regions in terms of the wind intensity.

Table 2. Development of WECSs in Turkey depending on years

Year	Cumulative installed power (MW)	Rate of change (%)	Cumulative rate of change (%)
1998	8.7	0.0	0.0
1999	8.7	0.0	0.0
2000	18.9	117.2	117.2
2001	18.9	0.0	117.2
2002	18.9	0.0	117.2
2003	20.1	6.3	131.0
2004	20.1	0.0	131.0
2005	20.1	0.0	131.0
2006	51	153.7	486.2
2007	146.3	186.9	1581.6
2008	363.7	148.6	4080.5
2009	791.6	117.7	8998.9
2010	1329.15	67.9	15,177.6
2011	1805.85	35.9	20,656.9
2012	2312.15	13	26,476.43

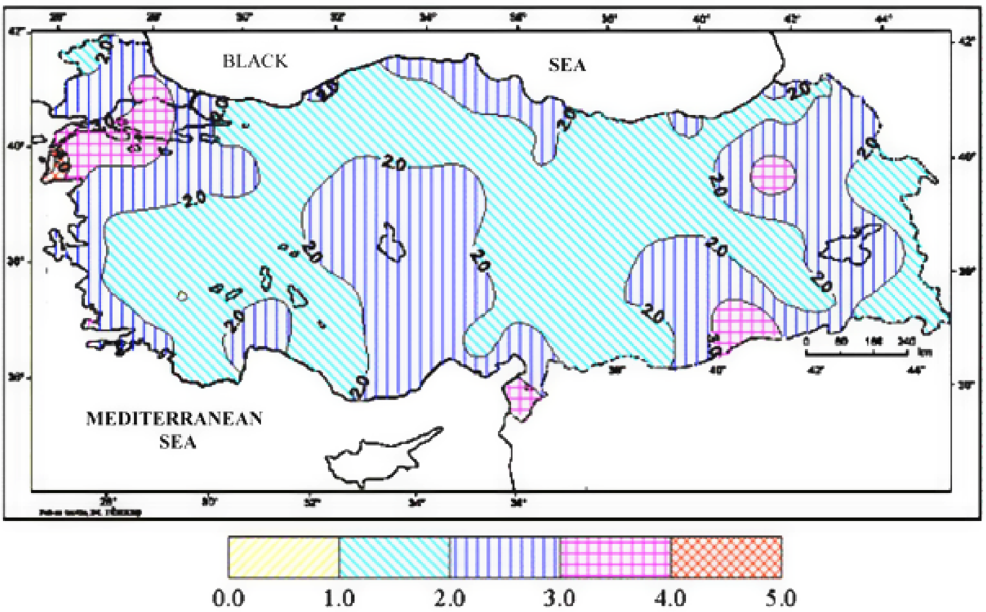

Figure 2. Wind map of Turkey for height of 10m [20]

Table 3. Wind energy potential in Turkey

Region	Annual average wind speed (m/s)	Annual average wind density (W/m^2)	Installed wind power (MW)	Available wind power (MW)
Marmara	3.29	51.91	923,65	46,996.28
SouthEastern(SE) Anatolia	2.69	29.33	-	2630.88
Aegean	2.65	23.47	852	29,228.96
Middle (M) Anatolia	2.46	20.14	72	7824.72
Mediterranean	2.45	21.36	384.50	13,286.08
Black sea	2.38	21.31	80	14,302.64
Eastern (E) Anatolia	2.12	13.19	-	2983.92

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Analysis of the annual energy demand in Turkey shows that approximately 40% of the energy is consumed in Marmara region [21]. Maximum usage of wind energy potential in this region will provide beneficial effects, such as reducing transmission losses, decreasing fossil fuel utilization and importing primary energy sources, increasing power capacity of the region...etc.
Status of installed, under constructed and licensed WECSs according to the regions of Turkey are shown in Figure 3 [19]. It is clearly seen that Marmara region stands out in terms of under constructed and licensed WECSs. Due to high wind power potential and energy demand, WECS investments increase in this region. It is the reason why Marmara region is investigated in this paper.

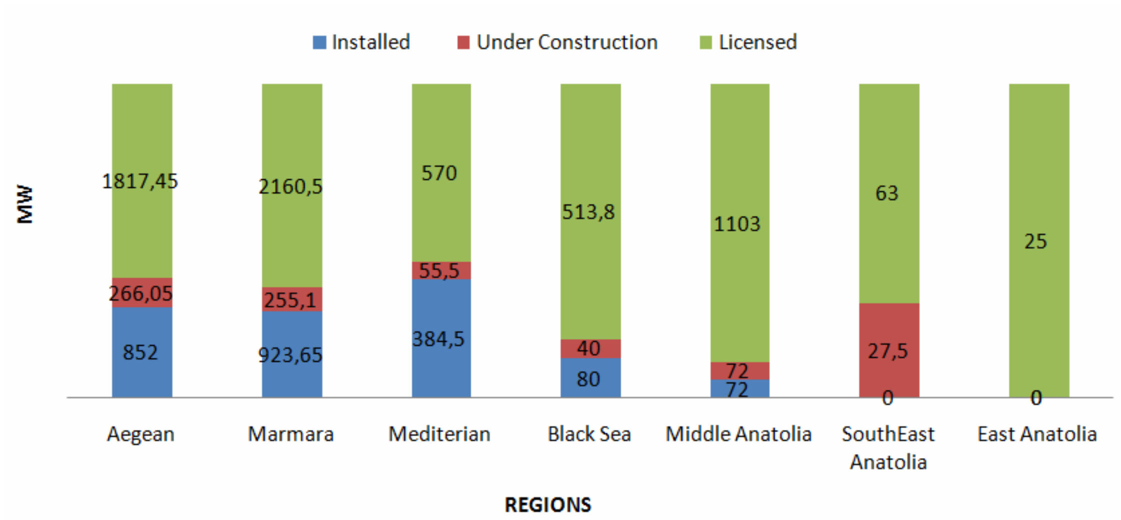

Figure 3. Status of WECSs in seven regions of Turkey

3. Wind Energy Potential in Marmara Region
Marmara region has the highest population density and developed industrialization in Turkey. Therefore, Marmara takes the first place in terms of energy needs. When Turkey's electricity generation is taken into consideration, it is obviously seen that considerable part of production is carried out at the large hydropower and fossil fuel power plants. This fact shows that the electrical energy demand of Marmara region have to be supplied from the hydropower plants or fossil fuel power plants. Both of these options have objections for the economical, sustainable and environmental growing of Turkey.
Large hydropower plants takes place at the eastern part of the country and electrical energy transmission is provided with long transmission lines to the Marmara region which takes place at the western location. Therefore, transmission losses are unavoidable. Also, hydropower potential is inadequate to provide the energy demand in Turkey.
Fossil fuel power plants consume natural gas, liquid oil and coal for electricity generation. Due to the lack of oil, gas and efficient coil reserves, Turkey is importing fossil fuels from other countries. Additionally, generating electrical energy brings economical and environmental problem together. Therefore, renewable energy sources have a great importance for Turkey. Nowadays, wind energy is one of the most popular alternative energy sources with the supports of the government.
Marmara region have the highest available wind power potential and this region is candidate for being the country's most important wind energy production area. As Marmara region has the largest electrical energy demand, significant wind energy potential is important for meeting the electricity requirements. In addition, providing the electrical energy from wind potential will bring an important decrease for import primary energy sources and transmission losses.
There are eleven cities in the border of Marmara region. Wind data for each city are given in Table 4 [18]. It is known that required average wind speed is assumed 7 m/s for economical wind energy conversion system. Table 4 is presenting the appropriate areas and power potentials in accordance with the wind speed data at 50 m height.
It can be clearly seen that all cities of the region are suitable for economical WECS establishment. However, particularly the cities of Balıkesir and Çanakkale have higher wind potential among the other cities. Balıkesir is the only city that has more than 9.5 m/s wind speed with 16.72 km^2 suitableareas. The most proper city for economical WECS installation is Balıkesir with 2,765.5 km^2. The second one

Çanakkale has 2602.52 km^2 sufficient area and 13,012.58 MW power potential. The cities such as Istanbul and Kocaeli that have more industrialization and population density are insufficient to provide energy demand.

Table 4. The wind potential of the cities in Marmara region

Cities	Wind speed (m/s)	6.8-7.5	7.5-8.1	8.1-8.6	8.6-9.5	>9.5
Balıkesir	Area (km^2)	1511.4	850.96	284.51	115.23	3.34
	Power (MW)	7557.1	4254.8	1422.6	576.16	16.72
Bilecik	Area (km^2)	61.73	-	-	-	-
	Power (MW)	308.64	-	-	-	-
Bursa	Area (km^2)	683.6	85.22	5.23	2.29	-
	Power (MW)	3418	426.08	26.16	11.44	-
Çanakkale	Area (km^2)	863,7	802.99	761.09	174.74	-
	Power (MW)	4318.5	4015	3805.4	873.68	-
Edirne	Area (km^2)	578.24	115.78	-	-	-
	Power (MW)	2891.2	578.88	-	-	-
İstanbul	Area (km^2)	832.91	2.48	-	-	-
	Power (MW)	4164.6	12.4	-	-	-
Kırklareli	Area (km^2)	572.66	43.22	-	-	-
	Power (MW)	2863.3	216.08	-	-	-
Kocaeli	Area (km^2)	15.57	-	-	-	-
	Power (MW)	77.84	-	-	-	-

Wind maps of Balıkesir and Çanakkale which cities have the most wind power potential in Marmara region are given for 50m height in Figure 4. As obvious in the figure, particularly shorelines have great energy potential. Although the areas that have high average wind speed has spread wide part of Çanakkale, this case could not be seen in Balıkesir.

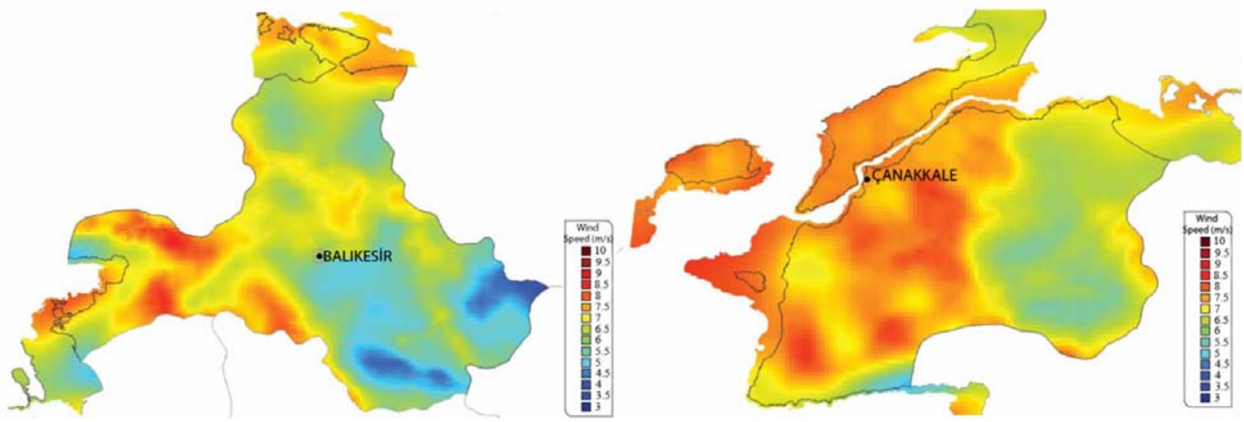

Figure 4. Wind maps of Balıkesir and Çanakkale [18]

The power capacities of installed, licensed and available WECSs are given in Table 5 [18, 19]. Based on available power and installed WECS power, Balıkesir takes the first place and Çanakkale is the second most appropriate city for wind power applications. It is remarkable that in five cities (Bursa, Kırklareli, Kocaeli, Sakarya, Yalova) there are no installed WECS.

When the received WECS licenses are investigated, it is recognized that Marmara region will be more popular for WECS installations in the near future. The locations of installed and licensed WECSs in Marmara region are shown in Figure 5.

Despite the potential to increase the WECS with licensed power plants, it is obvious that rate of usage capacity is still very low. Installed WECS power is 1.96% of the available power. Also, if it is assumed that the licensed plants are constructed, capacity will be only the 6.56% of the regions potential. This reality shows that the Marmara region have an attractive inappropriate wind energy resources.

Table 5. Wind power potential of cities in Marmara region

City	Installed WECS power (MW)	Available WECS power (MW)	Licensed power (MW)	Rate of capacity usage (%)
Balıkesir	616.1	13,827.36	338	4.45
Bilecik	40	308.64	120	12.96
Bursa	-	3881.68	59	-
Çanakkale	133.7	13,012.58	407	1.03
Edirne	15	3470.08	51	0.43
İstanbul	90.05	4177	382.5	2.16
Kırklareli	-	3079.38	247	-
Kocaeli	-	77.84	336	-
Sakarya	-	2	70	-
Tekirdağ	28.8	4626.6	84	0.62
Yalova	-	533.12	66	-
TOTAL	923.65	46,996.28	2160.5	1.96

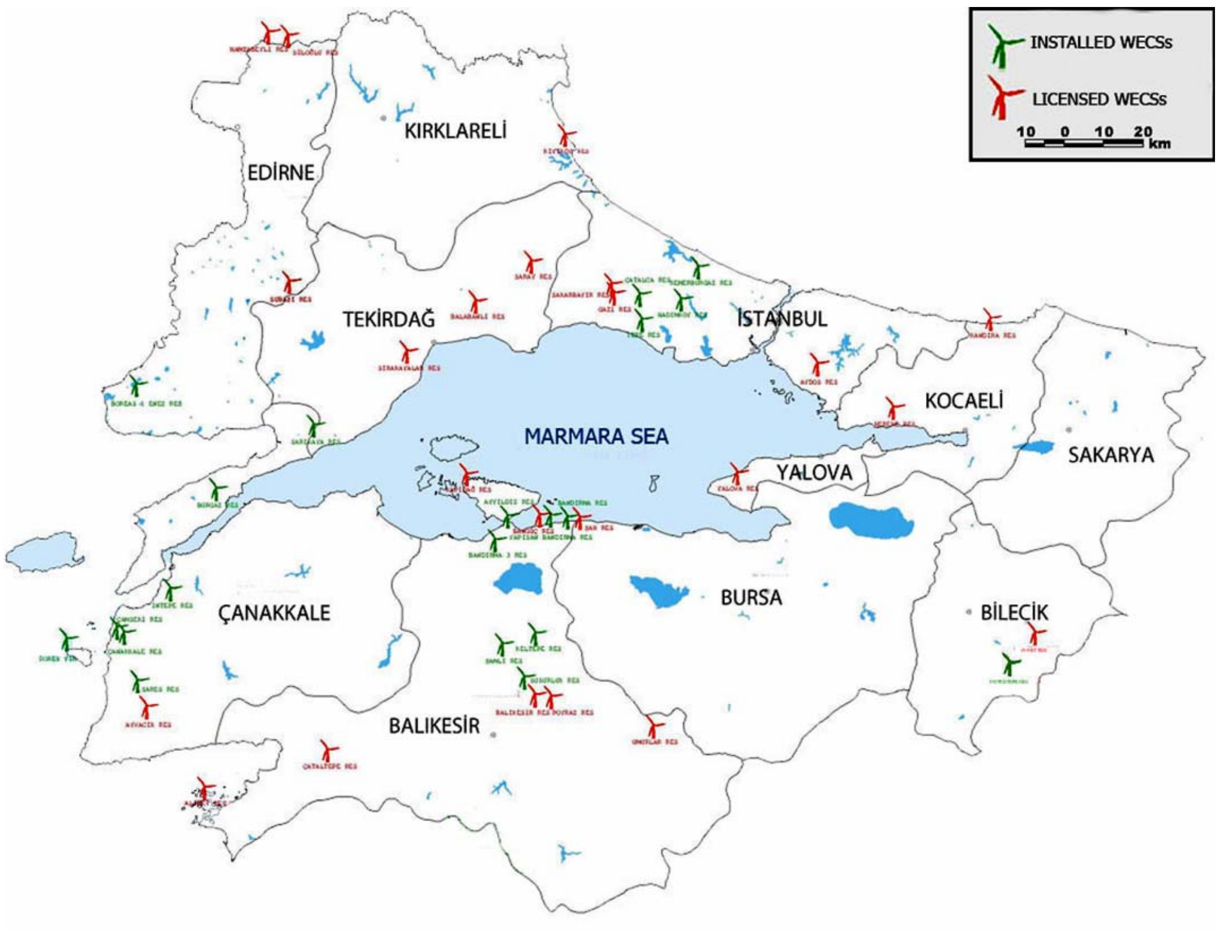

Figure 5. Installed and licensed WECSs in Marmara region [18]

The details of installed WECSs are given in Table 6 [19]. The first installed WECS project BORES is realized in Çanakkale-Bozcaada. This system was installed in 2000 and includes 17 wind turbines each has 0.6 MW power. The last installation was carried out in Balıkesir in 2012/2013 with 50 MW power of WECSs. Table 6 shows that installed power capacities of WECs and power capacity of turbines are increasing in recent years. That is because of the technological developments at wind turbine instruction and growing popularity of wind energy at this region.

Table 6. The installed power values of WECSs in Marmara region

Location	Project name	Installed Power (MW)	Turbine Brand	Turbine Power (MW)	Year of Installation
Çanakkale	Bozcaada RES	10.2	Enercon	0.6	2000
İstanbul	Tepe RES	0.85	Vestas	0.85	2006
Balıkesir	Bandırma-2 RES	35	Ge+Nordex	1.5+2.5	2006/2012
İstanbul	Sunjüt RES	1.2	Enercon	0.6	2008
İstanbul	Çatalca RES	60	Vestas	3	2008
Balıkesir	Bandırma-3 RES	25	Nordex	2.5	2008
Edirne	Boreas 1 Enez RES	15	Nordex	2.5	2008
Balıkesir	Şamlı RES	113.4	Vestas	3	2008/2010
Çanakkale	İntepe RES	30.4	Enercon	0.8	2009
Çanakkale	Bozcaada RES	10.2	Enercon	0.6	2009
Balıkesir	Keltepe RES	20.7	Enercon	0.9	2009
Balıkesir	Ayyıldız RES	15	Vestas	3	2009
İstanbul	Saray RES	4	Enercon	2	2009
Balıkesir	Bandırma RES	60	Vestas	3	2009/2010
Balıkesir	Çataltepe RES	16	Enercon	2	2010
Tekirdağ	Sarıkaya RES	28.8	Enercon	2+2+0.8	2010
Çanakkale	Burgaz RES	14.9	Enercon	0.8+0.9	2010
Çanakkale	SaRES	22.5	Ge	2.5	2010/2011
Çanakkale	Çamseki RES	20.8	Enercon	2+0.8	2011
Çanakkale	Ay RES	5	Vestas	1.8	2011
Balıkesir	Şah RES	93	Vestas	3	2011
Bilecik	Metristepe RES	40	Nordex	2.5	2011
Balıkesir	Susurluk RES	45	Nordex	2.5	2012
Çanakkale	Çanakkale RES	29.9	Siemens	2.3	2012
Balıkesir	Balıkesir RES	143	Ge	2.75	2012
Balıkesir	Poyraz RES	50	Enercon	2	2012/2013

4. Conclusion

In recent years, according to the increasing demand for electricity, decreasing fossil fuel reserves and environmental pollution, great importance is given to the investigation and investments for renewable energy sources in the world. The investments on construction of WECSs are rapidly increasing in Turkey where produces large amount of electrical energy from fossil fuels (oil, natural gas,..) and imports most of this fuels from foreign countries.

Marmara region investigated in this study is one of the seven regions in Turkey and it has share of 40% by 46,996.28 MW available wind power capacity of total capacity in Turkey. Due to the amount of population and developed industry, Marmara region has the highest requirements in terms of electric energy usage (62,531.068 MW). Also, Marmara has the highest average wind speed by 3.29 m/s in seven regions. This study reveals that Marmara region where has high average wind speed and areas with glamorous wind power, is the most suitable region for efficient wind energy production in Turkey. Especially Balıkesir and Çanakkale cities outshine with high wind speed potential.

Despite the vast electrical energy need, only 1.96 % of the available wind power capacity of this region is utilized. Large increases in capacity utilization are expected to occur in the near feature. This is a great opportunity for investors.

In this paper, it is clearly presented that related to the government supports and private enterprise investments; higher wind power energy can be achieved in this region. Installing new plants would significantly decrease energy dependence of Turkey on foreign resources. Furthermore, the installation of WECS would minimize the installation cost of transmission lines and reduce the transmission losses in Marmara region where large energy consumers exist.

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