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Regional solar and wind energy characteristics and it's energy potential in northwest of Turkey

Türkiye'nin kuzeybatısındaki bölgesel güneş-rüzgâr enerjisi karakteristikleri ve enerji potansiyeli

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Abstract
In this study, solar and wind energy properties and energy potentials around the Marmara Sea (North-West Turkey) are discussed from the perspective of climate change. The meteorological data of thirteen stations in this region were used. According to the results of 58 years between 1960 and 2017; temperature values of all stations increased between 0.8 and 1.7 ºC. This increase is considered to be related with climate change. In this context, the importance of renewable energy sources such as solar and wind is increasing. The solar energy potential in the region is estimated to be between 1108.4 and 1488.9 kWhm^{-2}yr^{-1} and the wind energy potential is between 1005.5 and 7007.9 kWhm^{-2}yr^{-1}. The evaluation of these energy reserves is very important in the prevention of climatic processes caused by fossil energies.

Keywords: Climate change, Renewable energy, Solar energy, Wind energy

Öz
Bu çalışmada, Türkiye'nin Marmara Denizi çevresinde (North-West Turkey) güneş ve rüzgâr enerjisi karakteristikleri ile enerji potansiyelleri, iklim değişikliği perspektifinden ele alınmıştır. Bu bölgede bulunan on üç istasyonunun meteorolojik verilerinden yararlanılmıştır. 1960 ile 2017 yılları arasındaki 58 yıllık ölçüm sonuçlarına göre; istasyonların tamamında sıcaklık değerlerinin 0,8 ile 1,7 ºC arasında artış gösterdiği tespit edilmiştir. Bu artışının iklim değişikliği ile ilişkili olduğu değerlendirilmektedir. Bu çerçevede güneş ve rüzgâr gibi yenilenebilir enerji kaynaklarının önemi daha da artmaktadır. Bölgede güneş enerjisi potansiyelinin 1108.4 ile 1488.9 m^{-2}yıl^{-1} arasında ve rüzgâr enerjisi potansiyelini ise 1005,5 ile 7007,9 kWhm^{-2}yıl^{-1} arasında olduğu hesaplanmıştır. Söz konusu enerji rezervlerinin değerlendirilmesi, fosil kökenli enerjilerin sebep olduğu iklimsel süreçlerin önlenmesinde oldukça önemlidir.

***Anahtar kelimeler**: İklim değişikliği, Yenilenebilir enerji, Güneş enerjisi, Rüzgâr enerjisi*

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1. Introduction

1. Giriş

One of the main problems in the globalizing world is the need to produce more energy in order to maintain industrialization and technological development. As a result of this, climate change and global warming occurs. In today's world, it is impossible to give up technological development.

Effects of climate change and global warming; it consists of parameters such as heat waves, drought, flood precipitation, heavy snowfall, ocean acidification, temperature change, extinction of species, etc. In addition to these, sea ice loss, sea level rise, longer and more intense heat waves, ice shrinkage, plant and animal areas change, trees bloom more earlier etc. there are also effects (Nasa, 2019). The temperature rise in northwestern Mexico caused a decrease in yield in production areas. This is a threat to grain products (Hernandez-Ochoa et al., 2018). However, it has been observed that it has positive effects on crops such as corn and oilseeds (Xie et al., 2020). Moreover, the increase in temperature in cities as a result of global warming has a significant impact on the energy consumption of buildings (Santamouris, 2014). Recent studies have shown that hydro, wind and solar technologies can eliminate all fossil fuels and provide 100% of the energy in the World (Bose, 2010).

How do we preclude global warming and climate change? In many articles on the causes of climatic changes and global warming (Longa & Zwaan, 2017; Patlitzianas et al., 2005; Abdullah et al., 2014), the role of energy use by fossil origin is emphasized. One of the best solutions is to use renewable energy sources instead of fossil energy sources.

Renewable energy sources consist of solar energy, wind energy, biomass energy, geothermal energy, hydraulic energy, wave energy, current energy etc. (Boyle, 2004). These resources have advantages as well as disadvantages. Solar energy is potentially the highest-value renewable energy source. However, the efficiency of converting the energy of solar radiation into useful energy is low. Wind energy is advancing rapidly as technology. These are suitable for unit energy production costs. However, it is not possible to work in the desired efficiency in places such as city centers. Economically; the search for available wind energy sources and locations is an extremely important requirement (Al-Abbadi, 2005).

The production technologies of biomass energy are well developed today. Biomass energy is stored in comparison with the sun and wind. However, in the world with a food deficiency problem, energy from biological origin products is an important ethical problem. Furthermore, greenhouse gas emissions of biomass are also higher than other renewable energy sources (Table 1; Amponsah et al., 2014). Geothermal energy; it has a multi-purpose usage areas such as obtaining electricity, heating, cooling, thermal tourism, and industry. However, due to some harmful chemicals found in their structures and to ensure the sustainability of the reserve, re-injection is required.

In electricity generation, the temperature of the source should exceed at least 100 degrees. Hydraulic power plants from renewable energy sources have the ability to become part of acting quickly when excessive energy is needed. Dams established for hydraulic energy can also be used for irrigation, erosion and flood control besides energy. On the other hand, the investment costs of hydraulic power plants are high and their construction takes a long time. The fact that the efficiency of hydraulic power plants is directly related to the amount of precipitation is one of the important problems. The dams that have been built also disrupt the ecological structure of the region.

There are some disadvantages such as the possibility of flooding of settlements and historical buildings. Wave energy and current energy can only be used in areas with sea or streams that have strong currents.

Table 1. Comparison of greenhouse gas emissions in electricity generation from renewable energy sources

Tablo 1. *Yenilenebilir enerji kaynaklarından elektrik üretiminde sera gazı emisyonlarının karşılaştırılması*

Resource	Mean ($gCO_{2eq}kW^{-1}h^{-1}$)	Reference
Onshore Wind	29.5	(Hondo, 2005)
Offshore Wind	13.0	(Chatzimouratidis & Pilavachi, 2008)
Hydro-power	37.4	(Varun et al., 2012)
Wave power	22.8	(Carbon Trust, 2019)
Tidal power	15.0	(Jungbluth, 2005)
Geothermal	41.0	(Covenant of Mayors, 2010)
Photovoltaic	49.2	(Lenzen, 2008)
Solar thermal	39.6	(Velmurugan & Sridhar, 2008; Lenzen, 1999)
Biomass	118.0	(Elsayed et al., 2003)

Greenhouse gas emissions are also associated with climate change. Renewable energy sources are used to reduce greenhouse gas emissions. Solar energy and wind energy usage in this study are also among renewable energy sources.

Many studies have been conducted for Turkey as a whole to date. These studies are valuable researches. In the present study, a general perspective covering the Marmara Region and carried out by analyzing the data spread over many years has been put forward. In this study, the temperature changes of northwestern Turkey were examined. Furthermore, it has been shown whether it is affected by global warming. Then, the solar energy potential and wind energy potential of the region were investigated. In the case of the usage of solar and wind energy potential whether or not the reduction of use of fossil power plants, were explorationed.

2. Site and data description

2. Araştırma alanı ve veri tanımlaması

Located in the northwest of Turkey and around the Marmara Sea, the region is referred the "Marmara region". Istanbul, which assembles the continents of Asia and Europe, is located in the center of this region. Istanbul is the most crowded city in the country with its population of 15.029.231. The research area involves an important part of the Marmara region. In addition, the population of this area is given as 20.417.299 according to official records (TUIK, 2018). This ratio corresponds to 25.3% of the country's population. This region has the Bosphorus (Istanbul Strait) to the northeast and the Dardanelles (Çanakkale Strait) to the southwest. Geographically, the highest points of the region are Uludag in the south-east and Istıranca mountains in the north. The location information of the thirteen stations selected in this study is shown in Figure 1. At these stations, climatic data are recorded instantaneously and daily.

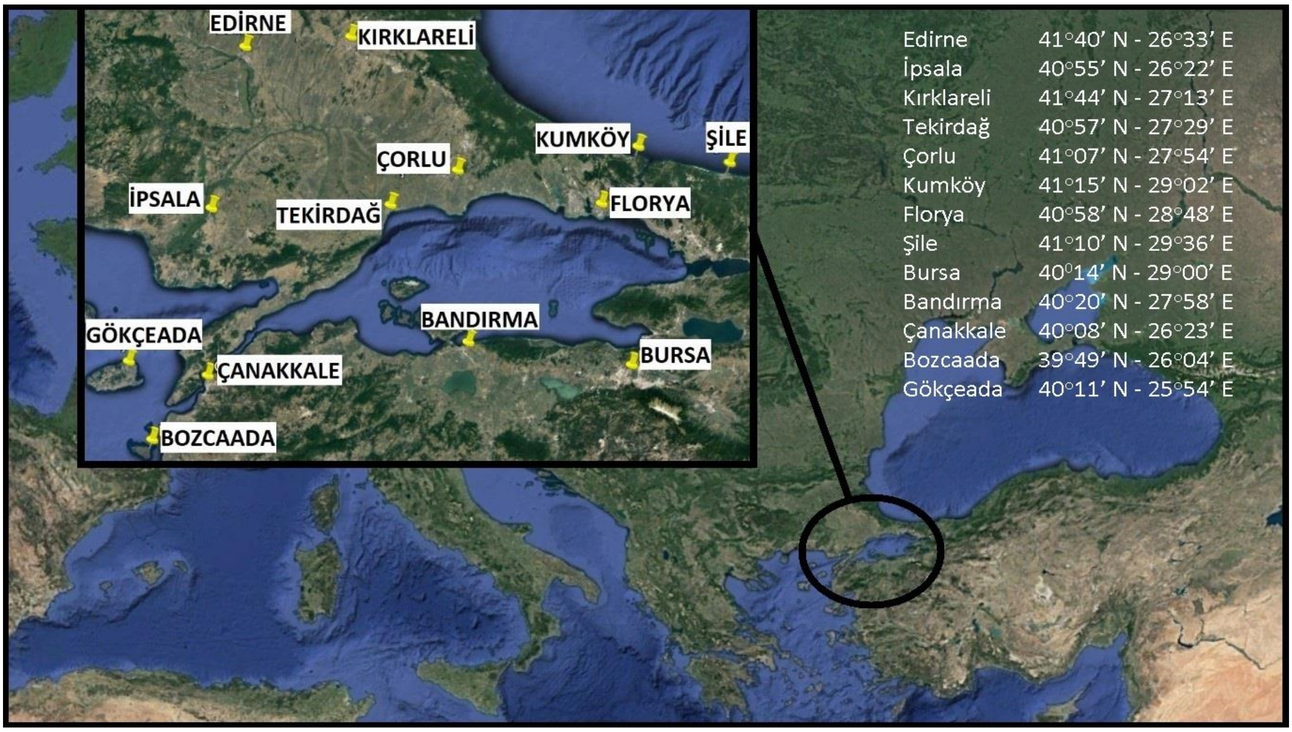

Figure 1. The positions of stations in North-West Turkey on the map (Google Earth, 2019)
Şekil 1. *Kuzey-Batı Türkiye'deki istasyonların haritadaki konumları*

3. Methodology

3. Metot

Thirteen meteorological stations were evaluated for 58 years between 1960 and 2017 (TSMS, 2008). Data were analyzed and temperature distributions of each station were determined. The differences between the averages of temperatures (temperature anomalies) were analyzed separately for each year. Apart from the temperature, precipitation, cloudiness, hours of sunshine, solar radiation, wind speed changes, and wind direction were studied. Solar energy and wind energy potential were examined after analysis of climatic parameters. For each station, the solar radiation (I) power per unit area and the monthly solar energy potential (E) per unit area were calculated with the help of equation (1) and equation (2) (Mentens, 2011; Zahoransky et al., 2010).

$$E/A = I \cdot t \cdot \eta \quad (1)$$

$$P = E/t \quad (2)$$

Related to wind energy were calculated to equation (3) primarily wind speed at 100 m height from the ground level of the station values. In the calculations, Von Karman constant was taken as 0.4 (Gasch & Twele, 2011). In the determination of roughness length (Z_0), surface roughness class and roughness coefficients (Vindmolleindustrien, 2019) were taken into consideration. The following equation (3) was used for the adaptation of the wind speed from ground level to 100 m (Pelletier, 2006; Klug, 2001).

$$v(h) = (u^*/k) \cdot ln(h/Z_0) \quad (3)$$

With the help of wind speed values adapted to 100 m above the ground surface were calculated wind power (power density) per unit area and monthly wind energy potential per unit area.

In the meteorological stations, the measured hourly and daily mean values were converted to monthly and yearly mean values, with the equation (4), and equation (5), respectively (Soysal, 2000).

$$M_m = \sum x/n = (x_1 + x_2 + x_3 + \cdots + x_n)/n \quad (4)$$

$$M_y = \sum x/m = (x_1 + x_2 + x_3 + \cdots + x_n)/m \quad (5)$$

The *minimum* and *maximum values* of the data obtained from meteorological stations, *arithmetic averages* and *differences from the average*, time-dependent *correlations*, *significance tests* and graphs were created with the help of Microsoft Excel and IBM SPSS Statistics 23 programs.

4. Results and discussion

4. Bulgular ve tartışma

Hourly and daily recorded in meteorological stations temperature, precipitation, cloudiness, sunshine duration, solar radiation, wind speed, and wind direction data were analyzed. In 13 different stations of the region, solar radiation intensity, solar energy potential, wind velocity frequency distribution, wind power density, and wind energy potential were obtained. These results were presented and discussed under three main headings below.

4.1. Climatic characteristics and variations

4.1. İklim özellikleri ve varyasyonları

When the average temperature of the region is examined, the lowest temperature in winter months in Edirne and Kırklareli stations was recorded as 4.4 ºC, 2.4 ºC, and 4.0 ºC. The highest temperature averages in the same period were saved as 9.7 ºC, 8.1 ºC and 8.5 ºC in Bozcaada station. In the summer months, the lowest temperature averages of 20.0 ºC, 22.5 ºC and 22.6 ºC were determined in Şile and Çorlu stations and the highest temperature averages were found to be 22.4 ºC, 24.9 ºC and 24.9 ºC in Gökçeada and Çanakkale stations (Table 2).

Table 2. Temperature averages
Tablo 2. *Ortalama sıcaklıklar*

	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
Bursa**	5.2	6.3	8.5	12.8	17.5	22.0	24.3	24.2	20.2	15.4	10.8	7.3
Edirne**	2.4	4.4	7.7	12.9	17.9	22.2	24.5	24.3	20.0	14.2	9.0	4.4
İpsala**	3.7	5.2	8.0	12.8	17.8	22.2	24.4	24.2	20.1	14.6	9.9	5.7
Kırklareli**	2.7	4.0	6.8	11.9	17.1	21.4	23.8	23.5	19.3	14.2	9.0	4.9
Tekirdağ**	4.9	5.4	7.5	11.8	16.6	21.1	23.6	23.8	20.1	15.6	11.2	7.2
Çorlu**	3.3	4.2	6.6	11.4	16.2	20.6	22.8	22.6	18.9	14.2	9.7	5.5
Çanakkale**	6.2	6.7	8.4	12.6	17.6	22.2	24.9	24.9	21.0	16.2	12.0	8.3
Gökçeada**	6.7	7.1	9.0	13.3	17.9	22.4	24.5	24.4	20.8	16.1	12.2	8.6
Bozcaada**	8.1	8.5	10.1	13.7	17.7	21.6	23.1	23.1	20.7	16.7	13.0	9.7
Kumköy**	5.8	5.9	7.4	11.1	15.7	20.3	23.1	23.5	20.1	15.9	11.8	8.1
Florya**	5.7	5.9	7.6	11.8	16.5	21.2	23.8	23.9	20.4	16.0	11.9	8.0
Şile*	5.6	5.7	7.2	11.0	15.4	20.0	22.5	22.8	19.5	15.5	11.4	7.8
Bandırma**	5.2	5.9	7.9	12.1	16.7	21.3	23.6	23.7	20.3	15.8	11.1	7.2

*, **: significant at p/0.05, and p/0.01

Between 1960 and 2017, there has been an increase in temperature averages of all stations. This increase is 0.8 ºC at Şile station, 1.0 ºC at Bandırma station, 1.2 ºC at Bursa, Çanakkale, Bozcaada and Kumköy stations, 1.3 ºC at Edirne, Ipsala, Tekirdağ and Çorlu stations, 1.6 ºC at Florya station, 1.7 ºC at Kırklareli and Gökçeada stations. When statistical data was evaluated (IBM SPSS Statistics 23), temperature data showed normal distribution and time-dependent temperature increases were found to be significant at 0.05 level in Şile and 0.01 at all other stations. Figure 2 and 3 shows the average temperature distributions of Gökçeada and Şile.

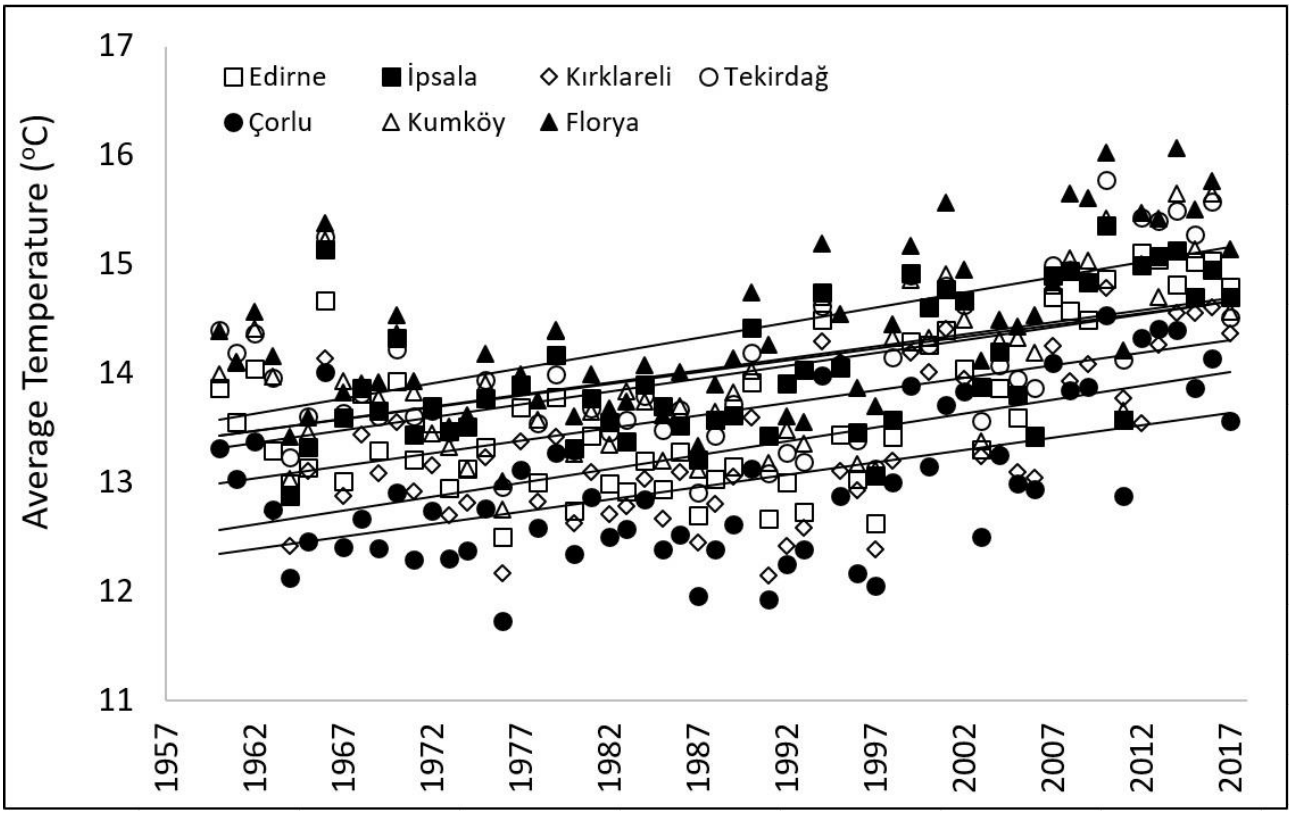

Figure 2. Average temperature changes (North Marmara)
Şekil 2. *Ortalama sıcaklık değişimleri (Kuzey Marmara)*

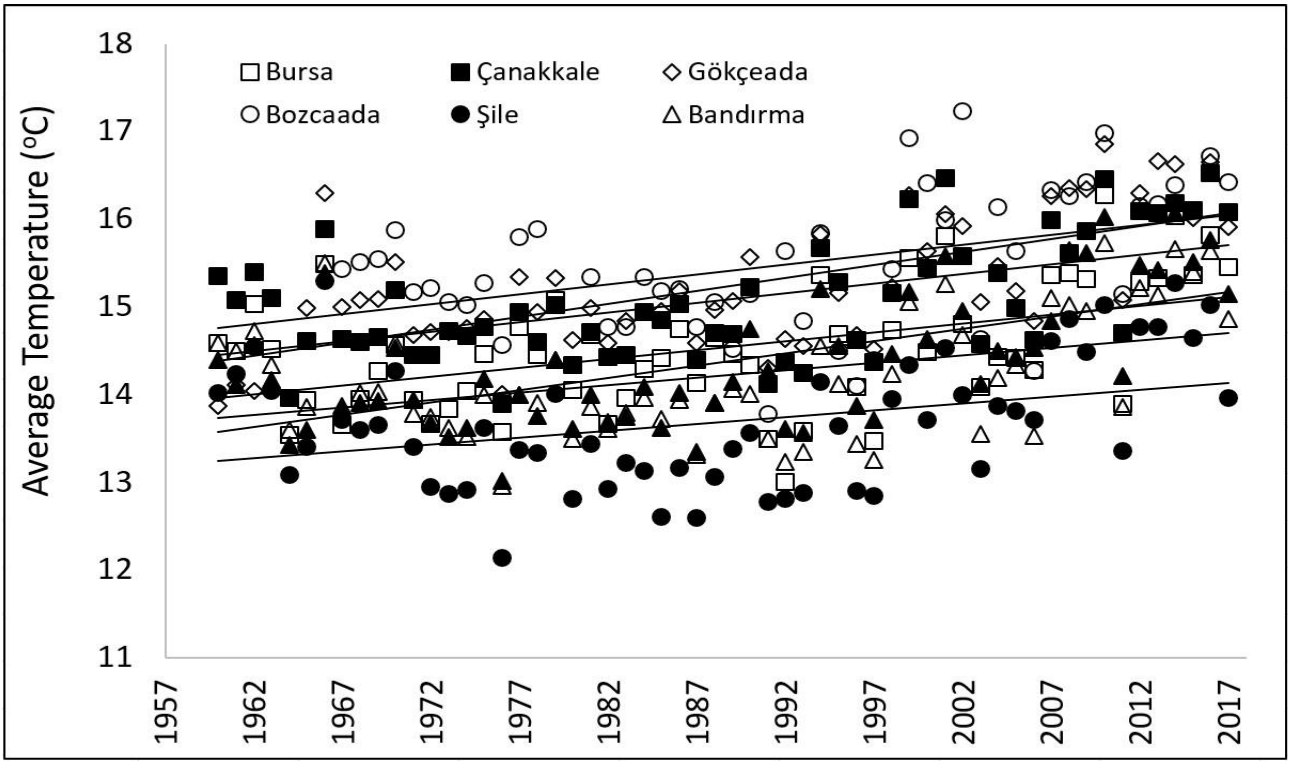

Figure 3. Average temperature changes (South Marmara)
Şekil 3. *Ortalama sıcaklık değişimleri (Güney Marmara)*

The difference in temperature averages for each year from the general average (temperature anomalies) was examined. 15 years of the temperature averages last 20 years have increased over the general average for long years. Temperature averages remained below the general average for only 3 years and remained close to the average for 2 years. Especially in 11 years of the last 12 years, the average temperatures were above the general average (Figure 4).

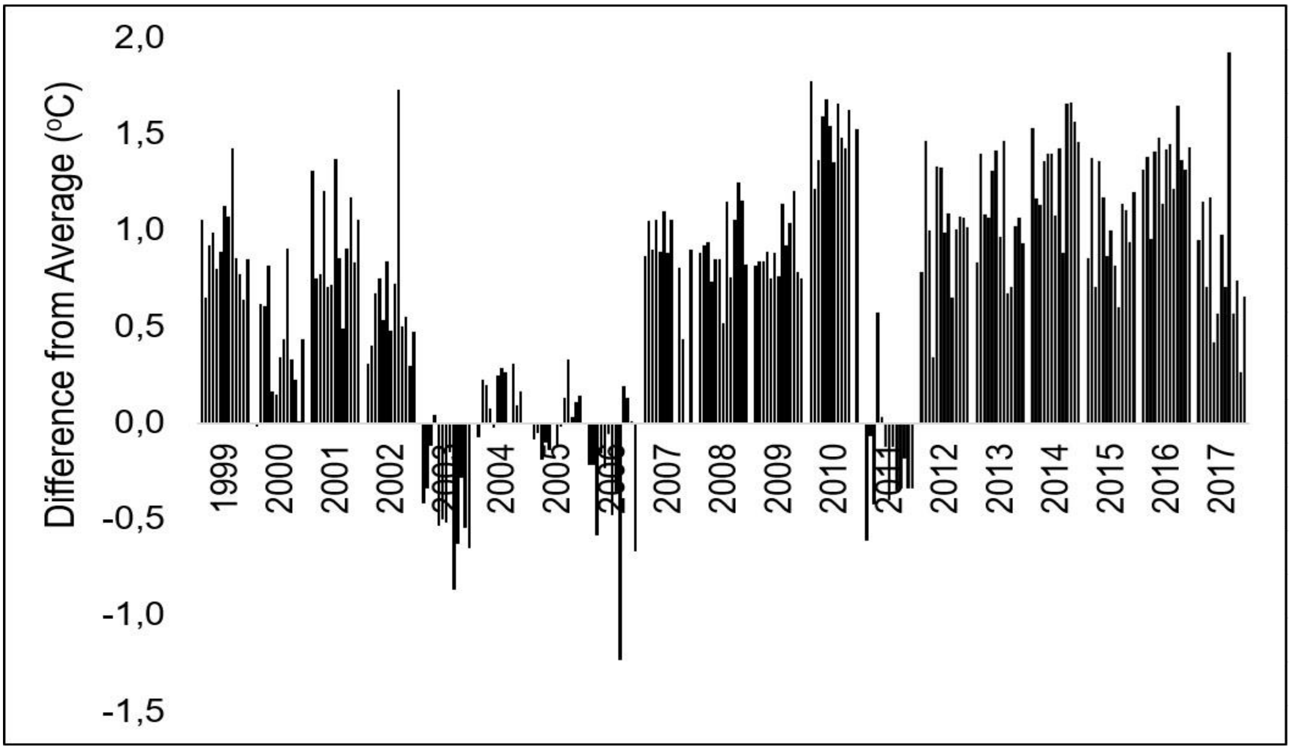

Figure 4. Temperature anomalies of the last two decades
Şekil 4. *Son yirmi yılın sıcaklık anomalileri*

It is known that the average land and ocean temperatures around the world show a linear trend. The data sets produced independently an increase in temperature between 0.65 and 1.06 ºC (average 0.85 ºC) between 1880 and 2012 years (Stocker et al., 2013).

According to NASA global warming surveys, an average temperature increase of 0.9 ºC was observed in recent years. As far as NASA, when 136 years of temperature data was analyzed, 17 of the hottest 18 years were achieved after 2001 (Nasa, 2017). The results obtained from the research area clearly show that the region is affected by global warming.

When the changes in the rainfall parameters of the region were examined, no statistically significant increase or decrease was detected.

In the cloudiness rates, a decrease is observed in all stations. Especially in Bursa, Çorlu, Tekirdag and Kırklareli stations, their value of the decrease in the cloudiness rate is above 0.5. Since 1992, in all stations that are subject to research, cloud averages have always been below the general average for many years. The average of only 3 years in the last 25 years was over the overall average for many years, whereas the average of 22 years was below the overall average for many years. Changes in the sunshine duration of the region were not found to be a statistically significant increase or decrease. The shortest period of sunshine in the region was indicated in Kumköy with 5.5 hd^{-1} and the longest sunshine duration was 7.4 hd^{-1} in Gökçeada.

In this study, it is understood that North-West Turkey is affected by climate change like many regions of the world. In many articles on the causes of climatic changes and global warming, the role of energy use by fossil origin is emphasized. In this part of the study, solar energy and wind energy potentials of the region were analyzed.

4.2. Solar energy potential

4.2. Güneş enerjisi potansiyeli

When the average solar radiation density and solar energy potential of the region are examined, it is seen that the lowest potential is in Edirne with 124.2 Wm^{-2} and 1108.4 $kWhm^{-2}yr^{-1}$.The highest potential was found at Kırklareli station with 166.8 Wm^{-2} and 1488.9 $kWhm^{-2}yr^{-1}$. These values are considered to be a sufficient level of energy potential for the world as a whole due to the influence of the geography in which the country is located. For comparison, the annual solar energy potential for München, Germany, is reported as 1112.1 $kWhm^{-2}yr^{-1}$ (GSA, 2022). In Turkey's solar energy potential atlas, the Marmara Region is given as 1400-1450 $kWhm^{-2}yr^{-1}$ (TSEM, 2022).

Table 3. Annual solar energy potentials of stations

Tablo 3. *İstasyonların yıllık güneş enerjisi potansiyelleri*

Stations	Average Annual Power (Wm^{-2})	Annual Energy Potential ($kWhm^{-2}yr^{-1}$)
Bursa	145.8	1299.3
Edirne	124.2	1108.4
İpsala	155.6	1389.3
Kırklareli	166.8	1488.9
Tekirdağ	152.9	1365.2
Çorlu	151.7	1332.5
Çanakkale	166.4	1485.8
Gökçeada	146.0	1282.5
Bozcaada	148.4	1304.3
Kumköy	146.9	1311.6
Şile	140.6	1255.7
Florya	143.5	1280.7

The highest potential values were observed in Kırklareli during the summer and in Çanakkale during the winter months. The lowest potential values belong to Edirne in both summer and winter months. The solar radiation intensity and solar energy potential of the stations are given in Figure 5. Since the meteorological data on solar irradiation from the Bandırma station cannot be obtained in sufficient amounts, it is not included in the calculations of solar energy potential.

The change in solar energy potential will maintain its continuity unless the World's solar cycle and solar activities change. However, due to parameters such as climate change and air pollution, there may be changes in the reach of solar radiation to the surface in metropolitan areas.

4.3. Wind energy potential

4.3. Rüzgar enerjisi potansiyeli

When the annual wind speed averages for 100 m height were examined in the region, the lowest wind speed averages were found in the range of 4.8 to 6.9 ms^{-1} at Kırklareli station. The highest wind speed averages of 8.8 to 13.6 ms^{-1} were obtained at the Bandırma station. Minimum wind speeds in all stations were recorded in April, May, June, September and October. Maximum wind speeds were observed mainly in February and December.

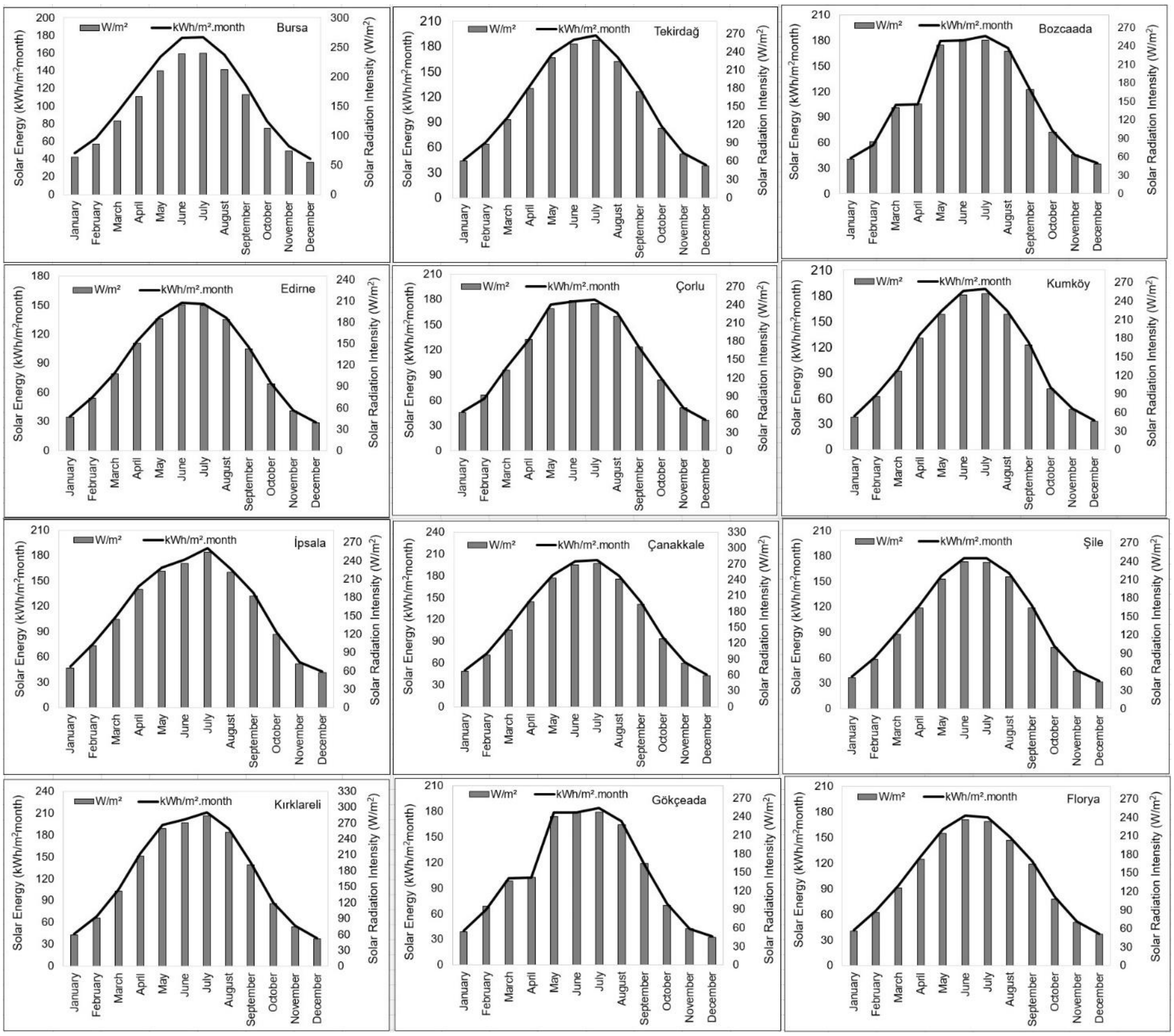

Figure 5. Solar energy potential
Şekil 5. *Güneş enerjisi potansiyeli*

When the wind direction is investigated, it is established that all the stations are wind blow directions N, NNE and NE. In addition, the prevailing wind direction in Edirne station can also be NNW. In Kumköy station, the direction of wind blowing was determined to be quite scattered. In this station, the dominant wind blowing direction is distributed as N, NNE, NE, ENE, E and SSE.

The wind power density and wind energy potential averages of the region were analyzed. The lowest potential is 115.1 Wm^{-2} and 1005.5 $kWhm^{-2}yr^{-1}$ in Kırklareli. The highest potential was found at the Bandırma station with 798.2 Wm^{-2} and 700.9 $kWhm^{-2}yr^{-1}$. In seasonal terms, the highest potential values are at Bozcaada station during the winter months and it is at Çanakkale station in Spring and November. It was recorded in the summer months and in September and October in the Bandırma station and then the lowest potential values belong to Kırklareli station in all seasons. Wind power density and wind energy potentials of the stations are given in Table 4 and Figure 6. In terms of wind potential, Bandırma, Bozcaada, Çanakkale, Gökçeada and Çorlu world wind potentials are observed at a fairly good level, especially when taken into account. For comparison, the wind power potential for München, Germany is reported as 160 Wm^{-2} (GWA, 2022). In a study on Turkey's wind energy potential, the wind power potential for the Marmara Region was given in the range of 100 Wm^{-2} and >500 Wm^{-2} (İlkilic, 2012).

Table 4. Annual average power and energy potentials of stations
Tablo 4. *İstasyonların yıllık ortalama güç ve enerji potansiyelleri*

Stations	Average Annual Power (Wm^{-2})	Annual Energy Potential ($kWhm^{-2}yr^{-1}$)
Bursa	249.6	2184.8
Edirne	149.2	1304.1
İpsala	301.2	2631.8
Kırklareli	115.1	1005.5
Tekirdağ	237.3	2079.1
Çorlu	471.6	4129.0
Çanakkale	696.6	6098.2
Gökçeada	542.4	4743.7
Bozcaada	724.8	6344.2
Kumköy	419.7	3667.6
Şile	303.7	2658.3
Florya	293.1	2569.2
Bandırma	798.2	7007.9

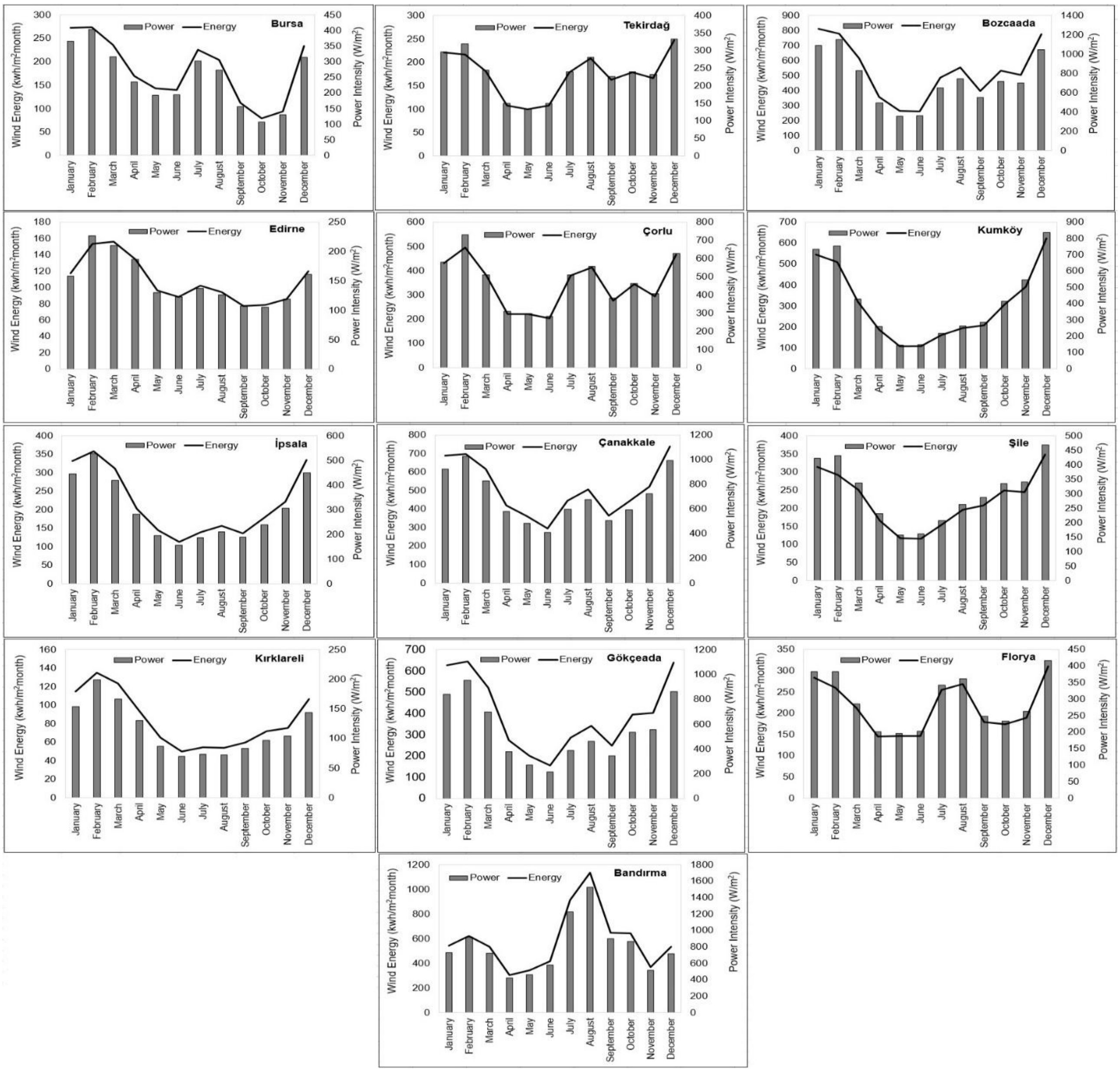

Figure 6. Wind energy potential
Şekil 6. *Rüzgar enerjisi potansiyeli*

The change in wind energy potential can be seen in places close to cities due to climate change and global warming as well as parameters such as excessive construction resulting from the increase in human population. In this study that especially in Edirne, wind speed values have been increasing for years. In the Bursa, Kırklareli, Tekirdağ, Çorlu, Çanakkale, Bozcaada, Kumköy, Şile and Florya stations, it was found that wind speed values were decreasing by years. When evaluated statistically, it was established that wind speed data showed normal distribution. The increase in time-dependent wind speed in Edirne was found to be significant at the level of 0.01. In Bursa, Tekirdağ, Çorlu, Çanakkale, Bozcaada, Kumköy, Şile and Florya stations, the decrease in time-dependent wind speed was occurred to be significant at the level of 0.01. In Kirklareli the significance level was determined as 0.05. On the contrary, no statistically significant change was observed in İpsala, Gökçeada and Bandırma. In the correlation tests performed with the data on the change of wind speed, r^2 values were contrived as 0.7166 and 0.928 in Kumköy and Şile, respectively. The r^2 values of the other stations remained below 0.35. This indicates a decrease or an increase in the wind energy potential in these regions.

5. Conclusion

5. Sonuçlar

In this study, data from thirteen different stations (site) located around the Marmara Sea in northwest Turkey were used. These data include 58 years between 1960 and 2017. The changes in the temperature of the Marmara region were investigated and it was revealed whether it was affected by global warming. Then, solar energy potential and wind energy potential of the region were analyzed.

When the changes in temperature averages are examined, there is a temperature increase in the whole research area. The increase in temperature averages ranged from 0.8 ^oC to 1.7 ^oC. When the temperature averages are compared to the general average for many years (temperature anomalies), it is seen that the average temperature of the 15 years in the last 20 years has increased over the years. Especially the average temperatures of 11 years of the last 12 years have been above the general average for long years. Solar energy potential was calculated between 1108.4 and 1488.9 $kWhm^{-2}yr^{-1}$ in the region. Kırklareli has the most solar energy potential in the region. The average annual wind speed of 100 m above ground in the region is between 4.8 and 13.6 ms^{-1}. The wind direction is mostly direction in N, NNE and NE in all stations.

The wind power density of the region is between 115.1 and 798.2 Wm^{-2} and the wind energy potential is between 1005.5 and 7007.9 $kWhm^{-2}yr^{-1}$. Bandırma is the region with the highest wind area. In this study that especially in Edirne, wind speed values have been increased by years. In the Bursa, Kırklareli, Tekirdağ, Çorlu, Çanakkale, Bozcaada, Kumköy, Şile and Florya stations, it was found that wind speed values were decreasing by years. In Kumköy and Chile, wind speed has decreased considerably over the years. It is evaluated that this situation is related to constructing.

When the results obtained from the research are examined, it can be clearly seen that the usage of fossil-based power plants can be reduced by the contructive assistance of using solar and wind energy potentials.

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Nomenclature

Semboller

Z_0 : Roughness length born of obstacles on the earth surface, m
x : Daily mean of the measured meteorological value
v : Wind speed, ms^{-1}
h : Height of Wind speed, m
u* : Wind speed altitude factor
k : Von Karman Constant
M_m : Monthly mean value
My : Yearly mean value
n : Days in the month
m : Days in the year
r^2 : Correlation coefficient
E : Energy, $kWhm^{-2}yr^{-1}$
I : Solar radiation, Wm^{-2}
A : Area, m^{-2}
t : Time, h
η : Yield
P : Power, kW

Author contribution

Yazar katkısı

Concept/Design: TB, AV; Data Collection and/or Processing: TB, AAA; Data analysis and interpretation: AV; Literature Search: TB, AAA; Drafting manuscript: TB, AAA, AV; Critical revision of manuscript: TB, AAA, AV

Declaration of ethical code

Etik beyanı

The authors declare that all of the rules stated to be followed within the scope of the "Higher Education Institutions Scientific Research and Publication Ethics Directive" were followed, and none of the actions specified under the title of "Actions Contrary to Scientific Research and Publication Ethics" have been taken.

Conflicts of interest

Çıkar çatışması beyanı

The authors declare that they have no conflict of interest.

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