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ORIGINAL PAPER

The significance, potential and the current use of renewable energy in TR83 region, Türkiye

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Abstract

This study aims to present the potential of hydroelectric, wind, solar and biomass sources of the TR83 Region which ensures the sustainability and security of the supply. Besides, it reduces the environmental pollution and greenhouse gas emission in the atmosphere. The study demonstrates the present use of both renewable and nonrenewable energy sources together with the plants that will be under construction in the future in the TR83 Region, consisting of the cities Amasya, Tokat, Çorum and Samsun in mid black sea region in Türkiye, also shows the potential of GHG emission reduction together with the present and estimated values. Furthermore, this study proposes to increase the public awareness about the usage of the current potential of the sources and encourages the investors to make investments in the region.

Keywords Renewable energy potential · Renewable energy sources · TR83 region

Introduction

Energy is one of the social and economic indicators affecting the quality of life for all countries. Energy need and consumption are the parameters increasing directly with the population growth and industry level. There have been many studies about replacing fossil fuel-based energy sources with the renewable and sustainable ones in the recent years. CO_2 emission, climate change effect and having limited source are some of the reasons for the decrease in the use of fossil-based energy sources. Besides, 70% of the greenhouse gas emission is caused by energy sector (Young and Brans 2017). Conversely, the use of renewable energy is increasing due to having clean, sustainable and unlimited sources.

Türkiye can supply only the one thirds of its energy from domestic sources, and the rest is supplied from neighboring countries. Energy, imported from other countries, makes the country's foreign dependent and causes economic problems (Alboyaci and Dursun 2008). In order to cope with these problems, countries struggle to use the domestic sources efficiently and find solution using renewable energy sources (RES). The reason for the increasing use of renewable energy sources is technological advance, life standards and high population. RES are supposed to meet about 65% of the energy consumed worldwide where the 70% of electricity demand is predicted to be supplied by RES. Using RES, energy production decreases the environmental pollution resulting from the fossil-based energy sources and also reduces foreign dependency. The reports given by the Turkish Statistical Institute declare that more than 70% of 526.000.000 tones greenhouse emission was produced by energy sector (Anonymous 2021).

Even though global warming is supposed to have less effect on Türkiye, scientists claim that droughts could be seen caused by the climate change (Gorgulu 2019; Kocabey et al. 2012). Furthermore, energy production from RES is handled as a state policy which reduces foreign dependency and global warming. As a result, supports on the use of RES projects have increased (Dursun and Gokcol 2014). Being as a bridge between Asia and Europe, having 769.604 km^2 land area and having strategical importance, Türkiye has a high quantity of fossil-based energy sources (Alboyaci and Dursun 2008). Its population is about 85 million in 2022 (TSI 2022).

In the report published by Turkish Electricity Transmission Corporation in May 2022, it is stated that the electric

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power has an installed capacity of 100.666, 5 MW. The installed power capacity comprises of 59.4% domestic source and 40,6% fuel imported from other countries. The report also claims that 53% of the installed power is produced by thermal plants, having the highest share among the other power plants, 32% share is met by hydroelectric plants, while 15% is produced by renewable energy power plants like geothermal, solar and wind power plants (Turkish Electricity Transmission Corporation 2022). The development of annual installed power capacity between 2000 and 2022 years is shown in Fig. 1 (Turkish Electricity Transmission Corporation 2022).

In order to ensure energy supply security and sustainability, it is essential to reduce the use of the resources imported from abroad to produce electrical energy. In 2014, a National Renewable Energy Action Plan was announced by the Turkish government in accordance with the 2009/28/EC instructions of European Council. Considering the high renewable energy potential of the country such as hydraulic, geothermal, wind and solar sources, it is aimed by the Turkish government to increase the ratio of renewable energy sources to a minimum value of 30% in 2023 (Dursun and Gokcol 2014).

According to Ministry of Energy and Natural Resources (MENR), electrical energy consumption of Türkiye was 303 TWh in 2018 which is 2.2% more than the previous year, and the electrical energy generation was 26.14 kTOE which is 2.2% more than the previous year. The annual gross electricity consumption in Türkiye in 2021 increased by 8.74% to 332.9 TWh, compared to the previous year. Electricity generation reached 334.7 TWh, increasing by 9.14% (MENR 2022a).

As seen from Fig. 2, TR83 Region includes the cities Samsun, Amasya, Tokat and Çorum. The region has a land area of 37.877 km^2 which points to 5% of the total area of the country. Moreover, the region has a population of 2.739.400 which constitutes 3.7% of the country's population (Anonymous 2011).

The most crowded city in TR83 Region is Samsun whose population is 1.250.000, and second one is Tokat with the population of 624.000. The next city is Çorum whose population is 624.000, and the least crowded city is Amasya with the population of 324.000. The rate of increase in population has been declining in the region since 1980s. The population of the region increased 3 times from 1927 to 2009, whereas the total population of Türkiye grew 5 times within these years. This downtrend occurred due to the fact that birth rates decreased, and there is immigration to other regions and cities. The region has a population density of 73 km^2/person. From the cities in the region, Samsun, whose population density is 138 km^2/person, has higher density of population than the average of Türkiye (Mbsda 2011).

There are only a few studies made for TR83 Region by means of the potential of renewable energy sources. This indicates the need for the related studies in the literature. This study aims to present the potential of hydroelectric, wind, solar and biomass sources of the TR83 Region which ensures the sustainability and security of the supply. Besides, it reduces the environmental pollution and greenhouse gas emission in the atmosphere.

The study demonstrates the present use of renewable energy sources in the TR83 Region, consisting of some cities of mid black sea region, also shows the potential of GHG emission reduction together with the present and estimated

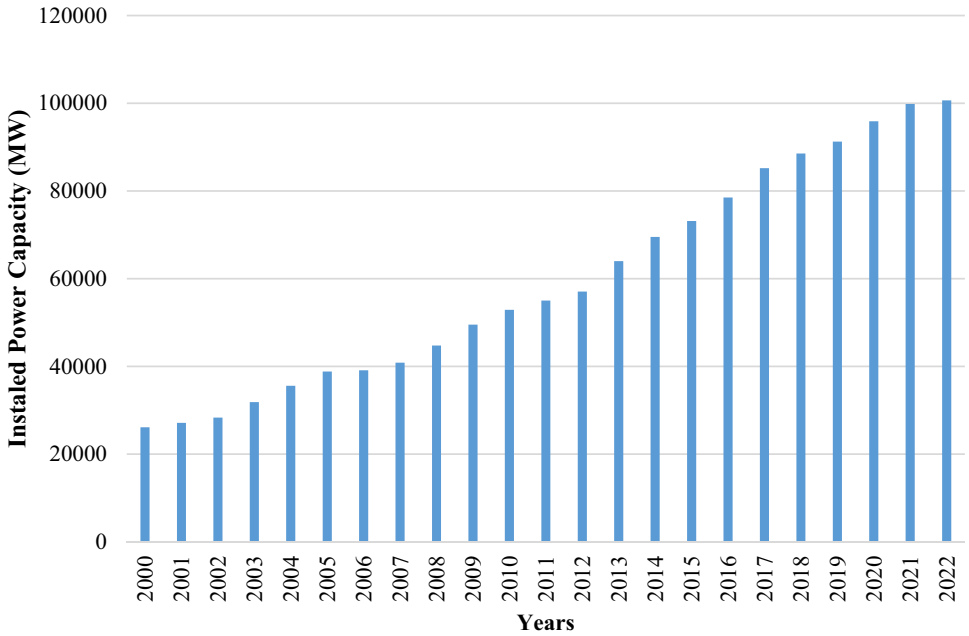

Fig. 1 Development of annual installed power capacity

Fig. 2 Provinces of TR83 Region

values. Furthermore, this study proposes to increase the public awareness about the usage of the current potential of the sources and encourage the investors to invest in the region.

Materials and methods

Türkiye's situation of renewable energy

Türkiye is a developing country whose electrical energy consumption is going up each day. Electricity consumption is expected to be 370 TWh in 2025 and 591 TWh in 2040 in the base scenario according to the Türkiye Electricity Demand Projection Report covering 2020–2040. The installed capacity of Türkiye was about 102.281 MW in September 2022. Türkiye has a variety of renewable energy source, that is why its renewable energy potential is rather high (Dursun and Aykut 2019; Dursun 2012). According to September 2022 data, the distribution of installed power by resources is as follows: 30.9% hydraulic, 24.7% natural gas, 20.6% coal, 10.9% wind, 8.8% solar, 1.6% geothermal and 2.4% other sources (MENR 2022a). The installed power according to the resources is shown in Fig. 3. As seen from the chart, hydro power has the highest share in the installed power capacity.

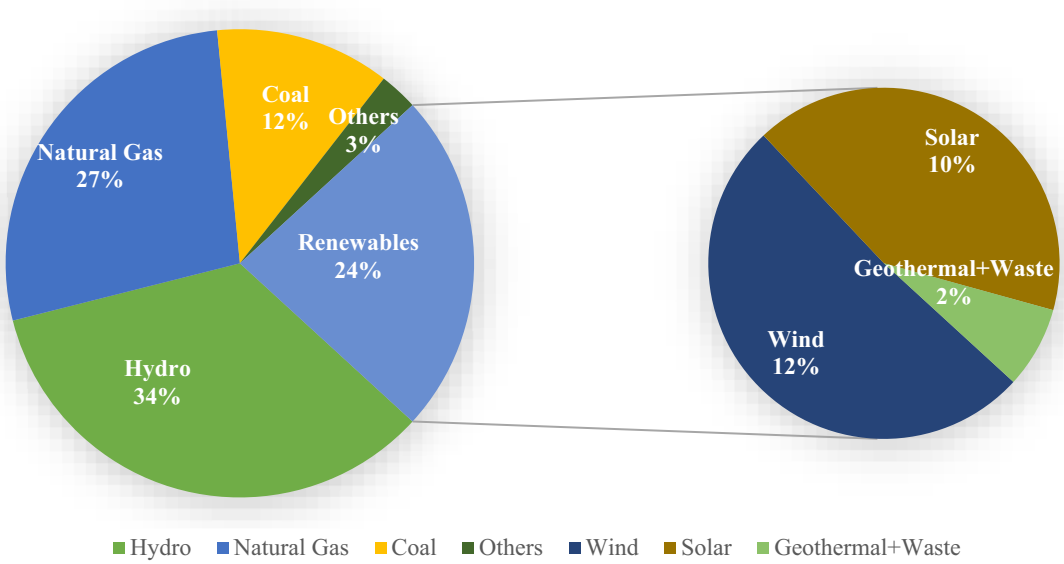

Fig. 3 Installed power according to the resources

Additionally, at the end of the September 2022, the number of electricity generation plants in our country has reached 11.142 (including unlicensed plants). The distribution of power plants according to the resources is as follows: 750 hydraulic, 67 coal, 357 wind, 63 geothermal, 345 natural gas, 9.071 solar and 489 other power plants (MENR 2022a).

Türkiye has a great potential of geothermal energy. The estimated potential of electrical energy production from geothermal sources is 4.500 MW. The installed capacity for geothermal based electrical energy production is 8.9 TWh in year 2020 (Dursun and Gokcol 2012; Melikoglu 2017a). Türkiye's Geothermal Potential Map is demonstrated in Fig. 4. West side of Turkey and also mid Anatolia has higher potential of geothermal energy.

The hydropower potential of Türkiye is 433 TWh which corresponds to the 1.1% of the total potential of the whole world whereas this potential is 13.75% within Europe. The economically usable amount of hydroelectric energy potential in Türkiye is about 130 TWh. Together with the new hydro power plants, being constructed now, the potential which is economically usable, is projected to be 43% throughout the country. Since hydropower energy is clean, renewable, less hazardous and domestic source, it is one of the most significant energy sources for Türkiye (Dursun and Gokcol 2011). Türkiye has been a member country of Kyoto protocol since 2009. The government aims to utilize all of the hydroelectric power potential of the before 2023 (MENR 2018). To achieve this, the energy sector is liberalized (Terzi 2021).

Moreover, it was stated in this plan that Türkiye would be using all the potential of 36GW hydroelectric power in 2023 (Melikoglu 2013, 2017b). According to the data of June 2018, 636 hydroelectric power plants (HEPP) with the installed capacity of 27.912 MW exist in Türkiye (Atalay and Yılmaz 2018). Moreover, as of June 2022, there are 730 hydropower plants making up 31,558 MW of the country's 100.000 MW generating capacity (Hydro 2022). Besides having high potential of hydropower, there is also significant amount of potential of solar energy in Türkiye, too (2005a, 2005b). According to the data received from Türkiye's Solar Energy Map (SEM), insolation time can be considered to be 2.741 h and yearly produced solar energy is totally 1.527 kWh/m^2 (Çeçen et al. 2022; Arslan and Terzioglu 2020).

Türkiye's Solar Potential Map is shown in Fig. 5. In addition, it is estimated that solar collectors occupy 20.2 km^2 surface area in 2018 (Seker and Kahraman 2021). Moreover, also in 2022, there is 8725 solar power plant whose capacity is 8335.9 MW in Türkiye. Solar power plants were used to produce totally 8335.9 GWh electrical energy, having no harmful emissions in May 2022 (Turkish Electricity Transmission Corporation 2022). Besides, south and southeast sections of Türkiye have a good amount of potential of solar energy (Balat 2005b). Recent regulations allow consumers also to sell the excessive electrical energy to the network, produced by roof top solar panels up to 10 kW within 10 years period. Besides, it is aimed to increase electricity production from rooftop solar panel by utilizing the roofs (Gorgulu 2019).

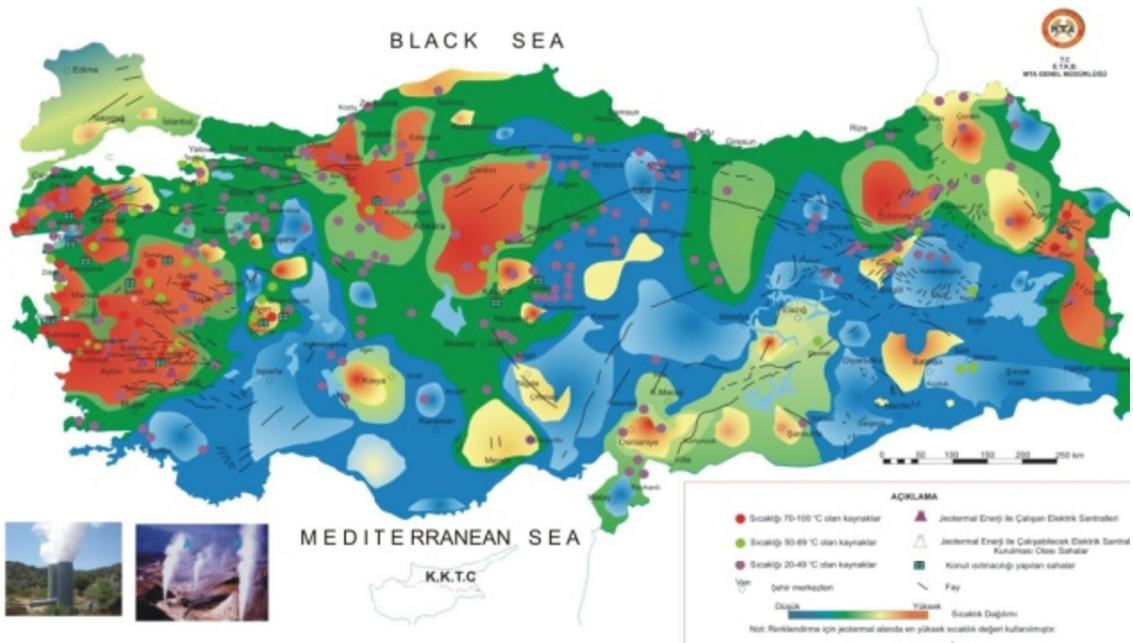

Fig. 4 Türkiye's geothermal potential map

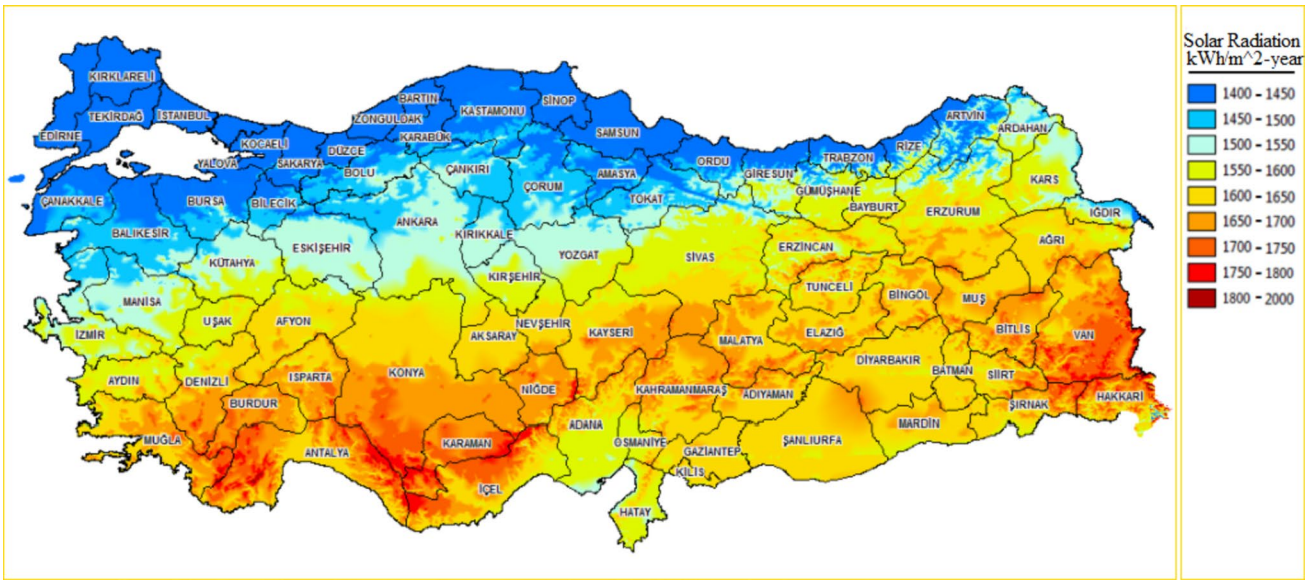

Fig. 5 Türkiye's solar potential map

Türkiye's overall installed wind plants capacity was 10.930.6 MW in May 2022 which stands for approximately 23% of the estimated potential. Besides, wind energy has a share of 11% of total electricity production in Türkiye in 2022 (Turkish Electricity Transmission Corporation 2022). Some locations of Türkiye are richer than other regions by means of wind speed. According to the data obtained from the Turkish National Committee of the World Energy Council, East Anatolia Region has 2.1 m/s wind speed and 13.19 W/m^2 density of wind power which is the lowest in Türkiye, while Marmara Region has 3.3 m/s wind speed and 52 W/m^2 density of wind power, which is the highest in Türkiye (Ilkiliç and Aydin 2015). The wind energy potential of Türkiye is estimated to be 48.000 MW (İlkiliç 2012; Dursun and Alboyaci 2010). Türkiye's overall installed wind plants capacity is demonstrated and is in Fig. 6. It can be seen that there is an exponential increase in installed capacity between the years 2000–2022.

Besides solar and wind energy, Türkiye also has a good amount of agricultural and livestock potential. Türkiye has also a significant potential of biomass. Since Türkiye also imports energy, domestic energy sources are crucial. Because of the limited fossil-based fuel sources, the efficient use of the sources and energy production is very important for Türkiye (Gokcol et al. 2009). That is why the renewable energy is getting more popular each day (Toklu 2017). In Türkiye biomass production is mainly based on wooden material, shells of nuts, wheat straw and fruit wastes (Melikoglu 2023). Türkiye's Biomass Potential Map is shown in Fig. 7.

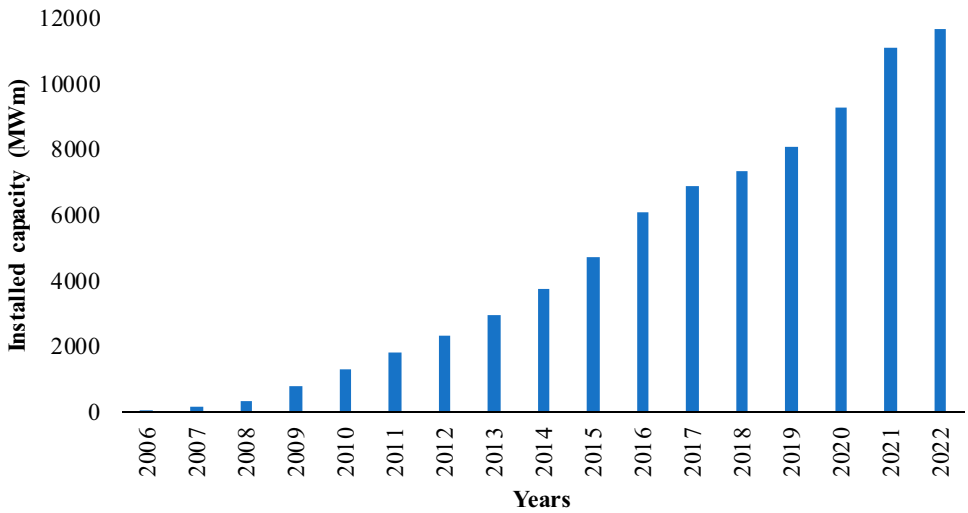

Fig. 6 Overall installed wind plants capacity of Türkiye

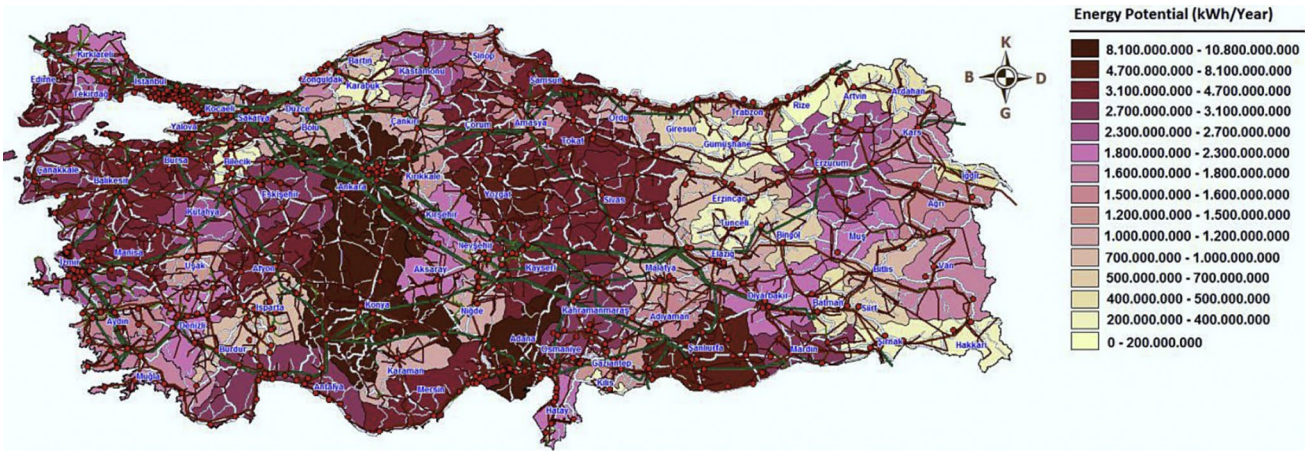

Fig. 7 Biomass potential map of Türkiye (Toklu 2017)

Even though the significance of renewable energy is known worldwide, because of technological and economic concepts, it is not widespread both in the world and in Türkiye. Biomass could be an option to meet energy for electrical energy generation, and household and industrial heating. Electrical energy generation from biomass depends on gasification and gas turbine technology with high efficiency. Nowadays, electrical energy can be produced by biomass, gasification and pyrolysis, and it is commercially available. An auxiliary use of biomass in steam power plants, also in some cases, can be possible (Toklu 2017). The annual biomass energy potential and installed biomass capacity is declared to be 372.000 GWh (Melikoglu 2023; Demirbas 2002) and the total energy to be recovered is determined to be nearly 197.000 GWh (Balat 2005b; Melikoglu 2023; Evrendilek and Ertekin 2003. There are more than 350 Biomass Energy Power Plants, using distinctive biomass sources such as vegetable waste, animal waste and biological wastes as fuel. The installed biomass energy in Türkiye was declared to be 1485 MW, and its percentage in total electrical energy generation was 1.8% in December 2020 (Bahadıroğlu et al. 2022).

Available renewable energy resources in TR83 region

TR83 Region includes the cities Samsun, Amasya, Tokat and Çorum. The land area of the region is 37.877 km^2 which stands for 5% of the total area of the country. Moreover, the region has a population of 2.739.400 which constitutes 3.7% of the country's population. The most crowded city is Samsun whose population is 1.250.000, and second one is Tokat with the population of 624.000. The next city is Çorum whose population is 624.000, and the least crowded city is Amasya with the population of 324.000. In TR83 Region, 27 pieces of small scale industrial areas and 16 pieces of organized industrial zones exist. There are also some specialized zones such as Food Organized Industrial zone and Fattening Organized Zone. In addition, in Samsun, there is a Free Zone which makes import and export easier. Therefore, it increases domestic and foreign investment to the region (Mbsda 2011). The highest potential of power source in the TR83 Region is determined as hydroelectric power according to the examination and the comparison of the energy sources (Balat 2005b).

Geothermal resources

There are many geothermal resources throughout the North Anatolia fault line in TR83 Region which is used for curing and treatment of some disease. There are some thermal springs in Samsun, Amasya, Çorum and Tokat (Mbsda 2011). At present, in Türkiye, instead of heat pumps, high temperature geothermal waters may be used for heating purposes (Balat 2006).

Hydropower resources

Another energy source used for the production of electricity in the region is hydroelectric power plants. Hydraulic and thermal energy production capacity is high in the region; therefore, energy is produced mostly from HEPPs (Mbsda 2011). In order to produce hydraulic-based electrical energy, rivers, lakes and dams have big significance. Kızılırmak and Yeşilırmak, two of the longest rivers pass through TR83 region which increases the hydroelectric potential. Besides, there are established hydroelectric power plants. Especially, these two rivers are suitable for hydroelectric power production. Rivers and lakes in TR83 region can be seen in table.

Wind resource

Wind-based electrical energy production is not efficient in the region since the wind potential is generally insufficient. Among the renewable energy sources, it can be seen that the wind energy potential is relatively lower in the Region. Assuming the required average wind speed is 6.5–7 m/s for the economical operation of the plant, Samsun has the highest energy potential in the region, but, anyway, it has still less potential than other cities of Türkiye. Yet, east and northeast side of central province of Amasya, North side of Suluova and Merzifon provinces, North and northwest side of Taşova province and northwest side of Gümüşhacıköy province exceed this wind speed limit. Therefore, it can be said that these regions are suitable for the investment of wind energy (Eroğlu et al. 2018; OKA 2012; MENR 2022b). Wind energy potential maps of the cities Amasya, Çorum, Samsun and Tokat are presented in Fig. 8, 9, 10, 11, respectively (Table 1).(Eroğlu et al. 2018)

Besides, other places having higher wind speed than 6.5–7 m/s are east side of central province of Çorum, southeast side of Alaca province, northwest side of Bayat province, south side of Boğazkale province, northwest side of İskilip province, north side of Kargı province, southeast side

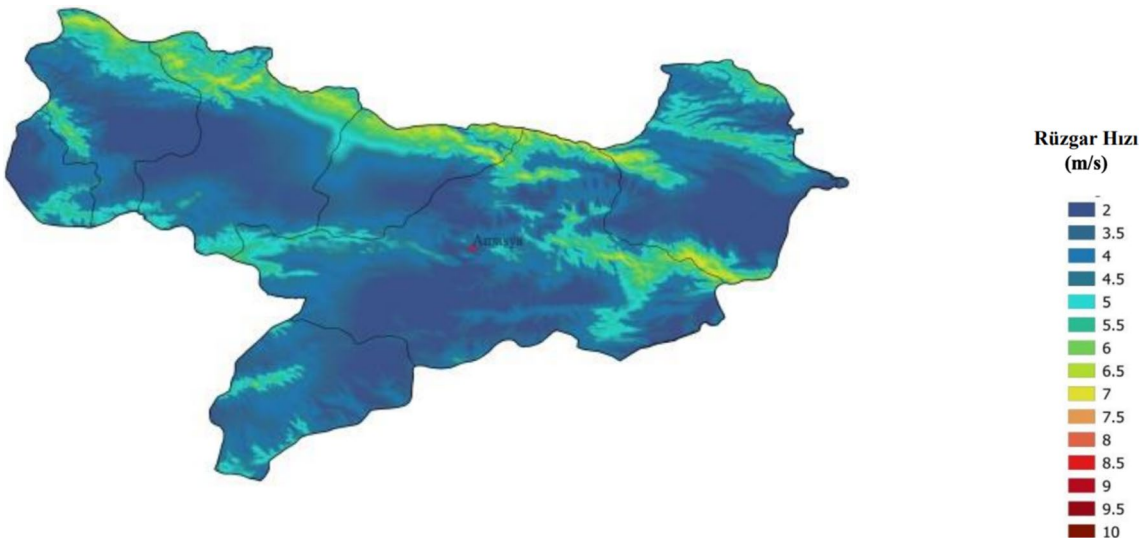

Fig. 8 Amasya wind energy potential map (MENR 2022b)

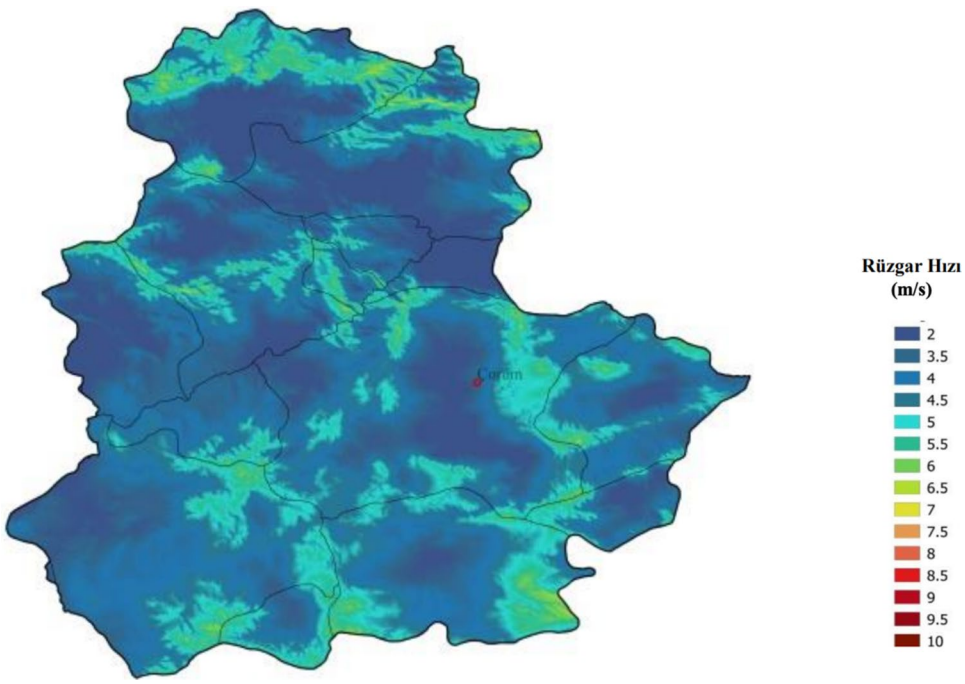

Fig. 9 Çorum wind energy potential map (MENR 2022c)

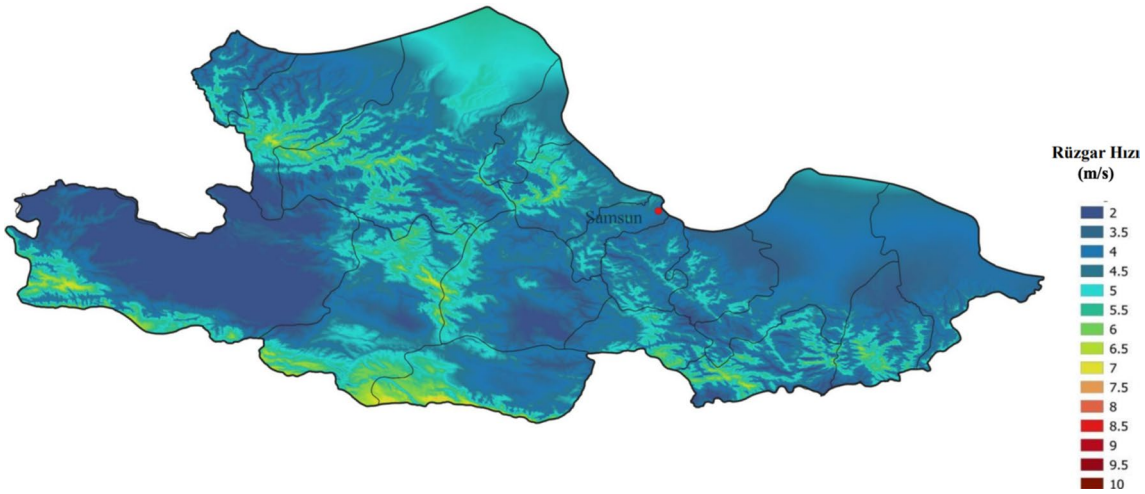

Fig. 10 Samsun wind energy potential map (MENR 2022d)

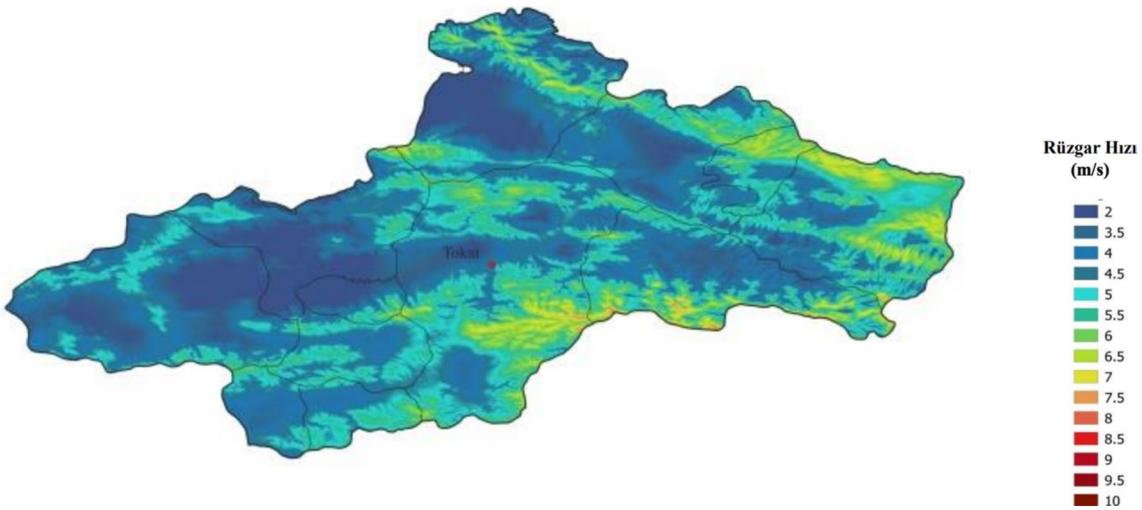

Fig. 11 Tokat wind energy potential map

Table 1 Rivers and lakes in TR83 region (Eroğlu et al. 2018)

Rivers/Stream		Lakes	
Budaközü river	Kelkit stream	Alaca dam lake	Kırgöz lake
Çat Water	Kızılırmak river	Almus dam lake	Ladik lake
Çekerek river	Kuruçay river	Altınkaya dam lake	Liman lake
Delice river	Mecitözü stream	Borabay lake	Obruk dam lake
Destek stream	Ovacık water	Çakmak dam lake	Simenit lake
Devrez stream	Terme stream	Derbent dam lake	Suat Uğurlu dam lake
Gökdere stream	Tersakan stream	Eymir lake	Uyuz lake
Hamamözü stream	Tozanlı river	Güllüköy lake	Zinav lake
Kavşak stream	Yeşilırmak river	Hasan Uğurlu dam lake	

of Sungurlu province, north side of Mecitözü, northeast side of Osmancık and middle side of Uğurludağ province (Eroğlu et al. 2018; OKA 2012; MENR 2022c).

In addition, north and west side of central province of Samsun, northeast and southwest side of Bafra, south side of Alacam, southwest of Vezirköprü, west side of Ladik, south side of Ayvacık and southeast of Salıpazarı have economically sufficient wind speed. Therefore, this region is also suitable for wind power investments (Eroğlu et al. 2018; OKA 2012; MENR 2022d).

Also, another side of TR83 region having high wind speed potential is southern side of central province of Tokat, South of Almus, north and south of Reşadiye, northeast of Niksar and Erbaa, northeast of Turhal, South of Pazar, North of Artova (Eroğlu et al. 2018; OKA 2012; MENR 2022e).

Solar resource

Since the Black Sea Region has the least insolation time throughout the country, energy production potential from solar sources is quite low. The insolation time and annual electrical energy production capacity per m^2 by means of solar panels with about18% efficiency for Amasya city's 7 provinces is presented in Table 2. It can be seen that the highest solar energy production potential and insolation time belongs to Göynücek province with 279.2 kWh/m^2, while average energy production of all provinces of Amasya is 273.67 kWh/m^2 (Eroğlu et al. 2018; OKA 2012).

Similarly, from Table 3, showing the same values for Çorum, it can be seen that Boğazkale has the highest solar energy production capacity with 287.1 kWh/m^2, while the average capacity is 278.16 kWh/m^2 for the provinces of Çorum (Eroğlu et al. 2018; OKA 2012).

According to Table 4, Ladik, Asarcık, Havza and Kavak Provinces of Samsun have the high solar electrical energy production potential. Among the provinces Ladik has the highest potential with 277.8 kWh/m^2, while the average production capacity of all provinces in the city is 265.47 kWh/m^2.

It is seen from Table 5 that even though the longest insolation time in Tokat city belongs to Sulusaray and Yeşilyurt provinces, maximum energy can be produced in Başçiftlik with 294.3 kWh/m^2 and Artova with 291.7 kWh/m^2, respectively. These provinces have more energy potential; therefore, more power can be produced here. Average power production of all provinces is 281.5 kWh/m^2.

Biomass and bioenergy resource

Bioenergy, which is classified into biodiesel, bioethanol and biogas, may be made up of living organisms and

Table 2 Solar-based electrical energy production Potential for the provinces of Amasya (Eroğlu et al. 2018; OKA 2012)

Province	Insolation time (hour/year)	Max power (W/m^2)	Optimum angle (°)	Total energy (kWh/m^2)	Max electrical production (kWh/m^2)
Hamamözü	2452	712,00	32,00	1525,70	274,60
Gümüşhacıköy	2422	716,00	32,00	1540,30	277,30
City center	2445	706,00	29,00	1481,90	266,70
Merzifon	2429	712,00	32,00	1536,70	276,60
Suluova	2421	702,00	32,00	1511,10	271,90
Göynücek	2486	693,00	32,00	1551,30	279,20
Taşova	2383	692,00	32,00	1496,50	269,40

Table 3 Solar-based electrical energy production potential for the provinces of Çorum (Eroğlu et al. 2018; OKA 2012)

Province	Insolation Time (hour/year)	Max power (W/m^2)	Optimum angle (°)	Total energy (kWh/m^2)	Max electrical production (kWh/m^2)
Alaca	2601	734,00	32,00	1587,80	285,80
Bayat	2525	721,00	32,00	1529,40	275,30
Boğazkale	2620	741,00	32,00	1595,10	287,10
Dodurga	2451	712,00	32,00	1511,10	274,60
İskilip	2486	729,00	32,00	1565,90	279,20
Kargı	2416	706,00	32,00	1507,50	271,30
Laçin	2452	713,00	31,00	1511,10	271,90
City center	2520	722,00	32,00	1551,30	279,20
Mecitözü	2497	719,00	32,00	1551,30	279,20
Oğuzlar	2460	719,00	31,00	15,289,40	275,30

their derivatives. Bioethanol can be obtained from corn, sugar beet and wheat and found in the region in significant amount. In order to determine the potential of biomass energy, the quantity of animal feces and waste, vegetable waste, and organic waste is significant. In Table 6, animal, vegetable, organic and urban waste belonging to Amasya, Çorum, Tokat and Samsun is presented.

It can be inferred from Table 6 that Samsun has the highest biomass-based energy potential among the other TR83 cities. In Samsun, animal, vegetables and urban waste quantity and total energy equivalent is higher than other cities which is followed by Tokat, Çorum and Amasya, respectively. In this region, sugar beet, corn and wheat are grown in a share of 8.2%, 3.24% and 9.7% in sequence among the

Table 4 Solar-based electrical energy production potential for the provinces of Samsun (Eroğlu et al. 2018; OKA 2012)

Province	Insolation time (hour/year)	Max power (W/m^2)	Optimum angle (°)	Total energy (kWh/m^2)	Max electrical production (kWh/m^2)
Alaçam	2295	679,00	32,00	1449,10	260,80
Asarcık	2343	705,00	32,00	1522,10	273,90
Ayvacık	2306	684,00	31,00	1449,10	260,80
Bafra	2314	681,00	32,00	1452,70	261,50
Çarşamba	2274	681,00	32,00	1460,00	262,80
Havza	2372	705,00	32,00	1511,10	271,90
Kavak	2342	698,00	32,00	1500,20	270,00
Ladik	2355	717,00	32,00	1540,30	277,80
City center	2288	681,00	32,00	1464,80	263,70
Ondokuzmayıs	2268	679,00	32,00	1452,70	261,50
Salıpazarı	2278	685,00	31,00	1463,70	263,50
Terme	2256	682,00	32,00	1463,70	263,50
Vezirköprü	2364	691,00	32,00	1474,60	265,40
Yakakent	2270	678,00	32,00	1441,80	259,50

Table 5 Solar-based electrical energy production potential for the provinces of Tokat (Eroğlu et al. 2018; OKA 2012)

Province	Insolation time (hour/year)	Max power (W/m^2)	Optimum angle (°)	Total energy (kWh/m^2)	Max electrical production (kWh/m^2)
Almus	2460	726,00	32,00	1587,80	285,80
Artova	2562	740,00	32,00	1620,60	291,70
Başçiftlik	2385	745,00	32,00	1635,20	294,30
Erbaa	2381	692,00	32,00	1489,20	268,10
City center	2507	714,00	31,00	1525,70	274,60
Niksar	2387	700,00	31,00	1489,20	268,10
Pazar	2520	710,00	32,00	1533,00	275,90
Reşadiye	2372	723,00	32,00	1569,50	282,50
Sulusaray	2603	735,00	32,00	1609,70	289,70
Turhal	2491	708,00	32,00	1533,00	275,90
Yeşilyurt	2602	736,00	32,00	1609,70	289,70
Zile	2545	719,00	32,00	1565,90	281,90

Table 6 Biomass energy potential of the cities in TR83 region

Cities	Animal waste quantity (ton/year)	Vegetable waste quantity (ton/year)	Urban waste quantity (ton/year)	Total energy equivalent of the waste (TEP/year)
Amasya	1.460.547,97	1.694.546,64	105.869,97	208.052,56
Çorum	2.380.071,93	1.801.673,99	174.096,79	235.708,00
Tokat	2.074.313,18	2.188.869,19	201.695,72	279.224,29
Samsun	3.379.355,07	3.262.869,24	429.465,82	415.851,66

countrywide. Similarly, also, 21% of soybean, 4.52% of sunflower, and 1.45% of reap are produced in the region, which are used to produce biofuel. In Çorum, winged animal husbandry is widespread, so the region has also high potential of biogas from animal waste (Mbsda 2011).

Results and discussion

Electrical energy production in TR83 region

Industrial sector has the highest electrical energy consumption compared to other ones. Industrial electrical energy consumption is 38% of total electrical energy consumption in the region. Similarly, electrical energy consumption in household use is 33%. In Türkiye, Industrial consumption is 46% and household consumption is 24% (Mbsda 2011). In this region, there are a lot of different energy resources. Some of them are conventional power generating systems that it produces electricity from coal, lignite, etc. The rest of them are renewable power generating systems.

Nonrenewable power plants in TR 83 region

Power generation plants from conventional energy sources region also exist in TR 83 region which can be seen in Table 7. The number of power plants producing energy by using fossil-based fuel is very little compared with other regions of Türkiye. Samsun, having more industrial area in the region, thus having more energy consumption, has the highest share of conventional-based installed power. The conventional-based power production of other cities in the region is neglectable compared with Samsun. Amasya has an installed power capacity from conventional sources of 7.76 MW, and Çorum has 7.22 MW, Tokat has 14 MW, while Samsun has 1766.75 MW.

Besides, Amasya Suluova Thermal Power Plant, being under construction now, with 270 MW installed power capacity, is planned to be operated in near future. With the addition of this power plant, conventional energy capacity in TR83 region will reach 2065.73 MW.

Renewable power plants in TR83 region

TR83 region has plenty of power plants producing energy from renewable sources. In this section, renewable energy power plants and their installed capacities in the region are evaluated in terms of the cities.

In Amasya, the installed power of electric plants is 330.03 MWe. There are 20 power plants in Amasya, producing 775 GWh energy. These power plants and their specifications can be seen in Table 8 (Atlas et al. 2022). Also, in Amasya, 134.81 MW of the installed power is achieved by hydroelectric power plant, while 126 MW is produced by wind energy power plant, 36.67 MW is obtained by solar energy power plant, and lastly, 3.84 MW is produced by biomass energy power plant. With this production quantity, 94% of the energy consumption of Amasya is met by these power plants (Atlas et al. 2022).

Moreover, in Amasya, there are 7 renewable energy power plants with 46.51 MW total installed power capacity, planned to be operated within 3 years. The Renewable Power Plants under Construction in Amasya are presented in Table 9.

With the addition of these 7 power plants, the renewable energy installed power capacity in Amasya will be 376.54 MW.

In Çorum, the installed power of electric power is 511 MWe. With the 13 electric power plant in Çorum, 919 GWh electrical production is achieved annually. These power plants produce 79% of the electrical energy consumption of the city. These power plants and their specifications can be seen in Table 10 (Atlas 2022c).

In addition, in Çorum, there are 6 renewable energy power plants with 81.38 MW total installed power capacity, planned to be operated in the near future. The Renewable Power Plants under Construction in Çorum are presented in Table 11.

With the addition of these 6 power plants, the renewable energy installed power capacity in Çorum will be 592.38 MW.

Similarly, the installed power of electrical production plants of Samsun is 3.245 MW and with the 22 power plants in the city 10.645 GWh electrical energy is

Table 7 Installed capacity of Nonrenewable power plants in TR83(Atlas et al. 2022; Atlas 2022a, 2022b, 2022c)

City	Power plant	Company	Capacity (MW)
Amasya	Amasya Şeker Thermal Power Plant	Amasya Şeker A.Ş	7,76
Çorum	Hayat Kağıt Thermal Power Plant	Çorum Hayat Kağıt	7,22
Samsun	Cengiz Enerji Samsun Thermal Power Plant	Cengiz Energy	610
	Samsun OSB DGKÇS	Yeşilyurt Energy Company	234
	Samsun Natural Gas Power Plant	Bilgin Energy Company	887
	Toros Tarım Waste Heat Plant	Toros Tarım	31
	Çarşamba Şeker Thermal Power Plant	Türkiye Sugar Factories	4,75
Tokat	Turhal Şeker Thermal Power Plant	Kayseri Sugar Company	14

Table 8 Power plants and its installed capacity in Amasya (Atlas et al. 2022; Atlas 2022a, 2022b, 2022c)

Plant name	Company	Power (MW)
Midilli HEPP	Masat Energy	33
Amasya Kale HEPP	Rönesans Energy	29
Yaprak HEPP	Boydak Energy	24
Yavuz HEPP	Masat Energy	23
Umutlu HEPP	Ağaoğlu Energy	20
Duru HEPP	Merge Energy	10
Osmancık HEPP	Rönesans Energy	9,02
Çarıklı HEPP	Delta Yatırım Holding	8,96
Bektemur HEPP	Diz-Ep Electric Generation Co	3,49
Taşova–Yenidereköy HEPP	Hameka Hydropower Generation Co	1,98
Durucasu HEPP	Met Duru Energy	1,07
Kayadüzü WEPP	Tokat Energy	75
Amasya WEPP	Mina Group	42
Arzu WEPP	Hırka Energy	9
Tekman Metal SEPP	Tekman Metal	0,25
Timay Tempo SEPP	Timay Tempo Co	0,22
Amasya University SEPP	Amasya University	0,20
Unlicenced SEPPs	Different Companies	36
Amasya BEPP	EYD Energy	1,84
Sigma Suluova BEPP	Sigma Electric Generation	2

Table 9 Renewable power plants under construction in Amasya (Atlas et al. 2022; Atlas 2022a, 2022b, 2022c)

Plant name	Corporation	Power (MW)
Karayel 1 HEPP	Hameka Hydroelectric Energy	12
Karayel HEPP	Hameka Hydroelectric Energy	9,91
Muzaffer ve Hüseyin Polat Amasya WEPP	Muzaffer ve Hüseyin Polat	1,70
Amasya Şeker WEPP	Amasya Şeker	1
Amasya İl Özel İdaresi WEPP	Amasya İl Özel İdaresi	0,90
Taşova WEPP	Ekores Energy	11
Amasya SEPP	Akfen Energy	10

Table 10 Power plants and its installed capacity in Corum (Atlas et al. 2022; Atlas 2022a, 2022b, 2022c)

Plant name	Corporation	Power (MW)
Obruk Dam and HEPP	EUAS	211
Kargı Kızılırmak HEPP	Statkraft	102
Ülkün HEPP	Turka Otelcilik	24
Pirinçli HEPP	Derya Electric Generation	19
İncesu HEPP	Aksa Energy	15
Yüksek Yayla WEPP	Yüksek Yayla WEPP	0,25
Menderes Boynuuzun SEPP	Menderes Boynuuzun	1
Tekin Karo SEPP	Tekin Karo SEPP	0,48
Çorum OSB SEPP	Çorum OSB	0,25
Çorum TSO SEPP	Çorum TSO	0,23
Çorum Best Oil SEPP	Çorum Best Oil	0,26
Unlicenced SEPPs	Different Companies	127
Çorum Mecitözü BEPP	Oltan ve Kölenoğlu Electric	5

Table 11 Renewable power plants under construction in Çorum (Atlas et al. 2022; Atlas 2022a, 2022b, 2022c)

Plant name	Corporation	Power (MW)
Topaz WEPP	RES Anatolia Holding	65
Atılgan ve Mays SEPP	Atılgan ve Mays SEPP	6,09
Özdemir Kılıç SEPP	Özdemir Kılıç	4,76
Sunerji SEPP	Sunerji Con	3,92
Uğurludağ Municipality SEPP	Uğurludağ Municipality	0,87
Amazon SEPP	Amazon Con	0,74

produced annually. This production quantity is 2.34 times of overall consumption quantity of Samsun. These power plants and their specifications can be seen in Table 12 (Atlas 2022b).

Furthermore, in Samsun, there are 3 renewable energy power plants with 18.10 MW total installed power capacity, planned to be operated in the near future. The

Renewable Power Plants under Construction in Samsun are presented in Table 13.

With the addition of these 3 power plants, the renewable energy installed power capacity in Samsun will reach 3263.10 MW.

Lastly, the installed power of the electrical production plants of Tokat is 706 MW and with the 24 power plants in the city, 1420 GWh of electrical energy is produced annually. This production quantity is 1.22 times of overall consumption quantity of Tokat. These power plants and their specifications can be seen in Table 14 (Atlas 2022a).

Lastly, in Tokat, there are 6 renewable energy power plants with 70.02 MW total installed power capacity, planned to be operated in the near future. The Renewable Power Plants under Construction in Tokat can be seen in Table 15.

With the addition of these 6 power plants, the renewable energy installed power capacity in Tokat will reach 776.02 MW.

Table 13 Renewable power plants under construction in Samsun (Atlas et al. 2022; Atlas 2022a, 2022b, 2022c)

Plant name	Corporation	Power (MW)
Beşpınar HEPP	Beşpınar HEPP	5,10
Çorum Municipality Ladik WEPP	Çorum Municipality	4
Polat -2 WEPP	Hırka Wind Power Plant	9

Electrical energy consumption in TR83 region

According to the data obtained from Turkstat in 2021, nearly 3.9% of the electrical energy is consumed in TR83 Region. Energy consumption, surface area and population data can be found in Table 16.

The electrical energy consumption is 824.47 GWh in Amasya. 94% of this consumption can be met by the power plants of Amasya and the remaining 6% of the consumption is met by the national electrical network in order to use uninterrupted, continuous and safe energy. Similarly, the electrical energy consumption is 1225.34 GWh in Çorum. 63% of which can be supplied by the power plants of Çorum and the remaining 37% of the consumption is supplied by the national electrical network. Moreover, the electrical energy consumption is 4549.15 GWh in Samsun. 1.92 times of the consumption can be produced by the power plants of Samsun. The power plants in Samsun not only meet the consumption in the city uninterruptedly, continuously, and safely but also transfer the excess energy to the national electrical network. Contrary to Amasya and Çorum, Samsun can meet its own energy demand and transfer the remaining energy to the national network. Lastly, the electrical energy consumption is 1163.94 GWh in Tokat. 1.22 times of which can be produced by the power plants of Tokat. The power plants in Tokat not only meet the consumption in the city uninterruptedly, continuously, and safely but also transfer the excess energy to the national electrical network. In other words, Tokat can meet its own energy demand and transfer the remaining energy to the national network similar to Samsun (Atlas et al. 2022; Atlas 2022a, b, c).

Potential reduction in CO_2 emissions

The existence of CO_2 emissions in the atmosphere in higher amounts causes global warming and climate change. Therefore, the reduction in CO_2 emissions is vital for the countries

Table 12 Power plants and its installed capacity in Samsun (Atlas et al. 2022; Atlas 2022a, 2022b, 2022c)

Plant Name	Corporation	Power (MW)
Altınkaya Dam and HEPP	EUAS	703
Derbent Dam and HEPP	EUAS	56
Duru HEPP	Ceyduru Electric	22
Kumköy HEPP	Koç Holding	17
Çarşamba HEPP	Çarşamba Energy Electric	11
Kuyma HEPP	Kuyma Electric	9,73
Suat Uğurlu Dam and HEPP	EUAS	69
Generji HEPP	Generji HEPP	4,47
Hasan Uğurlu Dam and HEPP	EUAS	500
Ladik Büyükkızoğlu HEPP	Met Duru Energy	0,40
Havza WEPP	Ekim Electric and Engineering	48
Ütopya Enerji Urla SEPP	Ütopya Energy	1
Resman Cam SEPP	Resman Glass	0,49
Samulaş SEPP	Samsun Municipality	0,24
Lisanssız GESs	Different Companies	25
Avdan Biogas Power Plant	Avdan Energy	8,40
ITC-Ka Samsun Çarşamba BEPP	ITC-Ka Energy	1,42

Table 14 Power plants and its installed capacity in Tokat (Atlas et al. 2022; Atlas 2022a, 2022b, 2022c)

Plant name	Corporation	Power (MW)
Akıncı HEPP	Aydem Energy	99
Köklüce HEPP	Gülsan Holding	90
Tepekışla Dam and HEPP	Sanko Energy	70
Reşadiye HEPP	Energo Pro	64
Niksar HEPP	IC İçtaş Energy	40
Tuna HEPP	Boydak Energy	37
Almus Dam and HEPP	Gülsan Holding	27
Tokat Çamlıca HEPP	Hidrogüç Energy Elect. Generation	23
Onur HEPP	Temmuz Elect. Generation	20
Omala Dam and HEPP	Adsel Elektrik Energy	16
Yeşilırmak 1 HEPP	Üründül Energy	14
Tokat Suçatı HEPP	Artı Değer Energy	8,32
Çilehane HEPP	NKD Elektrik Energy	7,20
Karakeçili 1 HEPP	Hatko Energy	6,95
Delice 1 HEPP	Energy 2023	6,66
Yeşilırmak 2 HEPP	Üründül Energy	6,24
Ataköy Dam and HEPP	Zorlu Energy	5,53
Killik WEPP	Eksim Energy	85
Bereketli WEPP	Kinesis Energy	30
Akyurt WEPP	Ado Energy Generation	13
Tokat OSB Yalçın WEPP	Tokat Governor	0,10
Unlicensed SEPP	Different Companies	20
Tokat Çöpgazı BEPP	Tokat Municipality	2,30

Table 15 Renewable power plants under construction in Samsun (Atlas et al. 2022; Atlas 2022a, 2022b, 2022c)

Plant name	Corporation	Power (MW)
Erbaa HEPP	Erbaa HEPP	47
Kutay Reg. and HEPP	ARC Elektromek. Energy Con	7,48
Turhal Dam and HEPP	EÜAŞ	5,36
Zinav HEPP	Zinav HEPP	4,18
Reşadiye Governorship WEPP	Reşadiye Governorship	1
Akfen Enerji Tokat SEPP	Akfen Energy	5

Table 16 Energy consumption, surface area and population data (Anonymous 2011; Mbsda 2011; OKA 2012)

City	Area (km^2)	Population	Energy consumption (kTOE/year)
Amasya	5520	324,000	11,957
Çorum	12,820	540,000	8,581
Samsun	9,579	1,250,000	26,584
Tokat	9,958	624,000	12,765
TR83 Region Total	37,877	2,739,400	59,887

and Türkiye. The emission is also caused by nonrenewable energy production plants (Rehman et al. 2023; Ozturk and Acaravci 2010). In this section, scenario-based 3 situations concerned with the reduction in CO_2 emission in TR83 region are evaluated.

According to the first scenario, all of the energy consumption is assumed to be met by conventional sources and the emission is calculated according to this situation. In the second scenario, it is assumed that all of the energy consumption is met by renewable sources. And in the last scenario, the emission will be calculated by concerning the current energy consumption according to the distinct renewable and nonrenewable sources. The calculated amounts of CO_2 emissions for the scenarios are presented in Table 17.

According to Table 17, In the current situation, the CO_2 emission in Samsun and Tokat is negligible. Çorum has the highest CO_2 emission in the region followed by Amasya.

Table 17 Scenarios for CO_2 emissions in TR83 region (RenSmart. 2023)

City	Scenerio-1 kton/year	Scenerio-2 kton/year	Scenerio-3 kton/year	Renewable fraction %
Amasya	192,216	0	11,536	94%
Çorum	285,596	0	71,340	79%
Samsun	1060,588	0	0	100%
Tokat	271,360	0	0	100%

Conclusion

To evaluate TR83 region by means of renewable energy sources potential. Firstly, it can be said that wind-based electrical energy production is not efficient since the wind potential is generally insufficient in the region. Secondly, there are many geothermal resources throughout the North Anatolia fault line in the Region. There are some thermal springs in Samsun, Amasya, Çorum and Tokat. So, even if the geothermal energy potential of the region is not sufficient for electrical production, it is sufficient for thermal tourism. Also, hydro and thermal energy production capacities are high in TR83 region; therefore, energy is produced mostly from HEPPs. Moreover, energy production potential from solar sources is quite low since the Black Sea Region has the least insolation time throughout the country. Lastly, the biomass energy potential of the region can also be considered as sufficient.

To summarize the use of renewable energy sources particular to the cities, it can be said that there are 8 conventional source-based energy production plants in TR83 region. Total installed power according to the cities is evaluated to be 7.76 MW for Amasya, 7.22 MW for Çorum, 14 MW for Tokat and 1766.75 MW for Samsun. Taking the Amasya Suluova Thermal power plant, being under construction, into account, the total installed capacity of TR83 will reach 2065.73 MW.

Furthermore, the installed power of renewable electric plants of Amasya is 330.03 Mwe. There are 20 power plants in Amasya, producing 775 GWh energy. In Amasya, 134.81 MW of the installed power is achieved by hydroelectric power plant, while 126 MW is produced by wind energy power plant, 36.67 MW is obtained by solar energy power plant, and lastly, 3.84 MW is produced by biomass energy power plant. With this production quantity, 94% of the energy consumption of Amasya is met by these renewable power plants.

Moreover, in Çorum, the installed power of electric power is 511 MWe. With the 13 electric power plant in Çorum, 919 GWh electrical production is achieved annually. These power plants produce 79% of the electrical energy consumption of the city. When the 6 renewable energy power plants with 81.38 MW, being still under construction, starts to operate, the installed power capacity of the region will reach 592.38 MW.

Similarly, the installed power of electrical production plants of Samsun is 3.245 MW and with the 22 power plants in the city 10.645 GWh electrical energy is produced annually. This production quantity is 2.34 times of overall consumption quantity of Samsun. When the 3 renewable energy power plants with 18.10 MW, being still under construction, starts to operate, the installed power capacity of the region will reach 3263.10 MW. Also, Samsun has the highest biomass-based energy potential among the other TR83 cities. In Samsun, animal, vegetables and urban waste quantity and total energy equivalent is higher than other cities which is followed by Tokat, Çorum and Amasya, respectively.

Furthermore, the installed power of electrical production plants of Tokat is 706 MW and with the 24 power plants in the city 1420 GWh electrical energy is produced annually. This production quantity is 1.22 times of overall consumption quantity of Tokat. After the 6 renewable energy power plants with 70.02 MW, being still under construction, starts to operate, the installed power capacity of the region will reach 776.02 MW.

About the CO_2 emission caused by the power plants in TR83 region, it can be said that the CO_2 emission in Samsun and Tokat is neglectable, Çorum has the highest CO_2 emission in the region followed by Amasya.

Declarations

Conflict of interest The authors declare no conflict of interest.

Ethical approval This article does not contain any studies on human participants or animals performed by any authors.

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