

Prediction of the solar photovoltaic potential for electricity generation in Turkey

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Abstract

Global warming, environmental pollution and energy crises lead researchers to obtain energy in a cheap and clean way. Solar energy, which is one of the renewable energy sources, has gained great importance in the developed countries in terms of having almost no adverse impact to the environment. In addition to providing a significant part of the world's energy needs, solar energy does not consume natural resources and does not cause gas emissions such as CO₂ to the air. Solar energy technologies offer a clean, renewable and domestic energy source, and are essential components of a sustainable energy in the future. Proper and adequate information on solar radiation and its components at a given location is very essential in the design of solar energy systems. Due to Turkey's location, solar energy potential is abundantly available. Consequently, it is worth to examine and conduct research on the solar energy source. The aim of this study is to predict the solar power capacity for electricity generation by using Geographically Weighted Regression (GWR) analysis method. According to model result, the southern and southeast regions of Turkey has over 1600 kWh/m².yr radiation potential and is considered as optimum surface area for the solar PV installation. This study also shows that there is a lot of solar energy potential in Turkey for solar thermal heating/cooling, solar PV and solar CSP for electricity generation.

Keywords: solar energy, solar radiation, geographically weighted regression

1. Introduction

Worldwide interest has been focused on the development of technologies using new and renewable sources of energy like biomass, geothermal, solar power, wind, and hydropower since the 1970s oil price crisis. Only ten years ago, renewable energy technologies used to address a rather sophisticated field, embodied around the objective of mitigation of conventional fuels so as to

combat climate change and create environmentally conscious energy generation [1]. Nowadays, renewable energy technologies are considered to be among the most applicable and fundamental solutions in order to provide environmental and economic sustainability and compensate for the global energy demand. Figure 1 shows net electricity generation of the world from renewable power [2].

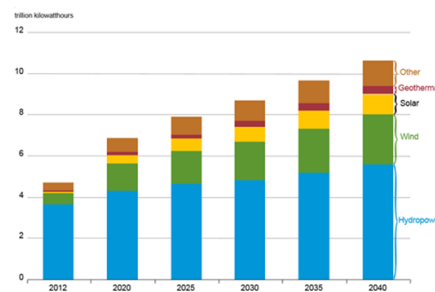


Figure 1. Net electricity generation of the world from renewable power.

Since the last decade, unlike other renewable energy resources, solar energy is no longer a niche market and is developing to become one of the main resources in electricity production. By the end of 2014, the photovoltaic power capacity reached 177

GW worldwide. By 2015, the projections indicate 55 GW of capacity addition, and by 2020, total installed capacity is expected to reach 500 GW. In this context, this report aims to reveal the current outlook of solar energy in the world and in Turkey to offer an

insight into Turkey’s future in the field, and contribute to the discussions under this topic in line with global developments, as solar energy is defined as the prominent energy resource of the future [3, 4].

According to the Solar-Power Europe’s Medium Scenario also envisages that global solar demand could grow by 12% year on year to 144 GW in 2020. In the following three years, new additions could reach 158 GW (+10%), 169 GW (+7%), and 180 GW (+6%), respectively. If those numbers are achieved, the world’s cumulative installed PV capacity would increase from around 600 GW at the end of this year to 900 GW in 2021, 1.1 TW in 2022 and about 1.3 TW by the end of 2023 [5-8].

China’s installed solar power is expected to increase by another 273 GW to 448 GW by 2023. India, which may become the world’s third-largest market by the end of the 2019-2023 period, could reach 116 GW, with new additions hitting 89 GW [9]. On the other hand, the U.S. market is forecast to add 70 GW over the next five years to bring its cumulative solar capacity to 116 GW, which would make it as the world’s second-largest PV market [10]. Japan will remain one of the world’s largest markets by 2023, with an expected cumulative capacity of 82.3 GW, but new deployments for the 2019-2023 periods will only reach roughly 26.5 GW [11-14]. Figure 2 shows total solar PV cumulative installed capacity by top ten countries in 2018.

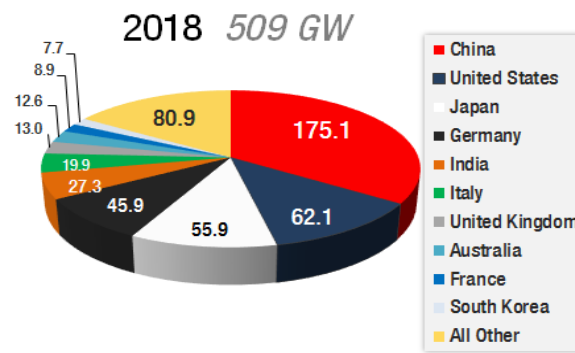


Figure 2. Total cumulative installed solar PV capacity by top ten country in 2018.

It is possible to assert that Turkey has the largest potential for solar power in Europe. Turkey has the technical potential to generate almost 190 TWh/year of solar electricity is 29% more than the second-placed Spain, and enough to meet almost 75% of Turkey’s current electricity demand [12, 13]. This potential suggests that 75% of Turkey’s current electricity demand can be met with solar electricity [14]. The developments in the PV markets in several

European countries, mainly Italy, Greece and Spain, suggest that if and when favorable conditions for solar energy installations are met, Turkey would be taking off in the market. To get there, initially the market needs to become livelier with potential installations of over 1.0 GW annually. Figure 3 shows global installed solar market capacity (GW) [10-14].

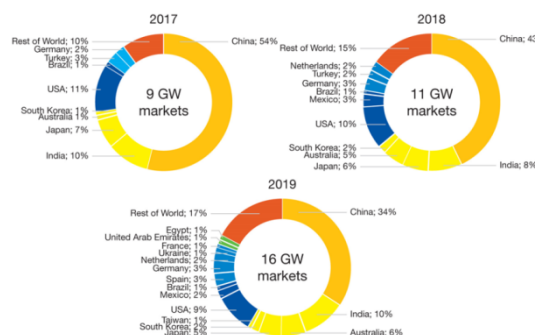


Figure 3. Global installed solar market capacity (GW).

In 2017, Turkey had 163 MW of PV power generation capacity installed. This figure represents a sharp increase over the 25 MW of installed capacity

just a year earlier. Even among nations with similar irradiance, such as Greece, Romania and Bulgaria, Turkey lags behind. When compared to other rapidly

growing medium-sized economies such as South Korea, South Africa and Mexico, even if the gap in installed PV capacity is narrowing down, Turkey still

features only at the bottom of the list as shown in Table 1.

Table 1. Global top solar market's prospects.

Country	2018 Total Capacity (MW)	2023 Total Capacity Medium Scenario by 2023 (MW)	2019-2023 New Capacity (MW)
China	176 143	465 234	273 246
India	27 348	116 124	88 760
United States	67 146	132 436	72 346
Australia	12 568	45 242	32 678
Germany	45 920	72 626	26 793
Japan	55 851	82 351	26 500
Spain	5 924	25 368	19 462
South Korea	7 768	24 786	17 124
Netherlands	4 196	20 132	15 878
Mexico	3 580	19 060	15 464
France	8 964	22 360	13 426
Saudi Arabia	36	11 564	11 422
Brazil	2 368	12 510	10 220
Italy	19 896	29 520	9 630
Taiwan	2 864	12 164	9 464
Pakistan	1 764	8 396	6 680
Ukraine	2 124	7 964	6 024
Turkey	5 096	10 986	5 768
Egypt	676	6 478	5 986

Rooftop solar systems, the typical application for projects smaller than 50 kW, follow a completely different economic structure from utility-scale PV. This is due to the fact that they compete directly with retail electricity prices, rather than with other power generation technologies. Rooftop solar projects under 50 kW are rarely seen in Turkey at the moment, as potential developers have been put off by reportedly as many as 35 to 50 different permits that need to be obtained [5]. However, financial returns of rooftop projects, implemented in accordance with the current legal framework, will stay far lower than, for instance, in Germany, where utility-scale PV generation costs more than twice as much as in Turkey. On the other hand, it is expected that PV cost reductions will make rooftop solar systems more

attractive by 2020. Still, the relatively limited availability of residential rooftop space is likely to keep a lid on the progress of rooftop solar systems in Turkey [5, 17, 18]. From the middle of the next decade, solar is likely to be competitive with other generation technologies, in particular coal and gas. Turkey's total installed solar capacity is expected to rise to more than 17 GW by 2030 [5]. As such, it will make up almost a third of capacity additions in Turkey's power sector over 2021-30, with the remainder being mainly coal and nuclear. For 2040, we project solar capacity to rise further to more than 40 GW, to represent just less than 30% of the total installed capacity [19-22].

2. Solar radiation calculation methods

Geographically Weighted Regression (GWR) and ordinary-kriging methods were applied in the modeling of radiation. The GWR is the multi-faceted approach to the analysis of spatial data. GWR opens a window through the data set to calculate local r^2 . On the other hand, the Co-kriging is an extension of ordinary-kriging method which takes into account the spatial cross-validation between two or more data [2]. In the modeling of spatial interpolation of radiation data, aspect, latitude, relative humidity and cloudiness were used as secondary variable. Best

results were obtained with the cloudiness and relative humidity parameters. Simple linear models generally are been solved by ordinary least square method is given below formula [2, 4]:

$$I = SRP_{air-humidity} + SRP_{cloud-cover} + ET \quad (1)$$

where;

I = Radiation (KWh/m²)

$SRP_{air-humidity}$ = Solar radiation parameters change with the air humidity

$SRP_{cloud-cover}$ = Solar radiation parameters change with the cloud cover

ET = Error term

In this study 16 weather stations radiation data were used which measured by the Turkish State Meteorological Service in the 1980-2000 climatic periods. In this study, also we used the following conversion units:

- 1Kcal = 1000 cal
- 1KWh/m² = 11.63 x Kcal/cm²
- PV equivalent = KWh/m² x 0.15
- 1MW/m² = 1000000 KWh/m²
- 1TEP = 85.9845 x MW/m²

Geographically Weighted Regression (GWR) and Co-kriging methods were applied in the modeling of

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Table 2. Calculated sunshine hours and radiation data for some selected cities in Turkey.

Name of Station	kWh/m ² -yr (observed)	kWh/m ² -yr (Model)	Photovoltaic (Equivalent)	City area (Km ²)	Sunshine hour (hours/year)
Adana	1421	1542	229.6	14 256	2704
Afyon	1596	1486	220.1	14 532	2461
Aksaray	1536	1564	235.6	8 051	2730
Ankara	1390	1444	217.2	25 615	2508
Antalya	1715	1720	242.6	20 600	3056
Burdur	1691	1676	237.2	7 238	2696
Diyarbakır	1631	1624	244.2	15 162	2860
Erzurum	1514	1528	220.4	24 742	2440
Gaziantep	1480	1596	250.6	7 194	2660
İstanbul	1306	1308	196.4	5 170	2164
İzmir	1590	1596	235.2	11 812	2894
Karaman	1739	1742	236.8	8 816	2928
Konya	1526	1516	234.2	40 824	2638
Mersin	1730	1722	228.2	15 738	2750
Niğde	1935	1868	234.6	7 318	2760
Sanlıurfa	1524	1634	258.4	23 322	2942
Trabzon	1086	1128	187.4	4 495	1554
Van	1756	1684	240.2	20 927	2901

3. Solar energy potential in Turkey

Due to the geographical location, Turkey is lucky country compared to the others in terms of solar energy potential. According to sunshine duration and radiation data measured by TSMS from 1971 to 2000, Turkey's annual mean total sunshine hours are

2573 (daily mean is 7 h) and mean total radiation is 1474 KWh/m²-year (daily 4 KWh/m²). Monthly and regional solar energy potential of Turkey has been given at Table 3 and 4 and Figs. 4-8 [5].

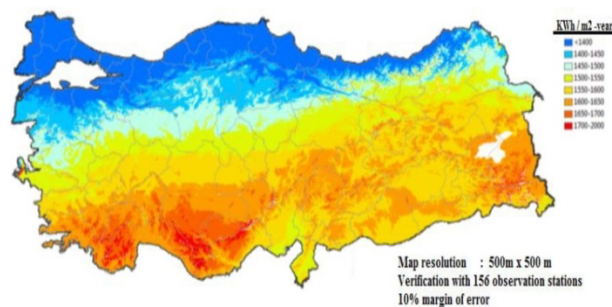


Figure 4. The Solar Energy Potential Atlas of Turkey [14].

Table 3. Monthly average solar potential of Turkey

Months	Monthly Total Solar Energy (kcal/cm ² .month)	Monthly Total Solar Energy (kWh/m ² .month)	Sunshine Duration (hours/month)
January	4.45	51.75	103.0
February	5.44	63.27	115.0
March	8.31	96.65	165.0
April	10.51	122.23	197.0
May	13.23	153.86	273.0
June	14.51	168.75	325.0
July	15.08	175.38	365.0
August	13.62	158.40	343.0
September	10.60	123.28	280.0
October	7.73	89.90	214.0
November	5.23	60.82	157.0
December	4.0	46.87	103.0
Total	112.74	1311	2640
Average	308 cal/cm²-day	3.6 kWh/m²-day	7.2 hours/day

Table 4. Regional distribution of solar energy potential of Turkey

Region	Total Solar Radiation (kWh/m ² .year)	Sunshine Duration (hours/year)
Southeastern Anatolia	1460	2993
Mediterranean	1390	2956
East Anatolia	1365	2664
Central Anatolia	1314	2628
Aegean	1304	2738
Marmara	1168	2409
Black Sea	1120	1971

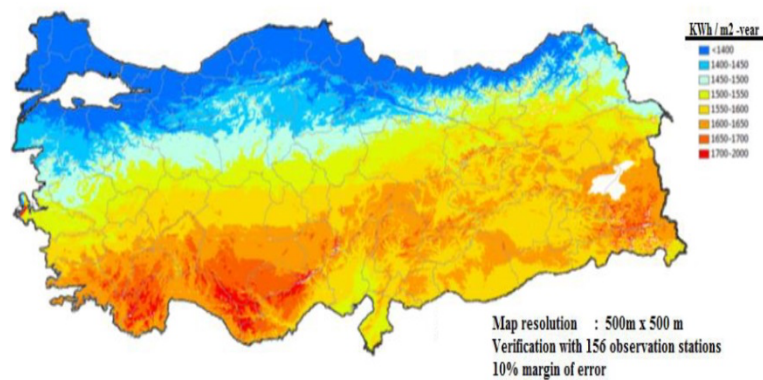


Figure 4. The Solar Energy Potential Atlas of Turkey [14].

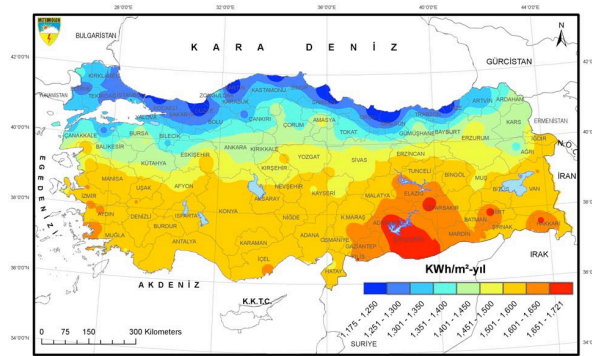


Figure 5. Long term modeled annual total radiation (kWh/m²-yr).

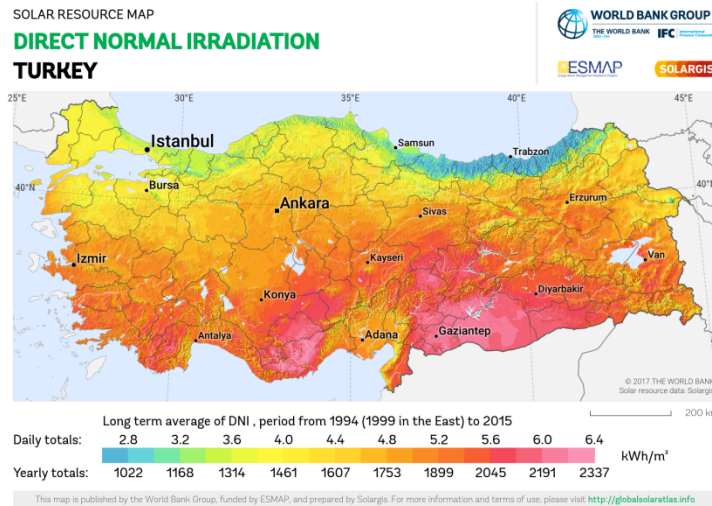


Figure 6. Direct normal irradiation (kWh/m²)

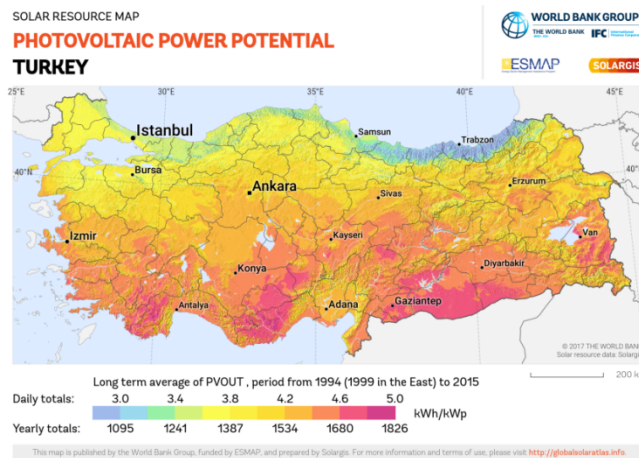


Figure 7. Photovoltaic power potential in Turkey.

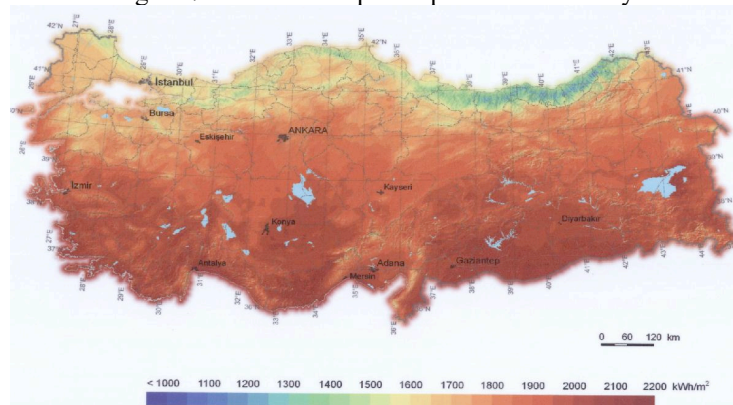


Figure 8. Solar Energy Potential taking into account the slope of 30° position.

Photovoltaic (PV), is a method of obtaining electricity from the sun through silicon crystals. Crystalline solar cell layer in the bottom portion covered with one of P-type material (e.g. Aluminum, Gallium, Indium) to create green spaces. N-type top layer, covered with chemicals such as arsenic, phosphorus or antimony which create traveler electrons. The light falling on the electrons stimulate them through the lower layers (P region). In the solar

cell, these electrons makes short-circuit in the ways drawn that separates two layers and circuit again through drawn road towards the entire N region and thereby generate electricity. With today's technology, depending on the used material on PV, approximately 15% of the total potential of the sun can be converted into electrical energy. Depending on the PV type and area, the amount of energy can be produced in Turkey as shown in Figure 9.

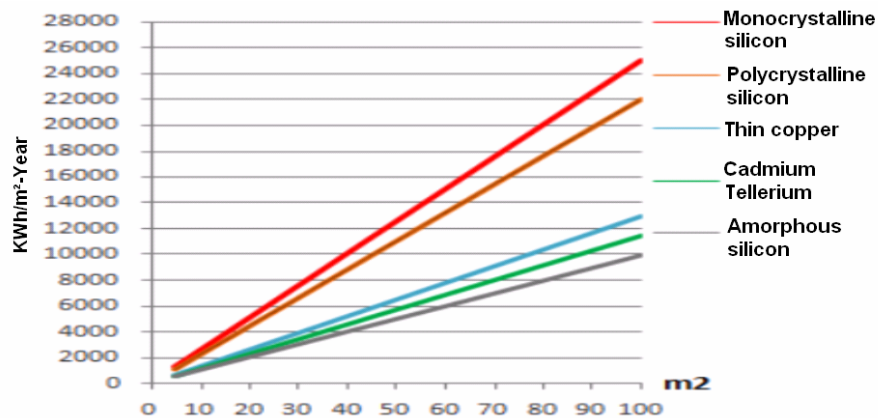


Figure 9. The amount of energy can be produced depending on the PV type and area (KWh/Year) in Turkey.

There are ambitious targets of Turkey for the energy sector in 2030. In this context, the investments to be made in order to meet the energy needs of 2030 are estimated to be around 110 billion \$. In line with these targets, it is envisaged to install 10000 MW solar power plants [1]. The geographical position of Turkey is in the Mediterranean sun belt which resembles to Portugal and Spain in accordance with solar radiation values. It is also a favorable location to establish solar power plants [5].

The atlas of solar energy potential in Turkey is given in Fig. 4 which includes direct, global, sunlight

duration and diffuse solar radiation. Generally solar energy is used for water heating and 18 million m² flat plate solar collector is currently being used and the annual production capacity of solar collectors is approximately 1.0 million m². Total photovoltaic capacity installed in places such as highways, off-grid houses, meteorological stations, forest fires, watching and communication towers is approximately 4000 kW [5]. As shown in Figs. 4-8, Turkey has a lot of solar energy potential for solar thermal applications and electricity generation by using both solar PV and concentrating solar power methods.

4. Conclusions

According to the residual map of modeling radiation data with the GWR method; Afyon, Burdur, Karaman, Niğde, and Van have been under estimated while Adana, Aksaray, Ankara, Antalya, Diyarbakır, Erzurum, Gaziantep, İstanbul, İzmir, Konya, Mersin, Şanlıurfa and Trabzon have been over estimated values were obtained. In the other places, model results are close to the observed value. According to the Local r² map of modeling radiation data with the GWR method; local r² values between GWR model output and observed radiation are higher in the Eastern region of Turkey.

In the modeling of spatial interpolation of radiation data, aspect, latitude, relative humidity and cloudiness were used as secondary variable. Best results were obtained with the cloudiness and relative humidity parameters. The lowest RMSE and highest r² values have been looked for between GWR model output and observed radiation. On the other hand, the results obtained by using Co-kriging and GWR models were compared. So, the lowest RMSE and highest r² values were obtained with GWR in the modeling radiation data. For this reason modeling of radiation data continued with the GWR method.

Relationship between radiation and latitude and aspect is low (r² 0.20 and 0.10). It has been found that cloudiness and relative humidity parameters are more effective on interpolation of radiation. Best model combination according to r² and RMSE are: Radiation (Relative humidity + Cloudiness).

According to the Local r² map of modeling radiation data with the GWR method; local r² values between GWR model output and observed radiation are higher in the Eastern Black sea Region (0.54) and lower in the Hatay, Adana and Mersin (0.42). In the other parts local r² values have been found in between these two values. On the other hand, the Co-kriging and GWR model results were compared by the lowest RMSE and higher r² values obtained in the model. Because of the RMSE is smaller and r² is greater than the Co-kriging result, GWR tool is been selected for modeling solar energy potential in Turkey. According to model result, southern and southeaster parts of the country (İzmir-Iğdır line) have over 1600 KWh/m²-yr radiation potential and is considered as optimum area for the photovoltaic installation.

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