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REGIONAL ENERGY PRODUCTION WITH PV AND CPV PANELS IN NORTH-WEST TURKEY

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ABSTRACT

In this study, solar radiation data and current energy potential analysis were made in 12 locations selected in the north west of Turkey and solar energy characteristics of the region were revealed. In the research, especially the technologies used in the production of electricity from solar radiation were discussed. On the basis of regional characteristics of solar energy, the solar panels can produce different amounts of energy were determined. In this context, while the regional average of 166.3 to 223.3 kWh/m^2 of energy can be produced from monocrystalline panels (PV) and the regional average of 155.2 to 208.4 kWh/m^2 of energy can be produced from polycrystalline panels (PV) were determined. Additionally, the regional average of 310.4 to 416.9 kWh/m^2 of energy can be produced from concentrator solar panels (CPV) was established.

KEYWORDS:
Renewable energy, Solar energy, Photovoltaik (PV), Concentrator (CPV), Turkey

INTRODUCTION

Today, many policies and technologies are being developed to promote the use of renewable energy. Considering that the sun is an endless source of energy, "Solar Energy" has special importance. Solar energy technologies in renewable energy technologies can be categorized in different ways such as solar collectors, thermal solar electricity, condensed solar power, photovoltaic systems and condensed photovoltaic systems. Photovoltaic solar energy (PV) and concentrated solar energy systems (CSP) are promising for electricity generation. They also help to reduce harmful gases and fossil fuel dependence [1]. In the production of photovoltaic power from solar energy, increasing energy conversion efficiency and decreasing investment cost are the most important problems [2]. Spain and the United States are the leading producers of electricity with condensed type solar panels (CSP). With CSP technology and Development Policies, states such as France, Italy, Portugal and Spain foresee to produce 20 TWh electricity by 2020 [3;4].

By concentrating the solar radiation, electrical energy can be produced in CSP plants. CSP plants are composed of various components such as solar power condensers, steam turbines and electric generators. To date, four different CSP power generation plants have been developed. These are solar parabolic dishes (SPD), parabolic corrugated collectors (PTC), solar towers (SPT) and linear fresnel reflectors (LFR) [5]. According to the data collected from the power plants in India, the parabolic trough collector and LFR showed good performance compared to solar tower technology [6]. Parabolic dishes technology is preferred for small-scale power generation, whereas the central receiver tower, parabolic trough collector, LFR are preferred for large-scale power generation [6]. While the photovoltaic industry has been developing rapidly with the growth of energy problems, photovoltaic technology (CPV), where solar radiation is intensified, has come to the fore among renewable energy technologies. In the experimental studies conducted with high condensation solar panels, the HCPV / T module has been shown to perform better with 26.5% electrical efficiency and 49.3% additional thermal efficiency [7]. Khan et all. (Article in press) in a study by; In the multi-production systems with hydrogen tank and solar panels, the electrical efficiency of the multi-joint CPV cell was found to be 40.8%. However, the overall energy efficiency of the system has been reported to be increased to 67.52% using the hybrid multi-generation CPV / T system [8].

Looking at the advances in PV technology, it is seen that costs per watt are falling. This encourages PV panels to widespread despite the low yield of 14-17% in the application. On the other hand, it prevents the spread of CPV technology with higher efficiency. However, this is not a sustainable position. In the absence of technological developments to increase the yield values of PV panels, it will be inevitable that the CPV technology, which will gradually decrease in cost per watt, will sooner or later become widespread.

In principle, two different CPV technologies using fresnel lens and reflector come to the forefront. In both technologies, solar radiation is directed to the solar cell by condensing. In typical silicon solar cells, if the concentration factor of sunlight is x=100, there is a 20% electric voltage increase. The yield of CPV cells in standard test conditions is 29.1%, and when solar radiation is intensified 66 times, this value increases to 35.2%. The record yield value (41.6%) was reached under the conditions of the concentration factor x = 364 [9].

The main objective of this study is to determine the amount of energy produced by PV and CPV solar panels on the basis of regional solar energy characteristics in north-west Turkey. In this context, especially CPV's impact on regional energy production is aimed to be revealed.

SITE AND DATA DESCRIPTION

The region chosen for the research is located in the north west of Turkey. The meteorological data obtained from 12 meteorological stations in the region were used. These stations are Edirne, İpsala, Kırklareli, Tekirdağ, Çorlu, Kumköy, Florya, Şile, Bursa, Çanakkale, Bozcaada and Gökçeada meteorological stations. The position of the stations on the map is shown in Figure 1.

50 years of measurements between 1968 and 2017 were taken into consideration in the determined locations in Bursa, Tekirdag, and Çanakkale. 38 years measurements between 1968 and 2006 in Florya and Edirne stations and Turkey Solar Energy Potential Atlas (GEPA) data, 8 years of measurements between 2009 and 2017 and GEPA data at Kırklareli station, 28 years of measurements between 1977 and 2005 and GEPA data at the Ipsala station , 22 years of measurements between 1984 and 2006 and GEPA data at the Şile station, GEPA data were evaluated at other stations [11;12]. Measurements evaluated in the study; The average daily values are solar radiation, sunshine duration, and cloudiness.

MATERIALS AND METHODS

In the study, firstly, solar radiation intensities, hours of sunshine and cloudiness ratios of the locations in the research area were calculated by considering the measurements made by meteorological stations in the region and GEPA data. Equation (1) and equality (2) were used to convert the measured values recorded daily in the meteorological stations to the monthly and annual average values [13].



FIGURE 1
The positions of stations in North-West Turkey on the map [10].

$$M_m = \frac{\sum x}{n} = \frac{x_1 + x_2 + x_3 + ... + x_n}{n} \quad (1)$$

$$M_y = \frac{\sum x}{m} = \frac{x_1 + x_2 + x_3 + ... + x_n}{m} \quad (2)$$

Regarding the solar energy, the solar radiation power per unit area and the monthly solar energy potential per unit area are calculated by means of equality (3) and equation (4) [9;14].

$$E/A = I \cdot t \cdot \eta \quad (3)$$

$$P = E/t \quad (4)$$

The PV / CPV panels and their properties that can be installed in the region are given below (Table 1).

In the calculation of the amount of annual energy that can be produced in the research area with the relevant solar panels, the parameters in Table 1 have also been used.

RESULTS AND DISCUSSION

Solar radiation analysis. When the solar radiation intensity of the subject area is examined, the lowest average is 49.8 W/m^2 in December. The highest average solar radiation intensity was detected in July with 247.6 W/m^2. The minimum solar radiation range from 39.4 to 204.7 W/m^2 and the maximum radiation intensities are between 58.9 and 283.4 W/m^2. The distribution of solar radiation intensity is given in Figure 2.

When the solar radiation intensity values of the locations in the study area are examined, the lowest annual average is 124 W/m^2 in Edirne. The highest annual average solar radiation intensity was 167 W/m^2 in Kırklareli and 166 W/m^2 in Çanakkale. The monthly variations of the solar radiation intensity of the locations in the region are shown in Figure 3 and 4.

When the average solar radiation intensity values of the locations in the research area are examined; Kırklareli 166.8 W/m^2, Tekirdag 166.8 W/m^2, Çorlu 166.8 W/m^2, Ipsala 166.8 W/m^2, Bursa 166.8 W/m^2, Edirne 166.8 W/m^2, Çanakkale 166.8 W/m^2, Gökçeada 166.8 W/m^2, Bozcaada 166.8 W/m^2, Kumköy 166.8 W/m^2, Şile 166.8 W/m^2 and Florya 166.8 W/m^2 were detected.

Sözen *et al*. (2005a, 2005b, 2004) In the study they conducted in Turkey, they found the average solar radiation at 500 W/m^2 in Edirne and 600 W/m^2 in Şile in summer months with 4 years of data [16-18].

TABLE 1
Photovoltaic panels specifications [15]

Cell Material	Maximum Efficiency (Lab.)	Maximum Efficiency (Series)	Typical Module Efficiency	Area (m^{-2}) required for 1 kWp
Monocrystalline Silicon	%24.7	%22.0	%15.0	6.7
Polycrystalline Silicon	%20.3	%17.4	%14.0	7.2
Amorphous Silicon	%12.1	%6.8	%6.0	16.7
CIS/CIGS (CuIn(Ga)Se$_2$)	%20.0	%11.6	%10.0	10.0
CdTe	%16.5	%12.0	%7.0	14.3
Concentrator (CPV)	%41.1	%36.5	%28.0	3.6

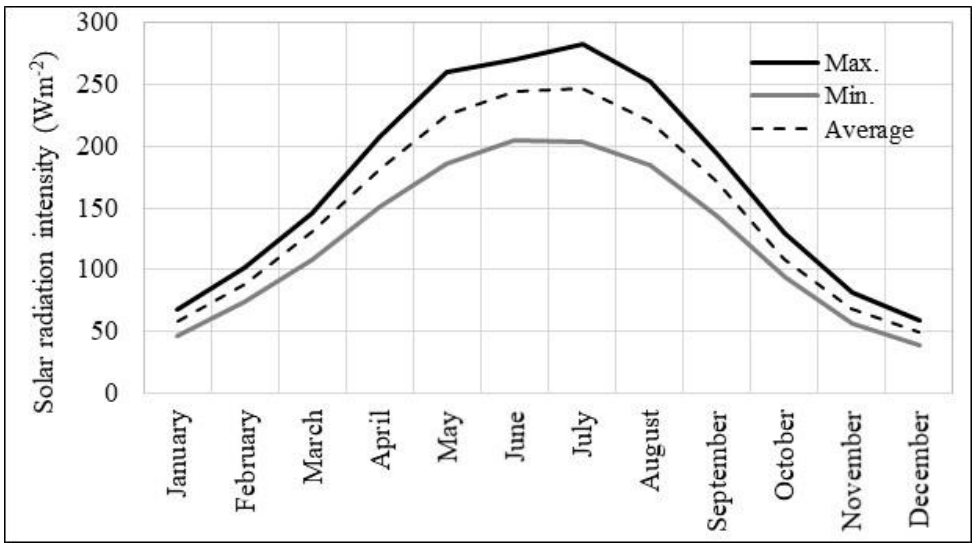


FIGURE 2
Seasonal variation of monthly mean solar power density of the total research area

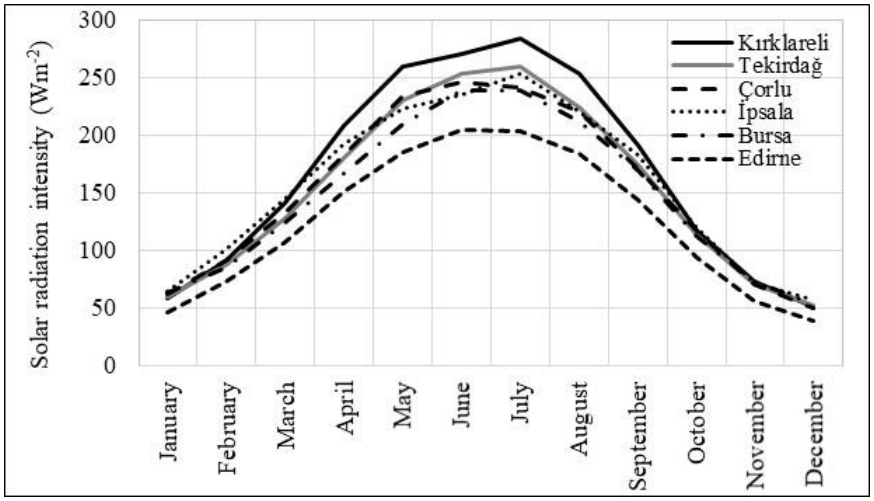


FIGURE 3
Seasonal variation of monthly mean solar power density of the locations

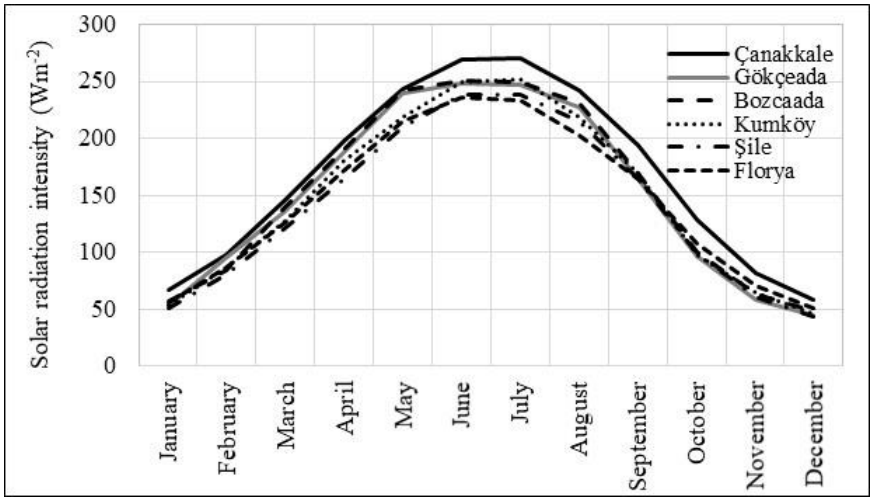


FIGURE 4
Seasonal variation of monthly mean solar power density of the locations

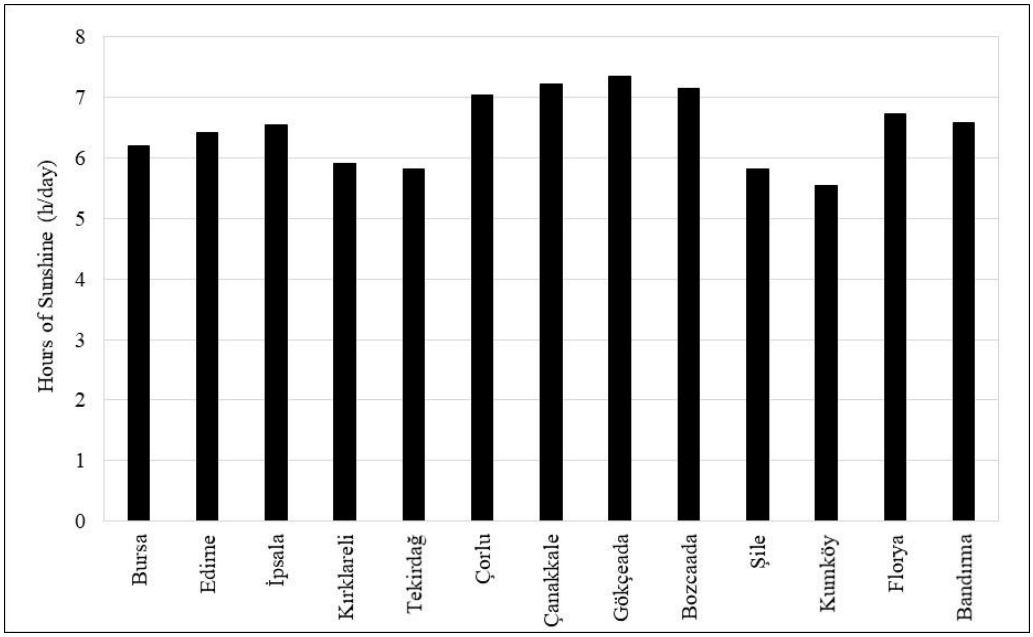


FIGURE 5
Hours of sunshine in research area (hour/day)

Hours of Sunshine. The average daily hours of sunshine is given in Figure 5. The locations that take 7 hours or more sunlight daily are determined as Çorlu, Çanakkale, Gökçeada, and Bozcaada. In contrast, Kırklareli, Tekirdağ, Şile and Kumköy are seen as locations with 6 hours of sunlight.

Sözen *et al.* (2005a, 2005b, 2004) the average hours of sunshine for 4 years were found 11 hours for Edirne, 9 hours for şile, and 8 hours for Bursa, Çanakkale, and Tekirdag [16-18].

By Kaygusuz and Sarı (2003) were determined the average sunshine time in the Marmara region (Nort-West in Turkey) to be 2528 h/y [19].

Cloudiness analysis. On average, the cloudiness of the region is given in Figure 6. The average cloudiness in Bursa, Tekirdağ, Çanakkale and Bozcaada was below 3.5 octaves. On the other hand, in Chile and kumköy, it was over 4.0 octaves.

Solar energy potantial analysis. When the potential solar energy values of the region are examined the lowest average of 37.1 kWh / m^2 month is seen in December. The highest average solar energy was found in July with 184.2 kWh/m^2 month. The minimum solar energy values ranged from 29.3 to 152.3 kWh/m^2month and the maximum solar energy values were between 43.8 and 210.8 kWh/m^2month. The distribution of the potential solar energy values in the region is given in Figure 7.

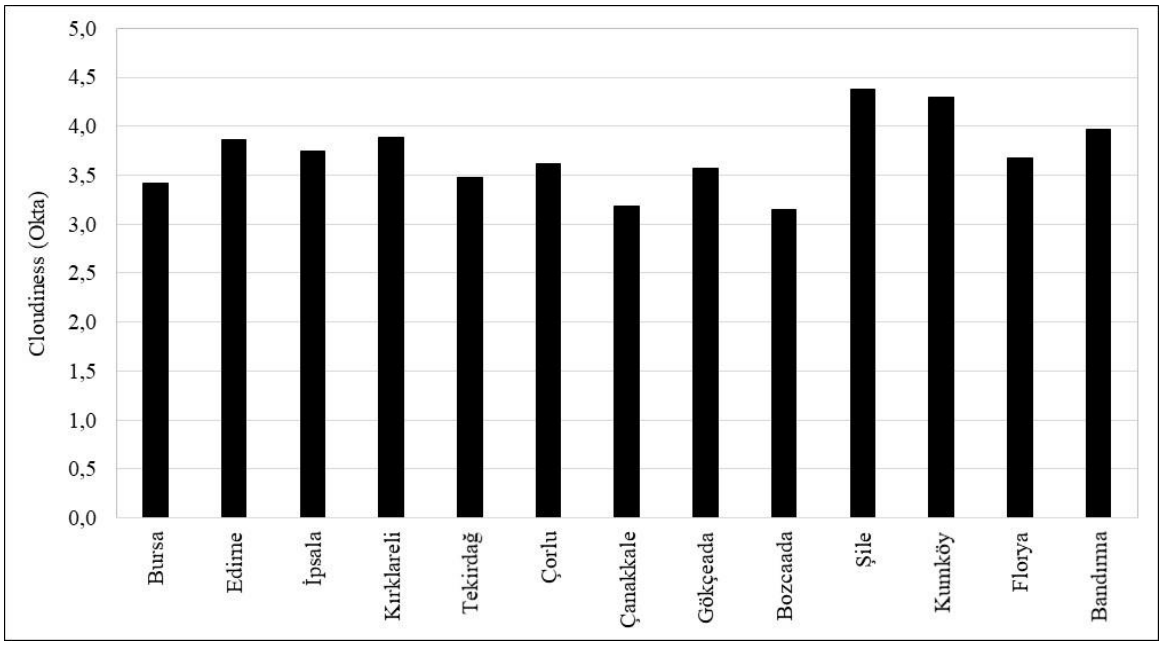


FIGURE 6
Cloudiness of the research area

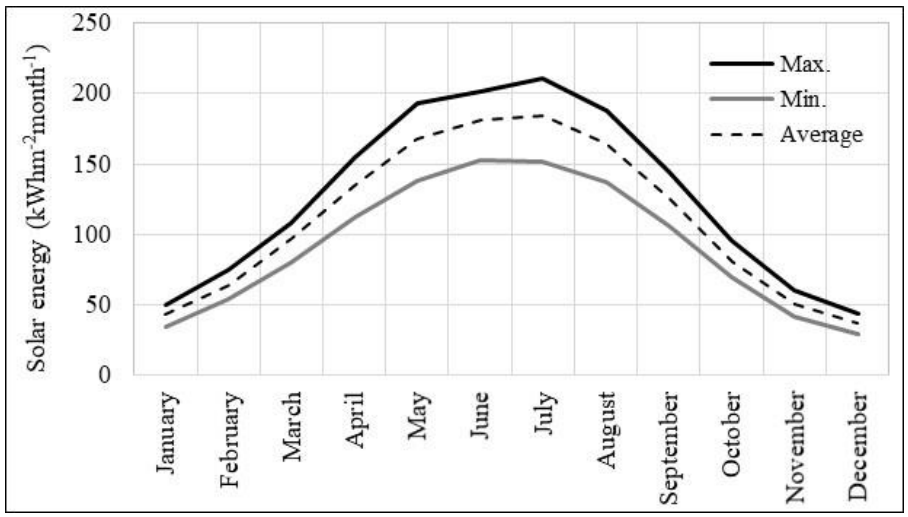


FIGURE 7
Seasonal variation of monthly mean solar energy potential

Sheikh (2009) in his study in Pakistan found the average daily sunbathing intensity is about 5-7 kWh/m^{2}day. Especially in the southwestern region of Belucistan and northeast of Sind, excellent conditions were offered to benefit from solar energy [20].

When the potential solar energy values of the locations in the region are examined, the lowest average is seen in Edirne as 1108.4 kWh/m^{2}yr.

The highest annual average solar energy value was found in Kırklareli with 1488.9 kWh / m^{2}yr and in Çanakkale with 1485.8 kWh / m^{2}yr. Monthly changes in the potential solar energy values of the locations in the region are shown in Figure 8 and 9.

When the average potential solar energy values of the locations in the research area are examined; Kırklareli 1488.9 kWh/m^{2}yr, Tekirdağ 1365.2 kWh/m^{2}yr, Çorlu 1332.5 kWh/m^{2}yr, Ipsala 1389.3 kWh/m^{2}yr, Bursa 1299.3 kWh/m^{2}yr, Edirne 1108.4 kWh/m^{2}yr, Çanakkale 1485.8 kWh/m^{2}yr, Gökçeada 1320.4 kWh/m^{2}yr kWh/m^{2}yr, Kumköy 1311.6 kWh/m^{2}yr, Sile 1255.7 kWh/m^{2}yr and Florya 1280.7 kWh/m^{2}yr determined.

In the Kaygusuz and Sarı (2003) surveys, the Marmara region found the minimum and maximum solar radiation values as 396 kWh/m^{2}yr and 1992 kWh/m^{2}yr, respectively. They also found the average solar radiation value to be 1144 kWh/m^{2}yr [19].

Sözen et al. (2005a, 2005b, 2004) The average solar radiation data with a 4-year study conducted in Turkey in the summer Çanakkale 25 MJ/m^{2}day, Tekirdag 23 MJ/m^{2}day in Bursa and 25 MJ/m^{2}day they were found [16-18].

Energy production analysis. When the electrical energy quantities of different solar panels can be produced in the research area are examined, a result is observed in favor of the concentrator. In the research area, the amount of electricity produced with amorphous silicon panel is 79.5 kWh/m^{2}yr per annum and the amount of electricity

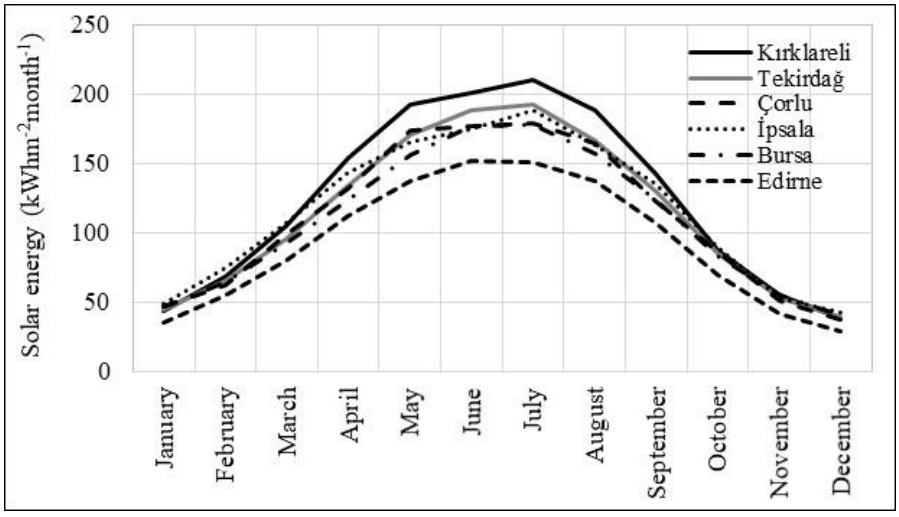


FIGURE 8
Seasonal variation of monthly mean solar energy potential of the locations

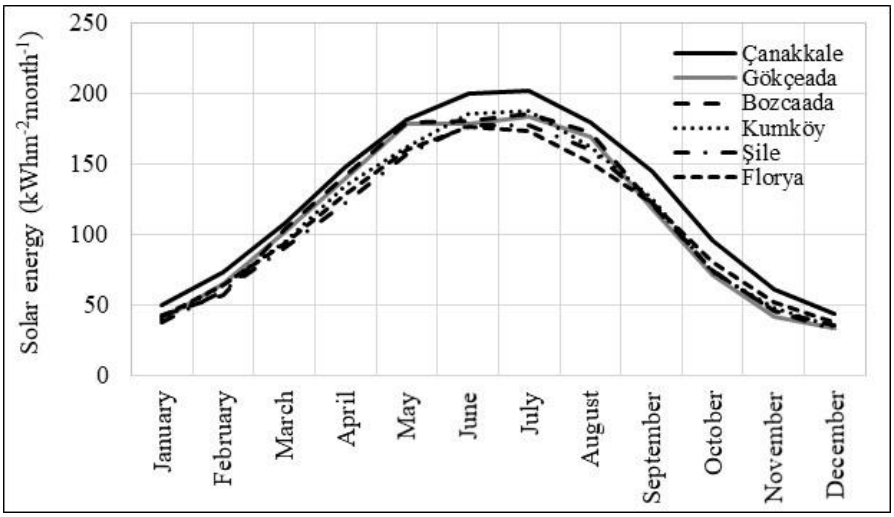


FIGURE 9
Seasonal variation of monthly mean solar energy potential of the locations

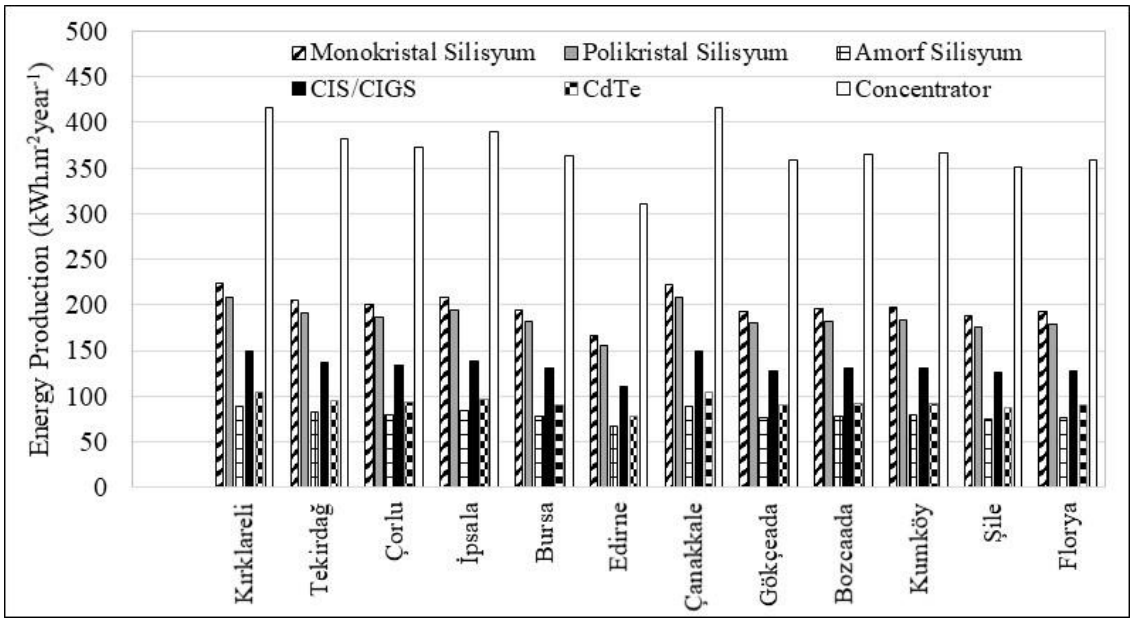


FIGURE 10
The amount of energy that can be produced by different solar panels ($kWhm^{-2}yr^{-1}$)

produced with monocrystalline panel is 198.8 kWh/m^{2}yr per annum and this value reaches 37.1 kWh/m^{2}yr in concentrator systems. This value is 363.8% compared to Amorphous Silicon panel and 86.4% more energy than Monocrystalline Silicon panel. The electrical energy quantities that different solar panels can produce on the basis of locations in the research region are given in Figure 10.

According to the results given in Figure 8, Kırklareli and Çanakkale locations stand out. Concentrator systems' annual electrical energy production at both locations was over 400 kWh/m^{2}yr. While a regional average from the monocrystalline panels 166.3 to 223.3 kWh/m^{2}yr energy can be produced, and 155.2 to 208.4 kWh/m^{2}yr are produced from polycrystalline panels. From amorphous silicon panels 66.5 to 89.3 kWh/m^{2}yr, from CIS / CIGS panels 110.8 to 148.9 kWh/m^{2}yr, from CdTe panels 77.6 to 104.2 kWh/m^{2}yr can be produced and concentrator solar panels (CPV), it was determined that 310.4 and 416.9 kWh/m^{2}yr energy could be produced on a regional average.

CONCLUSION

In this study, first of all, the research region and the solar radiation analysis were performed for the one by one locations. Then, hours of sunshine were determined in terms of locations. Finally, solar energy potential analysis and energy production analysis were performed. PV and CPV solar panels for energy production analysis are discussed. Monocrystalline silicon, polycrystalline silicon, amorphous silicon, CIS / CIGS and CdTe are considered as PV panels. According to the results of the solar radiation analysis conducted for the whole region; the average solar radiation value is 149.7 W/m^2. The average solar energy potential is 1331.6 kWh/m^{2}yr for the overall research area. The sunbathing time of the region was 6.5 hours and the average cloudiness was found to be 3.7 okta.

Energy production analysis results show that there is a significant difference between CPV and PV as expected. CPV; 366.8% from the Amorphous Silicon PV Panel, 299.8% from the PV Panel, 180.1% from the CIS / CIGS PV Panel, 100.1% from the Policristal Silicon PV Panel and 86.7% more than the Monocristal Silicon PV Panel can be producted energy.

NOMENCLATURE

E : Energy, kWh
I : Solar radiation, W/m^2
A : Area, m^2
t : Time, h
M_m : Monthly mean value
M_y : Yearly mean value
n : Days in the month
m : Days in the year
P : Power, W
η : Efficiency
x : Daily mean of measured meteorological value

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