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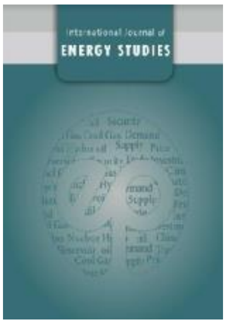

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Finding Optimum Tilt Angles of Photovoltaic Panels: Kütahya Case Study

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Highlights

- For Kütahya, optimum tilt angles of photovoltaic panels were calculated
- For Kütahya, optimum tilt angles were obtained on a monthly basis
- Monthly average daily radiation amount coming to the optimum tilted plane were calculated

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ABSTRACT

It is important to make the most efficient use of solar energy, which is a renewable energy resource whose importance and use is increasing day by day. Due to the movement of the earth around its axis and around the sun, the angles of the sun rays reaching the earth are constantly changing. In order to make maximum use of the sun's rays, it is necessary to place the solar energy systems at the right angle. In this study, optimum tilt angles of the districts of Kütahya province were found for solar energy systems. Meteorological data and latitude information were used in the calculations, the amount of radiation coming to the horizontal plane, the amount of diffuse radiation, the amount of radiation coming to the horizontal plane outside the atmosphere and the amount of radiation coming to the optimum tilted plane were determined.

Keywords: *Solar energy, Photovoltaic panel, Optimum tilt angle*

1. INTRODUCTION

The importance of renewable energy sources is increasing day by day at national and global level. The limited reserves of fossil-based fuels and their environmentally polluting properties make the use of renewable energy valuable at the global level, and our country's dependence on foreign energy at the national level. As can be seen in the world solar energy atlas given in Figure 1, our country has a high potential in terms of solar energy due to its location [1].

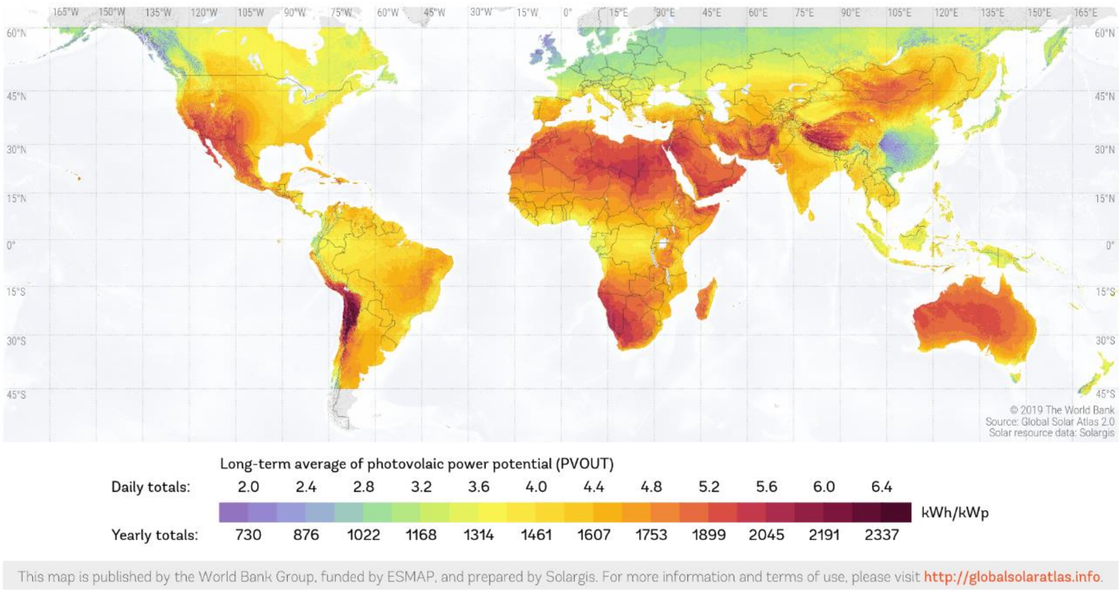

Figure 1. World solar energy atlas [1]

In our country, the installed power of solar energy and consequently the generation of electricity from solar energy is increasing day by day. As of February 2020, the installed capacity of licensed solar energy in our country has been 174.75 MW, and the installed capacity of unlicensed solar energy has been 5,883.41 MW [2]. Electricity production from solar energy in February 2020; 18,861.9 MWh with license and 556,037.06 MWh without license [2].

Due to the movement of the earth around its axis and around the sun, the angle of incidence of sun rays constantly changes throughout the day and year. In order to benefit more from solar energy, photovoltaic panels with solar tracking mechanism are installed, the tilt angles of the fixed panels can be changed seasonally or the panel is placed at the angle where the solar energy can produce the most. There are studies in the literature about the optimum tilt angles of solar panels.

Bakırcı has calculated optimum tilt angles for Adana, Ankara, Diyarbakır, Erzurum, İstanbul, İzmir, Samsun and Trabzon provinces and developed correlations for Turkey' s cities optimum tilt angles [3]. Handoyo et al. calculated the optimum tilt angle for solar collectors in Surabaya region of Indonesia. The results obtained were compared with other studies in the literature [4]. Kallioğlu et al. calculated the 12-month optimum tilt angles for Gaziantep province. Optimum tilt angles varies between 0^o and 57^o on a yearly basis [5]. Koçer et al. calculated the 12-month optimum tilt angles of solar collectors for Ankara province and its districts. It has been stated that when the tilts angles are changed twice a year, there will be an increase of 5% compared to fixed collectors and an 8% increase in efficiency compared to fixed collectors when the tilt angles are changed every month [6]. Zang et al. calculated the 12-month optimum tilt angles for the Chinese cities located in 6 different climatic zones [7]. Şadanoğlu has calculated the optimum angles for solar energy systems by making measurements in March, April, May and June for Eskişehir province [8]. Ajder calculated the optimum tilt angle for the city of Boston, USA using meteorological data. In the calculations for the range of 0^o-90^o, the optimum tilt angle was obtained as 49^o [9]. Calabro has developed an algorithm for calculating the optimum tilt angles of photovoltaic panels using solar radiation data from various meteorological stations [10]. Ayaz has modeled different types of photovoltaic modules using meteorological data and calculated the optimum tilt angles for these modules under Istanbul conditions [11]. Yılmaz calculated optimum tilt angles of all provinces of Turkey. In addition, various correlations have been developed to calculate the optimum tilt angle. [12]. Eren, using Visual C # language, has created an interface that calculates the optimum tilt angle. The optimum tilt angle calculated and evaluated for Turkey and Ankara [13]. Eker calculated the optimum tilt angle for the panel for the province of Bursa, and also examined the effect of the cooling effect of the wind on the panels [14]. There are studies on this subject in the literatüre [15-22].

2. MATERIAL

In this study, optimum tilt angles for 12 months of the year were calculated for the province of Kütahya and its districts.

Kütahya is a city located in the Aegean Region of our country, with a surface area of 11,634 km^2, consisting of 13 districts including its central district. The location of the province is between the 28.59-30.50 eastern meridians and 38.82-39.89 northern parallels. The solar energy potential map of Kütahya province, including the district boundaries, is shown in Figure 2 [21]. As can be seen from the figure, Kütahya province has a high solar energy potential. For the district centers of the province of Kütahya; General information including latitude, longitude, altitude, average daily solar radiation, average daily sunshine duration and annual average temperature are shared in Table 1 [23-25]. In the north of Kütahya, the annual average solar radiation values are 1450-1500 kWh/m^2, while in the southern regions of Kütahya this value reaches the levels of 1650-1700 kWh/m^2.

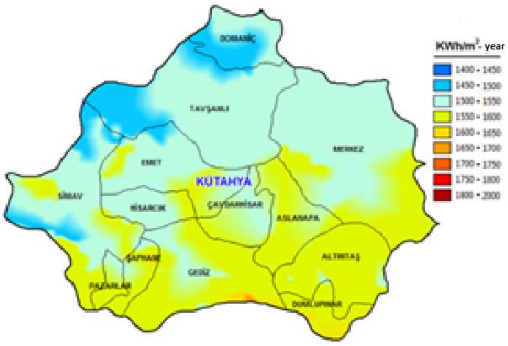

Figure 2. Solar energy potential map of Kütahya province [21]

In Kütahya province, the installed power of unlicensed photovoltaic solar power plants is 114.03 MW as of February 2020. 10,397.23 MWh of electricity was generated from these power plants in February 2020. The graph of installed photovoltaic solar energy power and electricity generation from these power plants covering the January 2016 - February 2020 period of Kütahya is shown in Figure 3. While the photovoltaic installed power in Kütahya was 1 MW in January 2016, this value has increased exponentially and reached 114.03 MW as of February 2020. When the electricity generation from solar energy with photovoltaic panels is examined, the production amount in January 2016 was 42.86 MWh, the production amount increased with the installed power and this value reached 10,397.23 MWh in February 2020 [2].

In Figure 4, the ratio of electricity generation from photovoltaic power plants to the total (lighting, residential, industrial, agricultural irrigation and commercial facilities) electricity consumption of Kütahya province can be seen. While the production / consumption rate was 0.3 ‰ in January 2020, this rate was 78.3 ‰ in February 2020. During the period examined, the ratio of the amount of electrical energy obtained from photovoltaic power plants to consumption reached up to 18% [2].

Table 1. General information for Kütahya districts

	Latitude (º)	Longitude (º)	Altitude (m)	Daily solar radiation (kWh/m^2.day)	Daily sunshine duration (Hours)	Annual ave. temp. (ºC)
Central	39.4	30	960	4.08	6.4	10.5
Altıntaş	39.1	30.1	1030	4.16	7.07	10.84
Aslanapa	39.2	29.9	1030	4.12	7.07	10.61
Çavdarhisar	39.2	29.6	1010	4.11	7.03	10.96
Domaniç	39.8	29.6	880	3.98	6.93	10.49
Dumlupınar	38.9	30	1225	4.22	7.21	10.33
Emet	39.3	29.3	900	4.07	7.14	11.21
Gediz	39	29.4	750	4.14	7.29	12.57
Hisarcık	39.3	29.2	760	4.07	7.26	11.92
Pazarlar	39	29.1	925	4.15	7.44	11.69
Simav	39.1	29	820	4.06	7.3	11.78
Şaphane	39	29.2	980	4.14	7.32	11.4
Tavşanlı	39.5	29.5	845	4.01	7.08	10.83

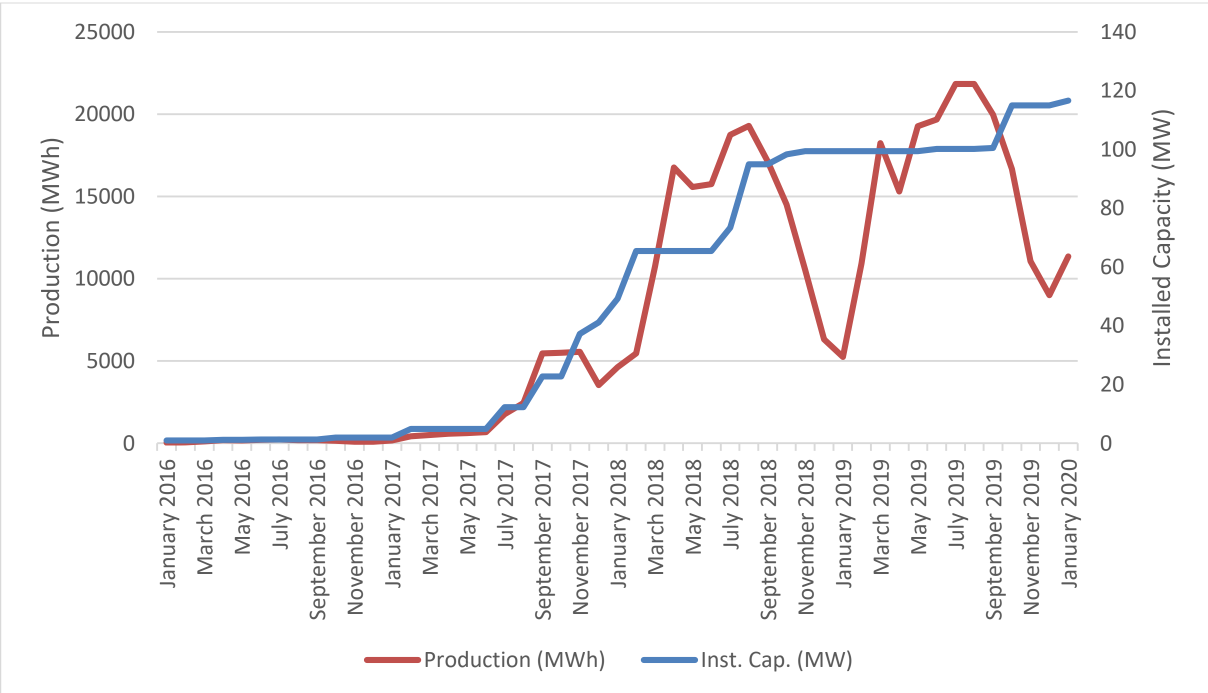

Figure 3. Photovoltaic installed capacity and production values in Kütahya [2]

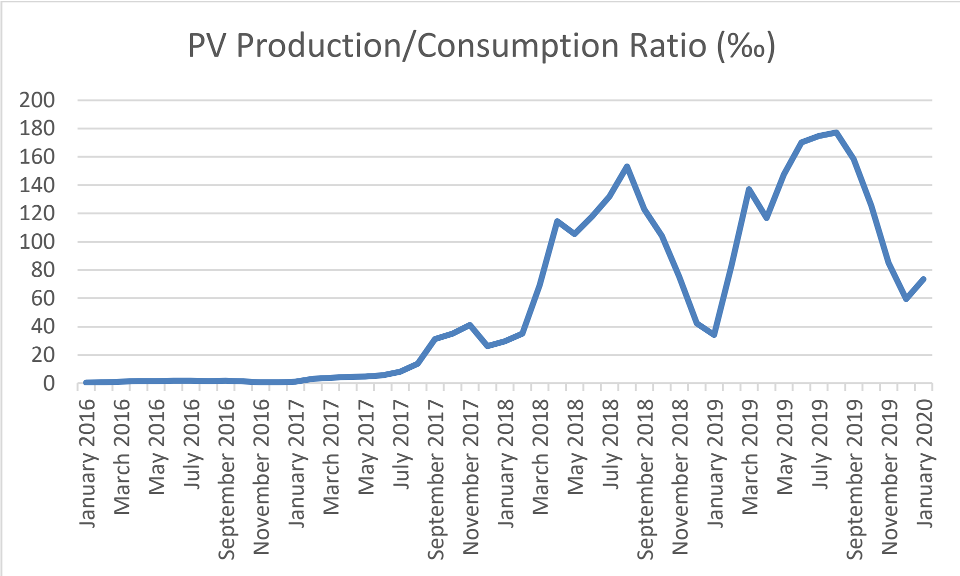

Figure 4. Kütahya PV production / consumption ratio

3. METHOD

By using meteorological data and latitude information for the districts of Kütahya province, optimum photovoltaic panel tilt angles were calculated. A method was developed by Liu and Jordan to determine the average daily radiation amount [26].

The total amount of radiation coming to the panels is the sum of direct, scattered and reflected radiation. The total amount of radiation coming to the inclined plane [27];

$$H_T = H.(1-\frac{H_d}{H}).R_b + H_d(\frac{1+\cos\beta}{2}) + H.\rho.(\frac{1-\cos\beta}{2}) \quad (1)$$

is calculated by the formula. In this formula, β represents the angle of tilt of the panel, ρ represents the reflection rate of the ground, R_b represents the ratio of direct radiation to horizontal radiation. H represents the monthly average daily radiation amount coming to the horizontal plane, H_d is the monthly average daily reflected radiation amount;

$$H_d/H=1-1.13.K_T \quad (2)$$

is expressed by the formula. K_T is the openness index;

$K_T=H/H_0$ (3)

is expressed by the formula. In this formula, the H_0 expression is the monthly average daily amount of radiation from the horizontal plane outside the atmosphere. R_b;

$$R_b = \frac{\cos(\phi-\beta).\cos(\delta).\sin(w_s)+w_s(\frac{\pi}{180})\sin(\phi-\beta).\sin(\delta)}{\cos(\phi).\cos(\delta).\sin(w_s)+w_s(\frac{\pi}{180})\sin(\phi).\sin(\delta)} \quad (4)$$

is expressed by the formula. w_s is the hour of birth angle;

$$w_s = \min\begin{bmatrix}\cos^{-1}(-\tan\phi.\tan\delta) \\ \cos^{-1}(-\tan(\phi-\beta).\tan\delta)\end{bmatrix} \quad (5)$$

is expressed by the formula. In these formulas, ϕ represents the local latitude angle, δ represents the declination angle. Declination angle;

$$\delta = 23.45.\sin(\frac{360.(284+n)}{365}) \quad (6)$$

is expressed by the formula. n represents the calendar day. H is the monthly average daily solar radiation coming to the horizontal plane;

$H/H_0=a+b.(n/N)$ (7)

is expressed by the formula. In this formula, a and b are constants and n / N represents the relative insolation rate. The correlation developed for a and b constants [28];

$$\begin{aligned} a &= 0.103+0.000017.Z+0.198.\cos(\phi-\delta) \\ b &= 0.533-0.165.\cos(\phi-\delta) \end{aligned} \quad (8)$$

is expressed by the formula. Z represents altitude. Monthly average daily radiation from the horizontal plane outside the atmosphere is H_0;

$$H_0 = 24.3600.\frac{G_s}{\pi}.(1+0.033.\cos(360.n/365)).(\cos\phi.\cos\delta.\sin w_s + ((\frac{\pi.w_s}{80}).\sin\phi.\sin\delta) \qquad (9)$$

is expressed by the formula. In this formula, G_s is the solar constant, taken as 1367 W / m^2.

4. RESULTS

The 12-month optimum tilt angles of photovoltaic panels were calculated using the given formulas with meteorological data and latitude information of the districts of Kütahya province.

For the districts of Kütahya province, monthly average daily radiation values from the horizontal plane outside the atmosphere (H_0) are calculated by Equations (5), (6) and (9), and shared in Table 2. The comparison of the monthly average daily radiation values of the districts from the horizontal plane outside the atmosphere can be seen in Figure 5. The highest monthly average daily radiation values of the districts are seen in June and July, and the lowest monthly average daily radiation values are seen in January and December. The annual average daily radiation values of the districts from the horizontal plane outside the atmosphere varies between 28.27 MJ / m^2.day and 28.59 MJ / m^2.day.

Table 2. Kütahya provincial districts monthly average daily radiation from the horizontal plane outside the atmosphere (MJ / m^2.day)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Ave
Central	15.63	20.63	27.7	34.8	39.73	41.72	40.64	36.54	30.06	22.68	16.72	14.11	28.41
Altıntaş	15.81	20.8	27.84	34.87	39.75	41.71	40.64	36.59	30.18	22.84	16.9	14.29	28.52
Aslanapa	15.75	20.74	27.79	34.85	39.74	41.71	40.64	36.57	30.14	22.79	16.84	14.23	28.48
Çavdarhisar	15.75	20.74	27.79	34.85	39.74	41.71	40.64	36.57	30.14	22.79	16.84	14.23	28.48
Domaniç	15.38	20.4	27.52	34.69	39.7	41.73	40.63	36.46	29.91	22.47	16.47	13.86	28.27
Dumlupınar	15.93	20.91	27.92	34.93	39.76	41.71	40.65	36.63	30.25	22.95	17.02	14.42	28.59
Emet	15.69	20.69	27.75	34.82	39.74	41.72	40.64	36.55	30.1	22.73	16.78	14.17	28.45
Gediz	15.87	20.86	27.88	34.9	39.76	41.71	40.65	36.61	30.21	22.89	16.96	14.35	28.55
Hisarcık	15.69	20.69	27.75	34.82	39.74	41.72	40.64	36.55	30.1	22.73	16.78	14.17	28.45
Pazarlar	15.87	20.86	27.88	34.9	39.76	41.71	40.65	36.61	30.21	22.89	16.96	14.35	28.55
Simav	15.81	20.8	27.84	34.87	39.75	41.71	40.64	36.59	30.18	22.84	16.9	14.29	28.52
Şaphane	15.87	20.86	27.88	34.9	39.76	41.71	40.65	36.61	30.21	22.89	16.96	14.35	28.55
Tavşanlı	15.57	20.57	27.66	34.77	39.72	41.72	40.64	36.52	30.02	22.63	16.66	14.05	28.38

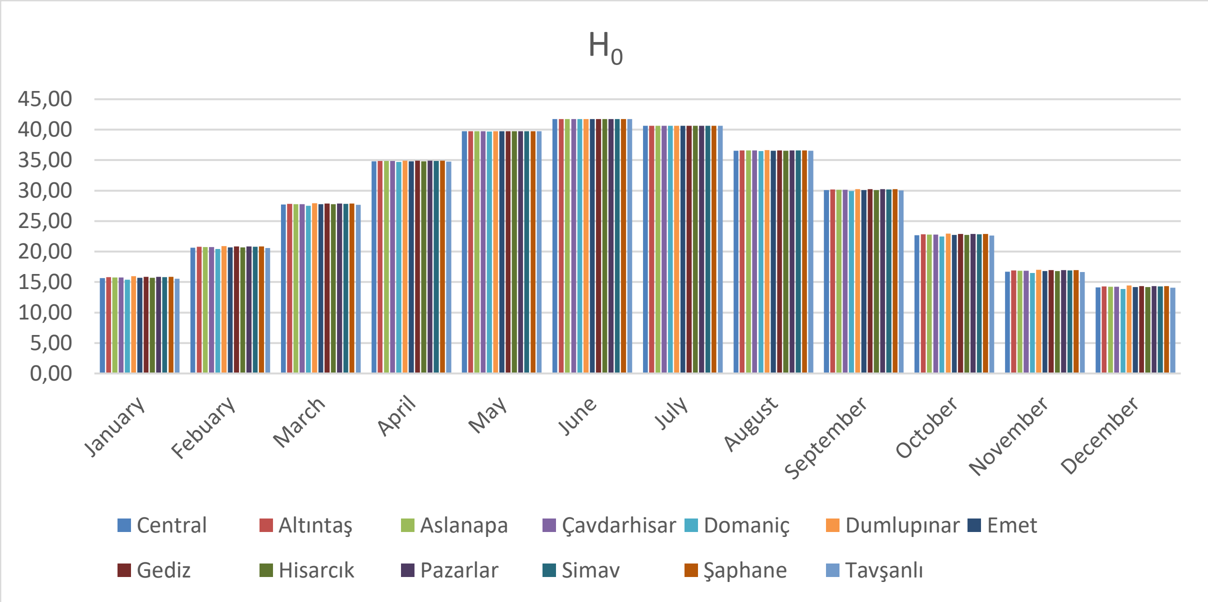

Figure 5. Kütahya provincial districts monthly average daily radiation from the horizontal plane outside the atmosphere (MJ / m^2.day)

For the districts of Kütahya province, monthly average daily solar radiation values coming to the horizontal plane (H) are calculated by using obtained H_0 values and Equations (7) and (8), and shared in Table 3. The comparison of the monthly average daily solar radiation values of the districts from the horizontal plane can be seen in Figure 6. The highest monthly average daily solar radiation values of the districts are seen in June and July, and the lowest monthly average daily solar radiation values are observed in January and December. The annual average daily solar radiation values of the districts from the horizontal plane varies between 14.1 MJ / m^2.day and 15.2 MJ / m^2.day.

For the districts of Kütahya province, monthly average daily reflected radiation values (H_d) are calculated by using obtained H values and Equations (2) and (3), and shared in Table 4. The comparison of monthly average daily reflected radiation values of the districts can be seen in Figure 7 The highest monthly average daily reflected radiation values of the districts are seen in May and June, and the lowest monthly average daily reflected radiation values are seen in January and December. The average daily reflected radiation values of the districts vary between 5.92 MJ / m^2.day and 6.04 MJ / m^2.day.

Table 3. The monthly average daily solar radiation values from the horizontal plane of the districts of Kütahya province (MJ / m^2.day)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Ave.
Central	5.66	8.69	11.6	15.96	20.67	23.53	23.04	20.42	16.78	10.76	7.24	5.23	14.13
Altıntaş	6.04	9.25	12.16	16.86	21.94	24.05	24.32	21.76	17.49	11.55	7.57	5.58	14.88
Aslanapa	6.01	9.13	12.59	17.12	21.94	23.9	24.17	21.61	17.34	11.32	7.47	5.49	14.84
Çavdarhisar	6.01	9.04	13.04	17.38	21.62	24.04	23.85	21.6	17.21	11.12	7.46	5.36	14.81
Domaniç	6.02	8.73	12.72	17.07	21.5	23.48	23.58	21.02	16.76	10.8	7.1	5.3	14.51
Dumlupınar	6.29	9.47	12.64	17.28	22.24	24.35	24.46	22.05	17.76	11.78	7.76	5.75	15.15
Emet	6.31	9.06	13.19	17.43	21.54	23.8	24.07	21.52	17.13	11.24	7.33	5.43	14.84
Gediz	6.42	9.18	13.31	17.53	21.76	23.85	24.13	21.6	17.25	11.47	7.52	5.54	14.96
Hisarcık	6.41	9.1	13.35	17.35	21.6	23.86	23.98	21.57	17.06	11.38	7.36	5.47	14.87
Pazarlar	6.75	9.33	13.73	17.77	22.03	24.13	24.4	21.85	17.34	11.63	7.57	5.65	15.18
Simav	6.62	9.18	13.54	17.55	21.8	23.9	24.18	21.63	17.14	11.37	7.44	5.53	14.99
Şaphane	6.62	9.26	13.64	17.66	21.92	24.02	24.29	21.75	17.37	11.56	7.59	5.67	15.11
Tavşanlı	6.16	8.89	13	17.23	21.64	23.61	23.88	21.32	17.06	11.07	7.25	5.37	14.71

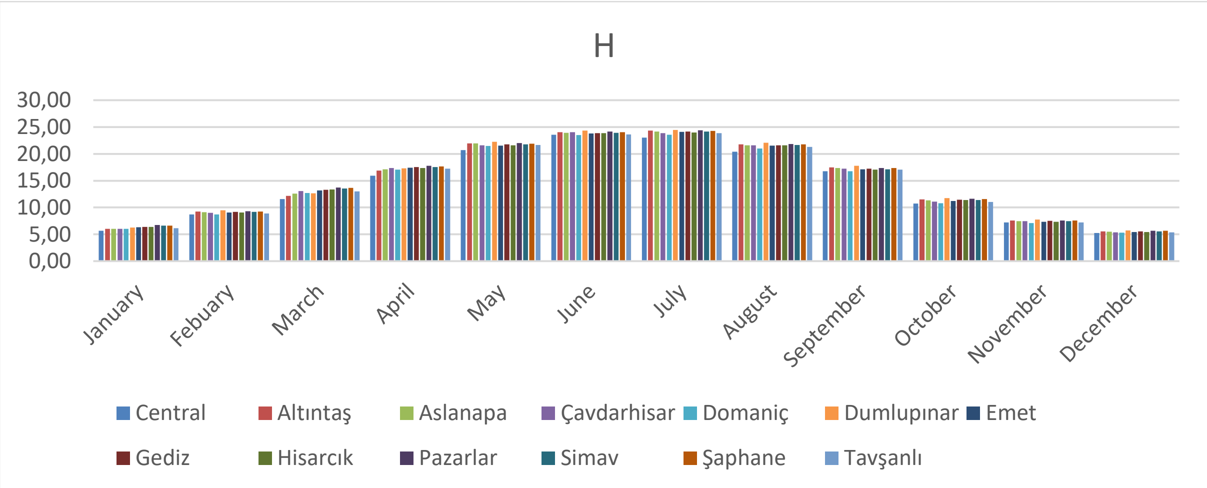

Figure 6. The monthly average daily solar radiation values from the horizontal plane of the districts of Kütahya province (MJ / m^2.day)

Table 4. Kütahya districts monthly average daily reflected radiation amount (MJ / m^2.day)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Ave
Central	3.34	4.55	6.11	7.69	8.52	8.53	8.28	7.52	6.2	4.99	3.7	3.04	6.04
Altıntaş	3.43	4.6	6.16	7.65	8.25	8.38	7.88	7.14	6.04	4.95	3.74	3.12	5.94
Aslanapa	3.42	4.59	6.14	7.62	8.25	8.43	7.93	7.18	6.07	4.96	3.72	3.1	5.95
Çavdarhisar	3.42	4.59	6.13	7.59	8.33	8.39	8.04	7.19	6.1	4.99	3.72	3.08	5.96
Domaniç	3.36	4.51	6.08	7.58	8.34	8.55	8.11	7.33	6.15	4.93	3.64	3.01	5.97
Dumlupınar	3.48	4.62	6.17	7.62	8.18	8.29	7.83	7.05	5.98	4.95	3.76	3.16	5.92
Emet	3.44	4.58	6.1	7.57	8.34	8.46	7.96	7.2	6.11	4.96	3.71	3.08	5.96
Gediz	3.49	4.61	6.13	7.58	8.3	8.44	7.94	7.2	6.12	4.98	3.75	3.12	5.97
Hisarcık	3.45	4.58	6.09	7.58	8.33	8.44	7.99	7.19	6.13	4.94	3.71	3.08	5.96
Pazarlar	3.51	4.61	6.09	7.55	8.24	8.35	7.85	7.11	6.1	4.95	3.75	3.14	5.94
Simav	3.49	4.6	6.1	7.57	8.29	8.42	7.93	7.18	6.14	4.97	3.74	3.11	5.96
Şaphane	3.5	4.61	6.1	7.56	8.26	8.39	7.89	7.15	6.09	4.96	3.75	3.14	5.95
Tavşanlı	3.41	4.55	6.09	7.58	8.32	8.51	8.02	7.26	6.11	4.95	3.68	3.05	5.96

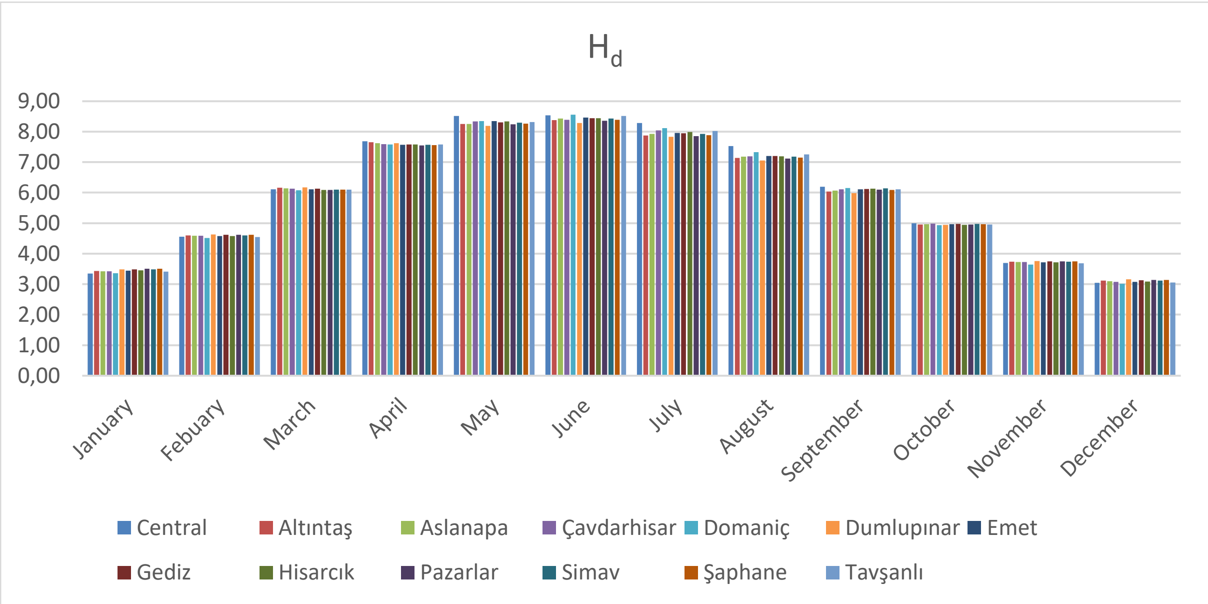

Figure 7. Kütahya districts monthly average daily reflected radiation amount (MJ / m^2.day)

In order to find the optimum tilt angles of solar energy systems on a monthly basis, calculations were made for all tilt angles between 0^o and 90^o using Equation (1), and optimum tilt angles were obtained. For the districts of Kütahya province, the monthly optimum photovoltaic panel tilt angles are shared in Table 5. The comparison of monthly optimum photovoltaic panel tilt angles values of the districts is shown in Figure 8. The tilt angles reach their highest value in the winter months and reach their lowest value in the summer months. While the highest optimum tilt angles of all districts are seen in December, the optimum tilt angle value for all districts is zero in June. For our country, which is located in the northern hemisphere, due to the movement of the earth around the sun, the sun rays in the summer are steep compared to the winter months.

Table 5. Kütahya provincial districts monthly optimum tilt angles (°)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Central	57	50	35	20	7	0	3	17	33	47	57	60
Altıntaş	57	50	35	20	7	0	3	17	33	48	58	60
Aslanapa	57	50	36	21	8	0	3	17	33	48	58	60
Çavdarhisar	57	50	36	21	7	0	3	17	33	47	58	60
Domaniç	58	50	37	21	8	0	3	17	33	48	58	61
Dumlupınar	58	50	35	20	7	0	2	17	33	48	58	61
Emet	58	50	37	21	8	0	3	17	33	48	57	60
Gediz	58	50	36	21	7	0	3	17	33	48	57	60
Hisarcık	59	50	37	21	8	0	3	17	33	48	58	60
Pazarlar	59	50	37	21	7	0	3	17	33	48	58	60
Simav	59	50	37	21	7	0	3	17	33	48	57	60
Şaphane	59	50	37	21	7	0	3	17	33	48	58	61
Tavşanlı	58	50	37	21	8	0	3	17	33	48	58	61

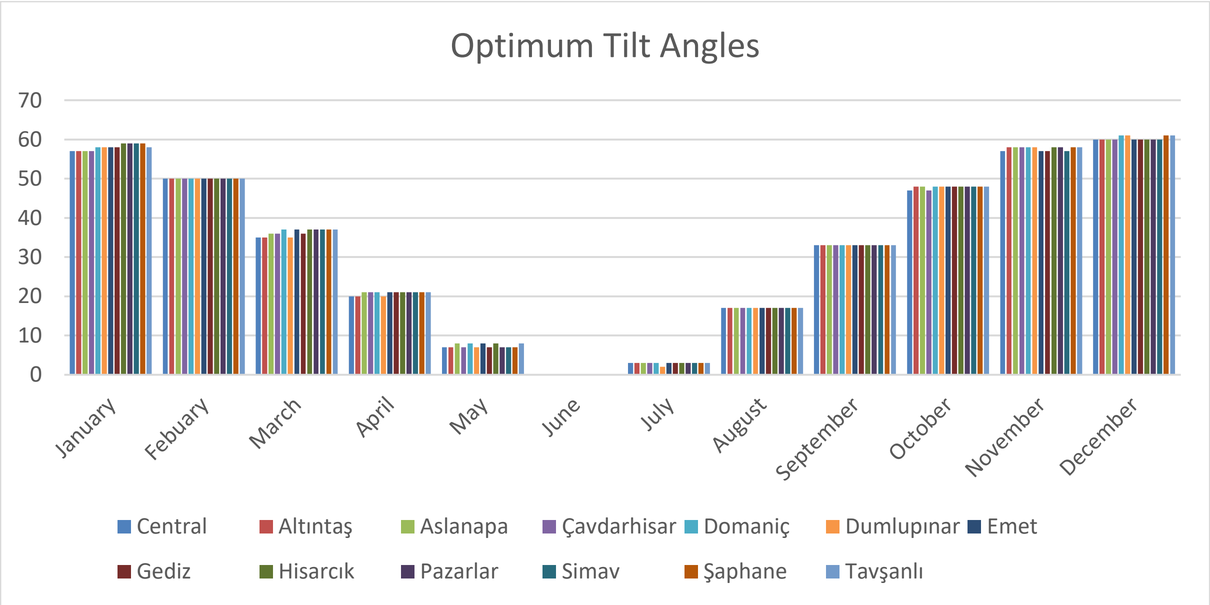

Figure 8. Kütahya provincial districts monthly optimum tilt angles (°)

Seasonal average optimum photovoltaic panel tilt angles for the districts of Kütahya province are given in Table 6. Photovoltaic panel tilt angles are at their lowest levels in summer and reach their highest levels in autumn and winter. In photovoltaic panels that do not have a solar tracking system, the tilt angles of the photovoltaic panels can be changed in certain periods such as monthly and seasonal in order to benefit from sunlight more efficiently. The average annual photovoltaic panel optimum tilt angles of the districts vary between 32.2^o and 32.8^o degrees.

Table 6. Kütahya provincial districts seasonal optimum tilt angles (^{o})

	Spring	Summer	Autumn	Winter
Central	20.7	6.7	45.7	55.7
Altıntaş	20.7	6.7	46.3	55.7
Aslanapa	21.7	6.7	46.3	55.7
Çavdarhisar	21.3	6.7	46	55.7
Domaniç	22	6.7	46.3	56.3
Dumlupınar	20.7	6.3	46.3	56.3
Emet	22	6.7	46	56
Gediz	21.3	6.7	46	56
Hisarcık	22	6.7	46.3	56.3
Pazarlar	21.7	6.7	46.3	56.3
Simav	21.7	6.7	46	56.3
Şaphane	21.7	6.7	46.3	56.7
Tavşanlı	22	6.7	46.3	56.3

Monthly average daily radiation values coming to the optimum photovoltaic panel tilt angled surfaces (H_T) of the districts of Kütahya province are presented in Table 7. The comparison of the radiation values of the districts is shown in Figure 9. The highest monthly average daily radiation values are observed in June and July, and the lowest monthly average daily radiation values are observed in December and January. The annual average daily radiation values of the districts of Kütahya on the optimum photovoltaic panel tilt angles range from 15.92 MJ / m^2.day to 17.31 MJ / m^2.day.

Table 7. Kütahya province monthly average daily radiation amount coming to the optimum inclined plane (MJ / m^2.day)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Ave
Central	8.46	11.71	13.18	16.59	20.76	23.53	23.05	20.98	19.05	14.12	11.24	8.4	15.92
Altıntaş	9.2	12.66	13.9	17.56	22.04	24.05	24.33	22.41	19.95	15.43	11.87	9.15	16.88
Aslanapa	9.18	12.47	14.5	17.85	22.03	23.9	24.18	22.25	19.78	15.06	11.68	8.97	16.82
Çavdarhisar	9.16	12.29	15.12	18.14	21.71	24.04	23.86	22.24	19.6	14.7	11.66	8.64	16.76
Domaniç	9.43	11.91	14.78	17.85	21.6	23.48	23.6	21.66	19.11	14.33	11.1	8.73	16.46
Dumlupınar	9.69	13	14.52	18.01	22.33	24.35	24.47	22.7	20.27	15.78	12.23	9.48	17.24
Emet	9.88	12.36	15.35	18.21	21.64	23.8	24.09	22.16	19.51	14.95	11.39	8.86	16.85
Gediz	10.02	12.49	15.46	18.3	21.85	23.85	24.14	22.22	19.61	15.25	11.71	9.01	16.99
Hisarcık	10.12	12.43	15.58	18.12	21.69	23.86	23.99	22.21	19.41	15.2	11.47	8.94	16.92
Pazarlar	10.81	12.78	16.06	18.56	22.12	24.13	24.41	22.49	19.73	15.55	11.83	9.27	17.31
Simav	10.55	12.52	15.81	18.33	21.89	23.9	24.19	22.27	19.48	15.11	11.56	9.02	17.05
Şaphane	10.5	12.64	15.94	18.45	22.01	24.02	24.3	22.38	19.76	15.41	11.86	9.31	17.21
Tavşanlı	9.64	12.11	15.12	18	21.74	23.61	23.89	21.96	19.45	14.71	11.31	8.78	16.69

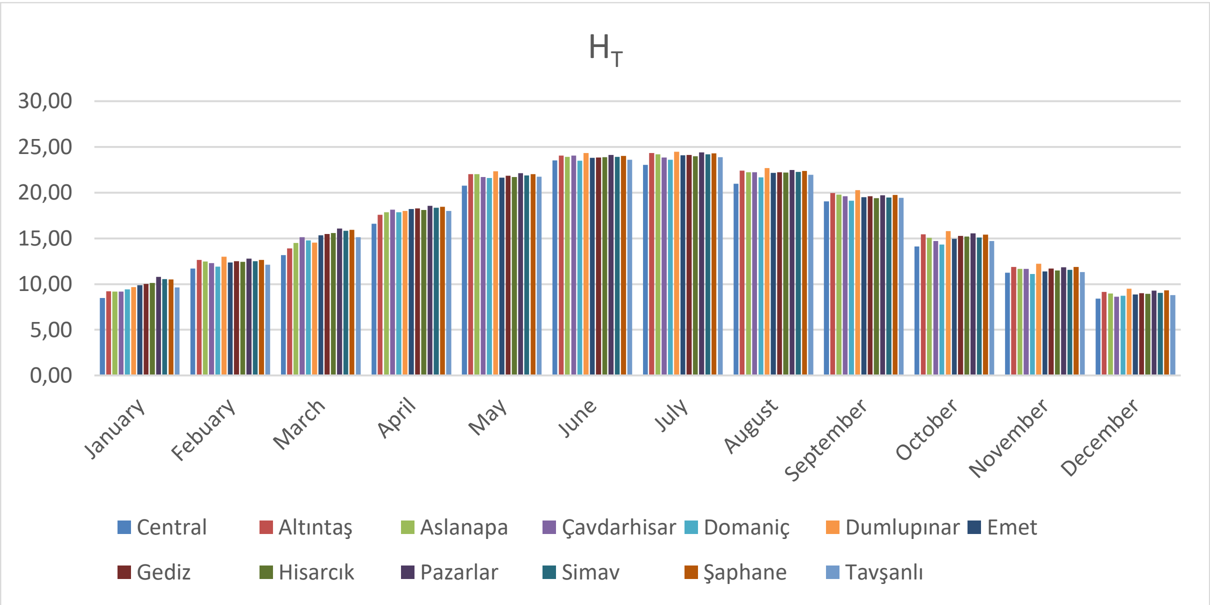

Figure 9. Kütahya province monthly average daily radiation amount coming to the optimum inclined plane (MJ / m^2.day)

5. DISCUSSIONS

The importance of renewable energy systems is increasing day by day in the world and in our country, which is dependent on foreign energy in terms of energy. It is important to use renewable energy sources in the most efficient way. One of the most important renewable energy sources is solar energy. In order to benefit from solar energy in the most efficient way, it is necessary to follow the constantly changing angles of sunlight due to orbital motion. For this purpose, photovoltaic systems with a solar tracking mechanism can be built or panels can be positioned to have the optimum tilt angle.

In this study, optimum tilt angles of the districts of Kütahya province were calculated for solar energy systems. Taking the calculated values into account, solar energy systems can be utilized to the maximum. The method used in the calculation can be applied to specific locations in our country, where the importance of solar energy systems is constantly increasing.

Declaration of Ethical Standards

The authors of the paper submitted declare that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

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