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RESEARCH ARTICLE

Optimization of the Tilt Angle of Solar Panels for Seven Cities in Türkiye

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ABSTRACT

Türkiye occupies a crucial position in harnessing solar energy due to its solar radiation and duration of exposure to the sun. To maximize energy yield from solar power, photovoltaic panels must be inclined at an optimum angle relative to the sun's position. This study employs the photovoltaic geographical information system program to determine monthly, seasonal, and annual optimum panel tilt angles for seven selected cities in Türkiye. By utilizing this data, adjustments can be made to the panel tilt angle to optimize energy production. This research contributes to advancing solar energy utilization in Türkiye and similar regions, facilitating sustainable energy generation. The results indicate that adjusting the panel tilt angle seasonally and monthly is more profitable compared to using the same panel tilt angle throughout the year. This profitability increases to 4.20% with seasonal adjustments and can reach up to 5.05% with monthly adjustments. While the seasonal and monthly adjustments of panel tilt angles have the most significant impact on Bartın, they have the most negligible impact on Kastamonu. These findings underscore the importance of location and tilt angle selection when establishing solar energy facilities to assess Türkiye's and neighboring countries' solar energy potential.

Index Terms—Maximum energy production, optimum tilt angle, PVGIS, photovoltaic panels

I. INTRODUCTION

In recent years, a growing global concern for the environment has led to increased research and practical applications in renewable energy and energy-saving technologies [1]. Solar energy has an essential place in meeting the rapidly growing energy needs around the world. Since fossil fuels have limited reserves and bring about global problems such as climate change and air pollution, the popularity of photovoltaic (PV) systems is increasing daily due to their applicability in various areas, low maintenance and operation costs, and long lifetime [2].

The ratio of solar energy to the total energy produced between 2018 and 2022 is shown in Table I for the world and Türkiye. In 2018, the total energy produced worldwide stood at 26 174.37 TWh. In 2022, this production reached 28 660.98 TWh. In Türkiye, the total energy production has been 303.86 TWh in 2018, rising to 326.11 TWh by 2022 [3].

Photovoltaic panels provide the utilization of solar energy for electricity production. Photovoltaic (PV) technology is proving to be a simple and efficient method for utilizing solar energy to generate electricity [4]. The panels contain solar cells. These cells consist of semiconductor materials and convert solar energy into current.

The energy obtained is directly proportional to the intensity of sunlight reaching the panel surface [5].

Standard PV panels' efficiencies vary between 16% and 22% [6]. Several factors affect the efficiency of PV panels, including temperature increases and panel overheating [7], accumulation of dirt on the panel surface [8], and low absorption of solar radiation due to sun rays scattering. There are several techniques to improve the efficiency of PV panels [9]. One of these methods is to reduce the panel's temperature by spraying water onto the PV surface [10]. Another method is to collect a high amount of sunlight and direct it onto the panel using concentrators created with optical lenses and mirrors [11].

The last method that can be applied to obtain maximum efficiency from PV panels is to change the panel tilt angle at specific intervals. This method increases the time that the sun's rays come vertically.

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TABLE I.
THE RATIO OF SOLAR ENERGY TO THE TOTAL ENERGY

	2018	2019	2020	2021	2022
World	2.20%	2.66%	3.23%	3.78%	4.61%
Türkiye	2.57%	3.05%	3.59%	4.18%	4.88%

In Chandel and Chandel's study, a performance analysis has been conducted for a 19-MWp solar power plant in India using fixed-tilt, seasonal adjustable-tilt, and horizontal single-axis solar tracking configurations. According to this analysis, the annual energy produced by the fixed-tilt configuration has been 6.0% less than that produced by the seasonal adjustable-tilt configuration and 15.4% less than that produced by the horizontal single-axis solar tracking configuration. When the average costs have been examined, the fixed-tilt configuration was found to be 8.0% cheaper than the seasonal adjustable-tilt configuration and 176.1% cheaper than the horizontal single-axis solar tracking configuration [12].

Gonul et al. has been study conducted on the results of manually adjustable tilt mechanisms for six provinces in Türkiye with different solar characteristics. According to this study, the discounted payback period with a manually adjustable tilt mechanism shortens by 8–10 months [13].

In Benghanem and Joraid's study, mathematical equations obtained from empirical observations have been utilized. The research proposes that the annual optimum tilt angle for the Medina region in Saudi Arabia is approximately equal to the region's latitude. Furthermore, it argues that the energy obtained based on the monthly optimum tilt angle is about 8% greater than that obtained based on the annual optimum tilt angle [14].

Khorasanizadeh et al. have calculated the fixed monthly, seasonal, semi-annual, and annual optimum tilt angles for solar panels in the Tabass region of Iran. The monthly optimum tilt angle ranges between 0° and 64°, with the annual optimum tilt angle at 33.6°. It has emphasized that the optimum yearly tilt angle closely aligns with the latitude of the Tabass region. The study utilized a mathematical model to predict horizontal irradiance [15].

Main Points

- In Turkey, the production of electricity from solar energy is steadily increasing, with the tilt angle of panels proving to be a significant factor impacting energy production.
- The PVGIS, a satellite- interacted simulation program, provides insight into the average energy production at a given location based on the selected panel tilt angle.
- For seven cities in Turkey, annual, seasonal, and monthly optimal panel tilt angles have been computed using the PVGIS.
- The gains have been calculated by comparing the energy production quantities at annual, seasonal, and monthly panel tilt angles.

Koçer et al.'s study in Ankara and its districts recommend adjusting the tilt angle of solar panels at least once a month or at least twice a year to enhance their efficiency. The study utilized a mathematical model to calculate the tilt angle, and a program based on Visual Studio has developed to facilitate the calculations for the desired district [16].

In Dal's study, the PVGIS program has been used for radiation values, and the Hottel-Woertz method has been applied to calculate tilt angles. The study demonstrated that it would be appropriate to reposition solar panels in Kayseri by changing the tilt angle twice a year [17].

In this article, annual, seasonal, and monthly optimum panel tilt angles have been calculated for seven selected cities from Türkiye—Ankara, Bartın, Kastamonu, Karabük, Zonguldak, Çankırı, Kırıkkale—using the PVGIS simulation program.

The accuracy of the PVGIS method has been confirmed by comparing the optimum tilt angles determined by the Hottel & Woertz mathematical method in the literature, particularly in Ankara. This analysis has been thoroughly examined, focusing on the profitability of changes in annual, seasonal, and monthly tilt angles while considering parameters such as angle, production, and cost.

The article has significantly contributed to the effective design and optimization of solar energy systems by presenting the gains of changing the tilt angle of solar panels. In practical terms, market research regarding the adjustment of solar panel tilt angles has also been conducted.

Furthermore, electricity distribution companies play a crucial role in delivering the energy generated by solar power plants to the grid. The main aim of this study has been to contribute to the literature in the sector by determining the potential profit from energy production through changes in panel tilt angles across all provinces within the jurisdiction of Başkent EDAŞ, one of the 21 companies distributing electricity in Türkiye.

II. CALCULATION METHODS

PVGIS is a simulation program developed by the European Commission and provided to users free of charge. PVGIS performs calculations using satellite-interacted meteorological data. Utilizing a database, PVGIS simulates hourly, daily, monthly, and annual solar radiation values for different options based on the desired geographical location and panel tilt angle [18].

The power P [W] is calculated according to equations (1–4), depending on solar irradiance and panel temperature [18, 19].

$$P\left(G_T',T'\right) = G_T' \begin{pmatrix} P_{SCT},m + k_1 ln\left(G_T'\right) + k_2 ln\left(G_T'\right)^2 \\ + k_3 T' + k_4 T' ln\left(GT'\right) \\ + k_5 T' ln\left(GT'\right)^2 + k_6 T'^2 \end{pmatrix} \tag{1}$$

$$G_T' \equiv G_T / G_{SCT} \tag{2}$$

$$T' \equiv T_{mod} - T_{SCT} \tag{3}$$

$$\eta_{rel}\left(G_T',T'\right) \equiv P\left(G_T',T'\right) / P_{SCT}, mG_T' \tag{4}$$

Equations (1–4) provide the normalized total solar irradiance, G_T', and panel temperature, T', in degrees Celsius. The coefficients k_1 to k_6 are dependent on data measured by the European Solar Test Installation (ESTI) specific to the type of PV panel. The term P_{STC}, represents the maximum power [W] under Standard Test Conditions (STC).

Furthermore, in Equations (1–4), the term T_{mod} denotes the module temperature [°C], with G_{STC} = 1000 [W/m^2] and T_{STC} = 25 [°C] at STC, and η_{rel} signifies efficiency.

Milosavljević et al. [20] have compared experimental data obtained by a 2 kW PV system in Niš and estimated data obtained from 14 different PV tools (PVGIS, PVWatts, SolarGIS, RETScreen, BlueSol, PVsyst, HelioScope, PV*SOL, Solarius PV, Solar Pro, PV F-Chart, PolySun, SAM and HOMER). The highest deviation in annual electricity production compared to experimental data is obtained from the HOMER Grid (63.97%), with the lowest deviation coming from PVGIS 5 (0.21%). Considering the climatic features of Serbia and areas with comparable weather conditions, the PVGIS simulation yields more precise data for photovoltaic power production than other PV tools.

In Yigit's thesis, the energy production of a 1 MW solar power system in Ankara has been compared using PVsyst and PVGIS programs [21]. According to these results, the deviation rate of the annual total energy value obtained from PVsyst compared to the actual value has been calculated to be approximately 4.6%. For PVGIS, this deviation rate has been calculated to be 0.943% [21].

PVGIS simulation program considers six different parameters while calculating monthly energy production: PV technology, installed peak PV power, system loss, mounting position, slope, and azimuth [18].

This study assumes that a free-standing Crystalline Silicon PV panel with a system loss of 14%, an azimuth angle of 0 degrees, and an installed power of 1 kW is used. The tilt angle and location have varied, as indicated in Fig. 1, to calculate the desired optimum tilt angles and energy production.

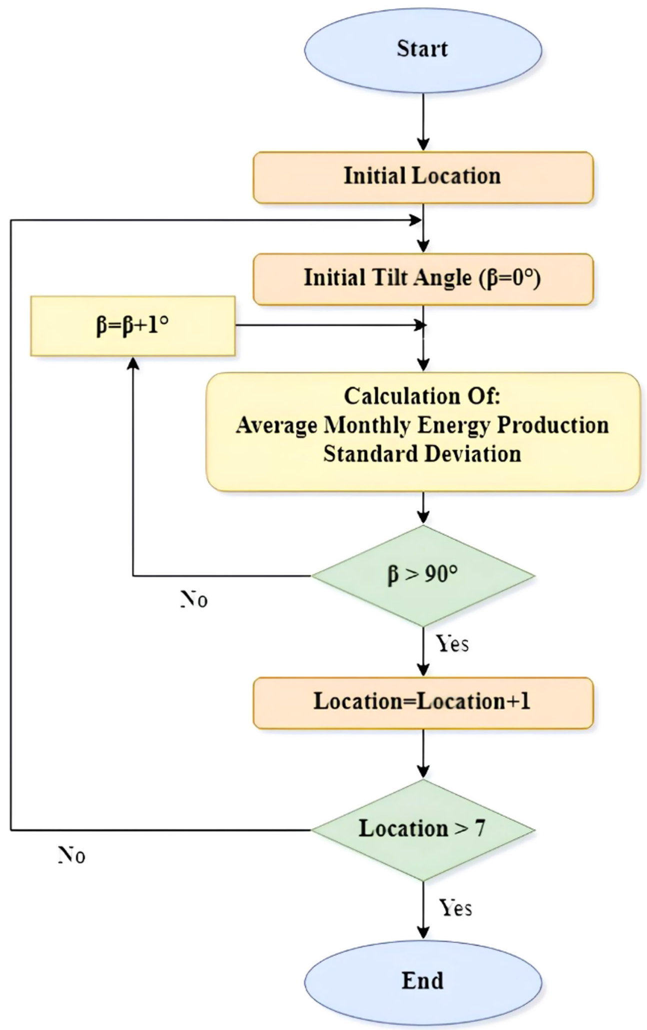

Fig. 1. Flowchart of calculation method.

III. RESULTS AND DISCUSSIONS

In order to determine the optimum panel tilt angle for maximizing production, six cities located in the inner and northern regions of Türkiye have been selected. These cities' geographical locations and latitude and longitude values are provided in Fig. 2 and Table II. The data extracted from the Koçer et al. study, where a mathematical approach has been utilized to compute annual, seasonal, and monthly tilt angles for Ankara, is systematically presented in Table III.

Upon comparing the results with the PVGIS simulation program, observable differences have been noted on an annual, seasonal, and monthly basis. The heightened precision of the PVGIS simulation program is attributed to its use of satellite-interacted meteorological data and its consideration of various parameters, such as system losses and panel type, in the calculation process. This observation leads to the assertion that, in contrast to the mathematical approach, the PVGIS simulation program provides superior precision results.

The PVGIS simulation program calculates each city's monthly energy production for tilt angles ranging from 0° to 90°. The optimum tilt angle (OTA (°)) for each month is determined as the angle at which the maximum energy production (MEP(kWh)) occurred during that month. To find the seasonal optimum tilt angle, the total production for the months within that season has been calculated, and the tilt angle corresponding to the maximum among these productions has been identified.

The 12-month production data for each tilt angle has accumulated to determine the annual optimum tilt angle, and the tilt angle at which the maximum production occurred has been calculated. This process was repeated for each of the seven cities; the results are presented in Table IV.

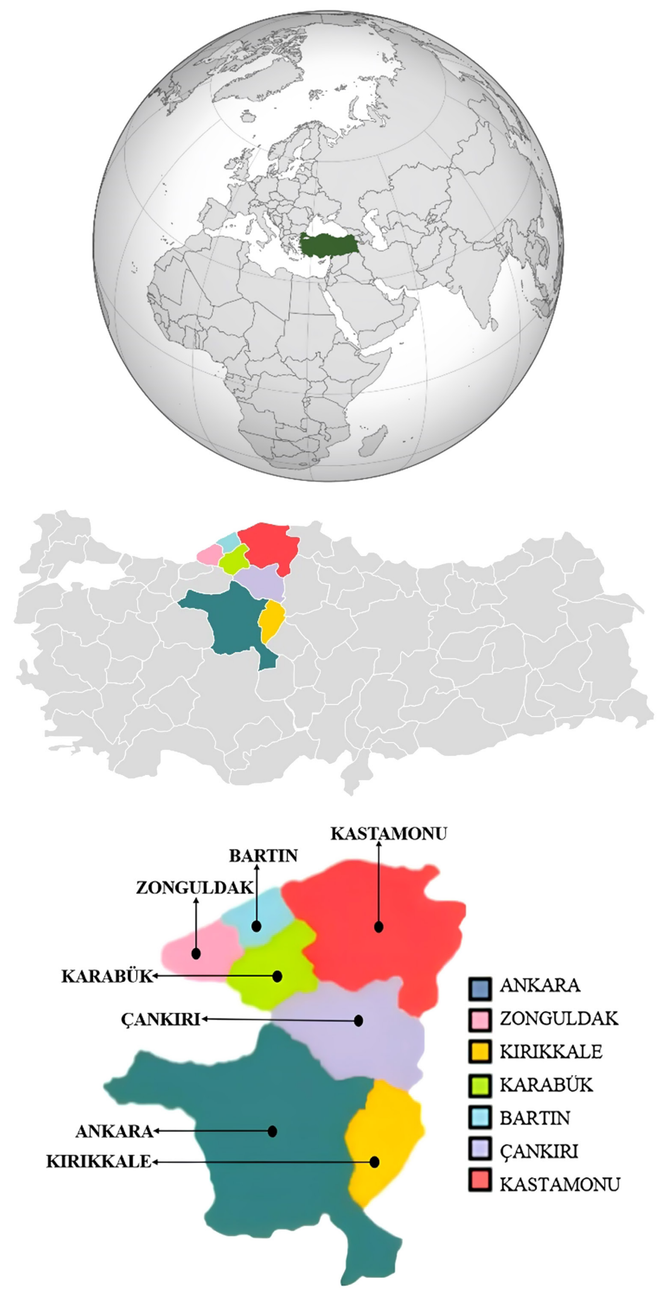

Fig. 2. Geographical locations of selected cities.

According to the PVGIS simulation for these seven cities annually, MEP (kWh) differs from city to city because of their longitude values and irradiance. The northmost city, Kastamonu, has a lower annual MEP (kWh), and the southernmost city, Ankara, has a higher annual MEP (kWh).

To maximize solar energy absorption, the sunlight must incident the solar panels at a perpendicular angle. During the winter, sunlight reaches the regions of these seven cities at a narrow angle, requiring an increase in the panel tilt angle to achieve a perpendicular alignment. As a result, as indicated in Table IV, the optimum tilt angle during the winter months fluctuates between 57° and 60°.

TABLE II.
LATITUDES AND LONGITUDES OF SELECTED CITIES

Cities	Latitude	Longitude
Ankara	39.926′	32.856′
Kırıkkale	39.836′	33.494′
Çankırı	40.583′	33.618′
Karabük	41.206′	32.634′
Kastamonu	41.377′	33.779′
Zonguldak	41.456′	31.788′
Bartın	41.627′	32.330′

On the other hand, since the angle of sunlight reaching the region of the seven selected cities is close to a perpendicular angle, the tilt angle of the panel is expected to decrease in summer. As anticipated, the optimum tilt angle in summer varies between 11° and 15°.

The optimum panel tilt angles obtained with the PVGIS simulation program in autumn and spring are greater than the angles calculated for summer and less than the angles calculated for winter. In autumn, for the seven selected cities, the optimum panel tilt angles range between 47° and 50°, while in spring, their range is between 25° and 28°.

Considering all seasons, Kastamonu generally has the lowest maximum energy production, and Ankara has the highest. Data analysis across winter, spring, summer, and autumn shows that the maximum energy production difference between these two cities is 2.69%, 1.24%, 1.07%, and 2.03%, respectively.

TABLE III.
OPTIMUM TILT ANGLES FOR ANKARA [19]

December	67°	Winter	62°	Annually	34°
January	64°				
February	56°				
March	41°	Spring	23°		
April	23°				
May	7°				
June	1°	Summer	6°		
July	3°				
August	17°				
September	34°	Autumn	49°		
October	51°				
November	62°				

TABLE IV.
ANNUALLY, SEASONALLY, MONTHLY OTA (°) AND MEP (KWH) IN SELECTED SEVEN CITIES

			Ankara	**Kırıkkale**	**Çankırı**	**Karabük**	**Kastamonu**	**Zonguldak**	**Bartın**
Yearly	Annually	OTA (°)	33	32–34	33–34	33–34	32–33	32–34	34
		MEP (kWh)	1460.4	1458.1	1402.2	1320.6	1269.9	1302.1	1315.0
Seasonally	Winter	OTA (°)	57–59	57–58	57–58	57–58	54–55	58–59	59–60
		MEP (kWh)	245.1	234.7	218.2	214	193	198	207.1
	Spring	OTA (°)	25–26	25–26	27	26–27	25–27	26–27	26–28
		MEP (kWh)	393.4	397	387.4	359.2	350	361.1	358.5
	Summer	OTA (°)	11–13	12–13	14	13–14	14–15	13–14	13
		MEP (kWh)	499.8	501.2	479.5	469.9	451.6	480.6	479.3
	Autumn	OTA (°)	48–49	49	49–50	48	47–48	48–49	50
		MEP (kWh)	376.1	378	365	321.1	312.4	306.5	316.8
Monthly	January	OTA (°)	57	57	57	57	57	57	58
		MEP (kWh)	73.6	69.1	60.8	63.8	55.8	60	61.8
	February	OTA (°)	50	51	51	52	49	51	53
		MEP (kWh)	89	89.4	85.3	81.1	78.7	70.8	73.8
	March	OTA (°)	40	40	40	37	37	38	39
		MEP (kWh)	116.9	119.3	116.4	103.5	102.2	97.6	98.5
	April	OTA (°)	23	24	24	26	25	26	26
		MEP (kWh)	134.8	135.4	131.9	124.7	121.7	125.2	124.1
	May	OTA (°)	10	11	12	14	12	12	13
		MEP (kWh)	146.8	147.7	144.1	134.9	129.9	142.3	140.1
	June	OTA (°)	4	5	4	6	6	6	5
		MEP (kWh)	159.2	161	154.8	146.6	141.9	156	153.9
	July	OTA (°)	7	8	8	10	9	10	8
		MEP (kWh)	177.3	176.5	167.6	168.1	159.1	169.4	168.9
	August	OTA (°)	20	21	22	22	22	22	24
		MEP (kWh)	166.1	166.5	159.6	157.7	153	157.7	159
	September	OTA (°)	36	36	36	36	37	36	37
		MEP (kWh)	146.2	146.9	141	130.3	125.6	125.7	127.9
	October	OTA (°)	50	51	51	49	48	48	50
		MEP (kWh)	123.6	126.4	121.2	105.4	102.3	98.8	102.2
	November	OTA (°)	61	59	60	58	57	58	60
		MEP (kWh)	110.8	109.1	107	88.7	87.7	85.4	90.5
	December	OTA (°)	63	62	61	62	59	61	64
		MEP (kWh)	83.1	76.7	72.6	69.5	58.8	67.7	72.1

The highest optimum tilt angle calculated with the PVGIS simulation program occurs in Bartın in December at 64°. The variation between optimum tilt angles in December is 59–64°. The lowest optimum tilt angle occurs in Ankara in June at 4°, and the variation between optimum tilt angles in June is 4° and 6°.

Examining the maximum energy production every month for Ankara, Kırıkkale, Çankırı, Karabük, Kastamonu, Zonguldak, and Bartın reveals that the difference between the month with the highest production and the month with the lowest production is respectively 140.89%, 155.39%, 175.66%, 163.66%, 185.33%, 182.33%, and 173.41%. Among these cities, Kastamonu exhibits the highest difference in energy production between months, while Ankara demonstrates the lowest.

The graph in Fig. 3 illustrates the variations in the optimum tilt angle calculated for seven selected cities, with specific attention given to the capital city, Ankara, the inner city of Çankırı, and the northern city of Bartın. Given Ankara's southernmost location, it displays a comparatively higher monthly angle variation than other cities. In contrast, Bartın, positioned in the northernmost part, exhibits a less curved trend, as observed in the graph.

The highest optimum tilt angle occurs in January, while the lowest optimum tilt angle is observed in June for all three selected cities. The highest optimum tilt angle is 57° for Ankara and Çankırı, while it is 58° for Bartın. The lowest optimum tilt angle is the same for Ankara and Çankırı, both being 4°, whereas it is 5° for Bartın.

The average monthly energy production amounts are provided in Fig. 4 for Ankara, Çankırı, and Bartın based on the monthly optimum panel tilt angle. The standard deviation depicted in Fig. 4 represents the variation in the highest and lowest average monthly energy production for that city in the respective month. The magnitude of the standard deviation illustrates the distribution of all average monthly energy production values corresponding to tilt angles ranging from 0° to 90°.

For example, in January, the minimum average monthly production for Çankırı occurs at 0° panel tilt angle with 37.8 kWh, while the maximum monthly average output occurs at 57° panel tilt angle with 60.8 kWh. According to Fig. 4, the standard deviation is higher in the winter and lower in the summer.

In examining seasonal average energy productions across the seven cities in Fig. 5, a noticeable reduction of output occurred as one moves northward in Türkiye, attributed to a decrease in radiation. The increased production during the summer and spring seasons are particularly significant, influenced by the extended duration of sunlight exposure.

Traditionally, the tilt angle of solar panels is determined using the latitude angle of the respective city. In this context, the total energy productions obtained by the PVGIS method based on the latitude angle for the examined seven cities are presented in Table V. Table V includes the total energy productions (TEP) calculated using annual, seasonal, and monthly optimum tilt angles and the increase ratio compared to the output calculated with the latitude angle.

The gain difference between using the city's latitude angle as the panel tilt angle and using the annually calculated optimum tilt angle with PVGIS is higher in northern cities but lower in inner cities presented in Table V. Table V includes the total energy productions (TEP) calculated using annual, seasonal, and monthly optimum tilt angles and the increase ratio compared to the output calculated with the latitude angle.

According to the decision announced by Türkiye's Energy Market Regulatory Authority (EPDK), the energy production unit cost in 2024 is determined to be a monthly average of 0.09 $/kWh [22]. When

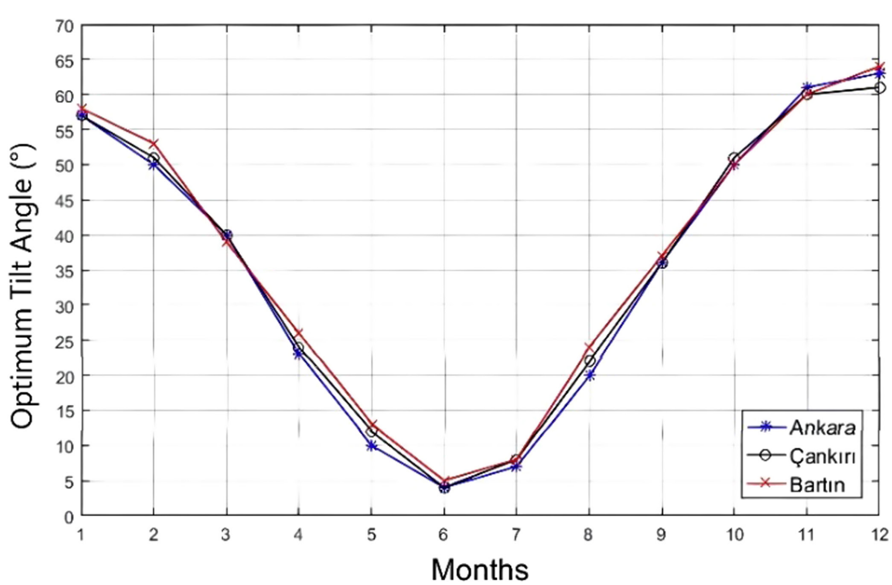

Fig. 3. Monthly optimum tilt angle changes for Ankara, Çankırı, and Bartın.

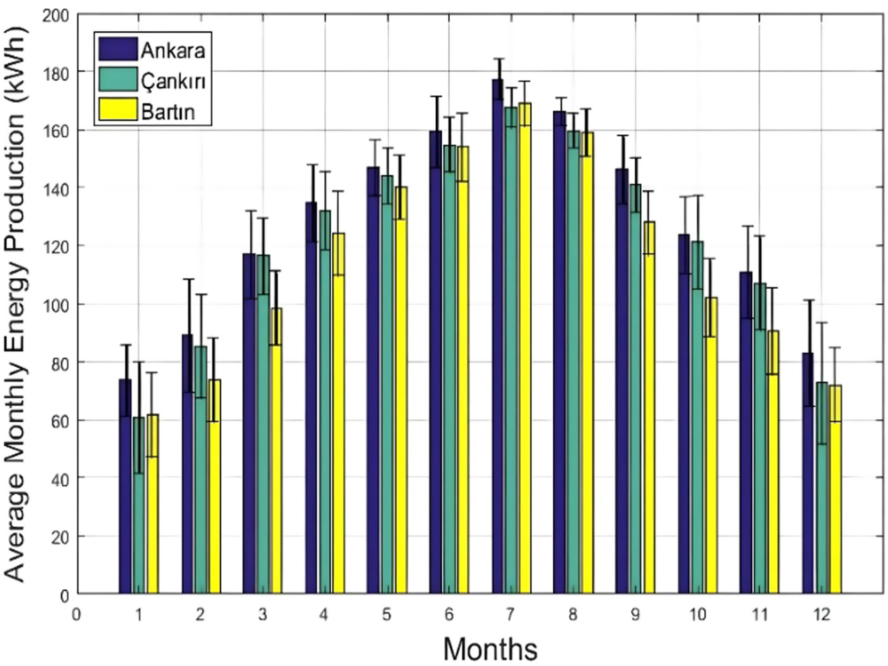

Fig. 4. Average monthly energy production for Ankara, Çankırı and Bartın.

the total energy production is calculated based on the current average gain and the optimum tilt angles for latitude, annual, seasonal, and monthly, the results are multiplied, and the resulting values are presented in Table V.

The gain difference between using the city's latitude angle as the panel tilt angle and using the annually calculated optimum tilt angle with PVGIS is higher in northern cities but lower in inner cities. The city with the highest gain difference is Kastamonu at 0.85%, while the city with the most inferior difference is Ankara at 0.38%. If the seasonally optimum tilt angle calculated with PVGIS is used as the panel tilt angle, a dramatic increase in gain is observed.

The difference between using the latitude angle as the panel tilt angle and using the seasonally optimum tilt angle as the panel tilt angle is the highest in Bartın at 4.2%, while it is lowest in Çankırı at 3.92%. The gain calculated based on the monthly optimum tilt angle calculated with PVGIS is slightly higher than that calculated

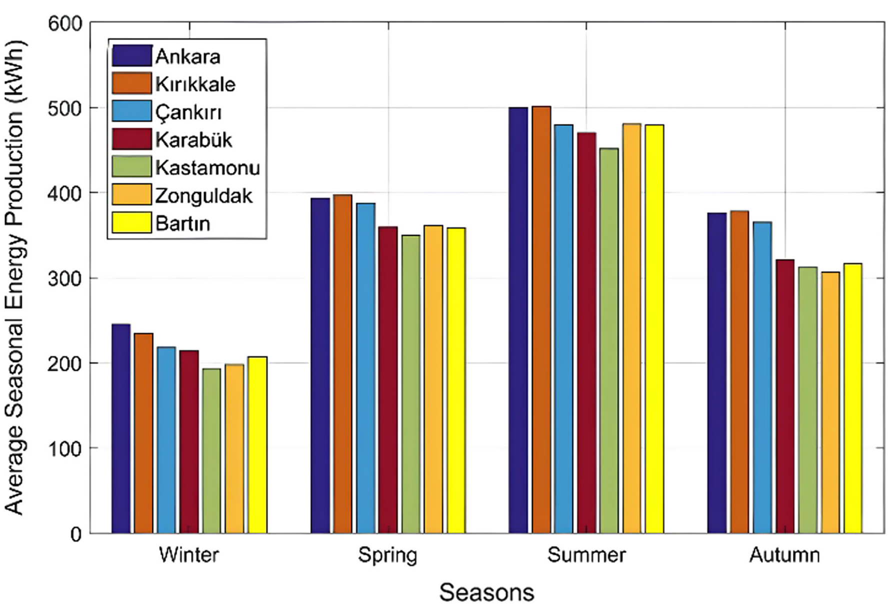

Fig. 5. Seasonal optimum tilt angles for PV panels and energy production potentials.

TABLE V.
ENERGY PRODUCTION POTENTIALS WITH LATITUDINAL, ANNUAL, SEASONAL AND MONTHLY OPTIMUM TILT ANGLES WITH GAINS

	Ankara	Kırıkkale	Çankırı	Karabük	Kastamonu	Zonguldak	Bartın
TEP with latitude angle (kWh)	1454.8	1452.2	1395.4	1311.6	1259.2	1292.3	1306.8
Gain with latitude angle ($/m2)	130.93	130.70	125.59	118.04	113.33	116.31	117.61
TEP with yearly OTA (kWh)	1460.4 (0.38%)	1458.1 (0.40%)	1402.2 (0.48%)	1320.6 (0.68%)	1269.9 (0.85%)	1302.1 (0.75%)	1315 (0.62%)
Gain with yearly OTA ($/m2)	131.44	131.23	126.20	118.85	114.29	117.19	118.3
TEP with seasonal OTA (kWh)	1514.4 (4.09%)	1510.9 (4.04%)	1450.1 (3.92%)	1364.2 (4.01%)	1307 (3.79%)	1346.2 (4.17%)	1361.7 (4.20%)
Gain with seasonal OTA ($/m2)	136.30	135.98	130.51	122.78	117.63	121.16	122.55
TEP with monthly OTA (kWh)	1527.4 (4.99%)	1524.0 (4.94%)	1462.3 (4.79%)	1374.3 (4.78%)	1316.7 (4.56%)	1356.6 (4.97%)	1372.8 (5.05%)
Gain with monthly OTA ($/m2)	137.47	137.16	131.61	123.69	118.50	122.09	123.55

based on the seasonally optimum tilt angle. Still, there is not as dramatic a difference between the gain from the latitude angle and the seasonally optimum tilt angle. Using the monthly optimum tilt angle as the panel tilt angle yields gain percentages of 4.99%, 4.94%, 4.79%, 4.78%, 4.56%, 4.97%, and 5.05% for Ankara, Çankırı, Kırıkkale, Karabük, Kastamonu, Zonguldak, and Bartın, respectively.

Numerical data has been shared regarding the calculation of the optimal panel tilt angle using the PVGIS simulation program for annual, seasonal, and monthly periods. Practical implementations in the literature have shown that different methods have also been used to determine the optimal tilt angle.

Daus and Yudaev's study has focused on the development of software designed to determine the optimal tilt angle of receiving surfaces [23]. By considering the intensity of solar radiation on variously oriented surfaces throughout the day, their program has aimed to enhance the utilization of solar energy potential over a specified period, reduce computation time, and improve decision-making effectiveness. The proposed computer program has the potential to be integrated as a structural element in designing microgrid systems, engineering facilities with solar energy modules, and both stand-alone and networked, rooftop or ground-based solar power plants [23].

Siraki and Pillay have worked on an urban application [24]. They have argued that new concerns, such as shading and sky obstruction effects, need to be considered. A simple method based on a modified sky model has been proposed to calculate the optimal installation angle for urban applications. The results obtained have shown that the optimal installation angle depends on latitude, weather conditions, and the surrounding environment [24].

IV. CONCLUSIONS

The main findings of this study, obtained by determining the annual, seasonal, and monthly optimum panel tilt angles using the PVGIS simulation program for seven selected cities in Türkiye and determining the maximum energy production amounts, are as follows:

- In the selected cities, using the optimum annual tilt angle calculated by PVGIS resulted in up to 0.85% higher energy production than using the latitude angle as the panel tilt angle. This difference was particularly noticeable in regions with higher latitudes.
- Seasonally adjusting the panel tilt angle can lead to a profit increase of up to 4.20%. Although the tilt angle value has a relatively minor impact on energy production during the summer months, a significant enhancement in efficiency has been observed during the winter months, mainly attributable to the latitude value.
- Adjusting the panel tilt angle monthly can increase profit by up to 5.05%. Considering the profit, cost, and workload considerations for the seven selected cities in this study, it is deemed more advantageous to change the panel tilt angle seasonally.
- Adjusting the panel tilt angles seasonally for these seven cities enables an annual profit of 4.94 $\$/m^2$. This rate is particularly significant in countries with high energy prices.
- It has been determined that adjusting panel tilt angles using mechanical methods is the most cost-effective approach, and PVGIS simulation program provides results closest to real field data.
- Future studies planned for this research aim to calculate the energy production efficiency of the panel by considering parameters such as humidity, altitude, and panel temperature. Based

on the selected sample cities, these calculations will be used to develop software that utilizes predictive modeling to calculate the annual, seasonal, and monthly optimum panel tilt for all of Türkiye.

Availability of Data and Materials: The data that support the findings of this study are available on request from the corresponding author.

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