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COMPARATIVE ANALYSES OF THE SOLAR ENERGY POTENTIALS OF GAZIANTEP, KONYA AND HATAY: A CASE STUDY FOR 1 MW OF PHOTOVOLTAIC SYSTEM

Gülsüm ZENGİN[a], Ali KOÇ[a], Sultan Büşra ARTAŞ*[b], Özkan KÖSE[a], Yıldız KOÇ[a], Hüseyin YAĞLI[c]

a Iskenderun Technical University, Hatay, Türkiye
b Necmettin Erbakan University, Konya, Türkiye
[c] Gaziantep University, Gaziantep, Türkiye
* busrartas@gmail.com

ABSTRACT
In recent times, there has been a rise in interest and research activities surrounding the topic of generating electricity from solar energy in our country. The installation of solar power plants has been increasing continuously, as a result of the numerous studies conducted to date. The purpose of this study is to compare various parameters for solar energy and 1 MW photovoltaic solar power plants in the provinces of Gaziantep, Konya and Hatay. Additionally, this study calculates and compares hour angles and azimuth angles for the provinces of Gaziantep, Konya, and Hatay on the 21st of June, which is generally the solstice of the year. This day marks the beginning of summer or winter, representing the time when the sun reaches its highest or lowest point of the year. Based on the calculations, the values for each province are as follows. Hour angles of provinces are 109.112° for Gaziantep, 109.703° for Konya and 108.508° for Hatay in 21st June. Azimuth angles of provinces are −60.101° for Gaziantep, −59.741 for Konya and −60.461° for Hatay in 21st June.

Key words: Solar Energy, Photovoltaic Panel, Solar Energy Potential, Renewable Energy

1. INTRODUCTION
The escalating demand for sustainable energy sources due to the increasing global need for energy has sparked an interest in clean and renewable energy sources such as solar energy. Solar energy is a universal resource, thanks to the sun's rays, providing the possibility of energy production regardless of geography. It has the highest potential for installation amongst other renewable energy sources, consequently enabling a wide range of applications and posing expansive development potential within the sustainable energy industry [1]. Furthermore, the continuous advancements in solar technology, coupled with decreasing costs of solar panels and increased efficiency, contribute to the growing feasibility and affordability of solar energy solutions. The embrace of solar energy is a pivotal step towards a cleaner and more sustainable future as the world collectively strives to reduce carbon emissions and combat climate change.

Solar photovoltaic energy technologies, originally used in space applications, are now viable in various locations where electricity is required. PV energy production is a well-founded and highly promising technology within the renewable energy sector [2].
The pressing issues of global warming and the fossil fuel crisis serve as compelling catalysts for advancing clean and renewable energy sources, with emerging photovoltaic (PV) technology identified as a highly promising alternative. Extensive research efforts have been dedicated to enhancing the power conversion efficiency of PV technology, leading to the widespread installation of numerous PV modules in recent decades [3].
This energy source holds significant strategic importance, particularly in areas with diverse geographic and climatic conditions, and should be considered in energy research and planning. Examining the latest decadal projection within our nation, renewable energy capacity increased by 171% from 69,249 GWh in 2013 to 118,555 GWh by the end of 2021. Examining the use of solar energy, it rose from 29 GWh in 2013 to 13,946 GWh by the end of 2021, aligning with the global trend. This trend has also been apparent in Turkiye [4]. Therefore, evaluating the potential for solar energy in different regions is crucial in determining regional energy strategies. The aim of this study is comparing the solar energy generation potentials of Gaziantep, Konya and Hatay provinces with certain parameters. It also aims to compare the parameters of 1 MW photovoltaic solar power plant using PVSYST program. The study analysed solar radiation data from Gaziantep, Konya, and Hatay provinces using information obtained from the Atlas of Solar Energy Potential. The performance statistics and 1 MW capabilities of the theoretically installed solar power plants were examined using the PVSYST tool. Furthermore, this study computes and contrasts the hour and azimuth angles for the regions of Gaziantep, Konya and Hatay on 21 June, which is typically recognized as the annual solstice. This event marks the beginning of either summer or winter and denotes the point at which the sun reaches its highest or lowest point of the year.

2. MATERIAL and METHOD

To achieve the main purpose of the research, solar radiation data in Gaziantep, Konya and Hatay provinces were carefully examined. Relevant data were obtained from the solar energy potential atlas. In addition, the 1 MW capacities and performance data of the solar power plants to be installed theoretically were analyzed with the PVSYST program. And geographical sites for mathematical calculations are given in following Table 1.

Table 1. Geographical situations of provinces

GEOGRAPHICAL SITES			
Province	**GAZIANTEP**	**KONYA**	**HATAY**
Atitude	37.06° N	37.87° N	36.21° N
Longitude	37.38° E	32.48° E	36.16° E
Altitude (m)	837	1034	93

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3. GENERAL OVERVIEW OF PROVINCES

3.1. GAZIANTEP

Gaziantep boasts abundant sunshine and minimal cloud cover. The pilot region for implementing the IRENA-developed SolarCity Simulator in our country is Sahinbey district in Gaziantep province. Our relevant institutions / organizations provided the required information which was sent to IRENA. IRENA has completed the 3D mapping of buildings in Sahinbey district. Within the project's scope, IRENA contributed to the development of a GIS-based software for designing and economically analyzing rooftop solar power generation facilities [5]. Objective analysis reveals that the city records peak radiation values of 6.78 kWh/m² per day in June [6]. Nonetheless, a discernible discrepancy arises when comparing PVSYST and GEPA data. Notably, July experiences the longest duration of sunshine. This figure amounts to 11.74 hours [6]. The following analysis of Gaziantep province values by PVSYST is presented in Table 2. Here, the global horizontal irradiation value of the province is recorded as 1903.2 kWh/m² annually. The highest daily recorded value of 8.19 kWh/m² was reached in June and July. The estimated annual clearness index is 0.635 Kt. Produced energy: 1,842,616 kWh year. Specific production: 1,841 kWh/kWp per year. Performance ratio: 84.21%.

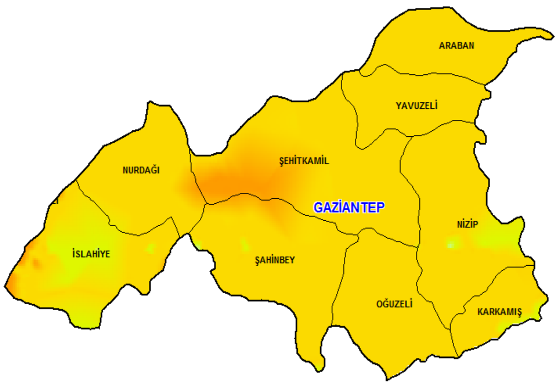

Figure 1. Solar energy potential atlas of Gaziantep province

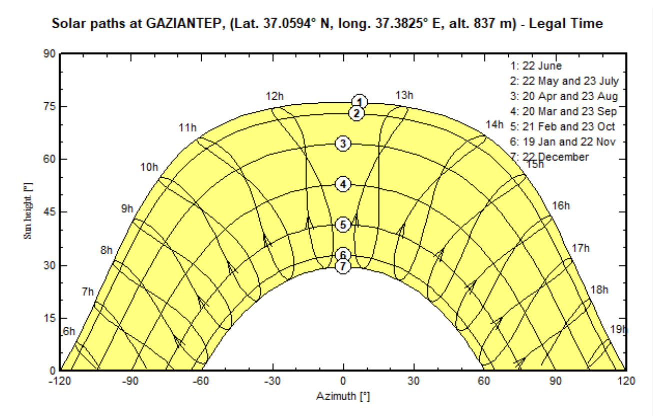

Figure 2. Variation of sun altitude according to azimuth angle of Gaziantep province

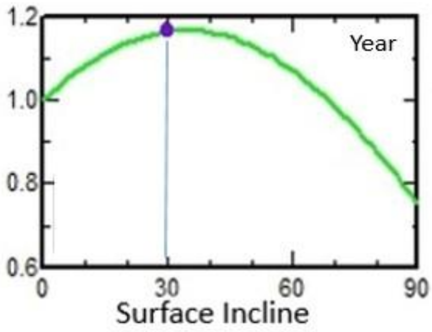

Figure 3. Annual transposition factor – angle graph of Gaziantep

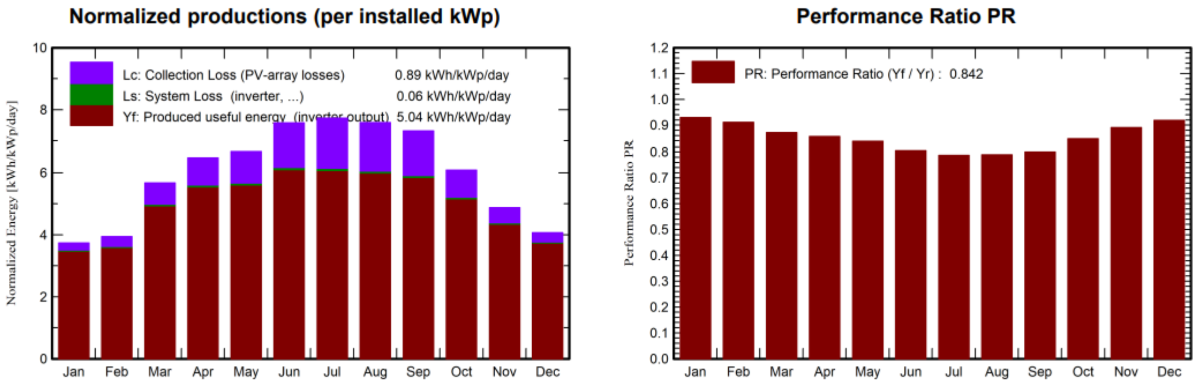

Figure 4. Normalized productions (per installed kWp) and Performance Ratio PR of Gaziantep

3.2. KONYA

Konya has a favorable potential for solar power plants owing to its vast lands and geographic features. According to the "2022 Activity Report" published by the Ministry of Energy and Natural Resources of the Republic of Turkiye, which details the Activities Conducted within the Scope of the Activity of Dissemination of the Use of Domestic Equipment in the Field of Energy Domestic and Renewable Energy Resources. As of December 24, 2022, the Konya-Karapınar project within the scope of YEKA SPP-1 (Karapınar YEKA-1 SPP) in Turkiye has achieved a total power of 1,000 Mwe [5]. Upon analyzing global radiation values, it was found that Konya receives its highest radiation value in July, with a measurement of 6.81 kWh/m² day. The month with the highest duration of sunshine is also July [6], reaching up to 11.97 hours [6]. The following table 2 presents an analysis of Konya province's values by PVSYST. Table 2 displays Konya's global horizontal irradiation value as 1759.1 kWh/m² per year, with the peak daily value reaching 7.46 kWh/m², occurring in June. Moreover, the annual clearness index stands at 0.592 Kt. The produced energy amounts to 1,721,597 kWh per year with a specific production of 1720 kWh/kWp year and a performance ratio of 85.73%.

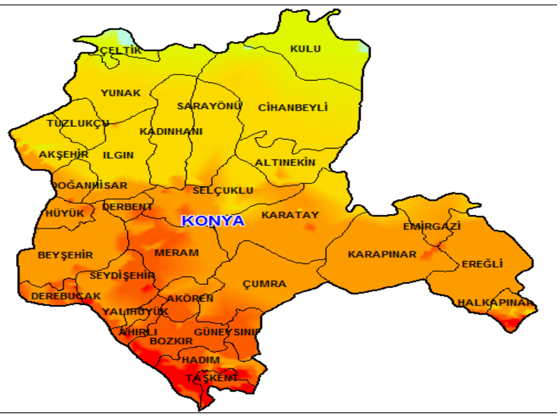

Figure 5. Solar energy potential atlas of Konya province

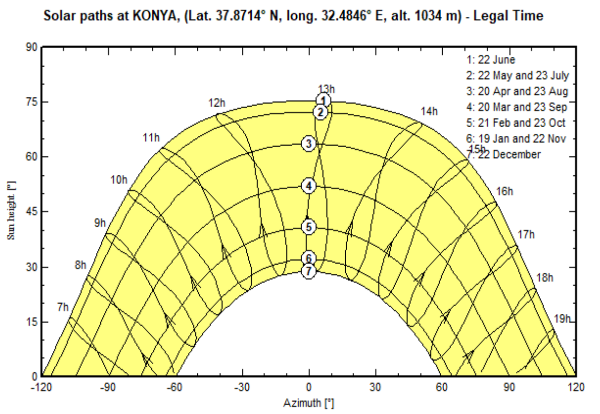

Figure 6. Variation of sun altitude according to azimuth angle of Konya province

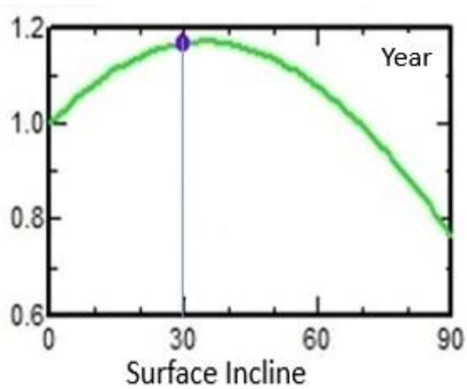

Figure 7. Annual transposition factor – angle graph of Konya

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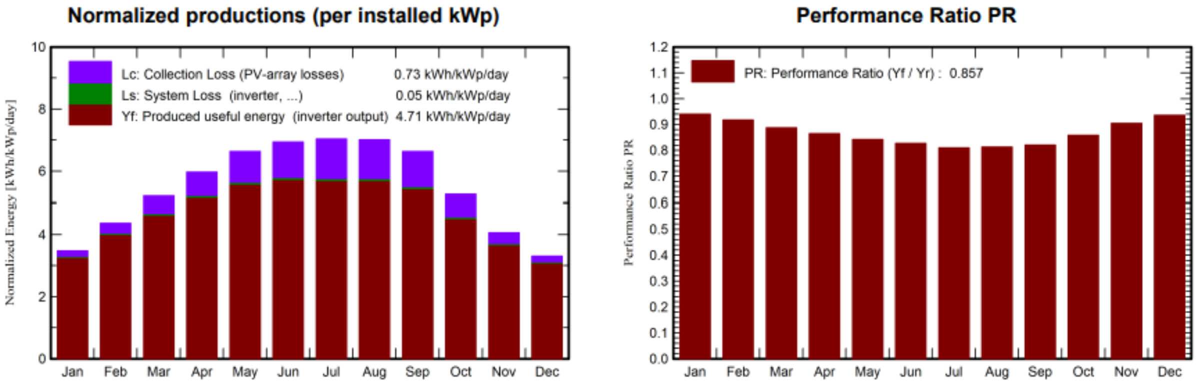

Figure 8. Normalized productions (per installed kWp) and Performance Ratio PR of Konya

3.3. HATAY

Hatay is notable for its elevated humidity levels and lower temperatures in coastal regions. Upon analysis of global radiation values, the month of June presents the highest radiation value for Hatay: measuring at 6.63 kWh/m² day [6]. In this same month, the region also experiences its longest duration of sunshine, which amounts to 11.14 hours [6].

The following table 2 presents an analysis of Hatay province values by PVSYST. Table 2 shows that this province's global horizontal irradiation value is 1781.7 kWh/m² per year. The highest daily value was recorded in June, at 7.77 kWh/m². The annual clearness index reached 0.589 Kt. The energy produced was 1694.67 kWh/year. The specific production was 1693 kWh/kWp/year. The performance ratio was 84.83%.

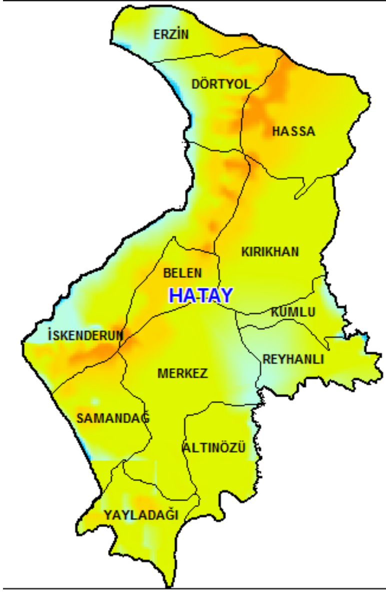

Figure 9. Solar energy potential atlas of Hatay province

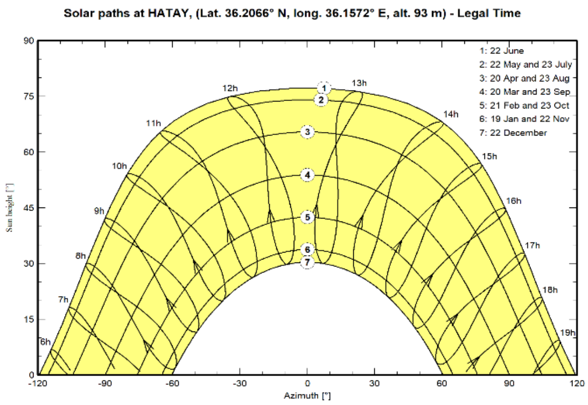

Figure 10. Variation of sun altitude according to azimuth angle of Hatay province

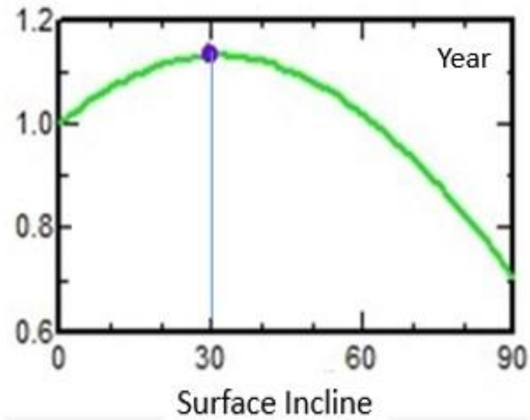

Figure 11. Annual transposition factor – angle graph of Hatay

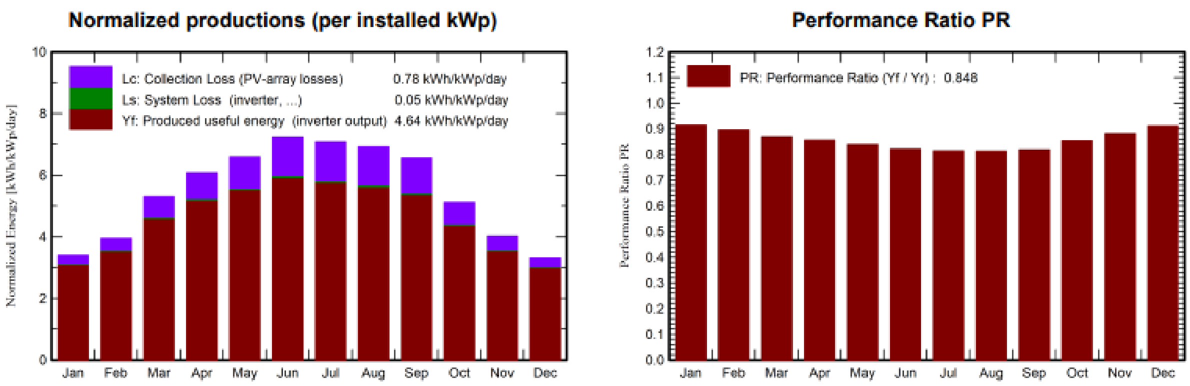

Figure 12. Normalized productions (per installed kWp) and Performance Ratio PR of Hatay

Table 2. Global Horizontal Irradiation (kWh/m²mth) per months and Clearness Index (Kt)

	Global Horizontal Irradiation (kWh/m²mth)			Clearness Index (Kt)		
	GAZIANTEP	**KONYA**	**HATAY**	**GAZIANTEP**	**KONYA**	**HATAY**
January	73.4	69.2	71.5	0.496	0.481	0.469
February	82.4	87.4	84	0.47	0.508	0.469
March	143.1	131.6	137.6	0.575	0.535	0.546
April	179.3	166.3	169.9	0.606	0.565	0.571
May	212.5	211.1	210.2	0.619	0.615	0.612
June	245.6	223.7	233	0.707	0.644	0.672
July	253.8	230.6	231.4	0.721	0.655	0.658
August	226.5	208.4	206.7	0.704	0.65	0.64
September	184	169.1	167.4	0.7	0.649	0.631
October	136.4	119.7	121.7	0.639	0.57	0.56
November	92.2	79.1	81.2	0.594	0.523	0.509
December	73.9	63.2	66.9	0.549	0.485	0.481
YEAR	**1903.2**	**1759.1**	**1781.7**	**0.635**	**0.592**	**0.509**

Table 3. Energy injected into grid of provinces (kWh)

	Energy injected into grid (kWh)		
	GAZIANTEP	**KONYA**	**HATAY**
January	107,824	101,387	96,298
February	100,604	112,199	99,291
March	153,347	143,459	142,803
April	166,583	155,068	155,969
May	174,036	173,402	171,517
June	183,338	172,371	178,186
July	188,673	176,875	179,08
August	185,966	176,863	174,505
September	175,784	163,456	161,154
October	160,081	140,201	135,811
November	130,529	110,388	106,608
December	115,852	95,927	93,406
TOTAL	**1,842,616**	**1,721,597**	**1,694,627**

4. DEFINITIONS AND MATHEMATICAL MODEL

4.1. Declination Angle (δ)

The declination angle refers to the angle that the sun rays make with the plane of the equator. This angle can be calculated in two ways, depending on the day. Equation 1 demonstrates these methods [7-8].

$$\delta = 23.45 \sin\left(360 \times \frac{(284+N)}{365}\right) \quad (1)$$

Here N refers to the number of days.

4.2. Hour Angle

The concept of hour angle is utilized when describing the Earth's rotation around the polar axis. Hour angle denotes the angular distance between the current location's meridian and the meridian of the sun's plane. Equation 2 can be utilized to obtain the hour angle ω_0 at the current position at 12:00 within the 24-hour time zone [8].

$$\omega_0 = cos^{-1}[-\tan(\delta)\tan(\phi)] \quad (2)$$

Here ϕ is the latitude angle. The hour angle of these three provinces was calculated according to the formula given above.

Gaziantep $\omega_{0G} = 109.112°$
Konya $\omega_{0K} = 109.703°$
Hatay $\omega_{0H} = 108.508°$

4.3. Azimuth Angle (A)

The azimuth angle, also known as the shading angle, represents the angular position of an object on the horizon with reference to the angle of incidence of the sun's rays from the north or south point. As Türkiye is situated in the northern hemisphere, sunlight arrives from the southern direction. Therefore, solar panels are typically oriented towards the south (azimuth = 0) [8-9].
To obtain the azimuth angle, the declination angle (δ), elevation angle (β), latitude angle (ϕ), and hour angle (ω) of the location must be known [7].

$$sin\beta = sin\delta\ sin\phi + cos\delta\ cos\phi\ cos\omega$$

$$A = sin^{-1}\left(\frac{-\cos\delta\ \sin\omega}{\cos\beta}\right) \quad (3)$$

The azimuth angle of these three provinces was calculated according to the formula given above. A_G is the azimuth angle value of Gaziantep; A_k is the azimuth angle value of Konya and A_H is the azimuth angle value of Hatay. And values are;

$$A_G = -60.101°$$

$$A_K = -59.741°$$
$$A_G = -60.461°$$

Table 4. Hour angles and Azimuth angles of provinces in 21st June

Province	GAZIANTEP	KONYA	HATAY
Hour Angle	109.112°	109.703°	108.508°
Azimuth Angle	−60.101°	−59.741	−60.461°

5. RESULTS

As a result of the analysis of the data obtained, some differences emerged between the solar energy production potentials of Gaziantep, Konya and Hatay. Climatic conditions, geographical location and topographic features specific to the provinces play an important role among the factors affecting solar radiation.

It is evident that Konya has the highest global radiation value. Although the values of Konya and Gaziantep are very close when comparing sunshine hours, Konya stands out when comparing overall values. Upon analyzing the global radiation values of Turkiye, it is observed that June has the highest radiation value of 6.57 kWh/m² day. Meanwhile, July has the highest duration of sunshine, which is 11.31 hours.

When comparing these three provinces with Turkiye's overall average, they all demonstrate higher global radiation values. However, Hatay falls below the national sunshine hour average. Upon examining all the data, it can be determined that Konya proves the most favorable region for solar energy.

The performance ratios indicate that Konya has the highest value following analysis using the PVSYST program.

This study compares the potential solar energy generation of Gaziantep, Konya, and Hatay, and provides valuable information for regional energy strategies. The results indicate that each province has unique advantages for solar energy projects. Therefore, it is crucial to formulate customized strategies for regional energy planning by considering the relevant provinces' characteristics.

Furthermore, this research conducts computations and contrasts hour angles as well as azimuth angles for the regions of Gaziantep, Konya, and Hatay on June 21st, typically recognized as the annual solstice. This occasion signifies the onset of either summer or winter, signifying the moment when the sun attains its zenith or nadir for the year. As a result of the calculations, it was found that the hour angles and azimuth angles of all three regions had very similar values to each other on 21st June.

In future research stages, it is advisable to conduct detailed analyses on developing proposals for enhancing the efficacy and efficiency of solar energy technologies, as well as investigating the impact of climate change on this potential.

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