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Experimental Investigation of Photovoltaic Panel Performance in Bingöl Province for Different Parameters

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Abstract: In the present study, an experimental research was conducted on the photovoltaic solar energy potential in Bingöl province. In the study, the electrical energy that the photovoltaic (PV) panel can produce hourly at an inclination angle of 39° and 45° and the panel surface temperature were investigated. The electrical energy that can be produced indoors and outdoors in winter conditions was calculated from the photovoltaic panel with 25 W power. It has been observed that the highest efficiency can be obtained at the 45° panel inclination angle. It has been concluded that while the average electric power produced at an angle of inclination of 45° is 9.68 W in outdoor conditions, it can be 1.22 W in indoor conditions. The data obtained will be an important reference in determining the panel size that will meet the consumption need and in the establishment of higher efficiency systems. It is stated that the payback period of grid-connected systems in provinces with high solar radiation such as Bingöl is 6 years on average. At the end of this period, it is clear that it will make significant contributions to both the landlords, the country's economy, and the environment in terms of reducing emissions.

Bingöl İli Fotovoltaik Panel Performansının Farklı Parametreler İçin Deneysel Olarak İncelenmesi

Anahtar Kelimeler
Bingöl,
Yenilenebilir enerji,
Güneş ışınımı,
Fotovoltaik panel,
Eğim açısı

Öz: Bu çalışmada Bingöl ilinde fotovoltaik güneş enerjisi potansiyeli üzerine deneysel bir araştırma yapılmıştır. Çalışmada, fotovoltaik (PV) panelin 39° ve 45° eğim açısında saatlik üretebileceği elektrik enerjisi ve panel yüzey sıcaklığı incelenmiştir. Kullanılan 25 W gücündeki panelden, kış şartlarında iç ve dış ortamda üretilebilecek elektrik enerjisi hesaplanmıştır. En fazla verimin 45° panel eğim açısında elde edilebileceği görülmüştür. 45° eğim açısında ortalama üretilen elektrik gücünün dış ortam şartlarında 9.68 W iken iç ortam şartlarında ise 1.22 W olabileceği sonucuna varılmıştır. Elde edilen veriler tüketim ihtiyacını karşılayacak panel büyüklüğünün tespitinde ve daha yüksek verimli sistemlerin kurulmasında önemli bir referans olacaktır. Bingöl gibi yüksek güneş ışınımına sahip illerde şebeke bağlantılı sistemlerin geri ödeme süresinin ortalama 6 yıl olduğu belirtilmektedir. Bu sürenin bitiminde, hem maddi yönden ev sahiplerine hem ülke ekonomisine hem de emisyonların azaltılması hususunda çevreye önemli katkılar sağlayacağı açıktır.

1. INTRODUCTION

Energy will be one of the most important issues on which research will continue as long as human life continues. As a matter of fact, it is the most important parameter required to meet the basic needs of human beings. According to TEİAŞ 2022 data, 197536.2 GWh of the total 326014.8 GWh electricity produced was produced from thermal power plants and 128478.6 GWh from renewable energy sources (hydraulic, geothermal, wind, solar) [1]. As can be seen, 61% of the annual electricity produced in Turkey is produced from thermal power plants, that is, fossil fuels, while the remaining 39% is produced from renewable energy sources. According to the same report, Turkey purchased 6414 GWh of electricity from foreign countries in 2022. On the other hand, 72536.1 GWh of energy, which is 36%

of the electrical energy produced from fossil fuels, was produced from natural gas [1]. Considering that the majority of natural gas is purchased from foreign countries, it is obvious that the importance to be given to renewable energy sources in our country should be increased. In addition, hard coal, lignite, liquid fuels and natural gas are used as fossil fuels in Turkey. Since the fossil fuels are about to run out and pollute the nature, use of them should be terminated and renewable energy resources should be expanded instead.

Renewable energy resources are more advantageous than fossil fuels in terms of being cleaner, cheaper, and unlimited resources, except for the initial cost [2]. The main renewable energy sources used in Turkey are hydraulic, geothermal, wind, solar and wave energy [3-8]. In addition, hydrogen energy, on which research has been intensified recently can be included in the class of clean and renewable energy sources, especially in terms of the fact that it can be obtained from both water and the sun, and only water is released as a result of combustion [9, 10]. One of these renewable energy sources, hydraulic energy sources known as hydraulic power plants (HES) cannot be said to be completely harmless for the environment. As a matter of fact, there are cases where many residential areas and forests are damaged in many HES regions. On the other hand, wind and wave energy is not the type of energy that can be obtained for every region of Turkey. In order to obtain the necessary efficiency from wind energy, continuous winds must blow at a speed of at least 5 m/s for most of the year in the region where the power plant will be established. This condition is provided only in a few provinces. Similarly, wave power plants can be installed on sea coasts with high tides. However, solar energy is not like that. Turkey is one of the luckiest countries in terms of solar energy. As it can be understood from the "Turkey Solar Energy Potential Map" taken from the website of the Turkish Ministry of Energy and Natural Resources, there is solar radiation in the amount of 1400-1450 kWh/m^2-year even in the region with the lowest solar radiation (Figure 1). In addition, the annual total sunshine duration in our country is 2741 hours, and the average annual radiation value is determined as 1527.46 kWh/m^2. From Figure 1, the average annual radiation value of Bingöl is in the range of 1500-1700 kWh/m^2 and it is understood that it is one of the leading provinces in terms of solar radiation [11]. As can be seen from Table 1, the total installed solar power in Bingöl province is 1487.5 MW. 14 MW of this is under construction and 260 MW is in the planning stage [12]. The hybrid GES (solar power plant) installed in Bingöl has a power of 500 MW and constitutes only 33% of the total installed power [12]. In Figure 2 and Figure 3, examples of solar power plants installed in Bingöl province are given [13, 14].

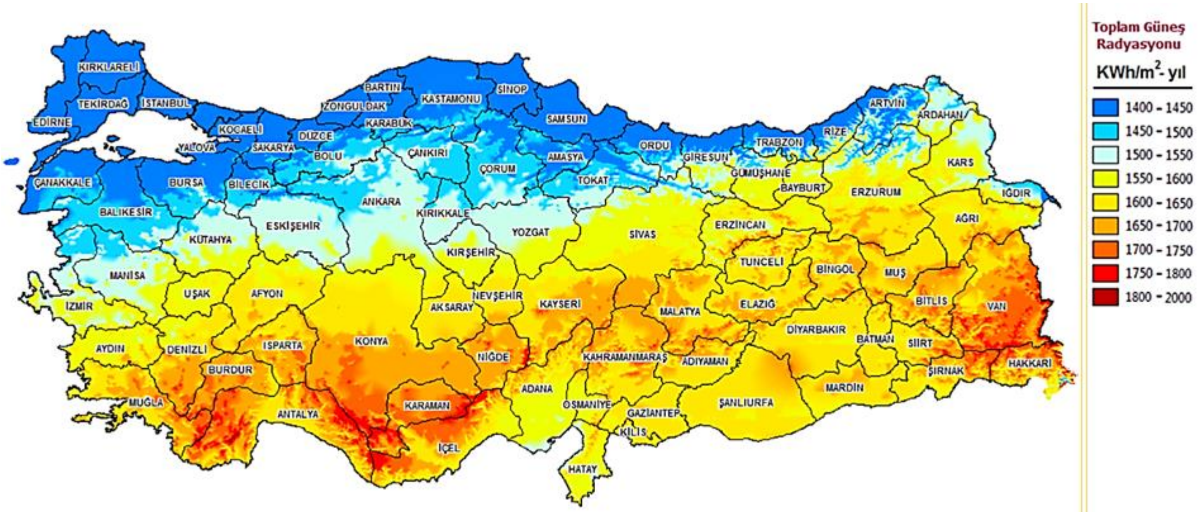

Figure 1. Turkey Solar Energy Potential Atlas [11].

Table 1. Installed capacity of existing renewable energy enterprises in Bingöl province [12].

Installed Energy	Capacities (MW)
Yukarı Kaleköy Dam and HES	627
Aşağı Kaleköy Dam and Hybrid GES	500
Özlüce Dam and HES	170
Kiğı Dam and HES	138
Yedisu HES	23
Saf 1 HES	16
Doğu HES	10
Metaphor Wind Power Plant (RES)	3.50
Grand Total	**1487.5**

Although Turkey is a lucky country in terms of solar energy, it is understood that it does not benefit enough from this energy in practice. As a matter of fact, although the importance of solar collectors is obvious in most academic studies, solar collectors are not used in some buildings today with the excuses that they damage the building statics. The sacrifice of solar energy to such rent-seeking activities reveals the fact that the importance of renewable energy is not fully understood.

Figure 2. Aşağı Kaleköy hybrid solar power plant (Genç/Bingöl-500MW) [13].

Figure 3. Solhan GES (Solhan/Bingöl-4MW) [14].

Many studies are carried out by those who are aware of the importance of solar energy in our country. When the studies were examined, the importance of the effect of different panel angles on yields was clearly observed. As a matter of fact, ensuring that the sun's rays come as perpendicular to the panel as possible will ensure that the results are more efficient. In this respect, studies on testing different angles and determining the optimum angle in provinces with different latitudes and longitudes are important. In the study of Keskin et al. (2019), the performance analysis of the relevant province was carried out in the model established using the V6.78 version of the photovoltaic panel PVsyst program in the province of Niğde. There was a 1.72% difference between the data obtained from the model and the actual data. A total annual installed power of 1994.8 kWh was achieved. The values obtained in the case of the panel angle of 33° were higher than the values obtained in the case of 10°. It is understood that better results are obtained at an angle close to the 37° latitude of the relevant location [15]. Atlım et al. (2019) compared two solar energy systems placed differently in Balıkesir on the basis of daily and monthly data. According to the results obtained from monocrystalline and polycrystalline solar energy systems, it was stated that the panel angles significantly affect the efficiency. In the related study, it was determined that the results obtained for the solar energy system with 27° angle were higher than the system with 9° panel inclination, and the best result was 29° panel angle according to the simulation program. [16]. Güven (2022) investigated the panel performance and its relationship with panel surface temperature for one year data in his study in Denizli. In the study, it is mentioned that the panel performance decreases by 0.3% for every 5 °C temperature increase on the panel surface [17]. Yıldırım and Aktacir (2021) investigated monthly average performance and panel surface temperature values for mono-Si, p-Si and CdTe type panels in Şanlıurfa. They explained that 345 kWh, 311 kWh and 234 kWh energy are produced in the unit area per year from Mono-Si, p-Si and CdTe type panels, respectively [18]. Kabul and Duran (2014), in their PV/T study in Isparta province, reduced the increased panel temperature by using cold water pipes, thus providing an efficiency increase of up to 7% and a power increase of 31% in the PV panel. In addition, they obtained hot water by using the heat from the hot panel surface. While the temperature of the uncooled panels was 95 °C in July, the surface temperature of the water-cooled panel was measured as 55 °C on average [19]. Kerem et al. (2020) investigated the effect of cooling the panel surface with water on the panel performance at Osmaniye Korkut Ata University Engineering Faculty. In the said study, an increase of 14% was achieved in the panel efficiency [20].

As it is understood from the studies carried out, it is necessary to determine the optimum working angles of each province with different latitudes in order to ensure the right angle to the panel surface. On the other hand, it is understood from the literature researches that such national studies were carried out for a limited number of provinces. Therefore, more studies are needed to form a general opinion in this area. In this study, the performance of photovoltaic panels at different angles has been investigated in the case of both indoor and outdoor use in Bingöl province. It is aimed to determine the best angle in Bingöl province by taking results for different angles.

2. MATERIAL AND METHOD

Bingöl province, with a surface area of 8125 km², is located in the Upper Euphrates section of the Eastern Anatolia Region. It is located between 38°27' and 40°27' east longitudes and 41°20' and 39°54' north latitudes. The central district of Bingöl has an altitude of 1125 m. The province has a climate that is hot in summers and very cold in winters with its altitude and cool air mass coming from the north. The annual average temperature is 12.1 °C and the annual average precipitation is 873.7 mm [21]. As stated in Turkey's solar map data, the annual sunshine duration of Bingöl province is 2719 hours and the annual radiation value is 1592 kWh/m^2 [22]. The annual solar radiation map by district is given in Figure 4.

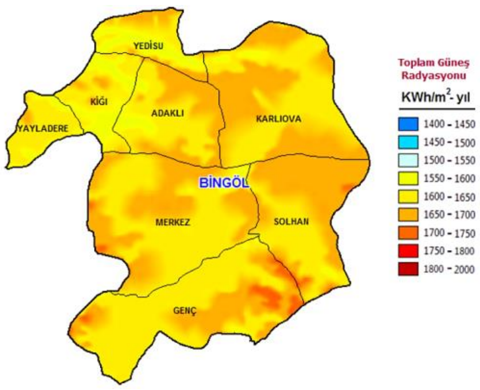

Figure 4. Solar radiation in Bingöl province [21].

The variation of daily radiation values according to months in the Central district of Bingöl province is given in Figure 5. According to Figure 5, while the months with the lowest solar radiation are December and January, the months with the highest solar radiation are June and July. The months with the highest and lowest sunshine duration are the same (Figure 6). In January, when the experiments were carried out, the daily average solar radiation was 1.83 kWh/m^2 (Figure 5) and the average daily sunshine duration was 4.14 hours (Figure 6).

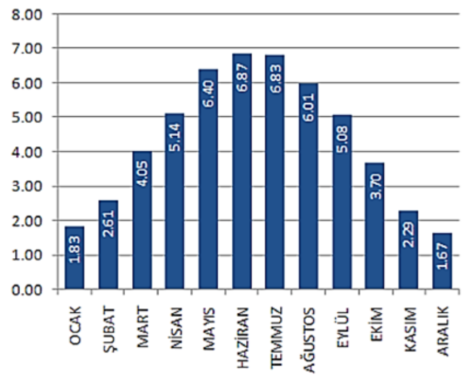

Figure 5. Global radiation values according to months (kWh/m^2-day) in the central district of Bingöl province [23].

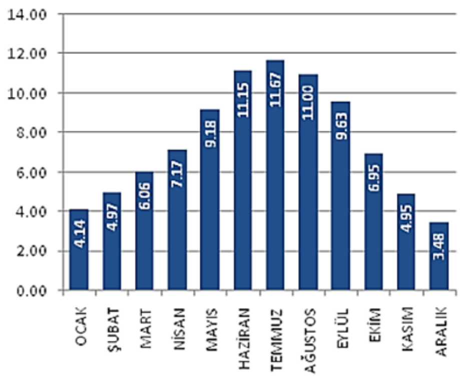

Figure 6. The daily sunshine duration (hours) according to the months in the Central District of Bingöl Province [23].

The electrical energy that can be produced varies according to the type and size of the solar panel used. As seen in Figure 7, the highest amount of energy is obtained from monocrystalline panels. Next come polycrystalline panels. Monocrystalline panels work much better in high-temperature environments and low-sunlight environments. In addition, monocrystalline solar panels have the highest efficiency of 15-20%. Compared to other panel types, they are more durable and have a longer lifespan of approximately 25 years. Monocrystalline solar panels consist of a single crystal, while polycrystalline panels consist of many crystals. While polycrystalline panels have lower efficiency (12-16%) than monocrystallines, their prices are cheaper. Polycrystalline solar panels perform much better in low temperature environments. Especially in cold countries, polycrystalline solar panels are preferred [24, 25]. For this reason, we preferred the monocrystalline solar panel, which has a longer life and high efficiency, in our study.

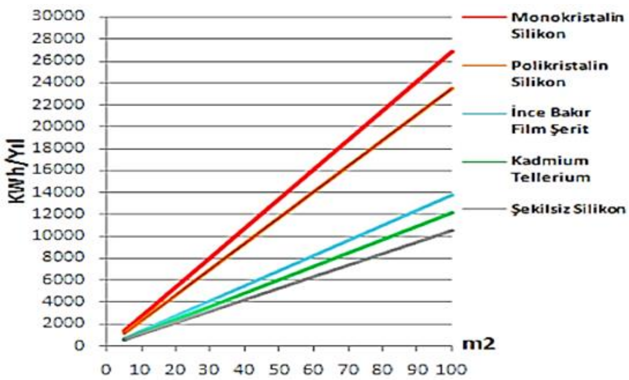

Figure 7. The annual amount of energy that can be produced (kWh-year) according to the type and area of the solar panel for the Central District of Bingöl province [23].

The experiments were carried out on sunny days in January. Hourly electrical power produced by photovoltaic panels in indoor and outdoor environments in Bingöl province was compared. The indoor environment experiment was carried out in the Fluid Mechanics Laboratory of the Mechanical Engineering Department of Bingöl University. The panel was placed in front of the sun-facing window in the laboratory as seen in Figure 8a. The outdoor experiment was carried out on an empty land in the city, away from the buildings, receiving direct sunlight (Figure 8b).

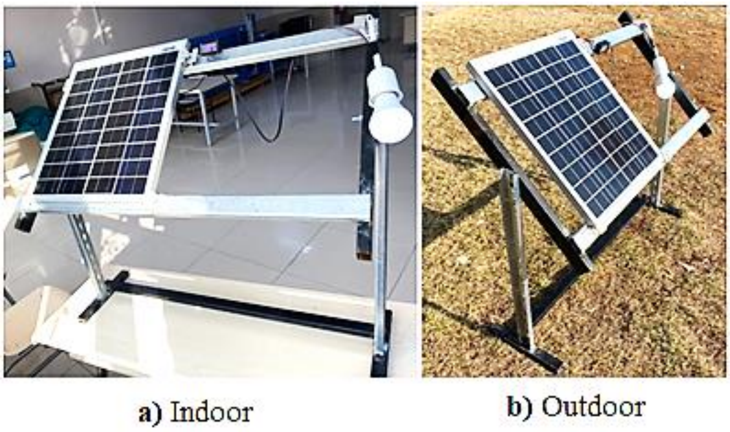

Figure 8. Experiment set set up for indoor (a) and outdoor (b) environments

Voltage and current values were read by connecting a voltmeter to the panel output. Panel surface temperature and ambient temperature measurements were made with a Cem brand 4-channel datalogger. In addition, a 9-Watt light bulb is connected to the panel output, and current output is provided. In the experiments, Lexron brand monocrystalline solar panel measuring 362 mm x 433 mm x 20 mm and a power of 25 W was used. The technical specifications of the solar panel used are given in Table 2. The solar panel has an area of 0.16 m^2 as calculated in Eq. 1. An angle-adjustable footrest is manufactured to place the panel. The photovoltaic panel is adjusted to 39° (Latitude angle of Bingöl province) and 45° angles in indoor and outdoor environments (Figure 9). One hour measurements were taken at different angles in the indoor and outdoor environments at noon when the sun comes vertically. Data were read at 2-minute time intervals.

$$\textit{Area of Solar Panel (A)} = 0.362 \text{ m x } 0.433 \text{ m} = 0.16 \text{ m2} \quad (1)$$

Table 2. Technical specifications of monocrystalline solar panel.

Power (W)	25
Number of Cells	36
Open Circuit Voltage (V)	24.84
Max. Voltage (V)	20.70
Short Circuit Current (A)	1.27
Max. Current (A)	1.21
Max. System Voltage (V)	1000
Module Dimensions (mm)	362*433*20
Weight (kg)	1.68

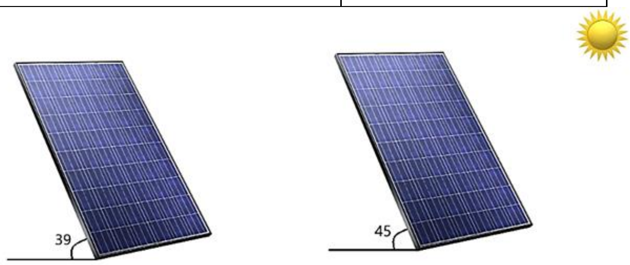

Figure 9. Photovoltaic panel inclination angles.

The average amount of power (P_{ave}, W) that can be obtained from a 25 Watt solar panel is equal to the multiplication of the average current (I_{ave}, amper) and the average voltage (V_{ave}, volt) in the panel (Eq. 2) [26, 27].

$$P_{ave} = I_{ave} \text{ x } V_{ave} \text{ (W)} \quad (2)$$

The total amount of energy (YE, W) coming to the surface of the panel is equal to the multiplication of solar radiation (G, W/ m^2) and the panel surface area (A, m^2). The electrical efficiency (η) of the photovoltaic panel is calculated by the ratio of the average electrical power (P_{ave}, W) to the total energy amount (YE, W) of the panel surface [26, 27]. It is given in Eq. 3 and Eq. 4.

$$YE = G*A \text{ (W)} \quad (3)$$

$$\eta = P_{ave} *YE^{-1} = P_{ave} *(G*A)^{-1} \quad (4)$$

3. RESULTS

Solar panels were placed in front of the window facing the sun in our laboratory for indoor conditions, and on an empty land in the city as an outdoor environment. The experiments were carried out at noon. The variation of panel surface temperatures according to the angle is given in Figure 10. According to Figure 10, indoor panel surface temperatures are maximum 30.6 °C and minimum 25.5 °C at a 45° panel inclination angle; At the 39° angle, it was observed that the maximum is 31.3 °C and the minimum is 29.6 °C. At the time of the experiments, the average indoor temperature was determined as 24.17 °C. At an inclination angle of 45° indoors, the maximum current on the panel is 0.13 A, and the voltage is 9.4 V; at an inclination angle of 39°, the current remained constant for one hour and was read as 0.10 A, and the maximum voltage as 9.4 V. The power change obtained according to these values is shown in Figure 11. In indoor winter conditions, a maximum of 1.22 W electrical power is obtained from a 25 W solar panel at an inclination angle of 45°, and a maximum of 0.94 W at an inclination angle of 39°. The hourly average power amounts calculated according to the data obtained from the experiments performed at different panel angles in indoor and outdoor conditions are given in Table 3.

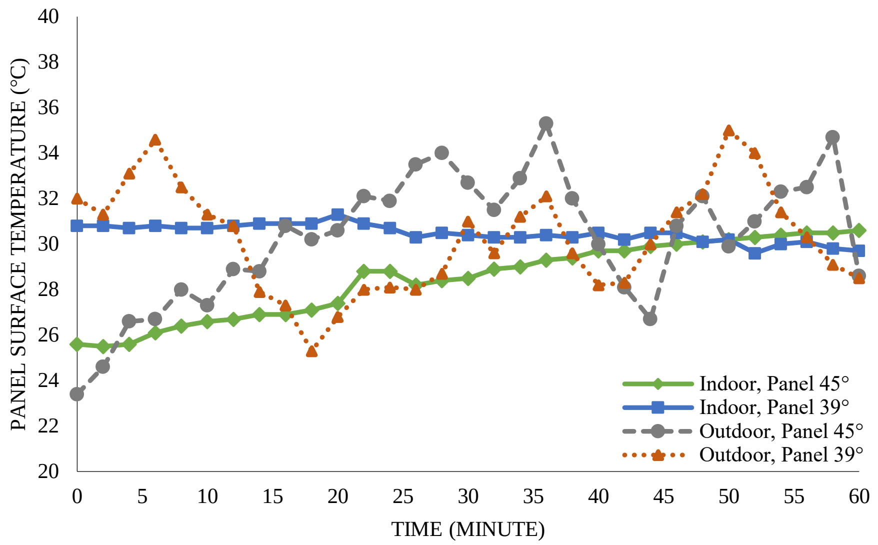

Figure 10. Variation of panel surface temperatures according to angle in indoor and outdoor conditions.

Table 3. Average hourly power amounts calculated at different panel angles in indoor and outdoor conditions [T_S: Panel surface temperature (°C), T_{amb}: Ambient temperature (°C)].

Panel Angles	Indoor					Outdoor				
39°	I_{ave}	V_{ave}	P_{ave}	T_s	T_{amb}	I_{ave}	V_{ave}	P_{ave}	T_s	T_{amb}
	(Amper, A)	*(Volt, V)*	*(W)*	*(°C)*	*(°C)*	*(Amper, A)*	*(Volt, V)*	*(W)*	*(°C)*	*(°C)*
	0.10	9.31	0.93	30.47	24.45	0.44	21.59	9.51	30.45	14.55
45°	I_{ave}	V_{ave}	P_{ave}	T_s	T_{amb}	I_{ave}	V_{ave}	P_{ave}	T_s	T_{amb}
	(Amper, A)	*(Volt, V)*	*(W)*	*(°C)*	*(°C)*	*(Amper, A)*	*(Volt, V)*	*(W)*	*(°C)*	*(°C)*
	0.13	9.35	1.18	28.45	23.88	0.44	21.65	9.53	30.27	12.29

It was observed that the current was generally constant at 0.44 A at the panel inclination angles of 39° and 45° during the noon hours when the experiments were carried out in outdoor conditions. It has been observed that the voltage varies between 21.5 and 22 V when the panel inclination angle is set to 45°, and between 21.3 and 21.7 when the panel inclination angle is set to 39°. The electrical power was obtained as maximum 9.68 W at 45° inclination angle and 9.59 W at 39° inclination angle. At the time of the experiments, the average outdoor temperature was measured as 13.42 °C.

Since the maximum electrical power of 9.68 W is obtained in the 25 W panel we use, the efficiency of the panel we use is around 38% as calculated in Equation (5) in outdoor winter conditions.

$$\text{Panel efficiency (\%)} = (100 \times 9.86)/25 = 38 \qquad (5)$$

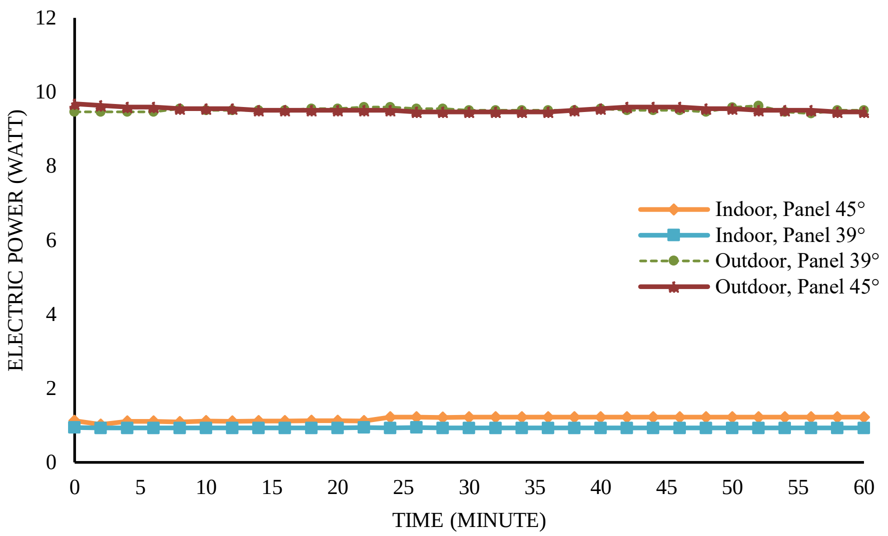

Figure 11. Electricity generation by angle in different conditions.

4. DISCUSSION AND CONCLUSION

In our study, it has been observed that a maximum hourly 1.22 W indoor and 9.68 W outdoor electric power can be obtained from a 25 W monocrystalline panel in the winter in the province of Bingöl at an angle of inclination of 45 °C. It is understood that the best results are obtained for the 45 degree angle in the outdoor environment. The panel surface temperature increased up to 35 °C in the outdoor environment. However, no significant change in electric power was observed.

According to the regulation made in 2018 in our country, it is allowed to install a maximum of 10 kW solar panels on the roof of a house. This means meeting the electricity needs of a house with an average monthly electricity consumption of 1400 kWh and an average daily electricity consumption of 4.6 kWh. According to the cost analyzes made by solar energy installation companies, an average of 24 monocrystalline panels with a power of 455 W should be used to meet this capacity. According to today's conditions, the totality of the panels, other necessary equipment, and installation costs is 206000 TL including KDV [28]. If such a system is off-grid, the payback period will undoubtedly be very long, thus incurring unnecessary expense to the home owner. As it is known, electrical energy cannot be stored and meets the needs of the house as soon as it is produced. However, the electricity produced is given to the grid when the house does not need it. In this respect, if such a system is grid-connected (On Grid), the electricity produced more than the house's needs can be given to the grid, and the repayment period can be reduced to an average of 6 years with the settlement method [28]. This will start the income generation process for the home owner after the first six years, and will make significant contributions to the country's economy, and reduction of emissions.

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