

Comparative Analysis with PVGIS and PVsyst for Solar Energy Production in Bahşılı Region of Kırıkkale

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Graphical/Tabular Abstract (Grafik Özet)

This study compares PVGIS and PVsyst simulations to evaluate the solar energy potential of a 15 MW fixed-axis PV system in Bahşılı, Kırıkkale. / Bu çalışma, Bahşılı/Kırıkkale'de 15 MW sabit eksenli bir PV sistemin güneş enerjisi potansiyelini değerlendirmek amacıyla PVGIS ve PVsyst simülasyonlarını karşılaştırmaktadır.

Table A. Comparison of PVGIS and PVsyst simulation results with the 30° tilt angle / **Tablo A.** (30 derece açı ile PVGIS ve PVsyst simülasyon karşılaştırılması)

Months	PVGIS Data (KWh)	PVsyst Data (KWh)
Jan.	1.075	1.710
Feb.	1.398	2.158
Mar.	2.051	2.782
Apr.	2.340	2.996
May.	2.473	3.348
Jun.	2.657	3.426
Jul.	2.951	3.541
Aug.	2.917	3.601
Sep.	2.543	3.273
Oct.	2.109	2.686
Nov.	1.697	2.009
Dec.	1.181	1.649
TOTAL	25.392	33.179

Highlights (Önemli noktalar)

- PVsyst enables detailed modeling of system components and loss mechanisms. / PVsyst, sistem bileşenleri ve kayıp mekanizmalarının ayrıntılı modellenmesini sağlar.
- PVGIS offers rapid estimations using satellite-based datasets. / PVGIS, uydu tabanlı veri setleriyle hızlı tahminler sunar.
- Tracking systems increase annual energy yield by approximately 24%. / Takip sistemleri yıllık enerji üretimini yaklaşık %24 oranında artırmaktadır.

Aim (Amaç): To evaluate the solar energy production potential of a fixed-axis photovoltaic system in Bahşılı, Kırıkkale, through a comparative analysis of PVGIS and PVsyst simulation tools. / Bahşılı/Kırıkkale bölgesinde sabit eksenli bir fotovoltaik sistemin güneş enerjisi üretim potansiyelini, PVGIS ve PVsyst simülasyon araçlarının karşılaştırmalı analizi yoluyla değerlendirmek

Originality (Özgünlük): This study provides a methodological comparison of PVGIS and PVsyst outputs for the same geographical location, emphasizing the impact of simulation parameters and modeling depth on energy yield predictions. / Bu çalışma, aynı coğrafi konum için PVGIS ve PVsyst çıktılarının yöntemsel karşılaştırmasını sunmakta; simülasyon parametreleri ile modelleme derinliğinin enerji üretim tahminlerine etkisini vurgulamaktadır.

Results (Bulgular): PVsyst estimated 33.179 GWh/year, while PVGIS predicted 25.392 GWh, revealing a 30% gap. Tracking systems raised this figure to 41.09 GWh./ PVsyst yıllık 33,179 GWh, PVGIS ise 25,392 GWh öngörerek %30'luk bir fark ortaya koymuştur. Takip sistemleri üretimi 41,09 GWh'ye çıkarmıştır.

Conclusion (Sonuç): The study shows that simulation tool choice and modeling approach notably influence energy forecasts. Tracking systems, though costlier, enhance performance and investment feasibility. / Çalışma, simülasyon aracı ve modelleme yaklaşımının enerji tahminlerini önemli ölçüde etkilediğini göstermektedir. Takip sistemleri, yüksek maliyetlerine rağmen performansı ve yatırım fizibilitesini artırmaktadır.



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Abstract

This study examines the energy production potential of a fixed-axis photovoltaic (PV) system in the Bahşılı region of Kırıkkale, using PVGIS and PVSyst simulation software. The research highlights the increasing significance of renewable energy in Turkey, particularly in light of the country's commitment to achieving net-zero emissions by 2053. Solar tracking systems have been identified as a promising technology for enhancing solar energy efficiency, yet their high initial costs and maintenance requirements present challenges. Through comparative simulations, the study finds that PVSyst estimates annual energy production at 33.179 GWh, approximately 30% higher than the 25.392 GWh predicted by PVGIS. This discrepancy is attributed to methodological differences, with PVSyst offering more detailed component analysis and loss evaluations. The research underscores the importance of simulation accuracy in project planning and emphasizes the potential benefits of solar tracking systems despite their limitations. Future work will focus on incorporating solar tracking systems into the analysis and validating simulation results with real-world field data. The findings contribute to more effective solar energy project planning and development of sustainable energy solutions in Turkey.

Kırıkkale Bahşılı Bölgesinde Güneş Enerjisi Üretiminin PVGIS ve PVSyst ile Karşılaştırmalı Analiz

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Öz

Bu çalışma, Kırıkkale'nin Bahşılı bölgesinde sabit eksenli bir fotovoltaik (PV) sistemin enerji üretim potansiyelini PVGIS ve PVSyst simülasyon yazılımları kullanarak incelemektedir. Araştırma, Türkiye'nin 2053 yılına kadar net sıfır emisyon hedefi doğrultusunda yenilenebilir enerji kaynaklarının artan önemine dikkat çekmektedir. Güneş takip sistemleri, güneş enerjisi verimliliğini artırmada umut vadeden bir teknoloji olarak öne çıkmakla birlikte, yüksek ilk yatırım maliyetleri ve bakım gereksinimleri nedeniyle bazı zorluklar barındırmaktadır. Karşılaştırmalı simülasyonlar sonucunda, PVSyst yazılımının yıllık enerji üretimini 33,179 GWh olarak tahmin ettiği, bunun da PVGIS tarafından öngörülen 25,392 GWh'ye kıyasla yaklaşık %30 daha yüksek olduğu belirlenmiştir. Bu fark, PVSyst'in daha ayrıntılı bileşen analizi ve kayıp değerlendirmeleri sunması gibi yöntemsel farklılıklardan kaynaklanmaktadır. Araştırma, proje planlamasında simülasyon doğruluğunun önemini vurgulamakta ve sınırlamalarına rağmen güneş takip sistemlerinin potansiyel faydalarını ön plana çıkarmaktadır. Gelecek çalışmalarda, güneş takip sistemlerinin analize dahil edilmesi ve simülasyon sonuçlarının saha verileriyle doğrulanması hedeflenmektedir. Elde edilen bulgular, Türkiye'de daha etkili güneş enerjisi projelerinin planlanmasına ve sürdürülebilir enerji çözümlerinin geliştirilmesine katkı sağlamaktadır.

1. INTRODUCTION (GİRİŞ)

Energy has been a determining factor in the development of civilizations throughout history. The adoption of fossil fuels as the primary energy source during the Industrial Revolution led to a

significant increase in global energy demand. However, the finite nature of fossil fuel reserves and their environmental impacts have heightened interest in renewable energy sources. In this context, solar energy, a sustainable and abundantly available energy source, is pivotal in transforming the global

energy supply [1]. In recent years, the share of solar energy in the global energy portfolio has been steadily increasing, emerging as one of the fastest-growing sectors among renewable energy sources. Studies indicate that solar energy significantly contributes to the global energy transition and accelerates the shift from fossil fuels to renewable energy. Additionally, it is emphasized that solar energy has the potential to enhance energy security and contribute to sustainable development, particularly in developing regions [2].

Solar energy is identified as a critical technology for global energy transition. For developing countries, solar energy offers economic and environmental advantages, positioning it as a key player in the renewable energy transition [3].

Türkiye's solar energy potential is high; however, numerous studies suggest that this potential has not been fully harnessed. Utilizing Turkey's solar energy potential effectively ensures a sustainable long-term energy supply. Turkey can significantly enhance its energy security and achieve its environmental targets by increasing investments in solar energy infrastructure [4].

Due to geographical advantages, Türkiye's substantial solar energy potential, if effectively utilized, is projected to contribute significantly to the country's renewable energy goals. These developments indicate that Türkiye is taking decisive steps to enhance its solar energy capacity, aligning with global trends [5]. As of 2024, Türkiye's installed solar energy capacity reached 20,016 MW (Ministry of Energy and Natural Resources [6]). This growth aligns with global renewable energy trends and supports Türkiye's goal of achieving net-zero emissions by 2053, according to the Paris Agreement [5].

Simulation software is critical in solar power plants' design, installation, and performance analysis. PVsyst and PVGIS are two prominent tools widely used for the performance analysis of photovoltaic (PV) systems. Both offer distinct advantages and may be preferred for different purposes. These tools model various processes—from initial plant design to optimization of energy production, assisting in evaluating the economic feasibility of projects [7].

PVsyst is considered a comprehensive tool for simulating PV systems. It utilizes various meteorological data to model and predict the energy production of plants [8]. Studies highlight the importance of considering local climatic conditions when using PVsyst, as it operates in harmony with

regional data to predict the efficiency of solar energy systems more accurately. Similarly, PVGIS, developed by the European Commission, is a geographic information system-based tool used to assess the energy production potential of PV systems [7]. It offers a quick and user-friendly analysis of solar energy potential for specific locations. Huld et. Al. (2020) note that PVGIS provides reliable results in analyzing solar energy potential across vast regions such as Europe and Africa.

Some studies in Türkiye have compared the performance analyses of PVGIS and PVsyst across different regions to evaluate the accuracy of these tools. For instance, a study conducted in Uşak and Kayseri found that PVsyst values were 4.3% higher than actual production data, while PVGIS estimates were 2.3% lower [9].

PVsyst can perform detailed analyses concerning system design and energy production estimates. Offering detailed modeling and performance analysis of system components can more accurately simulate the efficiency of solar energy systems under various conditions. Particularly for investors and engineers, PVsyst provides robust tools to assess the economic feasibility of solar power plants [10]. However, PVsyst requires more extensive data and necessitates users to have a comprehensive understanding of system design. On the other hand, PVGIS is a powerful tool based on large databases, such as the European Commission's Solar Energy Map, providing solar irradiance data geographically. PVGIS is effective, especially quickly and accurately, in providing solar irradiance data [11]. While PVGIS lacks detailed modeling and analysis features for system design, it is helpful for general efficiency assessments.

Several studies have examined the comparative performance of PVGIS and PVsyst under varying climate conditions and system configurations. For instance, Limem and Sezen (2021) evaluated both software tools for a 5.1 kWp grid-connected PV system in Central Anatolia, finding that PVsyst provided more accurate energy yield predictions due to its detailed treatment of system and component-level losses. Similarly, Karaoğlu and Öztürk (2023) investigated the efficiency of fixed and dual-axis tracking systems in Central Anatolia, highlighting that PVsyst accounts for factors such as temperature and shading more comprehensively. In contrast, PVGIS relies on extensive global datasets and thus offers a fast and user-friendly means of conducting preliminary feasibility analyses; however, it lacks extensive customization

options for specific panels and inverters. Across the literature, predicted energy output discrepancies between PVGIS and PVsyst are reported to range from approximately 2% to 30%, depending on local site conditions, the chosen meteorological database (e.g., SARA-2, HelioClim, or Meteonorm), and how system losses (including soiling, cable resistance, and module mismatch) are modeled. Consequently, when deciding between these tools, researchers and practitioners are advised to consider the scope and detail required by the project, the representativeness of the available data, and the necessity for advanced loss modeling or rapid preliminary estimates.

Both tools have their limitations. While PVsyst offers in-depth analysis for more complex systems, it may require users to have experience and technical knowledge. PVGIS, with its more straightforward and user-friendly interface, has limitations in conducting in-depth performance analyses.

This study aims to compare PVGIS and PVsyst software to evaluate the solar energy production potential of the Bahşılı region. Both tools are widely used to model and simulate the performance of photovoltaic systems, each with its advantages and limitations. In this study, conducted for a solar power plant with an installed capacity of 15 MW, we aim to analyze the accuracy of the results

obtained through both tools and assess the solar energy potential in the region. Additionally, considering solar radiation data and climatic conditions in the Bahşılı region, a comparison of simulations provided by both tools will be conducted. This analysis aims to contribute to developing recommendations to enhance the efficiency of solar energy projects in similar regions across Türkiye.

2. MATERIALS AND METHODS (MATERİYAL VE METOD)

2.1. Geographical and Solar Characteristics of the Region (Bölgenin Coğrafi ve Güneş Enerjisi Özellikleri)

In this study, the installation of a solar power plant in Kırıkkale province and the data obtained were examined. Analyses conducted using PVsyst and PVGIS software indicate that, according to data provided by the General Directorate of Renewable Energy, Kırıkkale's average solar radiation is approximately 1470 kWh/m². As shown in Figure 1, this value decreases to 1440 kWh/m² in the northern district of Sulakyurt, while it increases to 1490 kWh/m² in the southern district of Çelebi. Although Kırıkkale's solar energy potential is above the national average, it is generally considered low within the region [6].

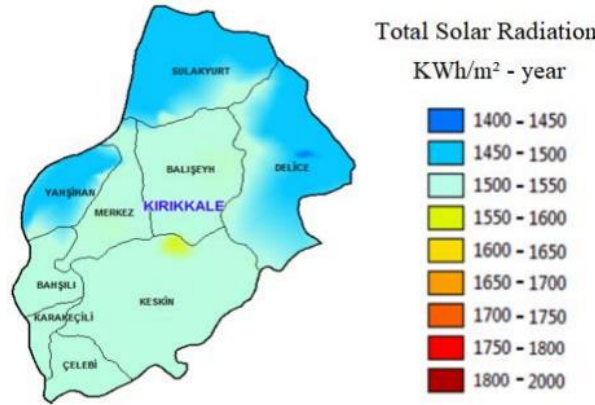


Figure 1. Solar energy potential of Kırıkkale [6] (Kırıkkale güneş enerjisi potansiyeli)

The location information and climate data of the Bahşılı region in Kırıkkale province are presented in Table 1. Kırıkkale's geographical coordinates are 39.8451° N latitude and 33.5065° E longitude, with an elevation of 700 meters above sea level. The province exhibits continental climate characteristics characterized by hot summers and cold winters. These geographical and climatic features play a significant role in evaluating the region's solar energy potential.

Table 1. Geographical and Climatic Characteristics of Bahşılı/Kırıkkale Province (Bahşılı/Kırıkkale İlçesinin Coğrafi ve İklimsel Özellikleri)

Characteristic	Value
Latitude	39.8451° N
Longitude	33.5065° E
Elevation	700 meters
Climate Type	Continental Climate

2.2. Simulation Methods (Simülasyon Metodları)

The use of up-to-date and reliable simulation tools is of great importance for the performance analysis and design of solar energy systems. In this study, data obtained from PVGIS and PVsyst software were used. These software tools are widely recognized for their capabilities in photovoltaic system design, efficiency analysis, and performance evaluation [12]. They are essential tools in the design and performance analysis of solar energy systems, playing critical roles in project planning and implementation. Particularly in countries with high solar energy potential, such as Turkey, these tools help optimize photovoltaic systems and enhance the accuracy of energy production forecasts [13].

2.2.1 PVGIS Photovoltaic Geographical Information Systems (PVGIS Fotovoltaik Coğrafi Bilgi Sistemi)

PVGIS (Photovoltaic Geographical Information System) is a simulation software developed by the Joint Research Centre (JRC) of the European Commission to assess solar energy potential on a global scale. In addition to providing solar radiation

data for specific geographical locations, this software estimates energy production for different photovoltaic (PV) system configurations [12]. Using long-term meteorological datasets, PVGIS enables predicting solar energy system performance in real-world conditions. Due to this capability, it is widely regarded as a valuable tool for investment feasibility studies and potential energy efficiency analyses. PVGIS relies on historical meteorological data to provide reliable solar radiation estimates, making it a crucial resource for preliminary feasibility assessments. The calculations performed by PVGIS are based on standard radiation models specified in the technical documents of the European Commission [13].

The simulation outputs provided by PVGIS allow users to estimate the potential energy generation of a planned PV system based on specific system parameters. However, PVGIS is limited to analyzing the performance of fixed-angle PV systems and does not directly evaluate solar tracking systems. Therefore, additional software tools are required for the comparative analysis of dynamic systems. The PVGIS system interface is illustrated in Figure 2.

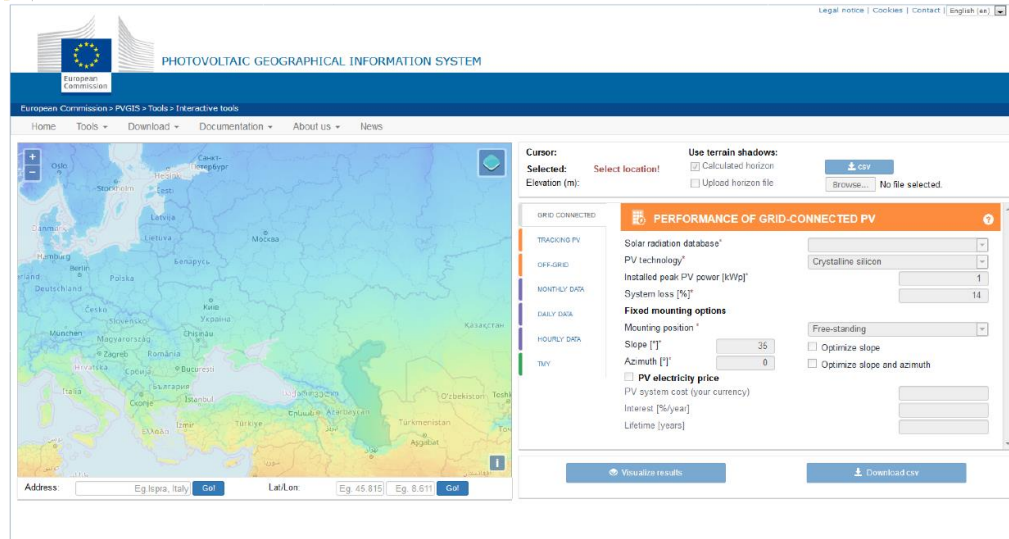


Figure 2. PVGIS system interface (PVGIS sistem arayüzü)

$$GT = G_{bT} + G_{dT} + G_{rT} \quad (1)$$

$$P(G'_T, T') = G'_T * (\rho_{SCT,m} + k_1 \ln(G'_T) + k_2 \ln(G'_T)^2) + k_3 T' + k_4 T' \ln(G'_T) + k_5 T' \ln(G'_T)^2 + k_6 T'^2 \quad (2)$$

$$\begin{aligned} G'_T &\equiv G_T / G_{SCT} \\ T' &\equiv T_{mod} - T_{SCT} \\ \eta_{rel}(G'_T, T') &\equiv P(G'_T, T') / (\rho_{SCT,m} G'_T) \end{aligned} \quad (3)$$

According to equation 1; GT represents the total radiation value the panel shares. GdT is the inclined direct radiation value, GdT is the diffuse radiation value, and GrT is the reflected radiation value [W/m^2] [14].

The PVGIS algorithm estimates the system's AC power output by accounting for losses from inverters, wiring, and soiling. According to research, total system losses typically range between 10% and 15%.

2.2.2 PVSyst / PV Systems (PVSyst / PV Sistem)

PVsyst is a simulation program developed by the University of Geneva in Switzerland for solar energy investments [15]. The software covers grid-connected and off-grid photovoltaic (PV) systems and offers various applications such as data analysis, system sizing estimates, equipment selection, and brand/model comparisons. Thanks to the Meteonorm database, users can access monthly and yearly temperature data for different countries and cities. At the same time, Google Maps integration allows them to examine land features and location information to identify suitable solar power plant sites [16].

One of PVsyst's key features is its ability to perform energy production simulations by considering meteorological data, shading losses, and system components (inverters, batteries, etc.) [10]. The software uses the single-diode model to predict the current voltage (I-V) characteristics of PV modules.

It ensures accurate system performance calculation under varying irradiance and temperature conditions [17]. By separately evaluating the direct, diffuse, and albedo radiation components, it calculates shading losses, thereby improving the accuracy of energy production forecasts [18]. The ability to conduct time series simulations by integrating hourly meteorological data helps optimize system performance during the pre-design phase of solar energy projects. This function is especially important for feasibility studies and financial evaluations in large-scale solar investments [19]. The PVsyst system interface is shown in Figure 3.

surface of the workpiece was leveled and the position of the workpiece was fixed by verifying with the "line" formed from one side of the keyseat. "t1" measurement results were obtained by calculating the plane on the ground and the extreme point of the outer diameter. The "b" measurement results were obtained with the lines obtained by contacting two points on the side surfaces of the keyseat. Radius (R) measurements were obtained with circles created by touching three points, and the distance measurement between the circles and the "L" dimension were checked. Perpendicular to the ground "line" was formed from the side walls of the keyseat, and perpendicularity checks were made with the plane on the floor. All calibration and measurement processes were carried out at 21°C. The experimental setup and workflow are shown in Figure 3.

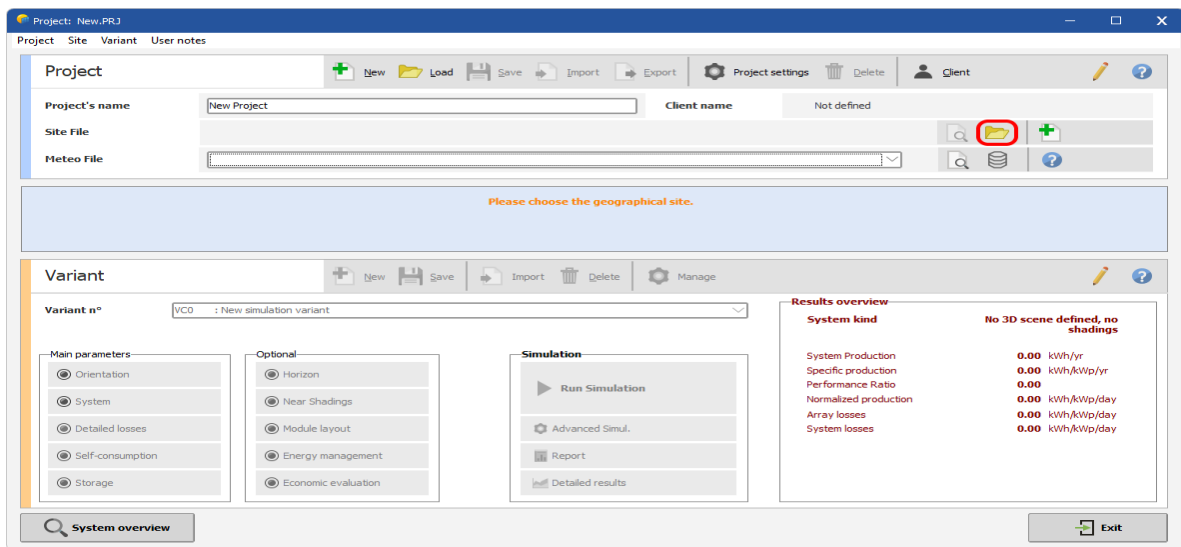


Figure 3. PVsyst system interface (PVSyst sistem arayüzü)

$$I = I_{ph} - I_0 \left[\exp \left(\frac{N_{cs} \cdot \gamma \cdot k_B \cdot T_c}{q \cdot (V + I \cdot R_s)} \right) - 1 \right] - \frac{V + I \cdot R_s}{R_{sh}}$$

PVsyst uses the single-diode model to simulate the electrical behavior of solar panel modules. This model defines the voltage-current (I-V) characteristics of a PV cell and is based on the following equation:

The meanings and scientific explanations of the parameters in this equation are as follows. I represent the current generated by the module (amperes), while V denotes the voltage across the module terminals (volts). I_{ph} represents the photovoltaic current (amperes), and I_0 indicates the reverse saturation current of the diode (amperes). R_s is the series resistance (ohms), and R_{sh} is the shunt resistance (ohms). q refers to the electron charge (1.602×10^{-19} C), while N_{cs} represents the number of cells connected in series. γ indicates the quality factor of the diode, and k_B represents the Boltzmann constant (1.381×10^{-23} J/K). Finally, T_c denotes the cell temperature (in Kelvin). This equation is used to predict the performance of solar panel modules by considering the effects of variables such as solar irradiance and cell temperature. Additionally, the PVsyst software analyzes the solar irradiance, composed of direct, diffuse, and albedo components, separately to calculate shading losses. For the direct irradiance component, a shading factor is determined based on the sun's position, while for the diffuse and albedo components, integration is performed over all sky directions [8]. This allows the shading factors to be calculated independently of the sun's position.

This model defines the current-voltage (I-V) characteristics of a PV module, allowing the prediction of its performance under varying irradiance and temperature conditions. Additionally, PVsyst separately analyzes the components of solar radiation, direct, diffuse, and albedo, and evaluates shading losses, calculating specific shading factors for each component. For the direct radiation component, a shading factor is determined based on the sun's position. In contrast, for the diffuse and albedo components, integration is performed over all sky directions, resulting in shading factors independent of the sun's position [8].

3. RESULT and DISCUSSINS (Sonuç ve Tartışma)

The findings obtained in this study provide a comparative evaluation of the performance of PVGIS and PVsyst simulation software in photovoltaic energy production forecasting. Previous studies conducted in Anatolia and surrounding regions have shown that PVGIS generally excels in large-scale regional analyses, while PVsyst stands out in more detailed system design and component optimization [4]. It is noted that PVGIS predicts average solar irradiance using satellite-based data, but it may not fully adapt to local conditions in detailed land-specific analyses [20]. On the other hand, due to PVsyst's more detailed calculation of meteorological data and system losses, it has been observed to provide more reliable results, especially in the investment and feasibility stages [20][21].

Our findings show that, compared to other studies conducted in similar climate conditions, PVsyst has a lower margin of error in energy production forecasts by more accurately modeling shading losses and temperature effects. However, it has been determined that PVGIS offers fast and accessible predictions on a regional scale using large datasets, providing an advantage especially in pre-feasibility analyses [22]. Other studies conducted in the Anatolia region also reveal that PVsyst provides more realistic results by accounting for detailed parameters such as system losses, panel temperature, and slope optimization [23]. Moreover, PVGIS's open database and the fact that it does not require any software installation provides a significant advantage, particularly for small-scale projects and academic studies.

The monthly average solar radiation data for the Bahşılı region of Kırıkkale obtained from PVsyst are presented in Figure 4. According to this graph, the highest radiation value for Kırıkkale occurs in July, while the lowest radiation value is observed in December.

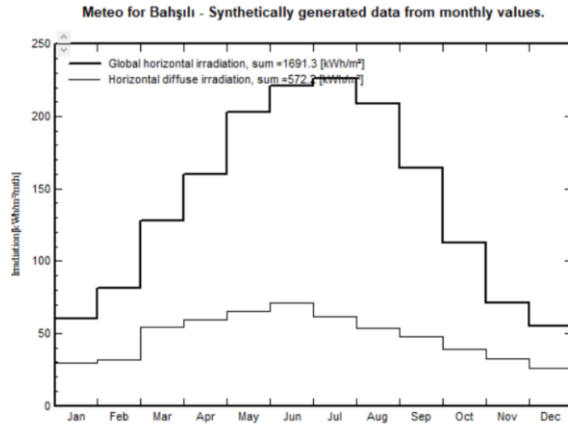


Figure 4. Kırıkkale PVsyst monthly radiation value (Kırıkkale PVsyst aylık güneşlenme değerleri)

3.1 PVGIS Result (PVGIS Sonucu)

In this study, the simulation for the Bahşılı region of Kırıkkale, Turkey, as specified in Table 2, was conducted using PVGIS. The PVGIS-SARAH-2 database containing solar irradiance data was used for the simulations. For the photovoltaic system performance analysis, the panel tilt angle was set to 30°, and the azimuth angle was set to 0°. In the system using crystalline silicon PV panels, the total installed capacity was modeled as 15 MW. The

obtained results provide an important reference for evaluating the solar energy potential of the region and analyzing the accuracy of the PVGIS simulations.

Table 2. PVGIS simulation inputs (PVGIS simülasyon girdileri)

Simulation Inputs	Values
Location	Bahşılı/Kırıkkale/Turkey
Database Used	PVGIS-SARAH-2
Tilt Angle	30°
Azimuth Angle	0°
PV Used	Crystal Silicon
Installed Power	15 MW

When the fixed-system solar power plant planned for the Bahşılı/Kırıkkale location is analyzed using the PVGIS database, the values presented in Figure 5 are obtained. The simulation results indicate specific losses, including a 2.74% loss due to the angle of incidence, a 0.46% loss from spectral effects, and a 7.59% loss related to temperature and low irradiance. The estimated total overall system loss is calculated as 9.71% in the final report.

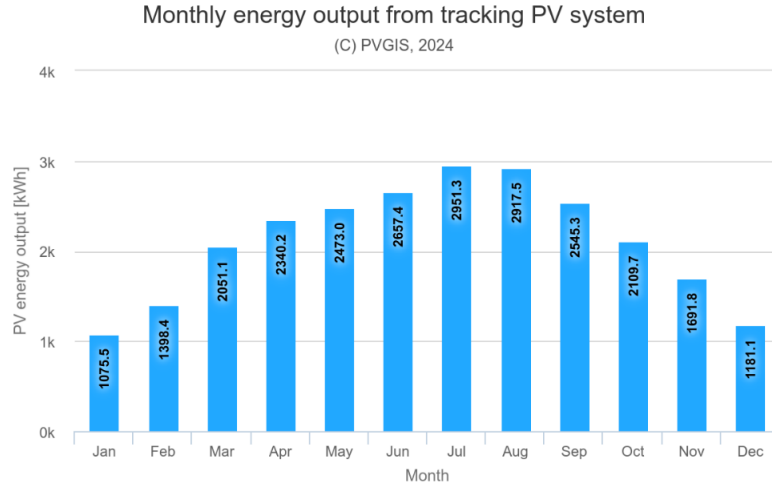


Figure 5. Monthly PVGIS energy output [kWh] (Aylık PVGIS enerji çıktısı [kWh])

3.2. PVsyst Result (PVsyst Sonucu)

In this study, the PS-550-M6H-24-TH-1500V photovoltaic panel from Phono Solar and the

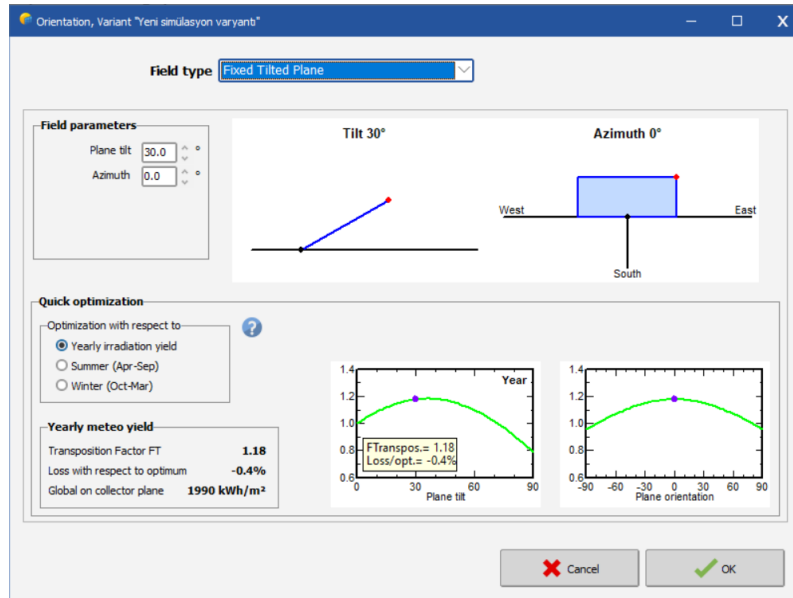
SUN2000-100KTL-M1-400Vac inverter manufactured by Huawei Technologies were selected. The details of these components are presented in Table 3.

Table 3. Panel and Inverter details used (Kullanılan panel ve invertör detayları)

Panel	Inverter
Manufacturer: Phono Solar	Manufacturer: Huawei Technology
Model: PS-550-M6H-24-TH-1500V	Model: SUN2000-100KTL-M1-400Vac
Unit Strength: 550 Wp	Unit Strength:100 kWac
Nominal (STC): 19.80 MWp	Operating Voltage:200-1000 V
Modules: 2250 String x 16 in Series	Pnom Ratio (DC:AC): 1.32
Total: 36000 Modules	Total: 150 Inverters

Fixed System (Sabit Sistem)

In this study, the tilt angle was set to 30° , as shown in Figure 6. This means that the angle between the photovoltaic panels and the ground surface is 30° . Considering that the system operates on a fixed axis, this configuration is optimized to ensure consistent solar irradiance exposure throughout the day. As a result, the energy received by the panel surface is maximized, enhancing the overall energy production efficiency throughout the year.

**Figure 6.** Fixed system placement angle (Sabit Sistem Yerleşim Açısı)

As shown in Figure 7, the total energy production of the system is 33.18 GWh per year. The analysis of system performance reveals that photovoltaic (PV) losses amount to 0.66 kWh per kWp per day, while inverter losses are calculated as 0.09 kWh per kWp per day. Considering these losses, the usable energy

output of the system is determined to be 4.59 kWh per kWp per day. These values emphasize the overall efficiency of the system and illustrate the influence of different loss factors on the total energy yield.

System Production

Produced Energy

33.18 GWh/year

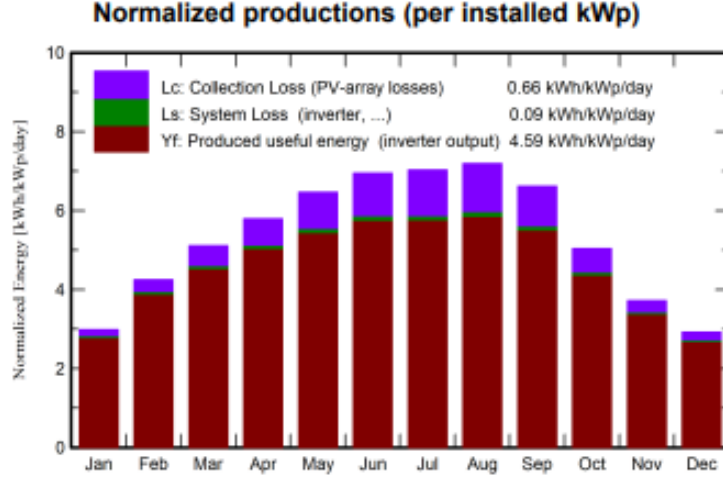


Figure 7. Monthly PVGIS fixed system energy output [kWh] (PVGIS sabit sisteminin aylık enerji üretimi [kWh])

Based on the calculations, the system is expected to generate 37.52 GWh of electricity. However, PV system losses, including inverter inefficiencies and cable resistance, significantly impact overall performance, as demonstrated in comparative studies as shown in table 4. Considering PV losses,

inverter efficiency, cable losses, and other technical factors, the net energy output is estimated at approximately 33.18 GWh. These losses are critical factors affecting the actual energy production of the system, and the calculations have been optimized with measures aimed at minimizing them.

Table 4. PVsyst Fixed system monthly value based on simulation data (PVsyst sabit sisteminin simülasyon verilerine göre aylık çıktıları)

	GlobHor kWh/m ²	DiffHor kWh/m ²	EArray GWh	E_Grid GWh	PR Ratio
Jan.	60.3	29.80	1.741	1.710	0.934
Feb.	81.2	31.70	2.197	2.158	0.917
Mar.	127.9	54.10	2.833	2.782	0.888
Apr.	159.6	59.30	3.051	2.996	0.872
May.	203.1	65.40	3.411	3.348	0.844
Jun.	221.4	70.80	3.492	3.426	0.830
Jul.	226.1	62.00	3.612	3.541	0.821
Aug.	209.1	53.60	3.675	3.601	0.816
Sep.	164.0	48.10	3.336	3.273	0.833
Oct.	112.3	38.80	2.735	2.686	0.868
Nov.	71.3	32.30	2.044	2.009	0.911
Dec.	55.0	26.30	1.679	1.649	0.921
Year	1691.3	572.20	33.807	33.179	0.860

Tracker System (Hareketli Sistem)

Tracking systems, unlike fixed systems, are not installed at a constant angle and adjust their orientation based on the sun's position throughout

the day. This movement is enabled by tracker systems and communication modules. Figure 8 in the PVsyst report illustrates the panel layout, tracking system mounting type, and maximum-minimum tilt angles relative to the surface.

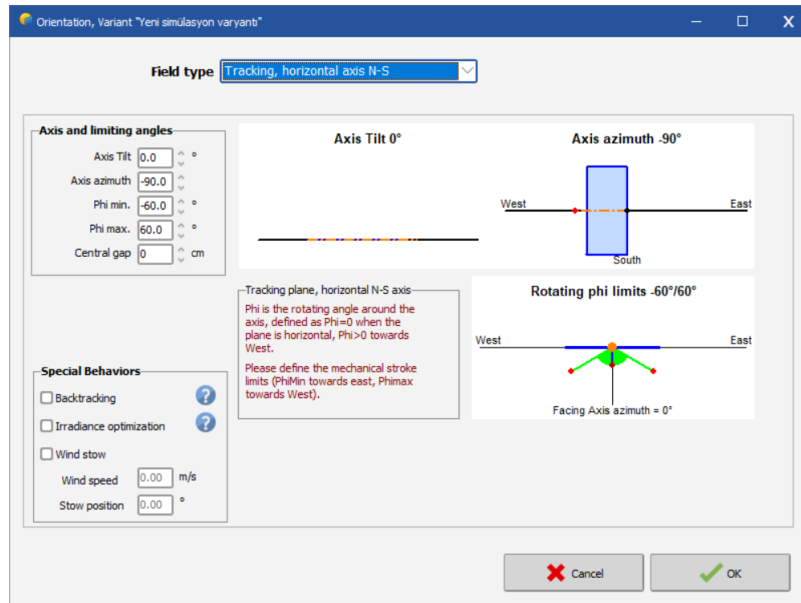


Figure 8. Tracker system placement angle (Takip sisteminin yerleşim açısı)

As seen in Figure 9 the total energy production is expressed in GWh/year, and the monthly losses are detailed as follows: PV losses (Lc) are 0.79

kWh/kWp/day, inverter losses (Ls) are 0.11 kWh/kWp/day, resulting in a usable energy output of 5.69 kWh/kWp/day.

System Production Produced Energy

41.09 GWh/year

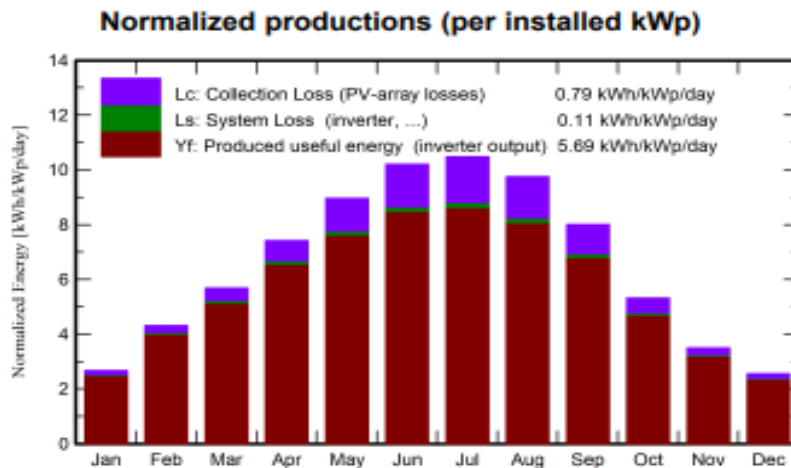


Figure 9. Monthly PVGIS tracker system energy output [kWh] (PVGIS sistemine ait aylık enerji çıktısı [kWh])

According to the report data obtained from the PVSyst simulation program (Table 5), it is projected that the 15 MW solar power plant, planned to be installed with a tracking system in the Bahşılı district of Kırıkkale, will generate a total of

approximately 41.088 GWh of energy over the course of a year. August contributes the highest share to this production, while December has the lowest production level.

Table 5. PVsyst tracker system monthly value based on simulation (PVsyst sisteminin simülasyona göre çıktıları)

	GlobHor kWh/m ²	DiffHor kWh/m ²	EArray GWh	E_Grid GWh	PR Ratio
Jan.	60.3	29.80	1.556	1.529	0.936
Feb.	81.2	31.70	2.263	2.223	0.928
Mar.	127.9	54.10	3.217	3.159	0.905
Apr.	159.6	59.30	3.974	3.902	0.886
May.	203.1	65.40	4.776	4.683	0.851
Jun.	221.4	70.80	5.147	5.045	0.832
Jul.	226.1	62.00	5.414	5.301	0.824
Aug.	209.1	53.60	5.067	4.961	0.829
Sep.	164.0	48.10	4.129	4.050	0.852
Oct.	112.3	38.80	2.938	2.886	0.885
Nov.	71.3	32.30	1.935	1.903	0.917
Dec.	55.0	26.30	1.472	1.447	0.922
Year	1691.3	572.20	41.887	41.088	0.864

The simulation outcomes obtained via PVSyst indicate that the annual energy yield for the fixed photovoltaic system configuration is approximately 33.18 GWh (E_Grid). In contrast, by setting the azimuth angle to -180° for the single-axis tracking configuration—while it was 30° for the fixed system—the projected energy output increases to 41.09 GWh annually. This analysis demonstrates that employing a tracking system enhances energy generation by approximately 23.82% compared to its fixed counterpart. It is important to note that these results were derived using PVSyst software, as PVGIS does not currently support energy simulations for tracking systems. Therefore, PVSyst was preferred in this study to enable a comprehensive comparison between fixed and tracking photovoltaic configurations.

3.3. Comparison of PVGIS and PVSyst (PVGIS ve PVSyst Karşılaştırılması)

Table 6 presents a comparative analysis of the PVSyst and PVGIS software, offering a comprehensive evaluation of their shared characteristics and distinct features. This comparison enables a systematic assessment of their capabilities in photovoltaic system modeling, including aspects such as meteorological data sources, simulation methodologies, system loss estimations, and performance evaluation metrics. By examining the similarities and differences between these two tools, it becomes possible to identify their respective strengths and limitations, thereby facilitating a more informed selection process based on the specific requirements of solar energy feasibility studies and system design applications.

Table 6. Comparison of PVGIS and PVsyst Simulation (PVGIS ve PVsyst simülasyonlarının karşılaştırılması)

Ability	PVGIS	PVsyst
Grid Design (On/Of Grid)	X	√
Meteonorm Data Access	√	√
PV and Inverter Selection	X	√
Loss Analysis	X	√
Radiation Value Data (KWh)	√	√
Determining the Tilt Angle	√	√
Fixed System Design	√	√
Tracker System Design	X	√

Table 7 presents a comparative analysis of the energy yield values obtained from PVGIS and PVsyst simulations for a fixed photovoltaic system with a tilt angle of 30°. This comparison provides insight into the consistency and variability of the results generated by both software tools, allowing for a detailed assessment of their accuracy in modeling solar energy production under identical system parameters.

Table 7. Comparison of PVGIS and PVsyst Simulation Results with the 30° Tilt Angle (30° panel eğimiyle PVGIS ve PVsyst simülasyon sonuçları karşılaştırması)

Months	PVGIS Data (KWh)	PVsyst Data (KWh)
Jan.	1.075	1.710
Feb.	1.398	2.158
Mar.	2.051	2.782
Apr.	2.340	2.996
May.	2.473	3.348
Jun.	2.657	3.426
Jul.	2.951	3.541
Aug.	2.917	3.601
Sep.	2.543	3.273
Oct.	2.109	2.686
Nov.	1.697	2.009
Dec.	1.181	1.649
TOTAL	25.392	33.179

The most apparent reasons for the differences in production estimates are:

- PVGIS does not allow the user to input specific information about the inverter and panel data, relying solely on the selection of land area.
- PVGIS cannot accurately account for material losses such as cables and panels.
- The methodological differences between PVGIS and PVsyst have been shown to cause significant deviations in energy efficiency predictions, especially in arid regions, as demonstrated in studies [24].

When comparing the simulation results obtained from PVGIS and PVsyst software for a 15 MW project, PVGIS predicts an annual energy production of 25,392 kWh, while PVsyst forecasts this value as 33,179 kWh. The difference between the two software predictions is approximately 30%, with the average annual energy production calculated as 29,285.5 kWh. This discrepancy arises from various factors, such as meteorological data sets, simulation algorithms, and underlying assumptions. PVsyst provides a more comprehensive simulation by offering a more detailed system component analysis and loss evaluations. Therefore, it is expected to provide higher production forecasts [25]. The analysis highlights the differences in energy production predictions between PVGIS and PVsyst software, offering valuable insights into which software might be more suitable for planning and evaluating solar energy systems.

4. CONCLUSIONS (SONUÇLAR)

This study comparatively examines energy production forecasts and economic feasibility analyses for a 15 MW capacity fixed-axis photovoltaic (PV) system in the Kırıkkale/Bahşılı region. The PVGIS and PVsyst simulation tools used in the study revealed significant differences in annual energy production. The annual energy production predicted by PVGIS was 25.392 MWh, while the production calculated by PVsyst was found to be 33.179 MWh. This difference of approximately 30.6% highlights the significant impact of the modeling approaches on energy production forecasts. PVsyst's ability to conduct detailed component modeling and loss analysis enables more realistic system performance predictions. In this context, the differences are mainly due to PVsyst considering losses such as thermal losses, contamination, shading, and

mismatch, whereas PVGIS uses a more simplified loss model [26].

Additionally, it has been observed that solar tracking systems can increase energy production by up to approximately 20%. In this case, annual energy production rises to around 41.09 GWh with tracking systems [4]. Although tracking systems involve additional investment costs, the increase in production they provide can further shorten the payback period [27]. Therefore, opting for tracking systems instead of fixed systems can be considered a strategy that strengthens the economic feasibility of the investment.

Future research could approach the cost-effectiveness analysis of fixed and moving systems from a more detailed perspective, examining installation, operation, and maintenance costs and the achieved energy production levels. Comparative feasibility studies conducted in different geographical areas, considering regional climate conditions and economic variables, can provide critical information for investment decisions. Furthermore, long-term performance analyses of solar tracking systems, including component lifetimes, maintenance requirements, and their effects on investment payback periods, should be investigated in detail [28].

Advanced cost optimization methods and artificial intelligence-supported modeling techniques can be used to calculate the leveling energy cost more accurately. Moreover, calibrating simulation tools like PVGIS and PVSyst with actual field data to enhance their accuracy will increase the reliability of energy production forecasts [26]. Additionally, not only the economic aspects of solar energy investments but also their environmental impacts should be considered, and analyses related to greenhouse gas emission reductions, carbon footprint, and sustainability should be integrated [29].

Moreover, this comparative approach underscores a key scientific insight: while PVGIS offers a quick estimation framework, PVSyst's detailed modeling of factors such as temperature, soiling, and shading more accurately reflects real-world conditions. By identifying an approximate 30% discrepancy, our results highlight the importance of careful tool selection and parameter calibration, especially in regions with less-studied climatic and geographic characteristics. As a result, we provide a methodological foundation for future research to enhance the precision of renewable energy

simulations, ultimately supporting more reliable feasibility assessments and investment decisions.

In this study, we performed a comprehensive evaluation of single-axis tracking systems relative to fixed-axis installations, highlighting the additional energy yield gained by using tracker technology. By incorporating the geographical and climatic characteristics of the Kırıkkale/Bahşılı region into data obtained from PVGIS and PVSyst, we found that, on average, annual energy production could increase by approximately 20% compared to fixed systems. This outcome is largely attributed to the dynamic alignment of the panels with the sun's path throughout the day, optimizing angles and orientations to minimize temperature and shading losses. Given the limited number of studies examining such systems at this level of detail, our findings offer new, practice-oriented insights for both local projects and comparable climatic regions. Consequently, stakeholders in solar energy ranging from investors to engineers—can more rigorously assess the feasibility and potential returns of single-axis tracking systems in project planning and system design processes

In conclusion, the methodological differences of simulation tools used for economic and technical feasibility analyses of solar energy investments should be considered, and comparative studies based on results validated with field data should be conducted. Future studies are expected to provide more robust data for investors and policymakers, contributing to optimizing solar energy systems.

DECLARATION OF ETHICAL STANDARDS (ETİK STANDARTLARIN BEYANI)

The author of this article declares that the materials and methods they use in their work do not require ethical committee approval and/or legal-specific permission.

Bu makalenin yazarı çalışmalarında kullandıkları materyal ve yöntemlerin etik kurul izni ve/veya yasal-özel bir izin gerektirmediğini beyan ederler.

AUTHORS' CONTRIBUTIONS (YAZARLARIN KATKILARI)

Beyza YILDIRIM: She performed the simulation studies, analyzed the results, and carried out the writing process.

Benzetim çalışmalarını gerçekleştirdi, sonuçlarını analiz etti ve yazım işlemini gerçekleştirmiştir.

Hidir DUZKAYA: He performed the simulation studies, analyzed the results, and carried out the writing process.

Benzetim çalışmalarını gerçekleştirdi, sonuçlarını analiz etti ve yazım işlemini gerçekleştirmiştir.

CONFLICT OF INTEREST (ÇIKAR ÇATIŞMASI)

There is no conflict of interest in this study.

Bu çalışmada herhangi bir çıkar çatışması yoktur.

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