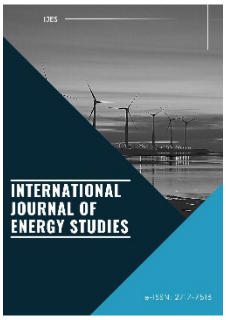
INTERNATIONAL JOURNAL OF ENERGY STUDIES

e-ISSN: 2717-7513 (ONLINE); homepage: https://dergipark.org.tr/en/pub/ijes



Research Article

Int J Energy Studies 2026; 11(2): 1239-1270

DOI: 10.58559/ijes.1859991

Received : 09 Jan 2026

Revised : 18 Apr 2026

Accepted : 20 Apr 2026

Investigation of the Kırklareli Kemalpaşa (Üsküp) solar power plant: A case study

Mustafa Acar *[a], Sena Esen Bayer Keskin [b], Engin Hüner [c]

[a]Department of Electrical and Electronics Engineering, Kirklareli University, 39000, Kirklareli, Türkiye, ORCID : 0000-0001-8271-5760

[b]Department of Electrical and Electronics Engineering, Kirklareli University, 39000, Kirklareli, Türkiye, ORCID : 0000-0001-8309-3393

[c] Department of Energy Systems Engineering, Kirklareli University, 39000, Kirklareli, Türkiye, ORCID : 0000-0001-5613-5439

(*Corresponding Author: mustafaacar@klu.edu.tr)

Highlights

- The solar energy potential of Kırklareli province has been analyzed, revealing that the region is moderately suitable for solar power plant investments.
- The production performance, efficiency rates, and annual energy outputs of Bilteks Çorapçılık's 715 kWp ground-mounted and 497 kWp rooftop solar power plants have been examined.
- The investment feasibility of the solar power plants, maintenance and repair requirements, efficiency-enhancing engineering solutions, and contributions to sustainable energy policies were comprehensively evaluated.
- The effects of engineering parameters such as panel inclination, distance between panel rows, shading effects, and inverter selection on photovoltaic (PV) power plant efficiency have been technically. Furthermore, rooftop and ground-mounted PV systems were evaluated in terms of natural disaster risks (wind, hail, snow load, flood, earthquake, lightning), and technical recommendations for risk mitigation were presented.

<u>You can cite this article as:</u> Acar M, Bayer Keskin SE, Hüner E. Investigation of the Kırklareli Kemalpaşa (Üsküp) solar power plant: A case study. Int J Energy Studies 2026; 11(2): 1239-1270

ABSTRACT

The growing impacts of global warming, the risk of fossil fuel reserves running out, and environmental pollution reaching critical levels have significantly increased interest in clean and sustainable energy sources. In this context, the production data of ground-mounted and rooftop solar power plants installed at an industrial facility in the town of Üsküp, Kırklareli Province, were analyzed. According to the findings, the ground-mounted solar energy system has an installed capacity of 715 kWp and generated a total of 1,183,829.00 kWh of energy over an 18-month period. The initial installation cost of this system was $560,000. The total revenue generated from the system during this period was $112,700.60, which corresponds to 20.13% of the investment cost. The economic analysis determined that the payback period for the ground-mounted system is approximately 89 months. The 497 kWp rooftop solar energy system generated a total of 1,600,499.00 kWh of energy over a 33-month operating period. From an economic perspective, the total revenue generated by this system after 33 months is $182,326.56. This revenue corresponds to 62.87% of the initial investment cost of $290,000, and the system's payback period has been calculated to be approximately 52.5 months. In general, rooftop solar power systems offer advantages such as higher efficiency, lower transmission losses, and a shorter payback period. Conversely, factors such as shading effects, transmission distance, and higher installation costs for ground-mounted systems can lead to a longer payback period.

Keywords: Solar panel, Solar energy, Solar power plant, Renewable energy

1. INTRODUCTION

In recent years, energy has become increasingly important on a global scale. Today, electrical energy is generated from a variety of sources, including hydropower, fossil fuels, nuclear energy, and renewable energy sources. Each category has its own broad sub-groups. While the reserves of fossil fuels such as coal, lignite, natural gas, and gasoline are facing the threat of rapid depletion (coal will be depleted in 150 years, gasoline in 90-120 years [1].), environmental factors are also seen to have a negative impact on this situation. In addition, the demand for renewable energy sources is increasing day by day. Among different energy sources, solar energy, in particular, is an area that attracts attention and is the subject of intensive research. Since our country is located in the northern hemisphere, it receives an average of 2741.07 hours of sunlight per year. The average daily sunshine duration is 7.50 hours. The total annual radiation amount is calculated as 1527.46 kWh/m², and the total daily radiation amount is 4.18 kWh/m² [2]. The sufficient duration of sunshine increases interest in solar energy.

Renewable energy sources are attracting increasing attention due to their lack of environmental harm, unlimited reserves, and absence of contributing to global warming or environmental pollution. With studies conducted worldwide and in our country on solar energy, the most common renewable energy source, the establishment of solar power plants is rapidly progressing. Turkey ranks among the top 15 countries worldwide in terms of installed solar power plant capacity as of 2024. Our perspective on solar energy is changing positively day by day, and as a society, we are becoming more aware. With the increase in projects carried out in this field, the use of solar energy in agriculture, industry, housing, public institutions, and many other sectors will also become increasingly widespread.

This study presents the following: Chapter 2 examines the energy situation in Turkey and globally, explaining the increase in global energy consumption and its causes (industrial electrification, electric household appliances, data centers, etc.). It examines energy development in Turkey between 1973 and 2025, with particular emphasis on the impact of early-stage energy investments made after 2000. Chapter 3 defines solar energy potential and determines Turkey's solar radiation characteristics. An evaluation of Kırklareli's annual irradiation and solar radiation conditions reveals that the region possesses moderate solar energy potential. Chapter 4 presents a detailed classification of ground-mounted and rooftop solar power plants at the Bilteks Sock Factory site in Kırklareli Üsküp. The technical specifications of the plants, along with their installation characteristics and monthly and annual production data, have been analyzed; performance, efficiency, and production comparisons have been made. Chapter 5 addresses the electrical analyses of modifications to the solar power plants. Shading analysis, changes in tilt angle, power distribution line layout, and natural disaster risks have been evaluated in detail, and the payback period has been calculated. In Chapter 6, the strategy and economic timeline for solar energy are highlighted; in the case of Kırklareli, rooftop systems have resulted in faster payback periods and higher-efficiency products. It is noted that ground-mounted and rooftop systems are not competitors but complementary solutions, and that both systems will play a significant role in Turkey's energy use.

Studies in the literature reveal that interest in energy sources is rapidly increasing due to the development and growth of fossil fuel reserves. Turkey has significant potential for solar energy investments thanks to its average annual sunshine duration of 2,741.00 hours and high solar radiation values. This situation has accelerated solar energy research both academically and practically. The literature focuses particularly on the site selection, technical performance analysis, and economic feasibility of solar power plants. Suitable plant locations are determined using multi-criteria decision-making methods (Analytic Hierarchy Process (AHP), Multicriteria Optimization and Compromise Solution (VIKOR)); the details of solar panel performance are analyzed in detail, taking into account factors such as sunshine duration, radiation, temperature, wind, shading, and sudden losses. Operating software such as Photovoltaic System Simulation Software (PVsyst) and TRaNsient SYstem Simulation (TRNSYS) are used to compare different panel types, inverters, and mounting efficiencies, energy production, and payback periods. Recent studies show that rooftop solar energy systems have shorter payback periods due to self-consumption savings, while ground-mounted systems support higher installed capacity and grid sales potential. Furthermore, agricultural photovoltaic systems that combine agriculture and energy production, building integrations, and energy storage solutions are emerging as new research areas in the literature. Overall, the study reveals that optimizing solar energy investments from a technical and economic perspective is critical for sustainability and efficiency [3-4].

With the growing global interest in renewable energy sources, studies evaluating the technical and economic performance of solar energy systems are becoming increasingly common. In this context, studies conducted under various climatic conditions, installation types, and simulation tools support the findings regarding ground-mounted and rooftop solar power plants examined in the Kemalpaşa district of Kırklareli. A study comprehensively addressing the performance of solar energy systems across Turkey analyzed five years of measurement data from 27 grid-connected photovoltaic plants installed in seven different climate regions. The study revealed that monthly average efficiency values ranged between 12% and 17%, while specific efficiency decreased linearly with elevation. Additionally, the study emphasized that the tilt angle and climate classification have a significant impact on system performance. This finding serves as an important reference for evaluating the plant's performance under the Thracian climate conditions addressed in our study [5].

The study, which conducted a techno-economic analysis of off-grid solar power plants in different climate zones, examined both ground-mounted and rooftop installations with a capacity of 1,215 kWp for seven cities in Turkey using the PVsyst simulation program. The study determined that the system performance ratio ranged between 75.92% and 80.07%; it was found that rooftop installations offer lower installation costs and higher payback potential compared to ground-mounted installations. It was concluded that scenarios where electricity is generated at the point of consumption represent the most economically advantageous option. These findings align with evidence indicating that the analyzed rooftop system has a shorter payback period [6].

The feasibility of rooftop solar energy systems for industrial facilities was also investigated using the PvSOL software on an industrial building in Turkey's Aegean Region. The economic analysis of this system, with an installed capacity of 573.75 kWp, calculated a payback period of less than four years. This finding confirms that rooftop applications at the industrial facility scale possess strong economic feasibility when compared to the approximately 52.5-month payback period of the 497 kWp rooftop system we examined [7].

This study, which examines the implementation of rooftop solar energy systems in university buildings, conducted a simulation using PV*SOL software on an 84.75 kWp system for the Faculty of Technology building at Marmara University in Istanbul. In this study, where the average performance ratio was calculated as 72.9% and the payback period as 12.52 years, the impact of solar irradiance and daily sunshine duration on system efficiency was emphasized. Our findings that the payback periods of ground-mounted systems are extended due to factors such as transmission losses and shading effects are also supported by this study [8].

An important comparison regarding the accuracy of simulation tools was conducted by Yıldırım and Düzkaya (2025) for a 15 MW solar power plant in the Kırıkkale/Bahşılı region. A difference of approximately 30.6% in annual production estimates was identified between the PVsyst and PVGIS software; it was demonstrated that PVsyst produces results closer to reality due to its more detailed modeling of loss parameters such as temperature, shading, and pollution. This finding highlights how critical the selection of simulation tools and parameter calibration is in solar energy projects and is also significant in terms of the reliability of the production data used in our study [9].

Taking into account the climatic conditions and electricity demand of Hatay Province, the economic and environmental impacts of a rooftop solar power plant were examined. Analyses conducted using PVsyst 7.4 software evaluated the investment cost, energy production, and payback period. According to the results, the system's annual production was determined to be 352,043 kWh, the performance ratio was 81.20%, and the payback period was approximately 4.2 years. Additionally, it was observed that the system prevents 3,543.4 tons of carbon emissions over its 25-year lifespan and that excess energy can be fed into the grid. The findings serve as a guide for solar energy projects, particularly during the post-earthquake reconstruction process[10].

Due to rising energy demand and environmental concerns, renewable energy systems are becoming increasingly widespread. This study examines the rooftop solar power plant installed at the Hidayet Türkoğlu Sports Complex. The facility is oriented east-west and has a capacity of 169 kWp. According to simulation results, the east-west orientation allows for a higher installed capacity compared to south-facing systems in the same area. Based on 2016 data, the system cost was calculated at 850,000 TL + VAT, the electricity unit price at 0.43 TL/kWh, and the payback period at 15.7 years. Currently, the cost has decreased to 750,000 TL + VAT, the electricity unit price is 0.82 TL/kWh, and the payback period is 6.7 years. The cost of a 110.5 kWp south-facing system evaluated under the same conditions was determined to be 515,000 TL + VAT, with a payback period of 6.5 years. As a result, while the initial investment cost of east-west oriented systems is approximately 235,000 TL + VAT higher, they offer the advantage of higher installed capacity per unit area. Additionally, the payback periods for such systems are shorter in regions closer to the equator[11].

For solar power plants to operate efficiently, it is critical to accurately analyze site layout, shading, panel tilt, equipment compatibility, and environmental conditions during the system design phase. Significant discrepancies may arise between theoretical calculations and actual production data due to temperature, solar irradiance, angle, equipment, and environmental losses. Roof-mounted solar power plants are typically installed with a focus on consumption and, due to space constraints, are fixed-angle systems; however, it has been determined that optimizing panel orientation, tilt angle, and placement in ground-mounted solar power plants results in higher efficiency. In particular, while selecting the appropriate angle and orientation is reported to increase efficiency by 6–8%, this increase can reach up to 20–40% in single-axis and dual-axis systems. However, in actual production values, losses of up to 40% compared to theoretical values may occur due to temperature effects, cloud cover, dust accumulation, shading, and system losses. This underscores the importance of proper equipment selection, regular maintenance, and optimal design in PV projects. In conclusion, the performance of rooftop and ground-mounted PV systems is directly related not only to installed capacity but also to design accuracy, environmental conditions, and operational processes. Therefore, analyses based on real-site data play a critical role in investment decisions and system optimization [12].

In this study, three different regions suitable for solar power plant construction were analyzed using multi-criteria decision-making methods. The AHP-VIKOR method was applied by evaluating the main criteria of economic, social, technical, and geographical factors and their associated sub-criteria, and Nevşehir was determined to be the most suitable location [13]. Factors affecting the performance of photovoltaic panels in an 8.6 kW grid-connected solar energy system installed in the UZAYMER building of Adana Çukurova University were investigated. According to solar radiation, wind speed, and temperature measurements, it was determined that increased wind speeds increased production, while dust, shading, and converter losses decreased production [14]. For the planned 5 MW PV system in Karaman, six panel types, three mounting types, and two inverter models were evaluated; energy analyses were performed using PVsyst, and economic analysis scenarios compliant with the Renewable Energy Law were created. The most suitable system was determined by calculating the payback period and internal rate of return [15]. In a study on the rooftop PV system of an industrial facility in Konya, investment payback periods and economic sustainability were evaluated using PVsyst analyses [16]. Another study addressed the design processes and performance analyses of photovoltaic systems according to different energy needs [17]. A study on agrivoltaic applications examined the Komşuköy Farm example; land use efficiency and the joint optimization of solar energy production were evaluated [18]. A PV system efficiency analysis and economic evaluation were conducted using TRNSYS software for a solar energy project designed for Trakya University [19]. In this study, the design and energy production of a 25 kW photovoltaic (PV) system were compared using the PVsyst, Photovoltaic System Design and Simulation Software (PV*SOL), Solar Energy Design and Simulation Software (Solarius), and Photovoltaic Geographical Information System (PVGIS) tools. According to the simulation results, it was determined that the system could produce 42-48 MWh of electricity annually, with a performance ratio in the range of 78-85%, and a reduction in annual CO_2 emissions of 18.66-22.23 tons. It was noted that the differences between the results were due to the solar radiation and meteorological databases used [20]. A thesis examining the operating principle, historical development, and efficiency of solar cells also included the design of a solar-powered device [21]. Another study on solar energy heat storage methods examined different storage techniques and the importance of insulation [22]. In a study on supporting buildings in the Trakya region with renewable energy, the integration of solar energy systems into buildings was evaluated [23].

Keçecioğlu et al. (2015) evaluated current and voltage harmonics as well as vibration (voltage flicker) parameters at the grid connection point of a 1 MW solar power plant (SPP) located in Adıyaman/Gölbaşı, based on field measurements conducted in accordance with EPDK and EN 50160 standards. The study found that total harmonic distortion (THD) values for voltage exceeded the limit (3%) throughout the day, while THD values for current exceeded the limit (5%) only for a short period during the morning hours when the plant was commissioned. It was noted that vibration intensity generally remained within limits, but in some cases, the short-term vibration (Pst) value reached twice the limit. These findings indicate that PV systems may cause transient harmonic distortion during startup and shutdown operations [24].

The efficiency of photovoltaic systems is directly affected by variable atmospheric conditions (solar irradiance and temperature) and load changes; this necessitates the continuous tracking of the maximum power point. In studies conducted in this field, modern methods such as artificial neural networks and fuzzy logic are frequently used alongside classical methods (Trial-and-Error, Hill Climbing, Gradient Descent). In particular, the neural-fuzzy control architecture provides adaptive control based on expert system predictions and offers better adaptation to changing operating conditions compared to classical methods. In this study, a two-loop maximum power point tracking system combining incremental conductance with neuro-fuzzy control is proposed for photovoltaic systems under variable load and solar irradiance conditions. It has been determined that this structure responds faster than the single-loop incremental conductance method, reduces steady-state power oscillations, and provides better adaptation to varying operating points [25].

2. ENERGY IN TURKEY AND THE WORLD

As of 2024, global energy demand has increased at a faster rate compared to previous years. According to the International Energy Agency's 2025 Global Energy Outlook report, energy demand rose by 2.2% in 2024. It is noted that this rate is nearly double the average of the last decade. The most important factor in this increase is the significant rise in electricity consumption. As of 2024, a 4.3% increase in electricity demand has been observed. The main reasons for this increase include weather conditions disrupted by global warming, electrification in the industrial sector (i.e., the widespread use of electricity instead of fossil fuels), the increase in the number of electric vehicles, and the rapid spread of data centers and artificial intelligence applications [26].
In 1973, Turkey's total energy capacity was approximately 2,000.00 MW, while by 2025, this figure had risen to 132,000.00 MW. The accelerated growth, particularly since the beginning of the 2000s, is closely related to Turkey's increasing energy needs, concerns about energy security, and investments in renewable energy. The rapid increase seen after 2015 is directly related to the rise in solar and wind energy investments.

Turkey's installed power capacity has shown rapid and continuous growth between 1973 and 2025. Installed capacity, which was 2,000.00 MW in 1973, reached 12,000.00 MW in 1983 due to the increasing energy demand and investments in the 1980s. Electricity consumption grew rapidly in the 1990s, and installed capacity reached 22,000.00 MW in 1993. The 2000s were a period marked by significant capacity increases, particularly in natural gas power plants and renewable energy sources (hydropower, wind, solar), with installed capacity rising to 38,000.00 MW in 2003. By 2013, the total installed capacity had reached 65,000.00 MW due to the impact of the rapid investment period. After 2020, the increase followed a more balanced course; installed capacity, which was 95,000.00 MW in 2020, increased by approximately 6,000.00 MW each year, reaching 120,000.00 MW in 2025. This process reflects the long-term impact of Turkey's policies and investments aimed at increasing energy supply security [27-28].

3. SOLAR ENERGY POTENTIAL

Solar energy potential indicates how much energy a region or surface can obtain from sunlight and reveals the possibility of converting this energy into electricity or heat. This potential, which is usually measured in kWh/m²-year, varies depending on various factors such as climate conditions, geographical location, duration of sunlight exposure, cloud cover, and atmospheric conditions. Countries with the most favorable solar energy potential are generally located in equatorial and subtropical areas and have large open areas that receive abundant sunlight throughout the year [29].

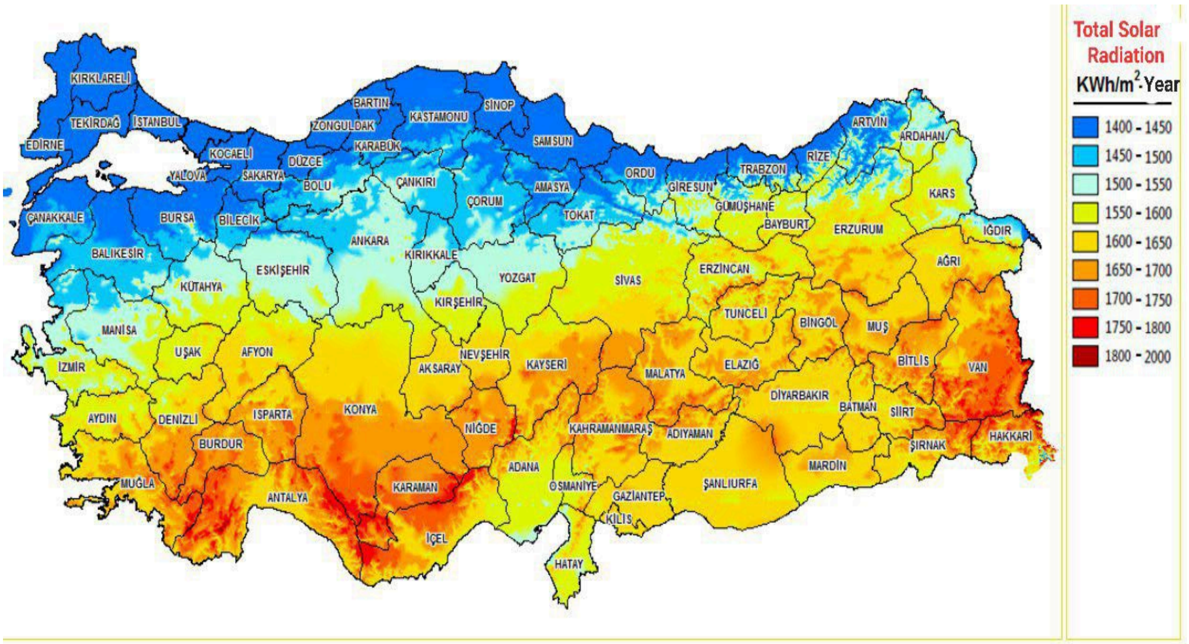


Figure 1. Kırklarelı solar power plants [2].

Solar power plant investments may operate at lower efficiency compared to other regions Annual solar radiation in Kırklareli ranges between 1400–1500 kWh/m²-year. This means that the solar radiation level is slightly below the Turkish average. This indicates that Kırklareli is not among the provinces with high solar radiation; however, it provides a moderate level of suitability. The solar energy potential in Kırklareli is suitable for regional investment, but it has a lower potential compared to the southern and inland regions of Turkey. Nevertheless, it is possible to meet part of the energy demand with solar energy systems, especially in districts such as Lüleburgaz and Babaeski, where industrial activities are concentrated [30].

- Kırklareli Global Radiation Values (kWh/m²-day): Maximum radiation values are observed in May, June, and July (5.9–6.0 kWh/m²-day). These values are very low in

December, January, and November (1.1–1.6 kWh/m²-day). This means that solar energy efficiency increases significantly during the summer months.

- Sunshine Duration (Hours): The longest sunshine durations in Kırklareli occur in June and July (11.4–12.5 hours). In December and January, the sunshine duration is quite short (2.9–3.7 hours). These durations are important in terms of solar panel efficiency [2].

4. GROUND-MOUNTED AND ROOFTOP SOLAR POWER PLANTS; THE EXAMPLE OF KIRKLARELI ÜSKÜP

Global climate change and the environmental damage caused by fossil fuels have increased interest in renewable energy sources. Thrace is one of the most suitable regions in Turkey in terms of solar energy potential. Kırklareli is a suitable location for solar power plants due to its average annual sunshine duration and radiation level. Therefore, both rooftop and ground-mounted solar power plants present significant investment opportunities for the region.

Figure 2. Kırklarelı solar power plants [29].

Ground-mounted plants are systems spread across different areas and have a large electricity generation capacity. It is preferred to establish these plants on land unsuitable for agriculture. In Kırklareli, large industrial facilities and agricultural businesses in particular are turning to rooftop solar energy systems. Rooftop systems can operate connected to the electricity grid or generate energy independently, and generally provide the advantages of generating energy at the point of consumption.

4.1. Ground-Mounted Solar Power Plant

Bilteks Sock Manufacturing Facility is located in the Üsküp region of Kırklareli province., has taken an important step towards environmental responsibility and sustainable energy use by installing a solar power plant on both the grounds and the roof of its production facility. This project enables Bilteks Çorapçılık to meet a significant portion of its energy needs from solar power. The solar power plant helps the company reduce its electricity consumption and save on energy costs. In addition, this investment contributes to environmental sustainability by reducing carbon emissions.

Table 1. Cost breakdown for a ground-mounted solar power plant

TYPE OF GOODS	AMOUNT	
• 1300 550-watt monocrystalline solar panels. • Total Installed Capacity: 550 × 1,300 = 715 kWp • 12 inverters, 50 kW each • Solar cable (6 mm red and black), 40000 meters • Aluminum Construction Materials • Galvanized Steel Construction Materials • PV Collection Panel • SCADA System • Cable Trays • AC Aluminum Cable • Grounding Cables and Strips • Protective and other auxiliary consumables • Transportation, Insurance, Design, Engineering, Labor	**560000 $** (Cost of a 1 MW power plant: $783,216.78 per MW)	
	TOTAL	560000 $

- 1300 Monocrystalline 550 Watt Solar Panels were used. High-efficiency monocrystalline panels were chosen. 1300 x 550W = 715kWp installed capacity will be achieved.
- 12 inverters with a capacity of 50 kW each were used. This provides a total inverter capacity of 600 kW.

Table 2. Monthly production data of the plant

Months	Total kWh produced monthly - Land	Solar Radiation (kWh/m²))	Maximum monthly production kWp	Rate of Performance (PR)
November 2023	27,171.00 kWh	75	53,625	51
December 2023	22,335.00 kWh	65	46,475	48
January 2024	33,628.00 kWh	75	53,625	63
February 2024	43,626.00 kWh	110	78,650	56
March 2024	62,830.00 kWh	130	92,950	68
April 2024	83,389.00 kWh	145	103,675	80
May 2024	92,082.00 kWh	175	125,125	74
June 2024	114,148.00 kWh	210	150,150	76
July 2024	105,070.00 kWh	235	168,025	63
August 2024	93,600.00 kWh	225	160,875	58
September 2024	80,730.00 kWh	185	132,275	61
October 2024	78,850.00 kWh	140	100,100	79
November 2024	44,150.00 kWh	75	53,625	82
December 2024	26,760.00 kWh	65	46,475	58
January 2025	35,800.00 kWh	75	53,625	67
February 2025	57,950.00 kWh	110	78,650	74
March 2025	85,170.00 kWh	130	92,950	92
April 2025	96,540.00 kWh	145	103,675	93

Basic formulas used in calculations:

1. Rate of Performance (PR):

$$PR = \frac{E_{AC}}{P_{DC} \times G_{PO}}$$

- EAC = Total AC energy fed into the grid during the measurement period (kWh)
- PDC = The system's nominal DC installed power under STC conditions (1000 W/m², 25°C, AM 1.5) (kWp)
- GPO = Total solar irradiance incident on the panel plane during the measurement period (kWh/m²)
- Emax,month = Maximum monthly energy production (kWh) [31].

2. Maximum monthly production:

$$E_{max,month} = EAC \times GPO$$

The Performance Ratio (PR) is a comprehensive performance metric that expresses the ratio of the system's actual output to its theoretical output, taking into account all losses occurring within the system. This parameter is defined based on the internationally recognized IEC 61724 Photovoltaic System Performance Monitoring Standard and enables the indirect assessment of losses within the system, such as those related to temperature, cabling, inverters, and shading. According to the IEC 61724 standard, the PR value is considered one of the fundamental criteria for evaluating actual system performance under field conditions. Table 2, which analyzes monthly PR values in our study, clearly illustrates the system's performance behavior. In particular, while an increase in PR values was observed during the summer months due to high solar irradiance, a downward trend in PR values was identified during the winter months due to the effects of reduced sunshine duration and changes in ambient temperature [32].

When examining the production data for the solar power plant:

- Installed capacity of the facility: 715 kWp
- Total generation: 1,183,829.00 kWh
- Average monthly generation of the facility: 65,768.28 kWh/month
- Monthly and annual generation from a single solar panel (550 W): 50.59 kWh/month, 607.08 kWh/year

4.2. Roof-Mounted Solar Power Plant

The plant was constructed on the roof of the factory belonging to Bilteks Çorapçılık in the province of Kırklareli. Since the Trakya region receives a significant amount of sunlight annually, it is highly suitable for solar power plant applications. The plant is designed to meet the factory's electricity needs and feed surplus energy into the grid. It operates in grid-connected mode, with excess energy being transferred to the grid.

Table 3. Cost breakdown of a rooftop solar power plant

TYPE OF GOODS		AMOUNT
• 920 monocrystalline solar panels, 540 watts each • Installed capacity: 540W × 920 = 497 kWp • 4 inverters, 110 kW each • Solar cable (6 mm red and black), 20,000 meters • Aluminum Construction Materials • Solar Power Plant Control Panel • SCADA System • Cable Trays • AC Aluminum Cable • Grounding Cables and Strips • Protective and other consumable materials, Transportation, Insurance, Design, Engineering, Labor		290000 $
	TOTAL	290000 $

- 920 panels, each with a capacity of 540 watts; Total capacity: 920x540 W=496,800.00 W = approximately 497 kWp.
- 4 inverters with a capacity of 110 kW each: Total AC capacity: 440 kW. This is the maximum power that the system can deliver to the grid.
-

Table 4. Monthly production data for the power plant

Months	Total kWh produced monthly - Rooftop	Solar Radiation (kWh/m²))	Maximum monthly production kWp	Rate of Performance (PR)

August 2022	73,100.00 kWh	225	111,825	65
September 2022	59,646.00 kWh	185	91,945	65
October 2022	43,764.00 kWh	140	69,580	63
November 2022	21,182.00 kWh	75	37,275	57
December 2022	15,810.00 kWh	65	32,305	49
January 2023	18,110.00 kWh	75	37,275	48
February 2023	35,260.00 kWh	110	54,670	65
March 2023	45,719.00 kWh	130	64,610	57
April 2023	54,257.00 kWh	145	72,065	75
May 2023	70,545.00 kWh	175	86,975	81
June 2023	82,152.00 kWh	210	104,370	79
July 2023	84,084.00 kWh	235	116,695	72
August 2023	79,700.00 kWh	225	111,825	71
September 2023	59,870.00 kWh	185	91,945	65
October 2023	39,900.00 kWh	140	69,580	57
November 2023	20,200.00 kWh	75	37,275	54
December 2023	16,100.00 kWh	65	32,305	50
January 2024	20,400.00 kWh	75	37,275	55
February 2024	29,000.00 kWh	110	54,670	53
March 2024	42,900.00 kWh	130	64,610	63
April 2024	56,600.00 kWh	145	72,065	79
May 2024	75,300.00 kWh	175	86,975	87
June 2024	89,500.00 kWh	210	104,370	85
July 2024	85,000.00 kWh	235	116,695	73
August 2024	74,700.00 kWh	225	111,825	67
September 2024	56,300.00 kWh	185	91,945	61
October 2024	46,700.00 kWh	140	69,580	67
November 2024	24,800.00 kWh	75	37,275	66
December 2024	17,000.00 kWh	65	32,305	53
January 2025	19,100.00 kWh	75	37,275	51
February 2025	30,500.00 kWh	110	54,670	56
March 2025	49,900.00 kWh	130	64,610	61
April 2025	63,400.00 kWh	145	72,065	88

The total energy production from the rooftop solar power plant from the date of installation through April 2025 is 1,600,499.00 kWh, which is equivalent to approximately 1.6 GWh. The average monthly production has been calculated as 48,499.96 kWh/month. This figure indicates that approximately 48,500.00 kWh was produced each month. On an annual basis, this amounts to 581,999.63 kWh/year.

- Installed capacity of the plant: 497 kWp
- Total generation: 1,600,499.00 kWh
- Average monthly production of the power plant: 48,499.96 kWh/month
- Monthly and annual production from a single solar panel (540 W): 52.71 kWh/month and 632.60 kWh/year were achieved.

The rooftop solar energy system generated 1,600,499.00 kWh in 33 months, while the ground-mounted solar energy system generated 1,183,829.00 kWh in 18 months.

The revenue generated from the rooftop solar power plant after 33 months is $182,326.56. In this case, the amortization rate was 62.87%. If current production data continues, the system is expected to be fully amortized in approximately 19.5 months (a total of 52.5 months).

In the ground-mounted solar power plant, however, the system has only recovered approximately 20.13% of the investment cost in 18 months. Based on this calculation, the system will pay for itself in an average of 89 months.

5. STUDIES ON THE DEVELOPMENT OF POWER PLANTS

Table 5. Technical Information on Power Plants

Kırklareli Üsküp Solar Power Plants	Ground-Mounted Solar Power Plant	Roof-Mounted Solar Power Plant
Panel	550 W monocrystalline × 1,300 units	540 W monocrystalline × 920 units
Total Installed Capacity	715 kWp	497 kWp
Inverter	50 kW × 12 units = 600 kW capacity	110 kW × 4 units = 440 kW capacity
Panel Efficiency	21%	20.79%
Inverter Efficiency	98.5%	98.5%
Temperature Coefficient (Pmax)	−0.35%/°C	−0.311%/°C
Panel Tilt Angle	22°	7° (roof pitch)
DC Cable	40 km	20 km
Net Output Power	551 kW	406 kW
DC/AC Ratio	1.191%	1.129%
System Age	2 years 4 months	3 years 7 months

- Shading: In photovoltaic (PV) systems, this is a critical engineering analysis used to determine the extent to which light reaching the panel surface is affected by surrounding obstacles. Factors such as the angle of sunlight, surrounding structures, trees, walls, chimneys, and the placement of other PV panels are decisive. Shading can cause significant losses in electricity generation from photovoltaic cells and may damage the cells, thereby shortening the system's lifespan. Since photovoltaic cells are connected in series, shading can affect the system's overall efficiency. The cell producing the lowest current in the series limits the total production capacity of the entire series. For ground-mounted PV systems: Nearby trees, poles, buildings, or other panel arrays can cast shadows during morning and evening hours. Panel placement should be adjusted according to the angles at which these shadows fall. For rooftop PV systems, obstacles such as chimneys, ventilation openings, and neighboring buildings must be properly modeled, and shading simulations should be performed considering summer and winter sun angles. Software such as PVsyst, Photovoltaic System Design and Performance Analysis Software (Helioscope), or 3D Modeling and Visualization Software (SketchUp) can be used for such analyses [33].
- Tilt Angle Analysis: In solar power plants (SPPs), the tilt angle refers to the angle between the photovoltaic panels and the horizontal plane, and it is one of the most critical design parameters that directly determines annual energy production. The primary objective is to ensure that sunlight strikes the panel surface as perpendicularly as possible throughout the year. An incorrectly selected tilt angle can result in an annual production difference of 8–15% between two plants with the same installed capacity. The optimal tilt angle varies depending on the facility's geographic latitude, the region's sunshine duration, and prevailing climatic conditions. For regions located at approximately 41–42° north latitude, such as Skopje and Kırklareli, this value is calculated using scientific methods to be 33–35°. Seasonal production losses are inevitable in fixed-mount systems. In large-scale projects, solar tracking systems (trackers) are used to reduce this loss; single-axis tracking can increase annual production by 20–30% compared to a fixed system. However, the additional investment cost may not make this solution economically viable for every project. Therefore, tilt angle analysis is a fundamental engineering calculation that must be performed during the project design phase using location-specific data [34–35].
- Analysis of Distance to the Power Transmission Line: An appropriate power transmission infrastructure is required for the energy generated by solar power plants to reach the power

grid. The distance between the solar power plant and this energy point has a direct impact on the system's efficiency, investment costs, and technical losses. If an appropriate distance is not determined, voltage drops, energy losses, additional infrastructure costs, and grid synchronization issues may arise. Electricity is transmitted from the plant to the distribution or transmission grid as alternating current (AC) or direct current (DC). In both cases, voltage losses and heat losses occur during energy transmission. Ground-mounted PV systems are typically located in large areas and are often situated on land outside city limits and far from distribution transformers. Thicker cables and higher voltage levels (MV/LV transformers) are required for long distances. Rooftop PV systems are usually directly integrated into the structure of buildings such as factories or schools. The energy generated here is fed directly into the building's internal electrical grid for its own consumption [36]. In terms of the overall efficiency of ground-mounted and rooftop solar energy systems, the length of the power transmission line is quite important. While long distances in ground-mounted systems lead to higher cable costs and transmission losses, the advantage of short distances in rooftop systems shortens the payback period of the investment. For both systems, cabling design, transformer placement, and transmission infrastructure should be a fundamental part of the system engineering process[37].

- Analysis of Natural Disaster Risks: Since solar power plants are long-term investments, not only site selection but also the risks of natural disasters in the region must be comprehensively assessed. Environmental factors such as wind, hail, snow, flooding, earthquakes, lightning, storms, and extreme temperatures directly affect system performance and resilience. In particular, strong winds can damage panel mounting systems, while snow load creates additional stress on roof systems, leading to structural risks and reducing energy production. Hail and heavy rainfall can cause physical damage, while flooding can lead to issues such as cabling problems and erosion, particularly in ground-mounted systems. In the event of an earthquake, mounting components may sustain damage, while lightning and sudden voltage fluctuations threaten sensitive equipment such as inverters. Additionally, high temperatures reduce panel efficiency, negatively impacting system performance [38]. Various engineering measures must be taken to mitigate these risks. Robust anchoring systems and low-profile mounting structures should be selected to withstand wind loads, and snow load calculations must be evaluated in conjunction with the roof's load-bearing capacity. Ensuring that panels comply with international durability standards, installing drainage systems on-site, and providing appropriate slopes reduce the risks of flooding and hail damage. In earthquake-prone regions, flexible connection elements and appropriate foundation designs should be used, and effective grounding and surge protection systems should be installed to reduce lightning risks. Additionally, inverters should be placed in cool, well-ventilated areas, and panels should be mounted in a way that allows for natural airflow. Ultimately, natural disaster risks are of critical importance regarding the lifespan, safety, and economic sustainability of solar energy systems and must be considered during the project phase.

Within the scope of this study, two separate solar power plants operating in the Üsküp Township of Kırklareli were examined in a comparative analysis based on their technical parameters. The plants in question consist of a ground-mounted solar power plant with an installed capacity of 715 kWp and a rooftop solar power plant with an installed capacity of 497 kWp. Both systems utilize monocrystalline photovoltaic panel technology and are directly connected to the grid.

HEAT LOSS:

An analysis of the loss data reveals that heat loss is the dominant loss factor for both systems.

$$P_{loss} = P_{max} \times \gamma \times (T_{cell} - 25)$$

Ground-Mounted Solar Power Plant

$\Delta T = 60 - 25 = 35°C$

Ploss = 0.35%/°C × 35°C = 12.25% Power loss = 715 kWp × 0.1225 = 87.6 kW

Roof-Mounted Solar Power Plant

Ploss = 0.311%/°C × 35°C = 10.89% Power loss = 497 kWp × 0.1089 = 54.1 kW

Assuming that the module operating temperature reaches approximately 60°C under the climatic conditions specific to Kırklareli Province, the thermal loss for the ground-mounted PV system, calculated using a temperature coefficient of −0.35%/°C, was determined to be 12.25% (87.6 kW). In a rooftop-type PV system, however, this loss remains at 10.89% (54.1 kW) due to a more favorable temperature coefficient (−0.311%/°C). This difference clearly demonstrates the decisive impact of thermal performance criteria on system efficiency during panel selection.

INVERTER LOSS:

Both systems use monocrystalline photovoltaic panel technology, and inverter efficiencies have been measured at 98.5%. Inverter Loss % = 100 − Inverter Efficiency

Loss = 100% − 98.5% = 1.5%

Ground-Mounted Solar Power Plant Power Loss = 715 kW × 0.015 = 10.7 kW

Roof-Mounted Solar Power Plant Power Loss = 497 kW × 0.015 = 7.45 kW

SHADING LOSS:

Open terrain → low risk of shading

Panel tilt angle: 22° → may cause shading between rows

Loss: 1.5% → 715 × 0.015 = 10.7 kW

Roof installation → chimney, ventilation, risk to adjacent structures

Panel tilt: 7° → advantage of low shadow angle

Loss: 2.5% → 497 × 0.025 = 12.4 kW

When shading losses are examined, the ground-mounted PV system exhibits a relatively low loss of 1.5% (10.7 kW) due to its open location and a panel tilt of 22°. In contrast, in the rooftop PV system, the loss rate rises to 2.5% (12.4 kW) due to partial shading caused by environmental obstacles such as chimneys, ventilation ducts, and surrounding structures.

OTHER LOSSES (Dirt + Mismatch + AC Losses):

In terms of total losses due to dirt, mismatch, and AC-side cabling, the ground-mounted PV system results in a loss of 3.0% (21.5 kW), while the rooftop PV system results in a loss of 2.5% (12.4 kW).

TILT ANGLE ANALYSIS:

The ideal fixed tilt angle for Kırklareli is approximately 33°–35°.

Current Situation: Ground-mounted PV system (22°)

Deviation: Approximately 12° lower than the ideal angle (34°).

Energy Loss: Compared to the ideal angle (34°), there is an annual loss of approximately 2.5%–3.5% in total production.

Current Status: Rooftop Solar Array (7°)

Angle Deviation: There is a deviation of exactly 27° from the ideal angle (34°).

Energy Loss: Compared to the ideal angle (34°), this results in a significant loss of approximately 9% to 11% in total annual energy production [39].

When all loss factors are considered together, the total loss was calculated to be 24.5% for ground-mounted photovoltaic systems and 28.9% for rooftop photovoltaic systems. This result indicates that the structural disadvantages of rooftop PV systems, stemming from their low tilt angles, significantly affect overall system performance. It is estimated that increasing the tilt angle to at least 15–20° in rooftop PV systems using a ballast-mounted installation system could result in a 6–8% increase in annual efficiency. In ground-mounted PV systems, it is projected that energy losses resulting from the current fixed angle could be offset by 8–12% through the integration of a single-axis solar tracking system (tracker). In this context, implementing technical improvements aimed at optimizing both systems is of critical importance in terms of long-term energy production efficiency and the payback period of the investment.

Table 6. Production, consumption, and sales data for factories and power plants

Date	**kWh fed into the grid**	**Total kWh generated by the rooftop system**	**Total kWh generated by the ground-mounted system**	**kWh consumed within the system**	**End-of-month exchange rate**	**Grid purchase price per kWh**	**TOTAL REVENUE $**
08. 2022	20.684,16	73.100,00	-	52,415.84	₺18,1714	3.36110 ₺	$12.726,75
09. 2022	14.849,92	59.646,00	-	44.796,08	₺18,5187	4,19803 ₺	$13.602,38
10. 2022	9.459,84	43.764,00	-	34.304,16	₺18,5915	4,05281 ₺	$9.478,37
11. 2022	1.742,08	21.182,00	-	19.439,92	₺18,6194	3,92578 ₺	$4.466,59
12. 2022	969,28	15.810,00	-	14.840,72	₺18,6983	4,20120 ₺	$3.538,25
1. 2023	1.790,40	18.110,00	-	16.319,60	₺18,7878	3,85420 ₺	$3.693,75
2. 2023	4.650,66	35.260,00	-	30.609,34	₺18,8647	3,31038 ₺	$6.132,19
3. 2023	8.891,52	45.719,00	-	36.827,48	₺19,1532	2,56439 ₺	$6.017,18
4. 2023	24.888,78	54.257,00	-	29.368,22	₺19,4268	2,36281 ₺	$6.355,78
5. 2023	21.131,46	70.545,00	-	49.413,54	₺20,6632	2,49139 ₺	$8.311,49

6. 2023	33.267,78	82.152,00	-	48.884,22	₺25,8231	2,10472 ₺	$6.451,18
7. 2023	31.648,68	84.084,00	-	52.435,32	₺26,9323	2,87206 ₺	$8.720,65
8. 2023	33.366,06	79.700,00	-	46.333,94	₺26,6658	2,88087 ₺	$8.348,45
9. 2023	15.634,08	59.870,00	-	44.235,92	₺27,3767	2,70648 ₺	$5.799,19
10. 2023	20.966,40	39.900,00	-	36.365,60	₺28,2366	2,96236 ₺	$5.859,33
11. 2023	17.711,82	20.200,00	27.171,00	29.659,18	₺28,8209	2,70768 ₺	$4.321,74
12. 2023	11.042,64	16.100,00	22.335,00	27.392,36	₺29,4382	2,69479 ₺	$3.439,83
1.2024	22.397,76	20.400,00	33.628,00	31.630,24	₺30,2952	2,77534 ₺	$4.794,69
2. 2024	35.631,54	29.000,00	43.626,00	36.994,46	₺31,1597	2,80168 ₺	$6.290,21
3. 2024	56.616,84	42.900,00	62.830,00	49.113,16	₺32,2854	3,12540 ₺	$9.868,01
4. 2024	97.445,88	56.600,00	83.389,00	42.543,12	₺32,3091	3,09146 ₺	$12.981,65
5. 2024	101.388,42	75.300,00	92.082,00	65.993,58	₺32,1339	3,09146 ₺	$15.738,49
6. 2024	146.642,58	89.500,00	114.148,00	57.005,42	₺32,8260	3,09146 ₺	$18.049,13
7. 2024	117.249,30	85.000,00	105.070,00	72.820,70	₺33,0835	2,84702 ₺	$18.588,52
8. 2024	120.747,06	74.700,00	93.600,00	47.552,94	₺33,9233	2,84700 ₺	$15.132,51
9. 2024	80.188,92	56.300,00	80.730,00	56.841,08	₺34,1210	3,82186 ₺	$14.566,34
10. 2024	77.168,70	46.700,00	78.850,00	48.381,30	₺34,1787	3,84190 ₺	$13.361,11
11. 2024	33.689,88	24.800,00	44.150,00	35.260,12	₺34,5794	3,81576 ₺	$7.284,21
12. 2024	17.512,74	17.000,00	26.760,00	26.247,26	₺35,2952	3,65438 ₺	$4.365,66
1.2025	24.570,00	19.100,00	35.800,00	30.330,00	₺35,7630	3,47170 ₺	$5.100,76
2. 2025	55.298,88	30.500,00	57.950,00	33.151,12	₺36,3812	3,84338 ₺	$8.838,11
3. 2025	98.227,08	49.900,00	85.170,00	36.842,92	₺37,7656	2,84702 ₺	$10.151,72
4. 2025	122.138,10	63.400,00	96.540,00	37.801,90	₺38,3684	2,95381 ₺	$12.652,95

The rooftop solar energy system generated 1,600,499.00 kWh of electricity over 33 months, and the revenue generated at the end of the 33-month period was $182,326.56. In this case, the payback period for the investment was calculated as 62.87%. If current production data continues, the system is expected to fully amortize in approximately 19.5 months (52.5 months in total). The ground-mounted solar energy system generated 1,183,829.00 kWh of electricity in 18 months. The installation cost of the ground-mounted solar energy system is $560,000. However, the ground-mounted solar power plant has recovered only approximately 20.13% of the investment cost in 18 months. Based on this calculation, the system will pay for itself in an average of 89 months.

5.1 Ground-Mounted Solar Power Plant

Annual Net Income Calculation

Given Data

- Initial investment cost (C_0) = 15,808,800 TL
- Annual energy production (E) = 789,219.36 kWh/year
- Electricity sales price (P) = 3.18452 TL/kWh
- Annual operating and maintenance cost (O&M) = 0 TL
- System lifespan (n) = 25 years
- Discount rate (r) = 10% (0.10)

Annual revenue:

- Revenue = Annual Energy × Electricity Price
- Revenue = 789,219.36 × 3.18452
- Annual Revenue = 2,513,475.53 TL/year

Net Present Value (NPV) Calculation:

NPV is one of the most commonly used economic indicators for calculating the present value of an investment [40].

$$\text{NPV} = \sum_{t=1}^{n} \frac{C_t}{(1+r)^t} + C_0$$

Here:

- Ct = annual net cash flow
- r = discount rate
- n = system life
- C_0 = initial investment cost

Present Value Factor

PV factor for 25 years:

$$\frac{1-(1+r)^{-n}}{r}$$
$$\frac{1-(1.10)^{-25}}{0.10}$$
$$= 9,077$$

NPV Result

NPV =2.513.000 × 9,077 − 15.808.000 TL NPV = 6.999.200 TL

Positive creates value for investors.

Internal Rate of Return (IRR) Calculation

The IRR is the value of r that makes the NPV equal to zero.

$$15.808.800 = 2.513.000 \times \frac{1-(1+IRR)^{-25}}{IRR}$$

$$\frac{1-(1+IRR)^{-25}}{IRR} = \frac{15.808.800}{2.513.000} \approx 6,29$$

$$IRR \approx 15 + \frac{6,46-6,29}{6,46-6,08} \times 1 \approx 15 + 0,45 \approx 15,45\%$$

Profitable, with a return exceeding the cost of capital (10%).

Levelized Cost of Energy (LCOE)

$$LCOE = \frac{I_0}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Current value of production:

$$\sum_{t=1}^{25} \frac{789.219,36}{(1,10)^t} = 789.219,36 \times 9,07704 \approx 7.164.000\,\mathrm{kWh}$$

$$LCOE = \frac{15.808.800\,\mathrm{TL}}{7.164.000\,\mathrm{kWh}} \approx 2,21\,\mathrm{TL/kWh}$$

LCOE ≈ 2.21 TL/kWh (selling price 3.18 TL/kWh → positive difference)

Below the selling price (3.18 TL/kWh) → a contribution of ~0.97 TL per kWh [41].

Roof-Mounted Solar Power Plant

Given Data:

- Initial investment cost (C_0) = 5,269,300 TL
- Annual energy production (E) = 581,999.52 kWh/year
- Electricity sales price (P) = 3.17453 TL/kWh
- Annual operating and maintenance cost (O&M) = 0 TL
- System lifespan (n) = 25 years
- Discount rate (r) = 10%
- Annual Net Revenue = 1,847,590 TL/year
- Net Present Value (NPV) = 11,501,000 TL

Strongly positive; the investment is highly valuable.
Internal Rate of Return (IRR) = 35% Well above the cost of capital (10%).
Levelized Cost of Energy (LCOE) = LCOE ≈ 1.00 TL/kWh Significantly lower than the sales price (~68% cheaper).

6. CONCLUSION

Solar power plants are an important, environmentally friendly, renewable, and increasingly cost-effective energy source. Growing energy needs, the harmful effects of fossil fuels, and climate change are accelerating the transition to solar energy. Turkey's high solar energy potential provides a significant advantage in this area. Therefore, the widespread adoption of solar power plants both increases energy supply security and contributes to sustainable development by reducing carbon emissions. Low operating costs after installation and high long-term efficiencies make these investments economically attractive. However, the efficiency of the plants depends on factors such as appropriate site selection, analysis of climatic conditions, planning of technological infrastructure, and regular maintenance. Despite this, obstacles such as high initial costs, bureaucratic processes, grid connection problems, and lack of information still persist. Central and local governments need to work together to solve these problems.

Table 7. Key technical and economic indicators for solar energy projects installed on roofs and on the ground

Criterion	Roof-mounted PV system	Ground-mounted PV system
Installed Capacity (kWp)	497 kW	715 kW

Annual Production (kWh)	581,999.52 kWh/year	789,219.36 kWh
Annual production fed into the system per 1 kW	1,171.02 kWh/year	1,103.80 kWh/ year
Investment Cost ($)	290,000.00 $	560,000.00 $
Unit Cost ($/kWp)	583.5 $/kWp	783.22 $/kWp
Inverter Capacity	440 kW	600 kW
Depreciation Period (years)	52.5 month	89 month
Space Requirements	Limited to the roof surface	Requires more land
Grid Integration	Direct distribution network	Direct distribution network

Although ground-mounted solar power plants and rooftop solar power plants operate on the same basic principle (converting sunlight into electricity), they differ significantly in terms of installation location, scale, cost, legal processes, and the advantages/disadvantages they offer.

Table 8. Ground-mounted PV systems and rooftop PV systems: a detailed comparison

Feature	Ground-Mounted Solar Power Plants	Roof-mounted PV systems
Installation Location	Non-agricultural land, idle areas, mining sites, reservoir surfaces.	Roofs and facades of residential, commercial, and industrial buildings.
Installation Scale	Typically large and medium-scale (MW level).	Typically small and medium-scale (kW or low MW levels).
Energy Consumption	Selling electricity directly to the grid or using it for consumption by large facilities.	Primarily designed to meet the building's own consumption.
Efficiency/Optimization	Possibility of achieving high efficiency with solar tracking systems.	Limited optimization depending on the slope and orientation of the roof.

Permit Processes	More complex and lengthy processes such as zoning, EIA (Environmental Impact Assessment), agricultural land permits, etc.	Connection agreement, building permit/approval, etc. are relatively simpler and shorter.
Equipment Lifespan	Panel life is similar in both systems (25+ years).	Similar in both systems.

Advantages and Disadvantages of Ground-Mounted Solar Power Plants:

Advantages:

- High Scalability: Massive systems can be installed on large plots of land, which reduces the total investment cost (per MW) and enables high energy production.
- Optimal Orientation and Tilt: Panels can be installed at the most efficient angle and orientation (usually south) without shading or roof constraints. Efficiency can be further increased with solar tracking systems (trackers).
- Energy Sales Potential: All or a large portion of the energy produced can be sold directly to the grid. This can shorten the investment payback period.
- Use of Idle Land: Areas unsuitable for agriculture, unproductive, or containing mining waste are converted into economic value.

Disadvantages:

- High Initial Investment Cost: Land acquisition, infrastructure, environmental safety, and grid connection costs are particularly high.
- Environmental and Legal Challenges: Long and complex legal processes are required, such as the EIA process, zoning plan changes, and agricultural land permits.
- Energy Transmission Losses: Losses occur when transmitting electricity to the grid from locations far from consumption centers.
- Land Cost and Use: Tying up large areas of land for long periods can result in opportunity costs due to land inflation [42].

Advantages and Disadvantages of Rooftop Solar Energy Systems:

Advantages:

- Production at the Point of Consumption: Electricity is produced where it is consumed, which reduces energy transmission/distribution losses to almost zero (one of the biggest advantages).

- High Profitability Through Self-Consumption: The energy produced reduces the building's own electricity bill (self-consumption) and provides a higher profit than the grid sale price.
- Faster and Simpler Permitting Processes: Since it is installed on an existing structure, the permitting and licensing processes are generally faster and simpler than for ground-mounted solar power plants.
- No Land Costs: Since the roof space is already available, there is no need to purchase land or incur related costs.
- Increased Building Value: Rooftop solar energy systems give buildings a green identity and increase their value in terms of energy efficiency.

Disadvantages:

- Limited Scale Capacity: Installation capacity is limited by the physical size of the roof, load-bearing capacity, and the building's electrical needs. Large-scale plants at the MW level cannot be installed.
- Roof Issues and Maintenance Difficulty: If the roof needs to be replaced, insulated, or structurally repaired, installation may not be possible or may incur additional costs. Access for maintenance and cleaning is more difficult.
- Shading Risk: Shading from elements such as chimneys, ventilation units, neighboring buildings, or trees can reduce efficiency.
- Direction and Slope Restrictions

Roof-mounted solar energy systems offer the most appropriate and efficient solution, particularly for residential and industrial self-consumption, while ground-mounted solar energy systems are large-scale energy sources necessary to ensure the country's overall energy supply security. These are not competing approaches but rather two complementary ones. These two systems should be evaluated based on the investor's goal (energy sales or self-consumption), capital size, and project scale. With advancing technologies and falling panel prices, both types of solar power plants will continue to play a critical role in Turkey's energy transition. In conclusion, in locations with abundant sunlight, such as Kırklareli, both rooftop and ground-mounted solar energy systems present a significant opportunity. However, to realize and benefit from this opportunity, detailed project planning and monitoring processes that integrate engineering, economic, and environmental considerations are essential to achieve good efficiency.

ACKNOWLEDGMENT

I would like to thank Ali BİLGİN for allowing us to use the data from the solar power plants installed within Bilteks Çorapçılık.

DECLARATION OF ETHICAL STANDARDS

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

CONTRIBUTION OF THE AUTHORS

Mustafa Acar: Conceptualization, Supervision, Manuscript Writing - Review & Editing

Sena Esen Bayer Keskin: Analysis, Data Visualization, Manuscript Writing, Manuscript Editing.

Engin Hüner: Analysis, Manuscript Writing, Manuscript Review.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

REFERENCES

[1] Özbektaş Ş, Şenel MC, Sungur B. Renewable energy status and installation costs in the world and turkey, Mühendis ve Makina, 2023; 64(711): 317–351.

[2] Ministry of Energy and Natural Resources (Turkey). GEPA – Turkey Solar Energy Potential Atlas, 2026. https://gepa.enerji.gov.tr/

[3] Aydın A, Dindar T, Alp E. Investigating the performance impact of solar panels: A sample application in Izmir province with the PVsyst program. International Journal of Energy Studies, 2025; 10(3), 951–962. https://doi.org/10.58559/ijes.1689142

[4] Dindar T, Sarkın AS, Esen V. Grid connected photovoltaic system design an example application for İstanbul province. International Journal of Energy Studies, 2023; 8(2), 189–200. https://doi.org/10.58559/ijes.1264183

[5] Ozden T. A countrywide analysis of 27 solar power plants installed at different climates. Scientific Reports, 2022; 12, 746. https://doi.org/10.1038/s41598-021-04551-7

[6] Bakır C, Yılancı A. Türkiye'deki farklı iller için şebekeye bağlı arazi ve çatı tipi lisanssız fotovoltaik güç santrallerinin tekno-ekonomik analizi. Mühendis ve Makina, 2022; 63(709), 560–584. https://doi.org/10.46399/muhendismakina.114780

[7] Sürücü B, Öztürk M, Çiftçi E, Tuncer AD. Software-based solar energy potential assessment for an industrial facility: A case study from Aegean Region of Turkey. International Journal of Energy Studies, 2022. https://doi.org/10.58559/ijes.1160477

[8] Akpolat AN, Dursun E, Kuzucuoğlu AE, Yang Y, Blaabjerg F, Baba AF. Performance analysis of a grid-connected rooftop solar photovoltaic system Electronics, 2019; 8(8), 905. https://doi.org/10.3390/electronics8080905

[9] Yıldırım B, Duzkaya H. Comparative analysis with PVGIS and PVsyst for solar energy production in Bahşılı region of Kırıkkale. Gazi Üniversitesi Fen Bilimleri Dergisi Part C: Tasarım ve Teknoloji, 2023. https://doi.org/10.29109/gujsc.1661431

[10] Kamacı İ, Yenteken A. Çatı tipi güneş enerji santrali tasarımı, ekonomik ve çevresel analizi (Hatay ili örneği). Afyon Kocatepe Üniversitesi Fen ve Mühendislik Bilimleri Dergisi, 2025; 25(2), 969–983. https://doi.org/10.35414/akufemubid.1574925

[11] Alkan S, Ateş Y. Production evaluation and economic analysis of rooftop east–west oriented optimized solar power plant compared to south-oriented system. European Journal of Science and Technology, 2020; (19), 375–385. https://doi.org/10.31590/ejosat.700182

[12] Doğan M. Güneş enerji santrallerinin incelenmesi ve verimlilik analizi (Yüksek lisans tezi). Sakarya Üniversitesi, Fen Bilimleri Enstitüsü, 2019.

[13] Demirkıran Göbeloğlu E, Ungan MC. Solar power plant location selection with AHP-VIKOR hybrid method. Sakarya Üniversitesi İşletme Enstitüsü Dergisi, 2023; 5(2), 95–109. https://doi.org/10.47542/sauied.1388986

[14] Gökce İ, Karakılçık M. Investigation of factors affecting electricity generation and performance from solar energy by using photovoltaic (PV) cells. Çukurova University Journal of Science and Engineering, 2020; 39(1).

[15] Girgin MH. Feasibility of a photovoltaic solar power plant: Energy production assessment and economic analysis for a 5 MW SPP in the Karaman region (Master's thesis), Istanbul Technical University, Energy Institute 2011.

[16] Yıldız MF. Financial analysis of solar power plants: The case of Konya province (Master's thesis). Selçuk University, 2025.

[17] Güneş S, Hacıoğlu R. Energy requirements based photovoltaic solar power plant analysis and design. Karaelmas Science and Engineering Journal, 2024; 14(2), 97–110. https://doi.org/10.7212/karaelmasfen.1447542

[18] Şentürk B, Kuzyaka D, Yalçın Ö, Akyıldız UM, Eröz M, Özden T. The analysis on dual land use efficiency: Integrating food and energy production in a case study of the Komşuköy agrivoltaic

farm model. Journal of Productivity, 2024; 58(3), 443–460. https://doi.org/10.51551/verimlilik.1430853

[19] Karataş A. Electricity generation from solar energy (Master's thesis). Trakya University, Institute of Science, 2012.

[20] Dindar T, Esen V, Sarkin AS. Comparison of simulation results for 25 kW power output rooftop PV system. European Journal of Technique, 2022; 12(2), 176–181. https://doi.org/10.36222/ejt.1175023

[21] Durgut T. Development of an alternative method for a solar panel system (Master's thesis). Trakya University, Institute of Science 2015.

[22] Uzun MH. Solar energy storage and evaluation of a method / Güneş enerjisi depolama olanakları ve bir yöntemin değerlendirilmesi, Trakya University, 2010.

[23] Baloğlu B. Energy-efficient building design in the Thrace region: The Çorlu case study (Master's thesis). Trakya University, Institute of Science, 2011.

[24] Keçecioğlu ÖF, Tekin M, Gani A, Açıkgöz H, Gemci A, Şekkeli M. Bir güneş enerji santralinin elektrik şebekesindeki güç kalitesi parametrelerine etkisinin incelenmesi. Kahramanmaraş Sütçü İmam Üniversitesi Mühendislik Bilimleri Dergisi, 2015; 18(2), 17–24. https://doi.org/10.17780/ksujes.41414

[25] Gani A, Açıkgöz H, Şekkeli M. Fotovoltaik sistemlerde değişken yük ve güneş ışınımı altında sinirsel-bulanık denetleyici ile maksimum güç noktası takibi. Avrupa Bilim ve Teknoloji Dergisi, 2020; (19), 734–745. https://doi.org/10.31590/ejosat.748384

[26] International Energy Agency. Global Energy Review 2025. [Online] Available from: https://www.iea.org/reports/global-energy-review-2025 (Accessed: 02/01/2026).

[27] Electricians Chamber of Turkey (EMO) 2025. [Online] Available from: https://www.emo.org.tr/genel/bizden_detay.php?kod=88369 (Accessed: 02/01/2026).

[28] Ergen E, Nazlıgül H. Energy criticism of Turkey and comparison with the world: energy harvesting, development, challenges, and opportunities. Adana Alparslan Turkes Science and Technology University Journal of Science, 2021; 4(1), 43–54.

[29] Global Solar Atlas. Global Solar Atlas 2025. [Online] Available from: https://globalsolaratlas.info/map?c=11.523088,8.173828,3 (Accessed: 02/01/2026).

[30] Emikönel S, Bilhan A. Analysis of Turkey's Solar Energy Potential in Different Regions. Osmaniye Korkut Ata University Journal of the Institute of Science and Technology, 5(Special Issue), 2022; 170–184. https://doi.org/10.47495/okufbed.1034175

[31] Google Earth. Google Earth Map 2025. [Online] Available from: https://earth.google.com/web/ (Accessed: 03/01/2026).

[32] Khalid AM, Mitra I, Warmuth W, Schacht V. Performance ratio – Crucial parameter for grid connected PV plants. Renewable and Sustainable Energy Reviews, 2016; 65, 1139–1158. https://doi.org/10.1016/j.rser.2016.07.066

[33] Adıgüzel E, Öztürk E, Dokur E, Ersoy A. Experimental analysis of shading in PV panels. AURUM Journal of Engineering Systems and Architecture, 2024; 8(2), 151–164. https://doi.org/10.53600/ajesa.1460733

[34] Yolcan OO, Köse R. Finding optimum tilt angles of photovoltaic panels: Kütahya case study. International Journal of Energy Studies, 2020; 5(2), 89–105.

[35] Aydınlatma.org. How to calculate solar panel angle / Güneş paneli (solar panel) açısı nasıl hesaplanır? 2025. [Online] Available at: https://aydinlatma.org/gunes-paneli-solar-panel-acisi-nasil-hesaplanir.html

[36] Cao T. Research on interactive development of China's energy and financial structure based on coupling coordination degree model. Energy Reports, 2022; 8(004), 1743–1751. https://doi.org/10.1016/j.egyr.2022.03.027

[37] Wang X, Gao X, Wu Y. Comprehensive analysis of tropical rooftop PV project: A case study in Nanning. Heliyon, 2023; 9(3), e14131. https://doi.org/10.1016/j.heliyon.2023.e14131

[38] Amin SB, Chowdhury MI, Ehsan SMA, Iqbal SMZ. Solar energy and natural disasters: Exploring household coping mechanisms, capacity, and resilience in Bangladesh. Energy Research & Social Science, 2021; 79, 102190. https://doi.org/10.1016/j.erss.2021.102190

[39] Deniz E. Güneş enerjisi santrallerinde kayıplar. Ulusal Tesisat Kongresi, İzmir, Türkiye, 2013.

[40] Melek A, Şakir S. Güneş enerjisi santrali yatırımlarının ekonomik analizi. Üçüncü Sektör Sosyal Ekonomi Dergisi, 2021; 56(4), 2177–2197.
https://doi.org/10.15659/3.sektor-sosyal-ekonomi.21.10.1575

[41] Short W, Packey DJ, Holt T. A manual for the economic evaluation of energy efficiency and renewable energy technologies (NREL/TP-462-5173). National Renewable Energy Laboratory, 1995.

[42] Dzamesi SKA, Ahiataku-Togobo W, Yakubu S, Acheampong P, Kwarteng M, Samikannu R, Azeave E. Comparative performance evaluation of ground-mounted and floating solar PV systems. Energy for Sustainable Development, 2024; 80, 101421. https://doi.org/10.1016/j.esd.2024.101421