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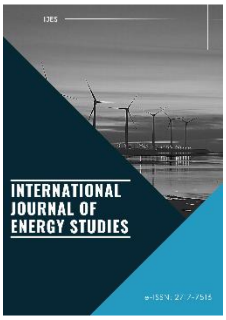

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Efficiency analysis of solar power plants: The impact of temperature, soiling, and panel aging on energy generation

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Highlights

- The difference between simulated and actual generation data was only 1.55% on an annual basis. Actual generation: 25.936 MWh Simulated estimate: 25.535 MWh.
- Soiling-related losses can reach up to 20% if regular cleaning is not performed, leading to an annual energy loss of 4,746 MWh. Generation with 0% soiling loss: 25.064 MWh Generation with 20% soiling loss: 20.318 MWh
- Panel aging (degradation) causes an annual energy generation loss of approximately 0.3% - 1%. Annual generation with 0.3% degradation: 23,936 MWh Annual generation with 0.6% degradation: 23,232 MWh
- As panel temperature increases, generation decreases. When the temperature coefficient drops from -0.35 to -0.65, annual generation is reduced by approximately 1,524 MWh. Annual generation at -0.35 temperature coefficient: 25.064 MWh Annual generation at -0.65 temperature coefficient: 23,540 MWh

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ABSTRACT

In this study, a rooftop solar power plant with an electrical capacity of 13,890 kWe and 18,361 kWp was modeled using the PVsyst software simulation program. Simulated and experimental data were compared and the difference between simulated and experimental generation data was found to be only 1.55% on an annual basis, demonstrating the accuracy of the modeling approach. In order to further analyze the system's performance, the impact of temperature, soiling, and panel aging on energy generation was evaluated as detailed. It was observed that soiling-related losses could reach up to 20% if regular cleaning was not performed, leading to an annual energy loss of 4,746 MWh, where generation decreased from 25,064 MWh at 0% soiling loss to 20,318 MWh at 20% soiling loss. Panel aging (degradation) also played a significant role, causing an annual energy generation loss of approximately 0.3% - 1%, reducing the output from 23,936 MWh at 0.3% degradation to 23,232 MWh at 0.6% degradation. Additionally, as panel temperature increased, generation efficiency decreased, with a temperature coefficient drop from -0.35 to -0.65 resulting in an annual generation loss of approximately 1,524 MWh, where output declined from 25,064 MWh to 23,540 MWh. These findings highlight the critical influence of environmental and operational factors on PV power plant performance and emphasize the importance of regular maintenance and optimized design strategies to enhance energy generation efficiency.

Keywords: Photovoltaic performance, Soiling losses, Panel degradation, Temperature effect, PVsyst

1. INTRODUCTION

The increasing energy demand and the risk of depletion of fossil fuel resources have heightened interest in renewable energy sources. Solar power plants stand out as a crucial solution for environmental sustainability and reducing energy generation costs. However, the efficiency of solar power plants is not solely dependent on design and installation processes; it is also closely related to accurately analyzing the impact of environmental and operational factors on generation. Verified optimization is equally important for the performance of a solar power plant. There is extensive literature on the simulation of solar power plants. These studies have been thoroughly reviewed. Abbasi [1] evaluated the benefits of an 8.6 kWp solar power plant in the village of Gagrawara, located in the Sindh region of Pakistan. The study focused on performance assessments and interviews with local residents, highlighting aspects such as energy access and socio-economic impacts. The findings demonstrated that the solar power plant provided reliable energy in rural areas, positively contributed to social development, and reduced dependence on conventional energy sources. Aldabbagh [2] designed a 100 MW photovoltaic (PV) power plant in Mosul using PVsyst software, optimizing the system's tilt angles and configurations. The annual energy generation was calculated as 181,136 MWh, with 98.5% of it being grid compatible. The study emphasized the importance of simulation tools for improving efficiency and cost-effectiveness in large-scale PV projects. Ay [3] investigated the feasibility of grid-connected, off-grid, and hybrid PV systems for various load profiles in Bartın, a region with low solar irradiation. Simulations conducted using PVSOL software demonstrated that hybrid systems increased the share of solar energy in total energy consumption by 16.6%, offering sustainable solutions under challenging climatic conditions. Karaca [4] modeled and compared a 75 kW PV system in Ankara using Matlab/Simulink and PVsyst. The study introduced the use of Maximum Power Point Tracking (MPPT) algorithms in simulations. The results indicated that Matlab/Simulink's enhanced MPPT models produced higher outputs under varying environmental conditions, while both tools provided consistent performance evaluations. Arslan [5] conducted a detailed investigation of azimuth and tilt angles to maximize energy generation from PV panels in Konya. Experimental and theoretical analyses identified an optimal tilt angle of 32.08°, emphasizing the significance of region-specific adjustments that can significantly enhance energy generation. Jalalzai [6] designed a grid-connected PV system with storage for a residential building in Edremit. PVSOL and PVsyst software were used for simulation and optimization. The study highlighted the potential of integrating storage systems to increase self-consumption rates and reduce dependence on external energy sources. Emre [7] evaluated a 15 kWp PV power plant in Isparta using real-time field data and PVSOL simulations. The comparison showed a 95.7% agreement between simulated and actual data. A financial analysis revealed that the investment could be recovered within 5.6 years. Egemen [8] analyzed the annual energy generation of a 990 kWp PV power plant at Tokat's Erbaa Municipality using PVSOL and PVsyst. Both simulation programs produced results closely aligned with real data, confirming their reliability for feasibility studies in municipal-scale projects. Çınaroğlu [9] conducted a cost and performance analysis of various solar tracking mechanisms for off-grid PV systems in Bilecik. Fixed, seasonal, horizontal, vertical, and dual-axis tracking systems were evaluated, emphasizing how tracking mechanisms impact energy output and cost-effectiveness in isolated systems. Uysal [10] analyzed the installation of a rooftop PV system to reduce energy costs for an industrial facility in Istanbul. The design, which evaluated monocrystalline and polycrystalline panels, resulted in a 50% reduction in energy costs. The study highlighted the potential of rooftop PV systems for urban industrial applications. Şahin [11] examined the compatibility of real generation data with PVSOL and PVsyst simulation programs for a PV system in Sirnak, Türkiye. The results confirmed the usefulness of these tools in planning and evaluating PV projects, with an accuracy rate exceeding 90%. Islamov [12] calculated the optimal tilt angles and corresponding irradiation levels for PV panels across 14 regions in Azerbaijan. The findings provided practical insights into PV system installation under various climatic conditions and highlighted the regions with the highest solar energy potential. Erakman Dirlik [13] conducted a comparative analysis of PVsyst and HOMER software for solar energy systems in Türkiye. The author's study states that PVsyst's error rate is 3.3%. This result demonstrates the accuracy of the PVsyst simulation program and its importance in solar energy projects. In another study conducted by Yiğit [14], the performance of a 1 MW PV power plant was examined. In this study, energy loss factors such as tilt angles, orientation, and system configuration were analyzed. The study provides detailed information on how to increase system efficiency and reduce losses.

In this study, experimental generation data was collected from an actively operating rooftop solar power plant. This plant was modeled in a simulation program with PVsyst. Simulation results were compared with experimental results to comprehensively analyze the factors affecting energy generation. Unlike previous literature studies, a separately established modeling approach was used to individually examine the impacts of temperature, soiling, and panel aging on energy generation, and recommendations were provided to minimize these effects. The proposed study experimentally analyzed a solar power plant with an installed capacity of 13,890 kWe AC and 18,361 kWp DC. Generation data collected throughout 2023 was compared with simulation results, and deviations in annual generation performance were analyzed. The success of the simulation model was evaluated by comparing it with experimental data, revealing that the obtained deviation values were remarkably low. Subsequently, the modeling approach was used to analyze the effects of panel aging, temperature variations, and surface soiling on the power plant's generation efficiency in detail. The results contribute to the development of optimization strategies aimed at improving the overall performance of the solar power plant.

2. TECHNICAL SPECIFICATIONS AND CAPACITY OF THE INSTALLED SOLAR POWER PLANT

The rooftop solar power plant with an electrical capacity of 13,890 kWe and a panel capacity of 18,361 kWp, is located in Kahramanmaras, Türkiye. A map view of the location is presented in Figure 1. The installed power plant consists of 42,700 panels, each with a nominal power of 430 W. The plant's electrical power is supplied by 136 inverters, each with a nominal power of 100 kW, capable of operating up to 110 kW. The total installed electrical capacity is 13,890 kW. The technical specifications of the power plant are summarized in Table 1.

Figure 1. Google earth view of the location of the installed PV power plant [15]

Table 1. Technical specifications of the installed PV power plant

Feature	Value	Description
AC Power (kWe)	13,890	Total power generated as alternating current, representing the grid-fed power.
DC Power (kWp)	18,361	Maximum direct current generation capacity of the panels.
PV Panel Power (kWp)	0,430	Nominal power of each panel.
PV Panel Quantity	42,700	Total number of panels used in the power plant.
Inverter Power (kWe)	100	Total AC power capacity of the inverters.
Inverter Quantity	136	Total number of inverters used, ensuring power balance.

3. NUMERICAL AND EXPERIMENTAL RESULTS

Obtained results provide a comprehensive analysis of the performance and efficiency of the solar power plant under different environmental and operational conditions. Key factors such as seasonal solar irradiation variations, energy generation performance, panel degradation, soiling losses, and the thermal effects on panel efficiency have been thoroughly evaluated. Additionally, the accuracy of simulation models was compared with real generation data, providing valuable insights into the system's behavior and areas for optimization. These findings have been analyzed in the context of minimizing energy losses and increasing energy generation, focusing on practical solutions to improve the overall performance and economic sustainability of the power plant.

The monthly electricity generation data for a rooftop solar power plant established in 2023 is shown in Figure 2. Generation values are shown in MWh. The annual total electricity generation was found to be 25,936 MWh. When examining the 2023 generation data, the highest electricity generation was achieved in July, reaching 3,617 MWh. Due to the long sunshine hours and high solar radiation in July, the highest generation was achieved in this month. Throughout the year, the highest generation occurs in June, July, and August. The lowest generation was recorded in December at 990 MWh. As sunshine hours decrease and solar radiation intensity declines, electricity generation decreases during the fall and winter months.

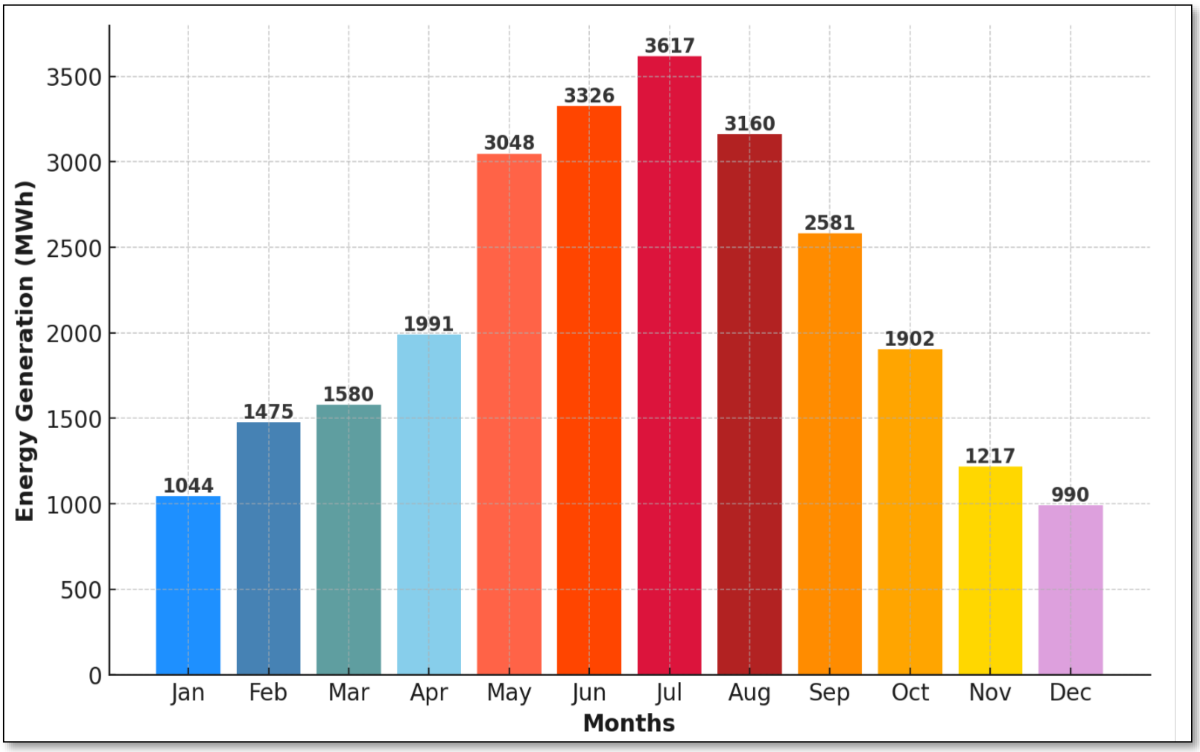

Figure 2. Monthly energy generation of the installed PV power plant based on experimental data

A solar power plant with the same technical specifications was modeled using PVsyst software. The simulated monthly generation values were compared with experimental generation data and analyzed. Table 2 presents the monthly generation data for 2023, highlighting differences between simulation results and actual generation values. In January and February, the simulation data underestimated generation by 12.93% and 19.45%, respectively. However, in March and April, this deviation reversed, with the simulation overestimating generation by 24.87% and 25.81%, respectively.

During May and June, the deviation dropped below 2%, indicating that the simulation closely matched real generation values. In July and August, real generation exceeded simulation values by 6.83% and 3.89%, respectively. For September and October, the difference remained within the 5% to 10% range. Meanwhile, in November and December, simulation data underestimated real generation by 11.17% and 14.34%, respectively.

When examining annual total values, the overall deviation between simulation and real generation was 1.55%, demonstrating that the simulation performed well in general. However, monthly deviations were observed during certain periods, which may have been caused by seasonal changes, weather conditions, or variations in system performance.

Table 2. Comparison of numerical and experimental data with percentage deviation

Month	Numerical Data (MWh)	Experimental Data (MWh)	Percentage Deviation (%)
January	909	1,044	12.93
February	1,188	1,475	19.46
March	1,973	1,580	-24.87
April	2,505	1,991	-25.82
May	3,110	3,048	-2.03
June	3,357	3,326	-0.93
July	3,370	3,617	6.83
August	3,037	3,160	3.89
September	2,445	2,581	5.27
October	1,712	1,902	9.99
November	1,081	1,217	11.18
December	848	990	14.34
Year/Total	25,535	25,936	1.55

PVsyst simulation program estimates energy generation by considering various detailed parameters such as solar irradiation, temperature, tilt angle, orientation, and system losses. However, it is not always possible to fully transfer all real field conditions into the model. The reasons behind the monthly deviations have been examined in detail as follows: (i) Meteorological Data Variability: After selecting the location in the simulation software, climate data from international sources such as Meteonorm are used, enabling accurate system design based on long-term average meteorological data. However, actual weather conditions can vary significantly from year to year. For instance, while the month of March in a previous year might have been clear and dry, resulting in high energy generation, the same month in another year could experience cloudy and rainy conditions, leading to lower generation. Experimental data from operational plants also show that, although year-to-year generation differences are generally around 5%, monthly variations can reach up to 20%. (ii) Panel Soiling and Maintenance Schedules: In some months, cleaning might have been delayed or not performed, resulting in lower actual generation than the simulated values. For example, a dust storm in one month may lead to mud formation on the panels, while in another month this might not occur. Therefore, panel cleaning frequency plays a critical role in maintaining generation efficiency. (iii) Temperature and Thermal Effects: The ambient temperatures used in simulations are based on long-term averages, which may differ from actual conditions. Even within the same month of different years, temperature variations can be significant. These discrepancies in weather conditions from month to month are among the main causes of the observed deviations between simulated and experimental data.

As a result of these variations, simulation values were higher than actual generation in some months, while in other months the opposite occurred. Nevertheless, the annual deviation was found to be only 1.55%, indicating that the model is generally accurate and reliable.

Figure 3 presents the monthly comparison of simulated and actual generation data. Upon examining the graph, it is observed that in March and April, the simulation values were higher than the actual generation data. In contrast, in February and December, the actual generation exceeded the simulated values.

Additionally, the simulation and experimental generation values were very close within months of May and June. It indicates that the model provided more accurate predictions during these months. Overall, the simulation accurately represents real generation values, but certain deviations occur in some months due to meteorological factors or modeling limitations.

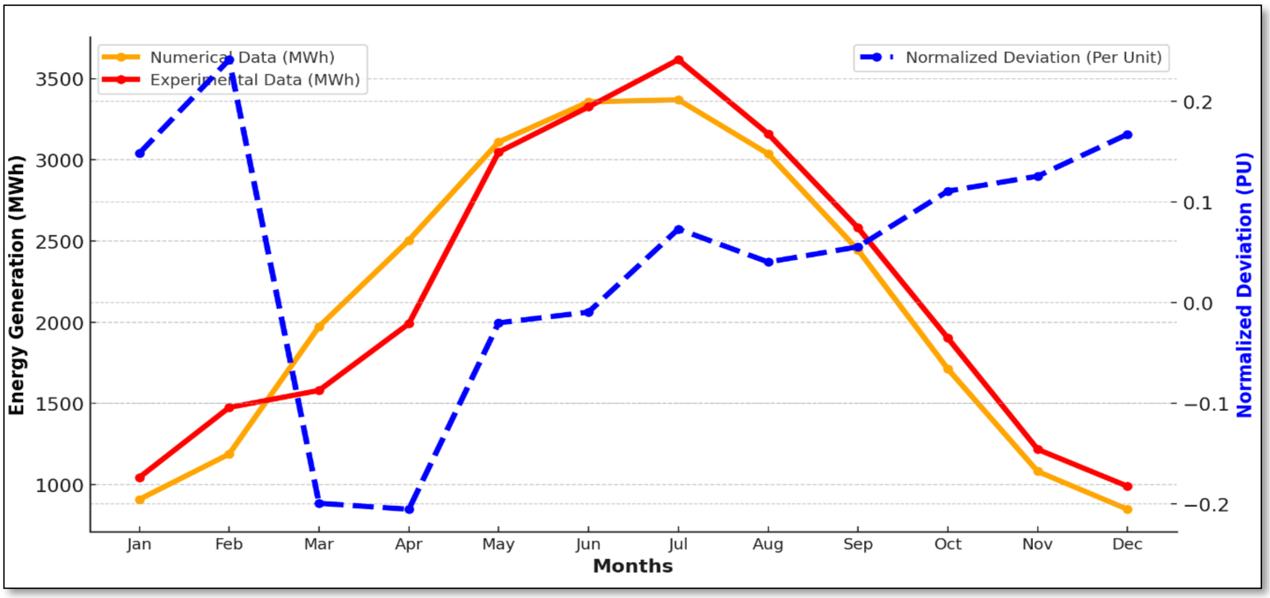

Figure 3. Comparison of numerical and experimental data with normalized deviation analysis

Table 3 presents the monthly energy generation and performance indicators from the simulation, alongside climate data. Solar energy data is expressed through GlobHor (global horizontal irradiation) and DiffHor (diffuse horizontal irradiation) values. These values fluctuate throughout the year, with the highest GlobHor value recorded in July at 228.2 kWh/m² and the lowest in December at 70.7 kWh/m². T_Amb (average ambient temperature) increases during the summer months, reaching its peak in July at 31.26°C, while the lowest temperature was recorded in January at 4.97°C. GlobInc (global irradiation on the inclined surface) and GlobEff (effective radiation reaching the module) are used to evaluate system performance. The highest GlobInc was recorded in June at 221.0 kWh/m², while GlobEff peaked in the same month at 215.7 kWh/m². On the generation side, EArray (total energy generated by the modules) and E_Grid (total energy transferred to the grid) values are included. The highest energy generation was observed in July, with EArray reaching 3,365,958 kWh and E_Grid reaching 3,307,592 kWh. The overall annual performance is assessed using the Performance Ratio (PR), which was calculated as an average of 0.843 throughout the year.

Table 3. Monthly and annual solar radiation, temperature and energy performance data

Month	GlobHor (kWh/m²)	DiffHor (kWh/m²)	T_Amb (°C)	GlobInc (kWh/m²)	GlobEff (kWh/m²)	EArray (kWh)	E_Grid (kWh)	PR (ratio)
Jan.	71.4	33.09	4.97	56.1	50.4	909,437	892,872	0.866
Feb.	83.4	40.34	7.44	71.4	66.6	1,187,943	1,166,424	0.89
March	131.7	60.06	12.1	119.0	114.2	1,973,359	1,936,856	0.886
Apr.	164.3	76.34	16.14	148.2	148.2	2,505,445	2,457,917	0.875
May	201.4	73.84	21.96	194.8	189.9	3,110,317	3,051,496	0.853
June	220.5	73.84	26.16	215.7	210.9	3,356,710	3,293,276	0.831
July	228.2	72.13	31.26	221.0	215.8	3,369,598	3,307,592	0.815
Aug.	210.8	62.91	28.51	199.4	193.9	3,037,277	2,983,265	0.815
Sept.	175.5	41.64	26.61	158.0	152.1	2,444,915	2,400,415	0.844

Oct.	127.6	39.71	19.57	108.0	101.8	1,711,594	1,681,083	0.844
Nov.	87.4	31.67	12.36	65.1	61.7	1,078,041	1,061,671	0.844
Dec.	70.7	29.51	7.32	54.1	47.4	847,839	832,666	0.839
Year	1,773.0	641.87	18.16	1,619.1	1,552.8	25,535,13	25,064,36	0.843

3.1. Impact of Pollution Loss on Solar Power Plant Efficiency and Energy Generation

Pollution loss in solar power plants refers to the energy generation loss caused by the accumulation of dust, dirt, bird droppings, leaves, and other foreign particles on the surface of the panels. These deposits block solar irradiation from reaching the panels, leading to a 1% to 30% reduction in energy generation capacity. This issue is particularly significant in dusty, arid, or industrial regions. Additionally, pollution can cause temperature variations on the panels (hot-spot effect), which may shorten the lifespan of the equipment.

To prevent or minimize pollution loss, regular cleaning is crucial. Proper tilt angle adjustment of the panels allows rainwater to act as a natural cleaner. Moreover, anti-reflective and dirt-repellent coatings can help reduce the impact of particle accumulation. Therefore, pollution reduces the economic gain of the power plant as it decreases electricity generation. PV panels that are not cleaned regularly can cause a loss of electricity generation ranging from 5% to 20% in a power plant. Regular cleaning is particularly necessary in power plants located along roadsides, in dusty areas, and within industrial facilities with chimneys. The impact of the pollution factor on electricity generation in a solar power plant has been analyzed in detail using the PVsyst simulation program. Obtained results are presented in Figure 4.

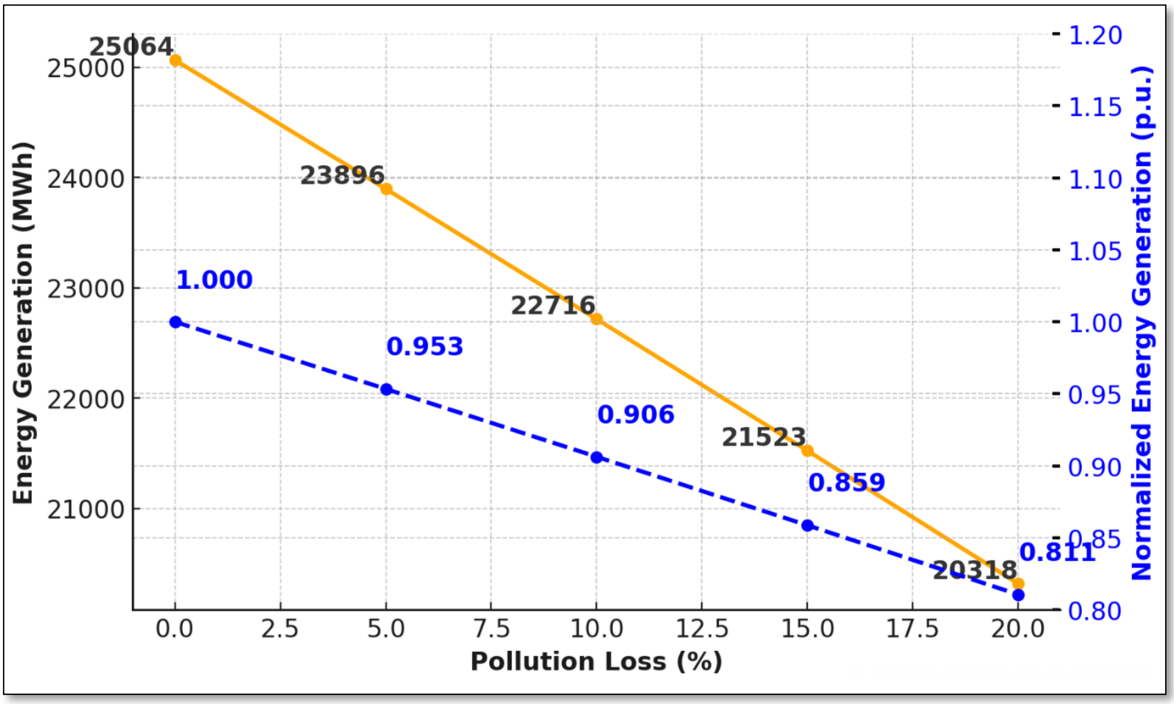

Figure 4. Comparison ımpact of pollution loss on PV plant energy generation

As pollution loss increases, the electricity generation of PV panels decreases. When pollution loss is 0%, the plant operates at maximum capacity and produces 25,064 MWh of electricity. However, when pollution loss reaches 20%, this electricity generation value drops to 20,318 MWh. Therefore, under such pollution conditions, the power plant will produce 4,746 MWh less electricity annually. The effect of fouling loss on the power plant's electricity generation can be calculated in its most basic form using Eq. (1) [16-18];

$$\eta = \eta_0 \times (1 - S) \tag{1}$$

Here, η represents the PV panel efficiency after soiling, η_0 represents the PV panel efficiency before soiling, and S represents the soiling rate value.

3.2. Analysis of Solar Panel Degradation and Its Impact on Energy Generation Using Monte Carlo Simulation

Photovoltaic panel performance declines over time due to environmental influences such as heat temperature, UV radiation, humidity, and microcracks. Rising temperatures reduce open-circuit voltage, lowering efficiency and extending the payback period as it known. Literature studies show degradation rates typically range from 0.5% to 1% annually, with faster deterioration in hot and humid climates. Effective mitigation strategies are essential to maintain long-term PV system performance. These findings demonstrate that the performance of PV systems is highly dependent on environmental conditions. generation. Monte Carlo simulation is used to examine the nonlinear dynamics of defect formation and to understand the temporal evolution of degradation. This modeling approach is beneficial not only for analyzing technical performance but also for predicting energy generation losses and optimizing system design. generationThe energy generationgeneration loss due to degradation can be calculated using Eq. (2) [19-22]:

$$P_t = P_0 \times (1 - r)^t \quad (2)$$

Where, P_t: Panel generation capacity at year t (Watt or MWh), P_0: Initial panel generation capacity (Watt or MWh), r: Annual degradation rate (e.g., 0.01 for 1%), t: Number of years elapsed.
For an initial capacity of P_0 = 500 kW, a degradation rate of r = 0.01, and a time period of t = 5 years, the remaining capacity can be calculated with Eq. (3):

$$P_t = 500 \times (1 - 0.01)^5 \approx 475.50\ kW \quad (3)$$

Thus, after 5 years, the panel's generation capacity will decrease to approximately 475.50 kW, resulting in a 4.90% total energy loss due to degradation. For a 10-year period, the panel's generation capacity is calculated with Eq.(4):

$$P_t = 500 \times (1 - 0.01)^{10} \approx 452.19\ kW \quad (4)$$

Thus, after 10 years, the panel's generation capacity will decrease to approximately 452.19 kW, indicating a 9.56% total energy loss due to degradation. In the modeling performed with PVsyst, the relationship between degradation rate and energy generation has been analyzed in detail. Figure 5 illustrates a negative correlation between the degradation rate and annual energy generation. The degradation rate represents the annual performance loss of solar panels, and as this rate increases, energy generation decreases. For instance, when the degradation rate is 0.3%, the annual energy generation is at its highest level, reaching 23,936 MWh. However, as the degradation rate increases to 0.4%, generation drops to 23,705 MWh. At a degradation rate of 0.5%, electricity generation falls to 23,474 MWh, and at 0.6%, it falls to 23,232 MWh.

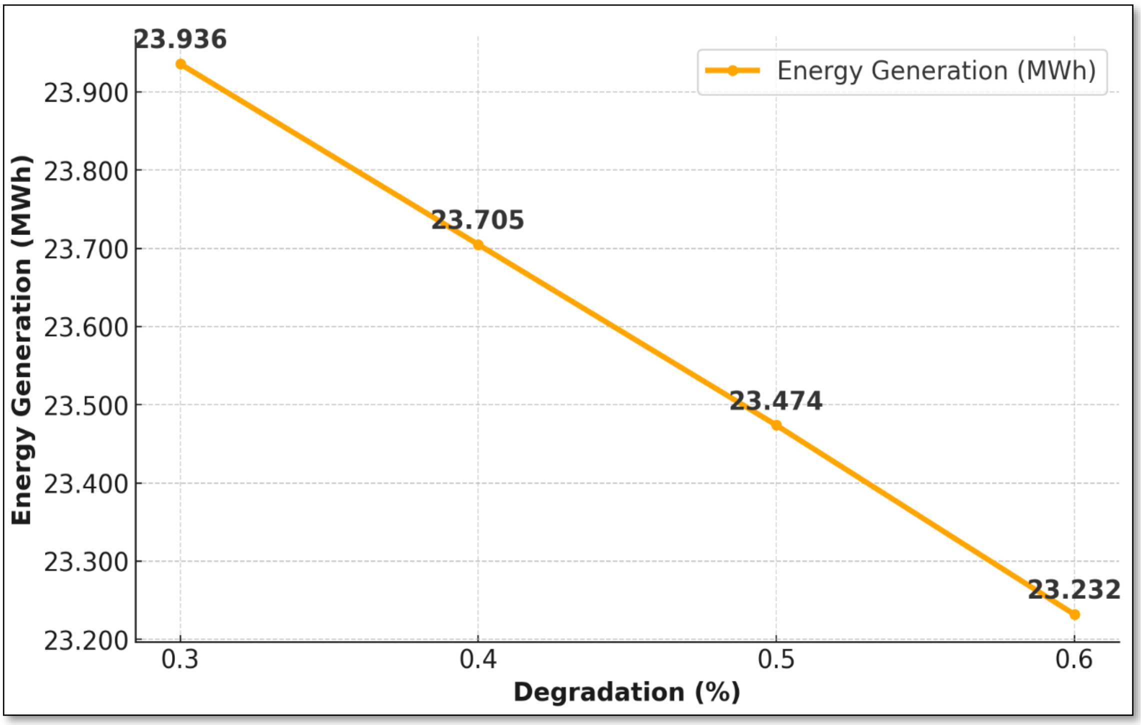

Figure 5. Comparison impact of degradation loss on solar energy generation

3.3. Impact of Panel Surface Temperature on Photovoltaic Power Generation: Temperature Coefficient Analysis

The surface temperature of PV panels is a critical factor that directly affects their electricity generation capacity. An increase in ambient temperature and solar radiation intensity causes an increase in the cell temperature of PV panels. This temperature increase reduces the electrical energy generation efficiency of the modules and, consequently, electrical energy generation. Additionally, high PV cell temperatures shorten the lifespan of the cells. Although there are various studies in the literature on the increase in efficiency achieved by cooling PV panels, these studies remain at the prototype stage. This is because energy is also consumed for cooling. There are temperature coefficients for the cells used in PV panels. These coefficients provide information on how open-circuit voltage, short-circuit current, and the panel's power value change with temperature. Therefore, the temperature coefficient should be considered not only in panel selection but also in power plant site planning, environmental condition assessments, and operating cost evaluations. Maximum power point temperature coefficient can be calculated with Eq. (5) for panel power at different temperatures [23-26].

$$P_t = P_{STC} \times [1 + \beta \times (T_{cell} - T_{STC})] \tag{5}$$

Where, P_t represents maximum power at the current temperature (W), P_{STC} represents maximum power at standard test conditions (STC: 25°C) (W), β defines P_{MPP} temperature coefficient, T_{cell} represents panel cell temperature (°C), T_{STC} defines STC temperature (typically 25°C).

Figure 6 illustrates the effect of the temperature coefficient on electricity generation. According to the data, as the temperature coefficient increases (becomes more negative), a decrease in generation value occurs. When the temperature coefficient is -0.35, the recorded generation value is 25,064 MWh. However, when the temperature coefficient reaches -0.65, the generation value drops to 23,540 MWh. This indicates that a more negative temperature coefficient reduces energy generation capacity. The reason behind this is that temperature increases negatively impact the efficiency of photovoltaic cells. The trend in the table shows that each 0.1% increase in the temperature coefficient results in a noticeable reduction in generation value. As the temperature of photovoltaic cells rises, their efficiency decreases, leading to energy generation losses. The graph demonstrates that even small changes in the temperature coefficient significantly impact generation capacity.

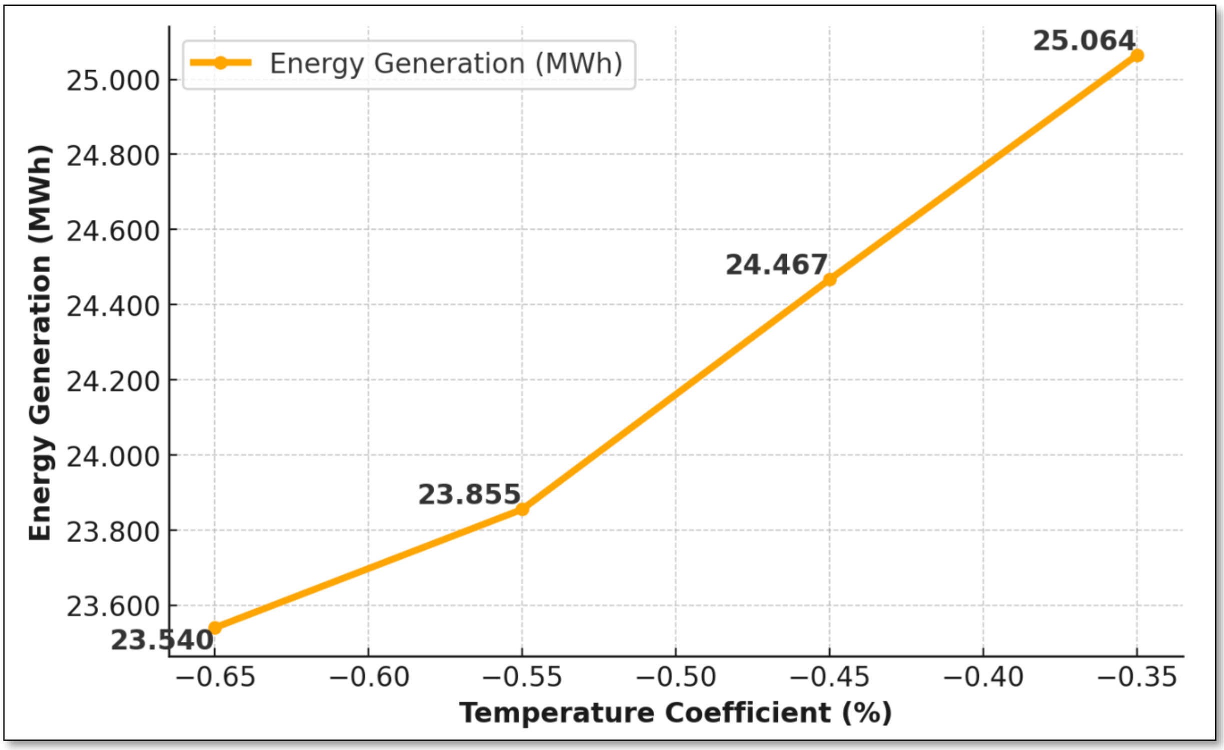

Figure 6. Comparison impact of temperature coefficient on PV plant energy generation

3.4. Impact of Light-Induced Degradation (LID) on Solar Panel Performance and Mitigation Strategies

In PV panels, degradation caused by radiation leads to performance loss over time due to factors such as UV radiation, thermal stress, humidity, photodegradation, and Potential Induced Degradation (PID). UV radiation causes chemical aging in protective materials, while temperature fluctuations create mechanical stress, leading to microcracks that reduce energy generation. LID (Light Induced Degradation) results in initial efficiency losses of 1% to 3% when panels are first exposed to sunlight. In Figure 7, it is shown that as the LID loss factor reaches 0.6%, generation decreases from 25,064 MWh to 24,916 MWh. To mitigate degradation, several strategies should be implemented, including the use of UV-resistant coatings to prevent material aging, thermal management systems to reduce temperature-induced stress, PID-preventive designs to limit potential-induced losses, and regular maintenance to ensure system reliability. Additionally, high-quality materials and low-degradation cells should be preferred to extend the lifespan and maintain efficiency. These approaches are crucial for preserving system efficiency and prolonging the operational life of solar power plants. Figure 7 shows the impact of the LID loss factor on PV plant energy generation. As can be seen from the figure, when the LID loss factor reaches 0.6%, electricity generation drops from 25,064 MWh to 24,916 MWh. To reduce the impact of LID degradation and prevent material aging, UV-resistant coatings should be used. To reduce temperature-induced stress, thermal management systems should be employed. To limit potential-induced losses, PID-preventive designs should be implemented. Additionally, regular maintenance should be conducted to ensure system reliability.

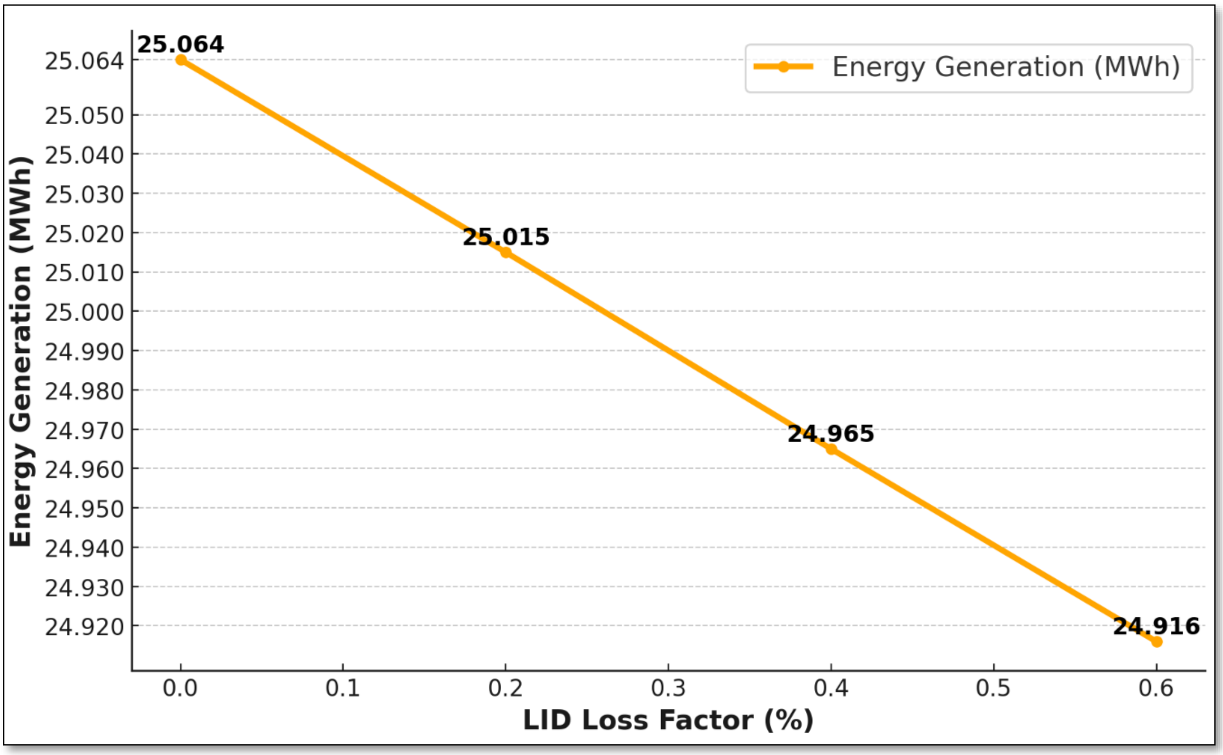

Figure 7. Impact of LID loss factor on PV plant energy generation

4. CONCLUSION

This study comprehensively analyzes the environmental and operational conditions that affect the performance of rooftop PV power plants. The comparison of experimental generation data with PVsyst simulation modeling not only evaluates the accuracy of the modeling but also provides a detailed analysis of the factors affecting plant performance. The study examines in detail the impact of factors such as temperature changes, panel soiling, panel aging (degradation), and radiation-induced panel degradation on electricity generation.

Modeling results obtained using PVsyst simulation software were compared with the actual generation data of the solar power plant for 2023, and the accuracy of the model was analyzed in detail. As a result of the comparisons, it was determined that the difference between the simulation and actual generation values on an annual basis was 1.55%. As it known that there are important factors that affect the electricity generation of a PV power plant. These are temperature, soiling, and panel aging.

In particular, due to the negative PMPP temperature coefficient, every 1°C increase in temperature reduces the electrical energy generation of PV panels by approximately 0.4%. This value may vary depending on the type of cell used in PV panels. When the temperature coefficient is -0.35, the recorded generation value is 25,064 MWh. However, when the temperature coefficient reaches -

0.65, the generation value drops to 23,540 MWh. This indicates that a more negative temperature coefficient reduces energy generation capacity.

Other parameter is pollution loss. As it increases, the electricity generation of PV panels decreases. When pollution loss is 0%, the plant operates at maximum capacity and produces 25,064 MWh of electricity. However, when pollution loss reaches 20%, this electricity generation value drops to 20,318 MWh. Therefore, under such pollution conditions, the power plant will produce 4,746 MWh less electricity annually.

Other parameter is degradation rate. When the degradation rate is 0.3%, the annual energy generation is at its highest level, reaching 23,936 MWh. However, as the degradation rate increases to 0.4%, generation drops to 23,705 MWh. At a degradation rate of 0.5%, electricity generation falls to 23,474 MWh, and at 0.6%, it falls to 23,232 MWh.

Another critical aspect is LID loss factor. Obtained simulated resyults show that it reaches 0.6%, generation decreases from 25,064 MWh to 24,916 MWh. To mitigate degradation, several strategies should be implemented, including the use of UV-resistant coatings to prevent material aging, thermal management systems to reduce temperature-induced stress, PID-preventive designs to limit potential-induced losses, and regular maintenance to ensure system reliability.

The study also confirmed that electricity generation varies significantly depending on seasonal changes. Although there is no significant change on an annual basis, there can be significant changes on a monthly basis. Electricity energy generation reaches its peak in summer months due to increased sunshine duration and solar radiation intensity, while generation levels decline significantly in winter months.

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DECLARATION OF ETHICAL STANDARDS

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

CONTRIBUTION OF THE AUTHORS

This study was conducted as part of the master's thesis of Ozgesu Çutay, under the supervision of Assoc. Prof. Dr. Furkan Dincer. The research planning, data analysis, and interpretation of the results were carried out jointly.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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