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Performance Comparisons of Bifacial Photovoltaic Modules on Surfaces With Different Albedo Values: PVsyst Simulation Study

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Abstract. The renewable energy sector is continually evolving to meet global energy demands and reduce environmental impacts. In this context, solar energy technologies, particularly photovoltaic (PV) systems, are playing an increasingly significant role in energy production. Photovoltaic module manufacturers and solar power plant investors are especially favoring the production and use of bifacial PV modules. The primary reason for this preference is that bifacial PV modules can capture sunlight on both their front and rear surfaces, offering a higher energy production potential compared to monofacial modules. However, this performance is significantly influenced by environmental factors such as ground albedo (reflectivity coefficient). In this study, the performance of bifacial PV modules on surfaces with different reflectivity coefficients was simulated using PVsyst software. Terrain topography and PV module layout at specified coordinates were modeled using SketchUp. The energy production performance of bifacial modules was examined under various ground albedo conditions, and the results were compared. Simulation results revealed a significant increase in energy production as albedo values increased. These findings demonstrate that the albedo value of the ground where bifacial PV systems are installed is a critical and decisive factor in system performance. The simulation data indicate that as the albedo level increases, both the Performance Ratio (PR) and the annual energy production capacity of the PV systems show a marked improvement. Transitioning from a 5% albedo level to a 70% albedo level resulted in an increase in PR from 85.36% to 93.98%, and in energy production from 1,792 kWh/kWp/year to 1,973 kWh/kWp/year.

Keywords: Bifacial Photovoltaic Modules, Albedo Effect, PVSYST, Energy Efficiency, Simulation, Solar Power Plants

1. Introduction

With the advancement of technology, bifacial PV modules are increasingly preferred over monofacial PV modules. This preference stems from the fact that bifacial modules, due to their cell technology and manufacturing processes, harness solar energy from both their front surfaces, which capture direct sunlight, and their rear surfaces, which utilize reflected light from the ground. Consequently, bifacial modules can achieve additional power generation from their rear surfaces, offering a distinct advantage over traditional monofacial modules [1]. A critical factor in the efficacy of bifacial technology in enhancing power output and achieving high energy production potential is the albedo effect.

Ground albedo refers to a surface's capacity to reflect sunlight, and this value is crucial for optimizing the effectiveness of the rear surfaces of bifacial photovoltaic modules [2]. Thus, the performance of bifacial modules can vary significantly depending on environmental factors such as albedo [3]. The objective of this study is to evaluate the performance of bifacial PV modules under various albedo conditions. Simulations were conducted using the PVsyst software to investigate how changes in albedo values impact the potential energy output of the modules. In this context, the study provides valuable insights for the selection and design of sites for installing bifacial PV systems.

While the influence of albedo on bifacial photovoltaic performance has been widely explored in the literature, existing simulation-based studies often employ simplified system layouts that fail to capture the installation and operational complexities of large-scale solar power plants [3], [4]. A detailed evaluation of M10-sized PERC modules in a utility-scale configuration (28.38 MWp) with a realistic terrain model remains limited. This work addresses that gap by conducting a comprehensive performance analysis of M10 bifacial PV modules with PERC cell technology, integrating the actual site coordinates of Karapınar, Türkiye, and extensive meteorological datasets into the PVsyst model. This approach combines three key elements: (1) a specific and modern module technology (M10-PERC), (2) a utility-scale, ground-mounted plant layout derived from real-world terrain data, and (3) a realistic albedo variability analysis tailored to this geographical location, enabling a more accurate and practical assessment of performance under varying albedo conditions.

2. Material and methods

In the study, land topography was utilized, and the installation and layout of PV modules at specified coordinates were carried out using SketchUp modeling software. Module layout plans and models were then uploaded to PVsyst, where separate simulations were conducted for each albedo value. PVsyst is a widely used tool for modeling the performance of photovoltaic systems and was chosen for its ability to simulate various environmental conditions. Similar PVsyst-based approaches have been previously employed to analyze the impact of ground surface albedo on the performance of bifacial photovoltaic systems [5]. The simulations were conducted using specific geographic locations and meteorological data. The focus was on analyzing the performance of bifacial PV modules on surfaces with different albedo values. In this context, parameters such as the installation site, mounting angle, and module type were also considered as part of the simulation.

2.1 Data input and parameters

The simulation study was conducted at a location with coordinates 37.80°N latitude, 33.59°E longitude, and an elevation of 985 meters in Karapınar/Konya/Turkey. The climate data for the region were obtained using Meteonorm 8.1 software. Meteorological data, including parameters such as temperature, humidity, and wind speed, were entered into the system for each month over a one-year period. The PV systems, designed to be grid-connected, were configured with a fixed mounting system, with a tilt angle of 25° and an azimuth angle of 0°. The total nominal power of the system was measured at 28.38 MWp. In photovoltaic [PV] systems, nominal power is defined as the maximum power output that solar panels can produce under Standard Test Conditions [STC]. These conditions are characterized by a specific solar irradiance [1000 W/m²], cell temperature [25°C], and air mass [AM 1.5].

Table 1. *Electrical parameters of pv modules used in the simulation*

Type	**M10/PERC GGF**
Maximum Power [Pmax] [W]	535
Open Circuit Voltage [Voc] [V]	49,53
Short Circuit Current [Isc] [A]	13,67
Maximum Power Voltage [Vmp] [V]	41,11
Maximum Power Current [Imp] [A]	13,02
PV Module Effective Efficiency [%]	20,65
Bifaciality Rate [%]	69

Table 2. *Geometric parameters of pv modules*

Long Edge	2285 mm
Short Edge	1134 mm
Thickness [Framed]	30 mm

Table 3. *Key parameters of the simulation study*

Coordinates of the Study Area	37.80 °N, 33.59 °E
Meteorological Data	Meteonorm 8.1
Unit Power of the PV Module	535 W
Number of PV Modules	53040
Nominal Power	28.38 MWp
Number of Inverters	77
Unit Power of the Inverter	300 kWac
Tilt/Azimuth	25/0°

The study utilized the KY-535-GF-HC module group, which belongs to the bifacial module segment and is manufactured using PERC cell technology. The dimensions of a single module are 2285 mm by 1134 mm, with a thickness of 30 mm [including the frame]. The bifaciality factor of the PV module is in the 70% segment, with each module having a unit power of 535 Wp. A total of 53,040 PV modules were installed at the specified location, resulting in a total nominal power of 28.38 MWp under Standard Test Conditions [STC]. The dimensions of the mounting structures [module group matrices] were set at 26*2, with a total of 1,020 tables installed. The spacing between the tables is 10.55 meters in the horizontal direction and 4.58 meters in the vertical direction. The height of the tables from the ground was adjusted to 1 meter. The total active module surface area engaged in production on the site is 137,437 m². The study employed the SUN2000-330KTL-H1-Preliminary V0.2 model inverter. A total of 77 inverters were used, each with a unit power of 300 kWac. The total nominal power of the inverters is 23,100 kWac, resulting in a system nominal power ratio of 1.23.

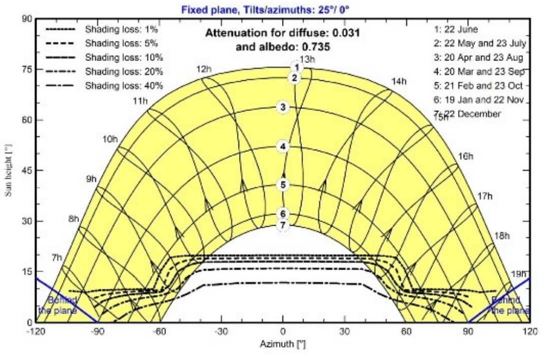

Figure 1. *Solar path diagram generated using PVSYST for the Konya/Karapınar/Turkey region*

Figure 1 displays the solar path diagram generated by PVsyst. This diagram graphically represents the sun's trajectory in the sky for a specific day and location. Analyzing this curve provides critical insights for optimizing the performance of your solar energy system and allows for necessary adjustments to maximize the efficiency of the PV system.

2.2 Simulation procedure

In the simulation study, five different scenario conditions were applied: [S1: 5%, S2: 10%, S3: 30%, S4: 50%, and S5: 70%]. Simulations were conducted separately for each albedo value. During the simulations, the variations in energy production of bifacial modules were analyzed based on the albedo values. All variables and parameters were kept constant, except for the ground reflectivity coefficient, with a focus on examining the impact of albedo on the performance of bifacial modules. For each scenario condition, array losses [such as soiling, thermal loss factors, wiring losses, series diode losses, losses due to LID effects, and module quality losses] were considered, and the influence of these parameters on the results was thoroughly evaluated.

Table 4. *PV array loss parameters and values*

PV Array Loss Parameters	Values [%]
Soiling Losses	3
Module Quality Losses	0,8
LID Losses	2
Mismatch Losses	2
DC Cabling Losses	1,5
Near-Shading Losses	1,33
Rear-Surface Shading Losses	5
IAM Factor Losses	2,56
Rear-Surface View Factor Losses	75,88

The study incorporated various user-defined parameters within the PVsyst software to ensure realistic modeling of PV systems, with particular emphasis on accurately representing loss factors [6].

3. Results

3.1 Simulation S1: Performance of the PV system at 5% albedo condition

In the scenario with a 5% albedo condition, the system operated with a Performance Ratio [PR] of 85.36%, which represents the ratio of actual energy produced to theoretical energy potential. Over a 12-month period, the system generated a total of 50,842,752 kWp/year of usable energy at the inverter output. The potential energy yield was measured at 1,792 kWh/kWp/year. Under the 5% albedo condition, the global irradiance reflected onto the rear surface of the module was measured at 2.48% [49 kWh/m²]. Considering the losses and gains from the albedo effect, the effective irradiance on the collector was determined to be 1,959 kWh/m². This value represents the total irradiance collected on the PV module surface, including gains from the albedo effect and system losses.

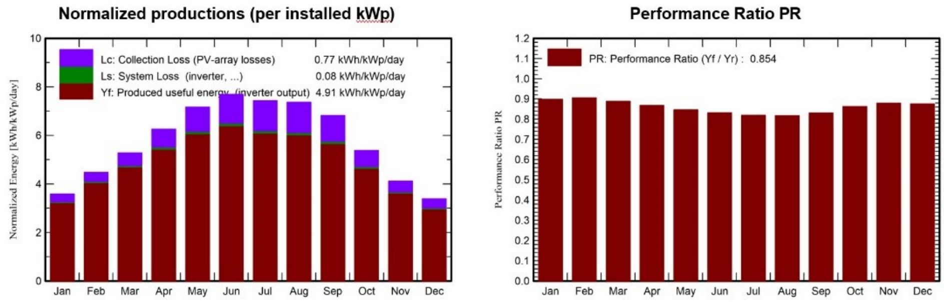

Figure 2. *Annual normalized production data at 5% albedo level and performance ratio indexes*

3.2 Simulation S2: Performance of the PV system at 10% albedo condition

In the scenario with a 10% albedo condition, the system operated with a Performance Ratio [PR] of 86.05%. Over a 12-month period, the system produced a total of 51,258,650 kWp/year of energy. The potential energy yield was re/corded at 1,806 kWh/kWp/year. Under the 10% albedo condition, the global irradiance reflected onto the rear surface of the module was measured at 3.76% [74 kWh/m²]. Considering the losses and gains from the albedo effect, the effective irradiance on the collector was determined to be 1,960 kWh/m².

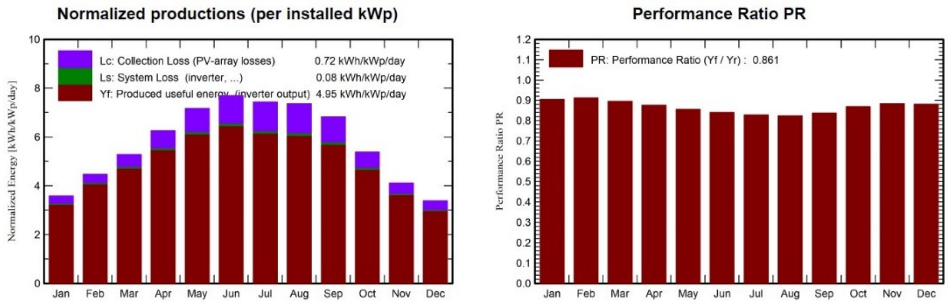

Figure 3. *Annual normalized production data at 10% albedo level and performance ratio indexes*

3.3 Simulation S3: Performance of the PV system at 30% albedo condition

In the scenario with a 30% albedo condition, the system operated with a Performance Ratio [PR] of 88.80%. Over a 12-month period, the system produced a total of 52,895,342 kWp/year of energy. The potential energy yield for this period was recorded at 1,864 kWh/kWp/year. Under the 30% albedo condition, the global irradiance reflected onto the rear surface of the module was measured at 8.87% [174 kWh/m²]. Considering the losses and gains from the albedo effect, the effective irradiance on the collector was determined to be 1,963 kWh/m².

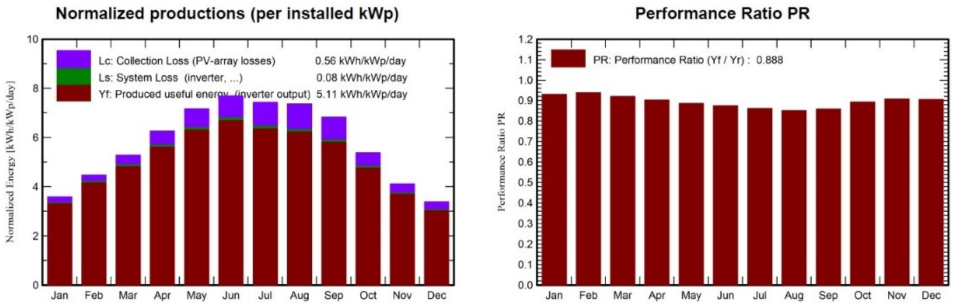

Figure 4*. Annual normalized production data at 30% albedo level and performance ratio indexes*

3.4 Simulation S4: Performance of the PV system at 50% albedo condition

In the scenario with a 50% albedo condition, the system operated with a Performance Ratio [PR] of 91.45%. Over a 12-month period, the system produced a total of 54,472,369 kWp/year of energy, with a potential energy yield of 1,920 kWh/kWp/year. Under the 50% albedo condition, the global irradiance reflected onto the rear surface of the module was measured at 13.95% [274 kWh/m²]. When considering the losses and the gains from the albedo effect, the effective irradiance on the collector was determined to be 1,967 kWh/m².

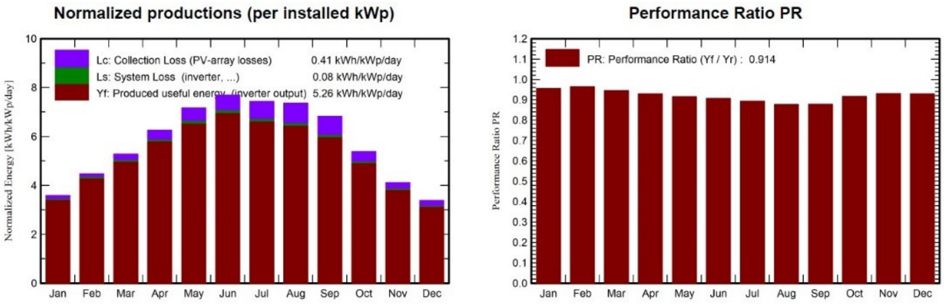

Figure 5. *Annual normalized production data at 50% albedo level and performance ratio indexes*

3.5 Simulation S5: Performance of the PV system at 70% albedo condition

In the scenario with a 70% albedo condition, the system operated with a Performance Ratio [PR] of 93.98%. Over a period of 12 months, the system produced a total of 55,982,210 kWp/year. The annual energy yield was calculated to be 1,973 kWh/kWp/year. Under the 70% albedo condition, the global irradiance reflected onto the rear surface of the module was measured at 375 kWh/m², which corresponds to 19.02%. When considering losses and the benefits resulting from the albedo effect, the effective irradiance incident on the collector was measured at 1,971 kWh/m².

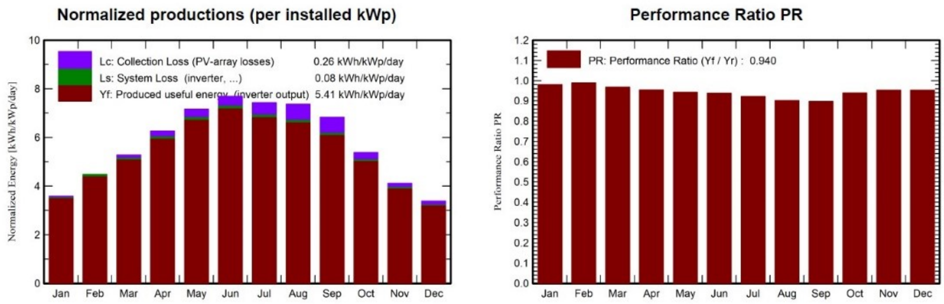

Figure 6. *Annual normalized production data at 70% albedo level and performance ratio indexes*

4. Conclusion and evaluation

Impact of Albedo on PV System Performance: The simulation data indicate that as the albedo level increases, both the Performance Ratio [PR] and the annual energy production capacity of the PV systems show a marked improvement. Transitioning from a 5% albedo level to a 70% albedo level resulted in an increase in PR from 85.36% to 93.98%, and in energy production from 1,792 kWh/kWp/year to 1,973 kWh/kWp/year. This proves the substantial positive effect of high reflectivity surfaces on the efficiency of bifacial PV modules.

Evaluation of Energy Production Increases: The analysis of energy production increases shows significant growth with increasing albedo levels. For each 5% to 20% increase in albedo level, notable enhancements in energy production were recorded. This indicates that higher albedo levels allow more sunlight to be reflected onto the rear surface of the PV modules, thereby increasing their energy production potential.

Relationship Between PR Ratio and Albedo*:* The Performance Ratio [PR], which reflects the overall efficiency of the system, improved by 8.62% with the increase in albedo from 5% to 70%. This demonstrates that albedo has a direct and strong effect on the energy production capacity of bifacial PV modules.

Losses and Effective Irradiance: Analysis of the losses diagrams for all scenarios reveals a significant increase in the effective irradiance on the PV system surface with higher albedo levels. The global horizontal irradiance across all scenarios was 1,845 kWh/m².

- At 5% albedo, the effective irradiance was 1,959 kWh/m².
- At 10% albedo, the effective irradiance was 1,960 kWh/m².
- At 30% albedo, the effective irradiance was 1,963 kWh/m².
- At 50% albedo, the effective irradiance was 1,967 kWh/m².
- At 70% albedo, the effective irradiance was 1,971 kWh/m².

These findings demonstrate that, either directly or indirectly, the global horizontal irradiance increases by approximately 3-4 kWh/m² on the PV system surface with the rise in albedo.

Table 5. *Comparative performance of pv systems at various albedo levels*

Albedo Level [%]	Energy Produced [kWh/year]	Energy Yield [kWh/kWp/year]	Performance Ratio [%]	PR Increase Value [%]
5	50.842.752	1.792	85,36	*
10	51.258.650	1.806	86,05	0,69
30	52.895.342	1.864	88,80	3,44
50	54.472.369	1.920	91,45	6,09
70	55.982.210	1.973	93,98	8,62

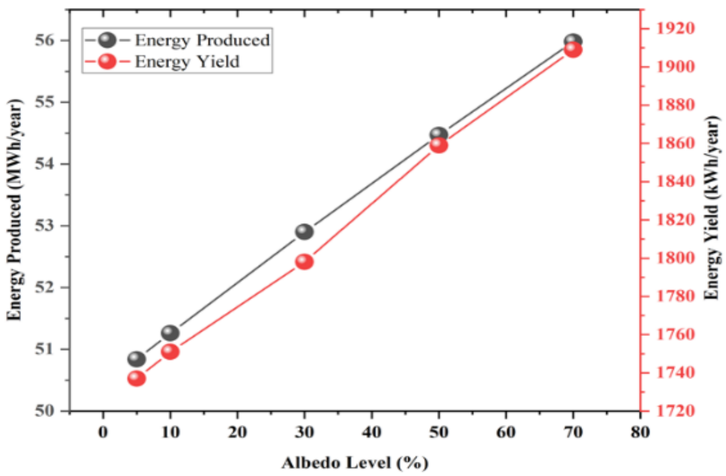

Figure 7. *Energy production performance of the pv system at different albedo conditions*

The findings of this study clearly indicate the need for careful consideration of ground albedo in the optimization of bifacial PV systems, as it has a significant impact on the overall efficiency of PV plants. The simulation results demonstrate that the albedo value of the ground plays a critical role in the selection of ground types for bifacial PV modules. High albedo surfaces significantly enhance energy production in PV systems. This suggests that increasing ground reflectivity could be a crucial optimization strategy in the installation of PV plants. Enhanced energy efficiency translates to greater energy production and, consequently, a shorter payback period, potentially making the projects more economically attractive for investors. Additionally, it contributes to environmental sustainability by reducing the number of modules and land area required.

Data availability statement

The research code, numerical results, and digital data obtained in this project are held on deployed servers that are backed up. The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Author contributions

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Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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