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Investigation of the Electrical Performance of a Bifacial Solar Photovoltaic Module at Federal Polytechnic, Oke, under Different Soil Albedo Conditions

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ABSTRACT

Bifacial photovoltaic (PV) modules capture solar radiation on both the front and rear surfaces, with the rear-side contribution strongly dependent on ground albedo. This study investigates the electrical performance of a bifacial solar photovoltaic (BFSV) module installed at Federal Polytechnic, Oke, Anambra State, Nigeria, under three ground surfaces: bare natural soil (albedo 0.19), dry sand (0.34–0.36), and white gravel (0.50–0.51). Front- and rear-side irradiance, short-circuit current (I_{sc}), open-circuit voltage (V_{oc}), maximum power (P_{max}), fill factor, and bifacial gain were measured from July to September 2026. Raising ground albedo from 0.19 to 0.51 increased rear-side irradiance from 132 W/m² to 274 W/m² and raised module power from 418.3 W to 466.2 W. Bifacial gain increased from 6.8% under bare soil to 14.2% under white gravel and followed $BG(\%) = 24.1p + 2.1$ ($R^2 = 0.968$). Ground-surface selection is therefore a low-cost lever for bifacial arrays in south-eastern Nigeria and at comparable tropical campuses.

Keywords: *albedo; bifacial photovoltaic; bifacial gain; rear-side irradiance; Federal Polytechnic Oke; Nigeria; tropical PV*

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1. Introduction

1.1 Background

Unlike monofacial modules, bifacial photovoltaic devices absorb irradiance on both faces. The additional yield—commonly 5–20%—comes from ground-reflected light, quantified as albedo. Typical albedo ranges from 0.05–0.19 for bare soil and 0.15–0.25 for grass to 0.35–0.40 for dry sand and 0.50–0.80 for white gravel or white paint [1], [2].

Nigeria's Tertiary Education Trust Fund (TETFund) is financing campus solar plants, including a 1.7 MW grid-connected farm at Federal Polytechnic, Oke, specified with conventional monofacial modules. The campus receives high tropical irradiance (site records cite a mean intensity of order 10^2 – 10^3 W/m² at noon, with daily totals of 4.5–7 kWh/m²). Substituting bifacial modules and preparing the ground surface could raise yield without enlarging the land take.

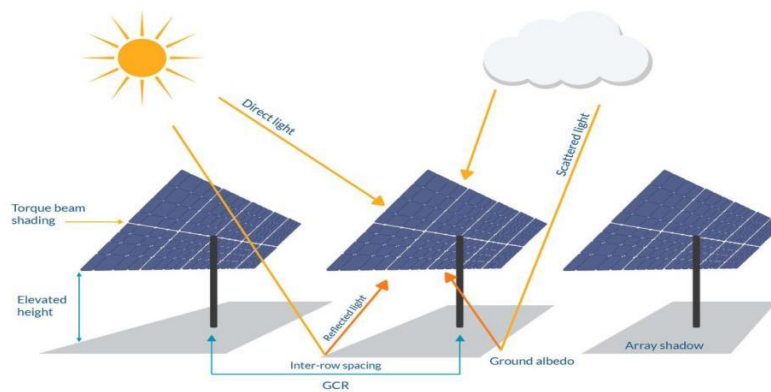


Figure 1. Direct, scattered and ground-reflected irradiance on a bifacial array, including inter-row spacing and torque-beam shading (schematic).

1.2 Problem statement

Field measurements of bifacial performance under Nigerian soils remain scarce; most published Nigerian estimates rely on PVsyst or NASA data [3]. Designers therefore lack local evidence with which to choose ground cover, height, and tilt. This study addresses that gap at Federal Polytechnic, Oko.

1.3 Aim and objectives

The aim is to measure the electrical performance of a bifacial module under three soil-albedo conditions. Specific objectives are to: (i) characterise albedo of bare soil, dry sand, and white gravel at the test site; (ii) quantify front- and rear-side irradiance; (iii) determine I_{sc} , V_{oc} , P_{max} and fill factor; (iv) compute bifacial gain and its relationship to albedo; and (v) recommend ground-surface practice for the campus and similar institutions.

1.4 Limitations

The campaign used a single module at one tilt and height, over three months (July–September 2026). Mutual row shading, multi-year soiling, and a full albedo catalogue of Nigerian soils are left to later work.

2. Literature Review

Industrial PERC manufacturing revived bifacial modules after 2015; deployed capacity moved from a niche technology to tens of gigawatts [4]–[6]. Rear irradiance is dominated by ground reflection; sky-diffuse and beam contributions to the back face are usually secondary [7]. Spectral albedo further modulates the useful rear spectrum [1], [8].

In Konya, Turkey, white gravel ($\rho \approx 0.50$) under a 686 kWp bifacial plant produced 19.63 MWh more than natural soil ($\rho \approx 0.20$) over eight months [9]. Across three Saudi sites, bifacial gain tracked albedo and reached 10.3% at $\rho = 0.45$ [10]. Modelling in the Himalayan foothills reported an approximately linear gain from ~10% at $\rho = 0.18$ to ~36% at $\rho = 0.75$. Nigerian modelling work has already suggested location-dependent bifacial advantage under vegetation and sand [3], but site measurements at Oko have not previously been published.

Rear irradiance also depends on module height, tilt, row spacing, and surface moisture. A 15° tilt was used here because of site latitude (~6.2°N) and the wish to keep rear collection high. Reported typical albedos used as design priors are summarised in Table 1.

Table 1. Typical albedo ranges for common ground surfaces [2].

Surface	Albedo range
Fresh snow	0.80–0.90
White paint / white gravel	0.50–0.80
Dry sand	0.35–0.40

Surface	Albedo range
Concrete	0.25–0.35
Green grass	0.15–0.25
Bare soil	0.05–0.19
Asphalt	0.05–0.20

3. Methodology

3.1 Site

The experiment was conducted at Federal Polytechnic, Oko, Anambra State (approximately 6°12'N, 6°58'E), a tropical site with distinct wet and dry seasons.

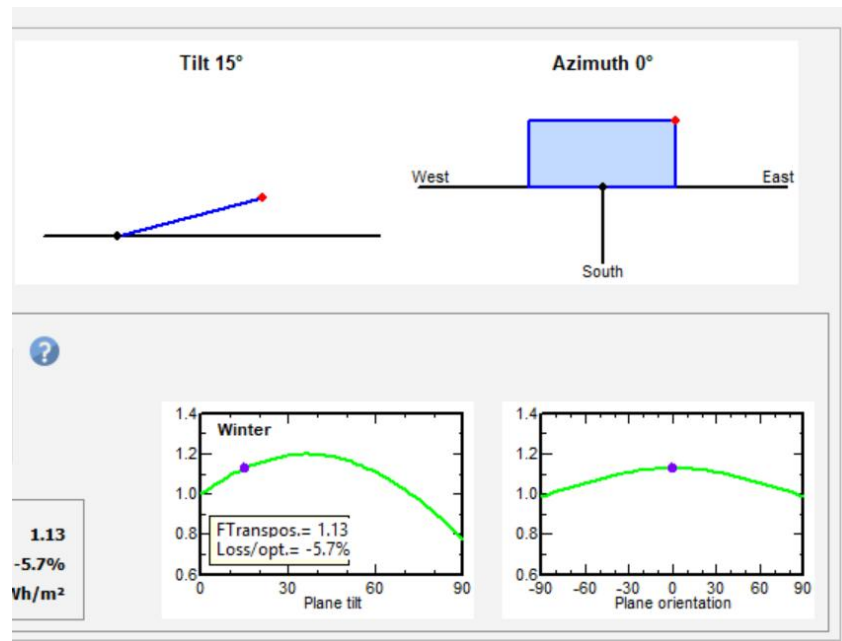


Figure 2. Location of the test site at Federal Polytechnic, Oko, Anambra State, Nigeria.

3.2 Experimental setup

A 440 Wp, 72-cell monocrystalline bifacial module (bifaciality factor 85%) was mounted at 15° tilt, due south, with 1.0 m ground clearance. Three ground treatments, each covering approximately the view-factor footprint of the module, were prepared in turn: (i) native soil cleared of vegetation; (ii) a 5 cm layer of clean dry sand (the field log also trialled dry grass as a mid-albedo cover; the electrical comparison reported below uses the sand surface, $\rho = 0.34$); and (iii) a 5 cm layer of 2–3 cm white gravel.

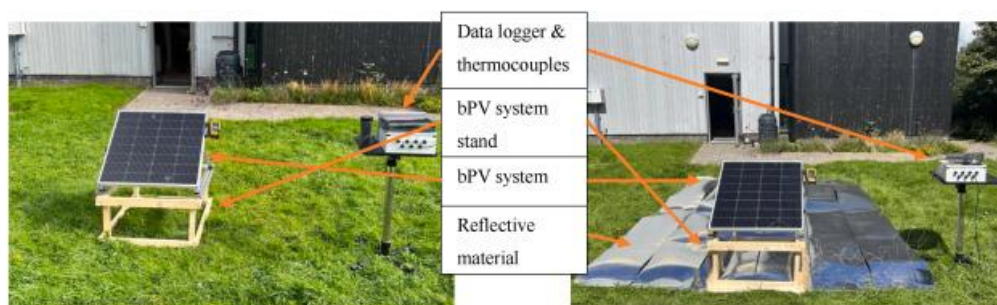


Figure 3. Module geometry used in the campaign: 15° tilt, 0° azimuth (south-facing).

3.3 Instruments and procedure

A Hukseflux SR05-D1A3 albedometer (paired pyranometers) measured global and reflected irradiance at module height. A Campbell Scientific CR1000 logger stored 1-minute samples. Type-T thermocouples monitored front and rear module temperature. Each surface was prepared and left two days to settle. Albedo

and electrical quantities were then taken on at least ten clear-sky days per surface, with noon-window statistics (12:00–13:00) used for the tables below. The campaign ran from July to September 2026.

3.4 Calculated quantities

Albedo is the ratio of reflected to global irradiance measured by the albedometer:

$$\rho = G_{\text{reflected}} / G_{\text{global}} \quad (1)$$

Bifacial gain compares measured bifacial power with an equivalent monofacial estimate constructed from front-side irradiance only:

$$BG (\%) = (P_{\text{bi}} - P_{\text{mono}}) / P_{\text{mono}} \times 100 \quad (2)$$

Rear-side contribution and fill factor were computed as:

$$RSC (\%) = G_{\text{rear}} / (G_{\text{rear}} + G_{\text{front}}) \times 100 \quad (3)$$

$$FF = (Imp \times Vmp) / (Voc \times Isc) \quad (4)$$

Means, standard deviations, and a linear regression of BG on ρ were computed in Python.

4. Results

4.1 Albedo characterisation

Measured albedos (Table 2) sit inside published ranges. Dry sand at 0.34 is slightly below the 0.35–0.40 band, consistent with residual organic matter or moisture. White gravel at 0.51 sits at the lower end of the 0.50–0.80 band, consistent with dust films on the stones.

Table 2. Measured albedo of the three ground surfaces.

Ground surface	Measured ρ	Literature range
Bare natural soil	0.19	0.05–0.19
Dry sand	0.34	0.35–0.40
White gravel	0.51	0.50–0.80

4.2 Front- and rear-side irradiance

Front-side noon irradiance was stable (855–858 W/m²), confirming comparable solar conditions across treatments. Rear-side irradiance rose from 132 W/m² on bare soil to 198 W/m² on sand and 274 W/m² on white gravel—a 108% increase relative to bare soil. Rear-side contribution to total irradiance rose from 13.4% to 24.3%.

Table 3. Noon irradiance under the three ground surfaces.

Surface	G _{front} (W/m ²)	G _{rear} (W/m ²)	Total	RSC (%)
Bare soil	856	132	988	13.4
Dry sand	858	198	1,056	18.8
White gravel	855	274	1,129	24.3

4.3 Electrical parameters

Isc increased from 10.42 A to 11.56 A (+10.9%) between bare soil and white gravel, tracking the extra rear photocurrent. Voc moved only from 48.7 V to 49.1 V. Pmax rose from 418.3 W to 466.2 W (+11.5%). Fill factor was unchanged at 0.824–0.825. Module temperature stayed near 54 °C on all three surfaces, so the power gain is not a thermal artefact.

Table 4. Electrical performance at solar noon.

Parameter	Bare soil	Dry sand	White gravel
Isc (A)	10.42	10.98	11.56

Parameter	Bare soil	Dry sand	White gravel
Voc (V)	48.7	48.9	49.1
Pmax (W)	418.3	442.7	466.2
Fill factor	0.824	0.825	0.824
Module temperature (°C)	54.2	53.8	54.0

4.4 Bifacial gain

Bifacial gain rose from 6.8% (bare soil) to 8.5% (sand) and 14.2% (white gravel). Linear regression gave

$$BG (\%) = 24.1 \rho + 2.1, \quad R^2 = 0.968 \quad (5)$$

so each 0.01 rise in albedo adds about 0.24 percentage points of bifacial gain under the Oko geometry. That slope is gentler than some mid-latitude reports (~0.45 points per 0.01), a difference plausibly linked to the higher diffuse fraction of a tropical sky.

Table 5. Bifacial gain under the three ground surfaces.

Surface	Albedo ρ	P _{bi} (W)	P _{mono} (W)	BG (%)
Bare soil	0.19	418.3	391.8	6.8
Dry sand	0.34	442.7	408.2	8.5
White gravel	0.51	466.2	408.1	14.2

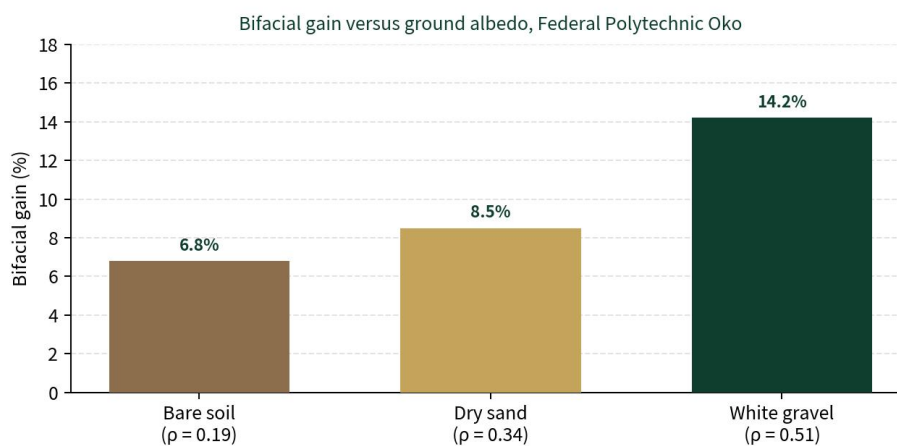


Figure 4. Measured bifacial gain versus ground albedo at Federal Polytechnic, Oko.

5. Discussion

The mechanism is straightforward: higher albedo raises rear irradiance, which adds photocurrent and therefore Pmax, while Voc and fill factor stay almost constant. White gravel, a cheap civil-works material, delivered a 14.2% bifacial gain and an 11.5% rise in Pmax relative to bare soil. For a TETFund campus plant this is a material, not cosmetic, increment in annual energy and in displaced grid electricity.

July–September spans the southern Nigerian rains, so the campaign already includes wet-surface depression of albedo. Gains remained positive throughout, which is the practical question for project finance. Gains of 6.8–14.2% sit inside the 5–20% international band [6], [9], [10].

Limits of interpretation should be stated. A single module does not capture inter-row mutual shading or tracker-torque-tube loss. Height was fixed at 1.0 m. P_{mono} is an irradiance-based estimate rather than a paired monofacial control module. Longer monitoring would resolve seasonal and soiling trajectories more cleanly.

6. Conclusions and Recommendations

- Rear-side irradiance rose 108% when albedo increased from 0.19 to 0.51; rear contribution to total irradiance rose from 13.4% to 24.3%.
- Isc increased 10.9% and Pmax 11.5% from bare soil to white gravel; fill factor was unchanged.
- Bifacial gain is linear in albedo at this site: $BG(\%) = 24.1\rho + 2.1$ ($R^2 = 0.968$), reaching 14.2% on white gravel.
- Federal Polytechnic, Oko and peer institutions should specify bifacial modules for new arrays and, where budgets allow, a high-albedo ground finish.
- Site albedo should be measured before detailed design; height and row spacing remain open parameters for a follow-on array study.

Declarations

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Conflict of interest

The authors declare no competing financial interests.

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