

Wind Speed and Solar Irradiance in Relation to Open-Circuit Voltage of Horizontal and Inclined Monocrystalline Photovoltaic Modules in Sahelian Niger

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Abstract In Sahelian field conditions, solar irradiance, temperature, wind, and mounting configuration vary together and can complicate the interpretation of photovoltaic measurements. This study examined relationships among wind speed, solar irradiance, module inclination, and open-circuit voltage (V_{oc}) for two identical 20 W monocrystalline silicon modules installed in Dosso, Niger. One module was horizontal; the other inclined at 15°, with both facing south. Measurements were recorded hourly from 07:00 to 18:00 in May and August 2021. Hourly Pearson and Spearman coefficients were treated as descriptive measures because the 12 clock-hour means are serially ordered and share a common diurnal cycle. Exploratory three-predictor regressions, multicollinearity diagnostics, and a daily sensitivity analysis for both module configurations were also applied. Hourly Pearson correlations between wind speed and V_{oc} were 0.846 and 0.833 in May and 0.801 and 0.808 in August for the horizontal and inclined modules, respectively. Corresponding irradiance correlations were 0.711 and 0.889 in May and 0.848 and 0.896 in August. The exploratory models explained 77.6–85.0% of hourly V_{oc} variation in May and 73.9–80.5% in August. However, coefficient confidence intervals were wide, and variance inflation factors indicated substantial predictor collinearity, particularly between wind speed and irradiance in August. Daily wind– V_{oc} associations were much weaker for both modules. The measurements therefore support a multivariable interpretation of outdoor V_{oc} variation; they do not directly demonstrate wind-induced cooling because module temperature, local module-surface airflow, and wind direction were not measured.

Keywords: photovoltaic module, open-circuit voltage, wind speed, solar irradiance, module inclination, Sahelian climate

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1. Introduction

Under field conditions, photovoltaic modules rarely operate at the fixed conditions used for standard testing. Irradiance sets the available solar input, while ambient temperature, wind, and mounting configuration shape the module's thermal balance. These interactions are particularly important in hot and semi-arid environments, where strong solar loading can raise crystalline-silicon module temperatures well above ambient levels [1,2].

Wind influences this balance by changing convective heat exchange at the module surface. Experimental and modeling studies show that module temperature depends

not only on wind speed but also on module orientation and the direction of the approaching airflow [3]. Mounting configuration therefore affects both the solar radiation intercepted by the surface and the way air circulates around the module. Wind-tunnel measurements on inclined PV modules have likewise shown that ventilation conditions can modify temperature patterns and electrical behavior [4].

Open-circuit voltage is useful for examining these field interactions because it responds to both irradiance and cell temperature. In crystalline-silicon devices, rising cell temperature generally lowers V_{oc} , while irradiance also changes the open-circuit condition [1,5]. IEC 60904-5 uses this relationship as the basis for an open-circuit-voltage method to estimate equivalent cell temperature

when the required corrections and coefficients are available [6]. IEC 60891 also provides standardized procedures for temperature and irradiance corrections to measured I–V characteristics [7]. V_{oc} is therefore informative, but it should not be interpreted as a direct measure of conversion efficiency.

Evidence from hot climates also points to a role for wind in PV thermal behavior. Field studies and reviews have reported that airflow and other cooling approaches can reduce module temperature and improve electrical performance under hot operating conditions [8,9]. The Dosso campaign was more limited in this respect: wind speed, ambient temperature, global irradiance, and V_{oc} were available, whereas module temperature and wind direction were not. For that reason, the present analysis focuses on statistical association rather than attributing the observed voltage changes directly to wind-induced cooling. An earlier publication from the same Dosso campaign examined the influence of air humidity on global solar radiation [10]. Recent field and performance studies further show that wind speed can materially influence PV thermal behavior and convective heat transfer under outdoor conditions [11,12].

The present study has a different focus. We examine the electrical response of two mounting configurations and assess how wind speed and global irradiance vary with V_{oc} during two contrasting seasonal periods.

The study had four objectives: to compare the diurnal V_{oc} response of horizontal and 15°-inclined monocrystalline PV modules; quantify the hourly relationships between V_{oc} , wind speed, ambient temperature, and global irradiance; determine whether wind remains an identifiable predictor when the environmental variables are considered together; and test how sensitive the observed relationships are to daily aggregation. This approach was chosen to separate statistical association from causal interpretation.

2. Materials and Methods

2.1. Study Area and Experimental Site

The experiment was conducted in Dosso, southwestern Niger. The measurement site was located at approximately 13°02'30" N and 3°11'15" E, at an elevation of about 217 m above sea level. The site was flat and free of major obstacles capable of producing persistent shading. Measurements were collected in May 2021, representing the hot pre-rainy-season period, and in August 2021, representing the humid season. Using the same site and instrumentation in both months allowed the analysis to compare two contrasting sets of outdoor conditions. The location of the experimental site is shown in Figure 1.

2.2. Experimental Setup and Instrumentation

The field setup combined the PV modules with portable instruments for meteorological and electrical measurements. Ambient temperature and relative humidity were measured with a SMART SENSOR AS847 thermo-hygrometer, wind speed with a UT363 BT mini-anemometer, global irradiance with an SM206-SOLAR

solarimeter, and V_{oc} with a DT9205A digital multimeter. Wind speed was measured manually at approximately 2 m above ground. During each reading, the hand-held anemometer was oriented into the apparent wind; wind direction itself was not recorded. Because the instrument was not mounted at a fixed position relative to the modules, the exact anemometer-to-module distance was not recorded. The multimeter was connected in parallel with the PV module under open-circuit conditions. Figure 2 documents the experimental measurement setup, and Table 1 summarizes the measured variables, instruments, and units.



Figure 1. Location of the experimental site in Dosso, Niger (13°02'30" N, 3°11'15" E; approximately 217 m a.s.l.)



Figure 2. Experimental measurement setup used at the Dosso site. The instruments shown include the AS847 thermo-hygrometer, DT9205A digital multimeter, SM206-SOLAR solarimeter, and UT363 BT mini-anemometer. Photograph from the authors' 2021 field campaign, previously published in Baare Ali et al. [10] and reproduced under the Creative Commons Attribution (CC BY) License

Table 1. Main Measurement Variables and Instrumentation

Variable	Instrument	Unit / role
Ambient temperature / relative humidity	SMART SENSOR AS847	°C / %
Wind speed	UT363 BT mini-anemometer	m/s; measured at ~2 m above ground
Global irradiance	SM206-SOLAR solarimeter	W/m ²
Open-circuit voltage	DT9205A digital multimeter	V; connected across module terminals

2.3. PV Modules and Mounting Configurations

Two identical SA-20 monocrystalline silicon PV modules were used. The PV modules were mounted approximately 15 cm above ground on cement-block supports, as shown in Figure 3, to prevent direct contact between the module frames and the soil. The horizontal module was positioned parallel to the ground plane (0°), whereas the second module was tilted at 15° relative to the horizontal. Both modules faced south. Using identical modules at the same site reduced differences related to technology and nominal electrical characteristics, allowing the comparison to focus on mounting configuration and the environmental conditions recorded during the experiment. Table 2 summarizes the module characteristics and mounting configurations.

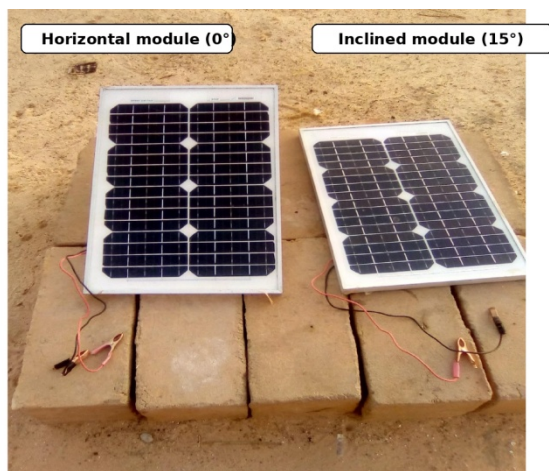


Figure 3. Monocrystalline PV modules used in the field experiment, mounted approximately 15 cm above ground on cement-block supports: horizontal (0°) and inclined (15°) configurations

Table 2. Electrical Characteristics and Mounting Configurations of the PV Modules

Parameter	Value
Technology	Monocrystalline silicon
Model	SA-20
Rated maximum power, P _{max}	20 W
Voltage at maximum power, V _{mp}	17.5 V
Current at maximum power, I _{mp}	1.14 A
Open-circuit voltage, V _{oc}	21 V
Short-circuit current, I _{sc}	1.28 A
Mounting angles	0° and 15°

2.4. Measurement Protocol and Data Processing

Measurements were recorded at hourly intervals from 07:00 to 18:00. The numerical analysis was performed directly from the available Excel measurement files. For variables supplied as daily matrices, monthly mean values were calculated at each clock hour. Zero wind-speed values were retained because calm conditions are physically possible. For temperature and V_{oc}, daytime zero entries that were incompatible with the measured quantity were treated as missing during averaging. This rule was applied consistently to both module configurations. No

module-temperature or wind-direction series was available; these variables were not estimated or reconstructed.

The irradiance values analyzed here are ground measurements from the SM206-SOLAR solarimeter, processed from the original experimental spreadsheets. They therefore differ from the HelioClim-3/SODA satellite-derived series used in our previous humidity-focused publication [10] and should not be interpreted as revised values from that study.

The analysis distinguishes between hourly and daily scales. The hourly analysis uses 12 clock-hour means per month to characterize diurnal covariation. These values are serially ordered and share a common solar cycle, so they are not treated as independent experimental replicates. A daily sensitivity analysis was therefore performed for both the horizontal and 15°-inclined modules using the 31 daily records available in each month. Daily means were calculated from the valid daytime observations for each date using the same quality-control rules described above.

2.5. Statistical Analysis

Pearson's correlation coefficient was used to describe linear association between V_{oc} and each environmental variable, while Spearman's rank correlation was used as a non-parametric sensitivity measure. Because the hourly analysis contains only 12 serially ordered clock-hour means per month and the variables share a pronounced diurnal cycle, inferential p-values are not reported for the hourly correlations. The hourly coefficients are interpreted descriptively in terms of direction, magnitude, and consistency between Pearson and Spearman measures.

For each month and module configuration, an exploratory multiple linear regression was fitted to the 12 hourly mean observations:

$$V_{oc} = \beta_0 + \beta_1 u + \beta_2 T_a + \beta_3 G + \varepsilon$$

where u is wind speed (m/s), T_a is ambient temperature (°C), G is global irradiance (W/m²), and ε is the residual error term. The regressions are treated as exploratory because only 12 observations are available for three predictors. Model fit is summarized using the coefficient of determination (R^2) and adjusted coefficient of determination (adjusted R^2). For each coefficient, a conventional 95% confidence interval is reported under independent-error assumptions; serial dependence limits its interpretation. Predictor intercorrelations and variance inflation factors (VIFs) were calculated separately for May and August to assess multicollinearity. The daily sensitivity analysis used Pearson correlations and conventional two-sided p-values for the 31 daily records per month and configuration; these daily tests are interpreted cautiously because of possible serial dependence and multiple comparisons.

3. Results

3.1. Diurnal Environmental Conditions

The two measurement periods showed distinct diurnal patterns. In May, mean wind speed rose from 0.69 m/s at

07:00 to about 1.55 m/s in the late morning and then generally declined toward 18:00. In August, the increase was more gradual, with a maximum of 1.45 m/s at 12:00. The processed irradiance series also peaked at 12:00, reaching 1203.17 W/m² in May and 925.55 W/m² in August. Mean ambient temperature reached approximately 41.9°C in May and 32.0°C in August. These irradiance maxima are based on the ground-measured SM206-SOLAR dataset described above; the earlier study [10] reported satellite-derived irradiance values and is therefore not numerically equivalent to the present series. Figures 4 and 5 show the corresponding diurnal profiles of wind speed and global irradiance, respectively.

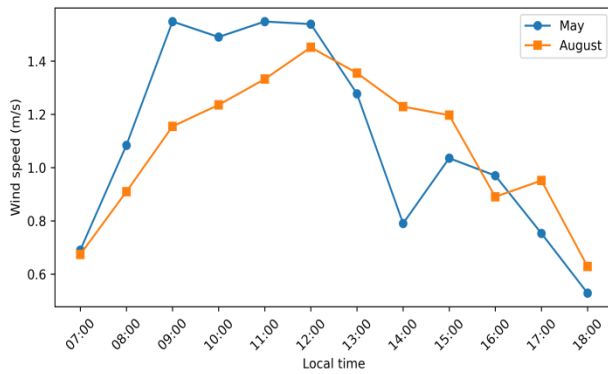


Figure 4. Mean diurnal wind speed during May and August 2021

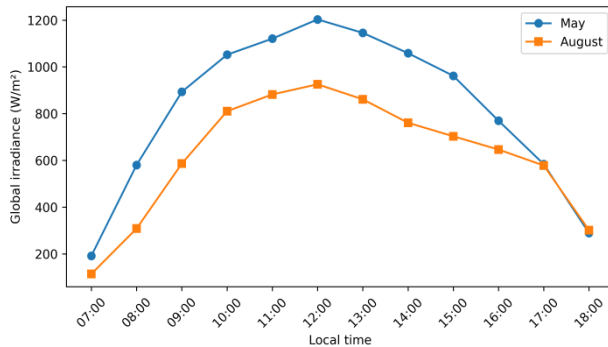


Figure 5. Mean diurnal global irradiance calculated from the available raw measurement spreadsheets for May and August 2021

3.2. Diurnal Open-Circuit Voltage

In both months, V_{oc} increased rapidly during the morning and declined later in the day. For the horizontal module, the maximum hourly mean V_{oc} was 17.789 V at 09:00 in May and 17.770 V at 10:00 in August. For the 15°-inclined module, the corresponding maxima were 17.826 V at 10:00 in May and 17.903 V at 10:00 in August. Figure 6 shows the four diurnal voltage profiles. The inclined module reached slightly higher maximum V_{oc} values in both periods, although the experiment does not isolate whether this difference arises from irradiance geometry, thermal behavior, or a combination of both.

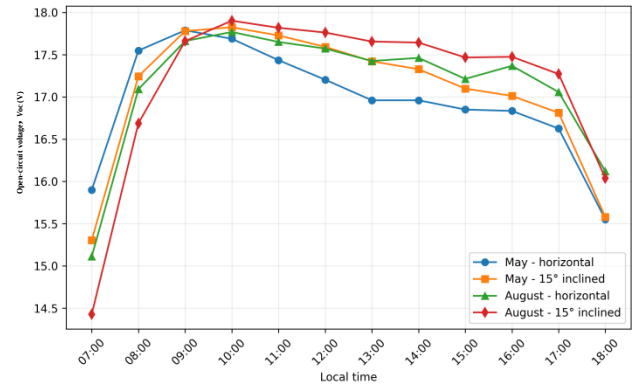


Figure 6. Diurnal open-circuit voltage of the horizontal and 15°-inclined PV modules during May and August 2021

3.3. Hourly Relationships between V_{oc} and Environmental Variables

At hourly resolution, V_{oc} was positively associated with wind speed for both mounting configurations. As summarized in Figure 7 and Table 3, Pearson r was 0.846 for the horizontal module and 0.833 for the inclined module in May; the corresponding August coefficients were 0.801 and 0.808. Spearman coefficients were also positive, ranging from 0.727 to 0.909. Because the 12 hourly means are serially ordered and strongly structured by the daily cycle, these coefficients are presented descriptively and no hourly correlation p -values are reported.

Global irradiance also showed strong descriptive associations with V_{oc} ; the Pearson correlations exceeded those for wind speed except for the horizontal module in May. For the horizontal module, Pearson r was 0.711 in May and 0.848 in August; for the 15°-inclined module, r was 0.889 and 0.896, respectively. Ambient-temperature correlations were weaker and less consistent, ranging from -0.124 to 0.519. Table 3 provides the corresponding Pearson and Spearman coefficients for all month-configuration combinations.

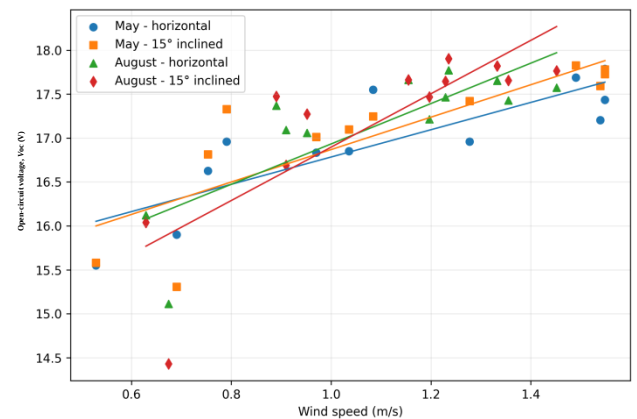


Figure 7. Open-circuit voltage as a function of wind speed for the two mounting configurations and measurement periods. Lines represent least-squares linear fits

Table 3. Hourly Correlations Between V_{oc} and the Measured Environmental Variables

Period	Module	Variable	Pearson r	Spearman ρ
May	Horizontal	Wind speed	0.846	0.890
May	Horizontal	Ambient temperature	-0.124	-0.298
May	Horizontal	Global irradiance	0.711	0.490
May	15° inclined	Wind speed	0.833	0.909
May	15° inclined	Ambient temperature	0.220	-0.091
May	15° inclined	Global irradiance	0.889	0.727
August	Horizontal	Wind speed	0.801	0.727
August	Horizontal	Ambient temperature	0.371	-0.056
August	Horizontal	Global irradiance	0.848	0.755
August	15° inclined	Wind speed	0.808	0.825
August	15° inclined	Ambient temperature	0.519	0.007
August	15° inclined	Global irradiance	0.896	0.867

3.4. Predictor Collinearity and Exploratory Multiple Regression

The hourly predictors showed substantial collinearity. In May, the pairwise correlations were $r(u, Ta) = -0.106$, $r(u, G) = 0.761$, and $r(Ta, G) = 0.460$; the corresponding VIFs were 6.35 for wind speed, 3.40 for ambient temperature, and 7.96 for irradiance. Collinearity was stronger in August, with $r(u, Ta) = 0.295$, $r(u, G) = 0.921$,

and $r(Ta, G) = 0.562$, and VIFs of 12.77, 2.82, and 17.05, respectively. These diagnostics indicate that the individual regression coefficients cannot be interpreted as cleanly separated environmental effects.

The exploratory regression results are reported in Table 4. The models explained 77.6% and 85.0% of hourly V_{oc} variation in May for the horizontal and inclined modules, respectively, and 73.9% and 80.5% in August. Adjusted R^2 values ranged from 0.641 to 0.794. All 95% confidence intervals for the individual wind, ambient-temperature, and irradiance coefficients included zero. Given the small sample and the VIF diagnostics, the results are interpreted as evidence of substantial overlap among the diurnally varying predictors rather than as confirmatory tests of independent causal effects.

3.5. Sensitivity to Daily Aggregation

At the daily scale, the descriptive Pearson correlations between wind speed and V_{oc} were lower than those observed at the hourly scale for both module configurations (Table 5). In May, the coefficients were 0.225 for the horizontal module and 0.352 for the 15°-inclined module; in August, they were 0.276 and 0.230, respectively. The daily irradiance- V_{oc} correlations were also lower than their hourly counterparts. This reduction in correlation strength suggests that part of the strong hourly association may reflect the shared diurnal variation of the environmental variables. The present data therefore do not support interpreting the hourly wind- V_{oc} relationship as evidence of an independent or causal wind effect.

Table 4. Exploratory Multiple Regression of V_{oc} on Wind Speed, Ambient Temperature, and Global Irradiance

Period	Module	R^2	Adj. R^2	Wind coeff. [95% CI]	Temp. coeff. [95% CI]	Irrad. coeff. [95% CI]
May	Horizontal	0.776	0.692	0.510 [-1.277, 2.297]	-0.071 [-0.194, 0.052]	0.00138 [-0.00080, 0.00356]
May	15° inclined	0.850	0.794	0.670 [-1.092, 2.432]	-0.0136 [-0.1348, 0.1076]	0.00166 [-0.00049, 0.00381]
August	Horizontal	0.739	0.641	-0.546 [-4.821, 3.730]	-0.0779 [-0.3297, 0.1739]	0.00340 [-0.00171, 0.00850]
August	15° inclined	0.805	0.732	-0.620 [-5.459, 4.220]	-0.0147 [-0.2997, 0.2704]	0.00415 [-0.00164, 0.00993]

Table 5. Daily Sensitivity Analysis for the Horizontal and 15°-Inclined Modules

Period	Module	Variable	n	Pearson r	p-value
May	Horizontal	Wind speed	31	0.225	0.2235
May	Horizontal	Ambient temperature	31	-0.376	0.0373
May	Horizontal	Global irradiance	31	0.228	0.2175
May	15° inclined	Wind speed	31	0.352	0.0520
May	15° inclined	Ambient temperature	31	-0.339	0.0623
May	15° inclined	Global irradiance	31	0.230	0.2141
August	Horizontal	Wind speed	31	0.276	0.1324
August	Horizontal	Ambient temperature	31	0.170	0.3617
August	Horizontal	Global irradiance	31	0.246	0.1823
August	15° inclined	Wind speed	31	0.230	0.2136
August	15° inclined	Ambient temperature	31	0.021	0.9112
August	15° inclined	Global irradiance	31	0.126	0.4978

4. Discussion

4.1. Interpreting the Wind– V_{oc} Relationship

Across both months and mounting configurations, the hourly data showed positive descriptive associations between wind speed and V_{oc} . One possible physical interpretation is enhanced convective heat transfer, since airflow may promote heat removal from the module surface and thereby limit module heating. Because V_{oc} generally decreases as cell temperature rises, a lower module temperature could help preserve the open-circuit voltage [1,2,3]. Experimental and review studies have reported similar cooling mechanisms under controlled or more fully instrumented conditions [8,9,11,12]. However, module temperature and local airflow at the module surface were not measured in the present study. The hourly wind– V_{oc} pattern shown in Figure 7 and summarized in Table 3 should therefore be interpreted as a statistical association, rather than as direct evidence of wind-induced cooling.

That mechanism cannot be quantified from the present dataset. Neither cell nor module-backsheet temperature was measured, and wind direction was not recorded. In addition, wind speed was measured at approximately 2 m above ground rather than directly at the module surface. Consequently, the present data do not allow estimation of a convective cooling coefficient, a wind-related module-temperature reduction, or an efficiency gain attributable to airflow. The observed hourly data show a statistical association between ambient wind speed and V_{oc} under the investigated field conditions, but they do not establish that wind independently caused the measured voltage variations.

The multivariable analysis also requires cautious interpretation. The predictor diagnostics revealed a strong correlation between wind speed and irradiance, particularly in August ($r = 0.921$), with corresponding VIF values of 12.77 and 17.05. Together with the small number of hourly observations, this substantial multicollinearity contributed to the wide confidence intervals reported in Table 4 and limited the precision of the individual regression coefficients. The regression results therefore should not be interpreted as evidence that wind has no independent contribution to V_{oc} . Rather, the available hourly data do not allow the separate contributions of wind speed, irradiance, and ambient temperature to be estimated with sufficient precision. The weaker daily wind– V_{oc} correlations reported for both module configurations in Table 5 are also consistent with the possibility that the common within-day evolution of the environmental variables contributes substantially to the stronger hourly associations.

4.2. Role of Solar Irradiance

Global irradiance also showed strong descriptive associations with V_{oc} , particularly for the 15°-inclined module, for which the Pearson coefficients were 0.889 in May and 0.896 in August (Table 3). These correlations indicate that irradiance is an important covariate when interpreting the hourly wind– V_{oc} relationship. From a

physical standpoint, changes in irradiance influence the photogenerated current and the open-circuit operating condition and may also affect module temperature through solar heating. In the exploratory multivariable analysis, however, the contribution of irradiance could not be estimated independently with high precision because it covaried with wind speed and ambient temperature, particularly in August (Table 4). Figure 5 provides the diurnal context for the observed irradiance variability. The hourly wind– V_{oc} relationship should therefore be interpreted together with irradiance rather than as a wind-only response.

4.3. Role of Module Inclination

The 15°-inclined module reached slightly higher maximum V_{oc} values than the horizontal module during both measurement periods and showed higher descriptive correlations between irradiance and V_{oc} (Figure 6 and Table 3). Module inclination changes the geometry of solar exposure and may also alter airflow around the front and rear surfaces. Previous studies have reported that mounting geometry can influence convective conditions and module temperature [3,4]. In the present experiment, however, plane-of-array irradiance was not measured separately for the two module configurations, and wind direction and local airflow at the module surfaces were not recorded. The radiative and aerodynamic contributions associated with the 15° configuration therefore cannot be separated from the available data. The observed differences should consequently be interpreted as configuration-dependent field responses rather than as evidence of a quantified performance benefit from the 15° tilt. Recent measurements in desert environments have likewise reported tilt-dependent differences in photovoltaic operating performance under harsh outdoor conditions [13].

4.4. Practical Implications

For field studies in hot Sahelian environments, wind speed is most informative when it is considered together with irradiance rather than as an isolated explanatory variable. Mounting arrangements that allow free air circulation remain physically reasonable, but the present dataset does not support a numerical energy-yield gain attributable to ventilation. Because only V_{oc} was analyzed, the findings should not be extended directly to maximum power or conversion efficiency. In these measurements, outdoor voltage in Dosso followed the combined diurnal evolution of wind and irradiance, and the pattern differed between the two mounting configurations. Taken together, Figures 4–6 show that wind speed, irradiance, and V_{oc} evolve within the same diurnal cycle, which supports interpreting these variables jointly rather than in isolation.

4.5. Study Limitations

- PV cell temperature and module backsheet temperature were not measured. Wind-induced cooling therefore remains a plausible physical mechanism rather than a directly quantified effect.
- Wind direction was not recorded. The hand-held anemometer was oriented into the apparent wind

during measurement, but the aerodynamic effect of wind incidence on the horizontal and inclined surfaces cannot be separated.

- Wind speed was measured at approximately 2 m above ground, whereas the modules were mounted only about 15 cm above ground. The recorded values therefore represent ambient site wind rather than local airflow within the module boundary layer. The exact anemometer-to-module distance was not recorded, limiting quantitative interpretation of wind-driven convective heat transfer. Recent field studies further indicate that the wind and thermal microenvironment around PV arrays depends on mounting geometry and array height, reinforcing the distinction between ambient wind measurements and local module-surface airflow [14,15].
- Only open-circuit voltage was used as the electrical response variable. Maximum power, fill factor, and conversion efficiency were not determined from complete I–V curves.
- The hourly analysis is based on 12 serially ordered clock-hour means per month. Inferential p-values are therefore not reported for the hourly correlations, and the regressions are treated as exploratory rather than confirmatory.
- Substantial multicollinearity was present among the hourly environmental predictors, especially wind speed and irradiance in August, which limits interpretation of individual regression coefficients.
- Plane-of-array irradiance was not measured separately for the horizontal and 15° surfaces; the irradiance variable represents the available global irradiance measurement.
- The campaign covers two selected seasonal periods rather than a full annual cycle, so the conclusions should be restricted to the investigated conditions.

5. Conclusions

This field study investigated the relationships between wind speed, global irradiance, module inclination, and open-circuit voltage (V_{oc}) using two monocrystalline PV modules with the same rated characteristics installed in Dosso, Niger. The interpretation was restricted to the measured variables, with the 12 hourly means considered as part of a common diurnal sequence rather than as independent observations.

At the hourly scale, wind speed and irradiance both showed strong descriptive associations with V_{oc} for the horizontal and 15°-inclined modules. However, the predictor diagnostics indicated substantial multicollinearity, particularly between wind speed and irradiance in August, while the exploratory regression coefficients were characterized by wide 95% confidence intervals. At the daily scale, the wind– V_{oc} correlations were considerably weaker for both module configurations. This contrast is consistent with the possibility that the stronger hourly associations partly reflect the common diurnal variation of wind speed, irradiance, temperature, and V_{oc} , rather than an independent wind effect.

The observations are compatible with the physical

possibility that airflow contributes to module cooling, but the experiment does not test that mechanism directly. In particular, module temperature, wind direction, and local airflow at the module surface were not measured. The most defensible conclusion is therefore that ambient wind speed is a covariate of the observed V_{oc} pattern, while solar irradiance is a concurrent environmental variable with a strong descriptive association with V_{oc} . Future measurements combining module temperature, fixed local airflow measurements, plane-of-array irradiance, and complete I–V characterization would allow these mechanisms to be separated more clearly.

Data Availability

The field measurement spreadsheets supporting the findings of this study are available from the corresponding author upon reasonable request.

Code Availability

No custom software was developed for this study. The statistical procedures are described in Section 2.5, and the calculation files used for the analysis are available from the corresponding author upon reasonable request.

Statement of Competing Interests

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

List of Abbreviations

PV: photovoltaic; V_{oc} : open-circuit voltage; I–V: current–voltage; IEC: International Electrotechnical Commission; VIF: variance inflation factor.

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