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YIELD AND PR ESTIMATION FOR VERTICAL AGRIVOLTAICS SYSTEMS

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Introduction

Photovoltaic systems interspersed with cropland are gaining ground. Given that both elements compete for radiation, determining the amount of light that reaches each of them is a matter of great interest. Vertical agrivoltaic systems (Figure 1) are presented as an alternative to other systems installed in crop fields, which interfere less with tillage and the passage of machinery. When these systems are composed of bifacial panels (Figure 2, Figure 3), energy capture increases to almost double that of a non-bifacial system.

To determine the profitability of a photovoltaic system, measurements of both actual production and expected output or performance ratio (PR) must be obtained. Likewise, if the system is agrivoltaic, agricultural production must not be substantially reduced. In this case, regulations set different limits depending on the country, with an extended objective of not assuming a reduction of agricultural production greater than 20%.

The calculation of the PR in a vertical system is something that is still open to debate when the panels are bifacial. In addition, when the system is oriented with a north-south axis, the maximum radiation can be strongly affected by nearby shadows, both from other parallel strings and from nearby obstacles. Given the sensitivity of a vertical system to these aspects, in this work we address the elements that will affect the correct understanding and design of vertical agrivoltaic plants.

Materials and Methods

The bifaciality of a bifacial PV panel is measured with the bifaciality coefficients. The bifaciality coefficient prescribed by the technical specification IEC 60904-1-2: 2024 is the bifaciality of current, φ_{Isc} , defined as the ratio between the short-circuit current (I_{sc}) generated exclusively by the rear face of the panel and the I_{sc} generated exclusively by the front face, with the condition that both currents are measured at STC (irradiance of 1000 W·m^{-2}, panel temperature of 25 °C, and with the IEC 60904-3 reference solar spectral irradiance distribution). To determine the φ_{Isc} , bifacial PV panels can be tested as showcased in Figure 4.

To qualify bifacial panels, the so-called bifacial standard test condition (BSTC) applies, characterized by a front irradiance of 1000 W/m^2, a rear irradiance of 135 W/m^2 and an equivalent irradiance G_E defined [1] in Eq.1, where $\varphi_{Isc} = I_{sc,rear} / I_{sc,front}$

$$\text{Eq.1. } G_E = (1000 + \varphi_{Isc} \cdot 135)\ W/m^2$$

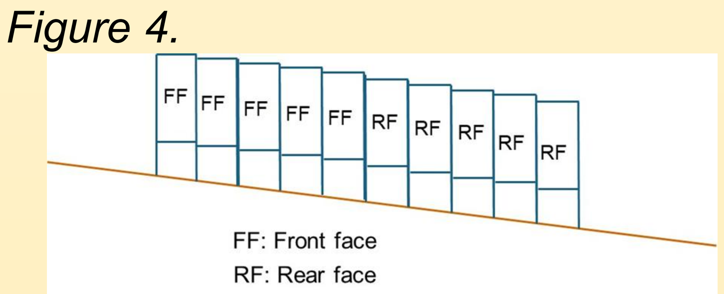

Figure 2: *Vertical bifacial PV panels, where FF is the main side and RF is the rear side.*

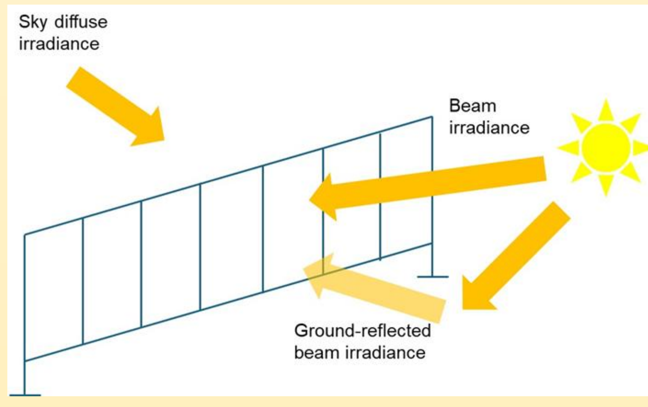

Figure 3: *Main radiation sources for bifacial PV panels.*

If our solar simulator can only illuminate the tested panel from one side, then the rear irradiance is transferred to the front by using an G_E higher than 1000 W·m^{-2} (Eq. 1). The bifacial power gain or BiFi [2] is determined from solar simulator test as the slope of the linear fit that corresponds to plotting $P_{max.}$ against G_{rear}

The conventional PR is given by Eq.2, where PSH is the Peak Solar Hours (kWh/m^2) on the generator's plane and Pp is the generator peak power.

$$\text{Eq.2. } PR = \frac{Yield\ (kWh)}{PSH\left(\frac{kWh}{1\ kW}\right) \cdot P_p\ (kW)}$$

In the case of vertical system, with main axis North-South and two parallel rows (strings), connected to independent MPPT, where one row has the main face oriented to the East and the other one to the West, we propose the PR expression of Eq.3, where the index 1 or 2 represents the Yield, PSH, Pp and bifaciality coefficient (φ_{Isc}) for each string.

$$\text{Eq.3. } PR = \frac{\frac{Yield_{(1)}}{PSH_{(1)} \cdot Pp1 \cdot (1+\varphi_{Isc(1)})} + \frac{Yield_{(2)}}{PSH_{(2)} \cdot Pp2 \cdot (1+\varphi_{Isc(2)})}}{2}$$

Note that in Eq.3., PSH is the daily irradiation in kWh/m^2 but taking into account both sides of the solar panel (main and rear), for each string.

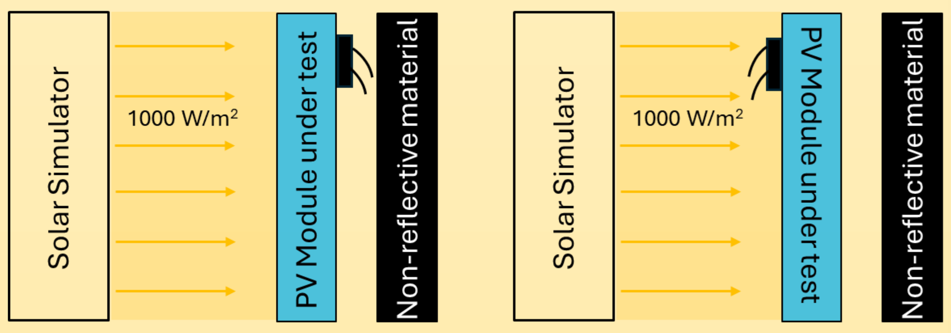

Figure 4: *Single-side illumination test method for bifacial PV panels.*

Figure 1: *Agrivoltaic system with vertical bifacial PV panels.*

Results and Discussion

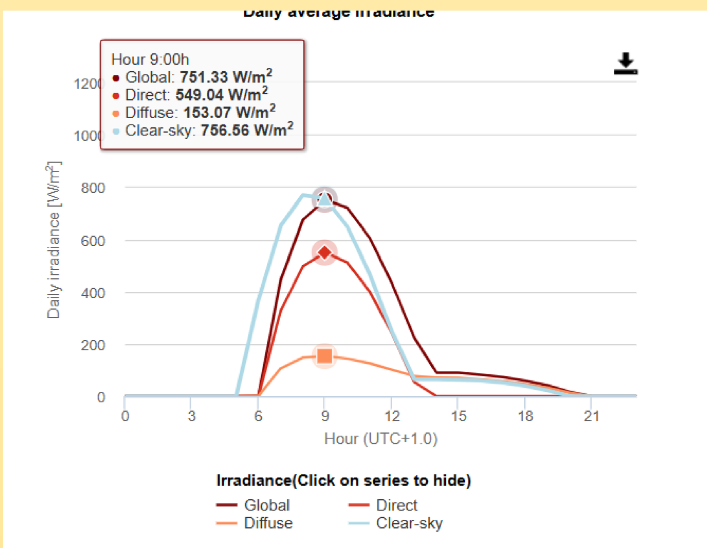

Figure 5: *PVGIS Stimated radiation on one side of a vertical east-oriented PV panel.*

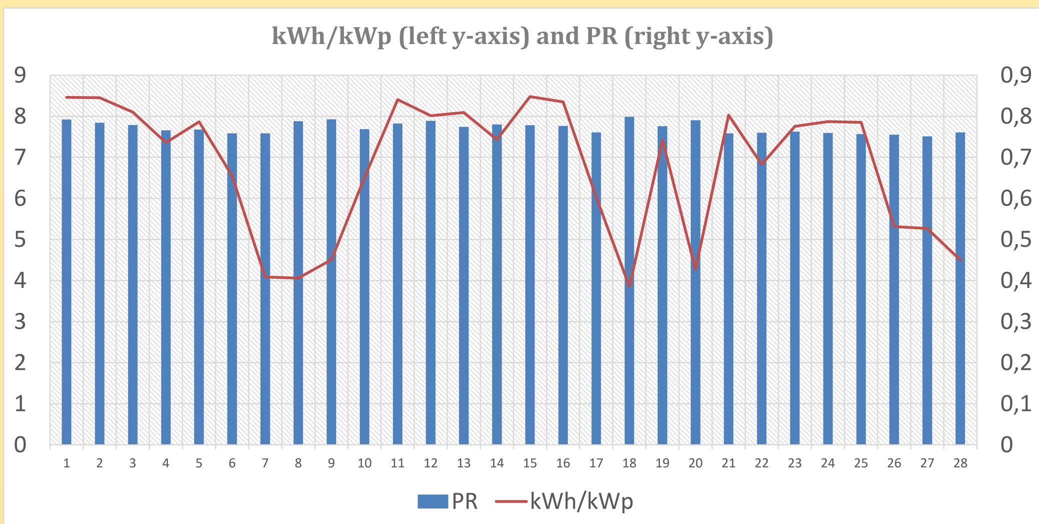

Figure 6: *June 2024 daily specific yield (kWh/kWp) and Performance Ratio of vertical bifacial system.*

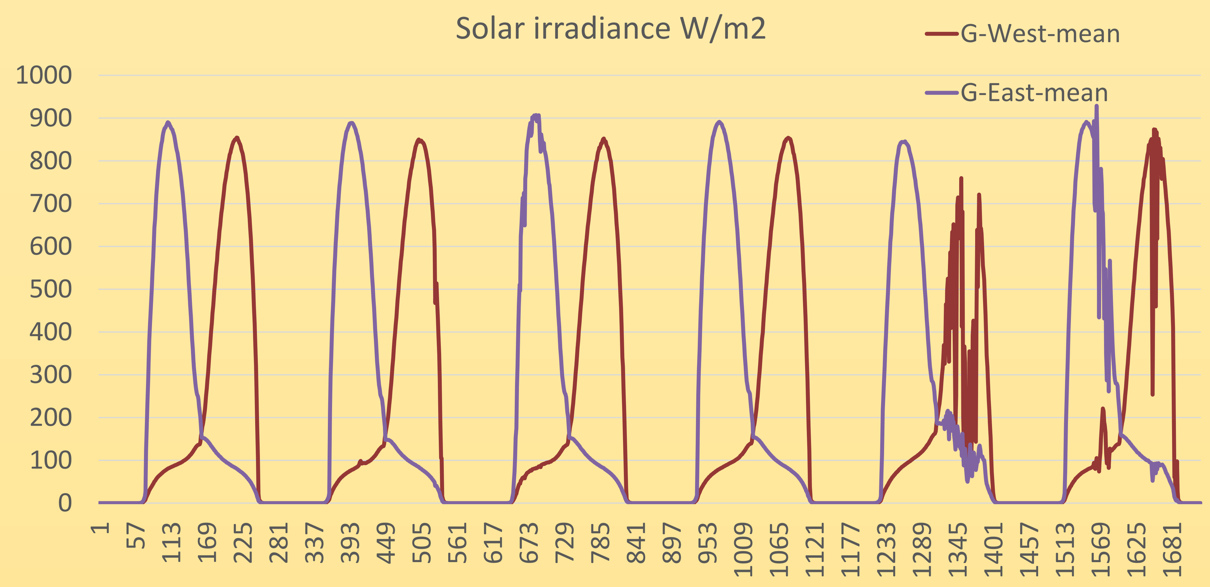

Figure 7: *Radiation measured on both sides (east and west) of a vertical mounted solar panel.*

For a vertical bifacial array of HJT photovoltaic panels, Badran and Dhimish [3] found that increased diffuse irradiance correlated with higher bifacial gain. Nonetheless, Muñoz-Cerón et al. [4] reported lower bifaciality coefficient for cloudy day (more diffuse irradiance) with respect to sunny day (less diffuse irradiance), although the bifacial panels in [4] were not vertical.

IEC 61724-1:2021 proposes to calculate PR of a bifacial array by Eq. 4:

$$\text{Eq.4. } PR_{BIF} = \sum \frac{P}{\frac{C \cdot P_0 \cdot G_{front} \cdot BIF}{\sum 1000\ W \cdot m^{-2}}}$$

, where P is the system AC power output, P_0 is the system DC power rating at STC, C is a temperature correction factor and BIF , that stands for bifacial irradiance factor, is equal to 1 + φ·(G_{rear} / G_{front})

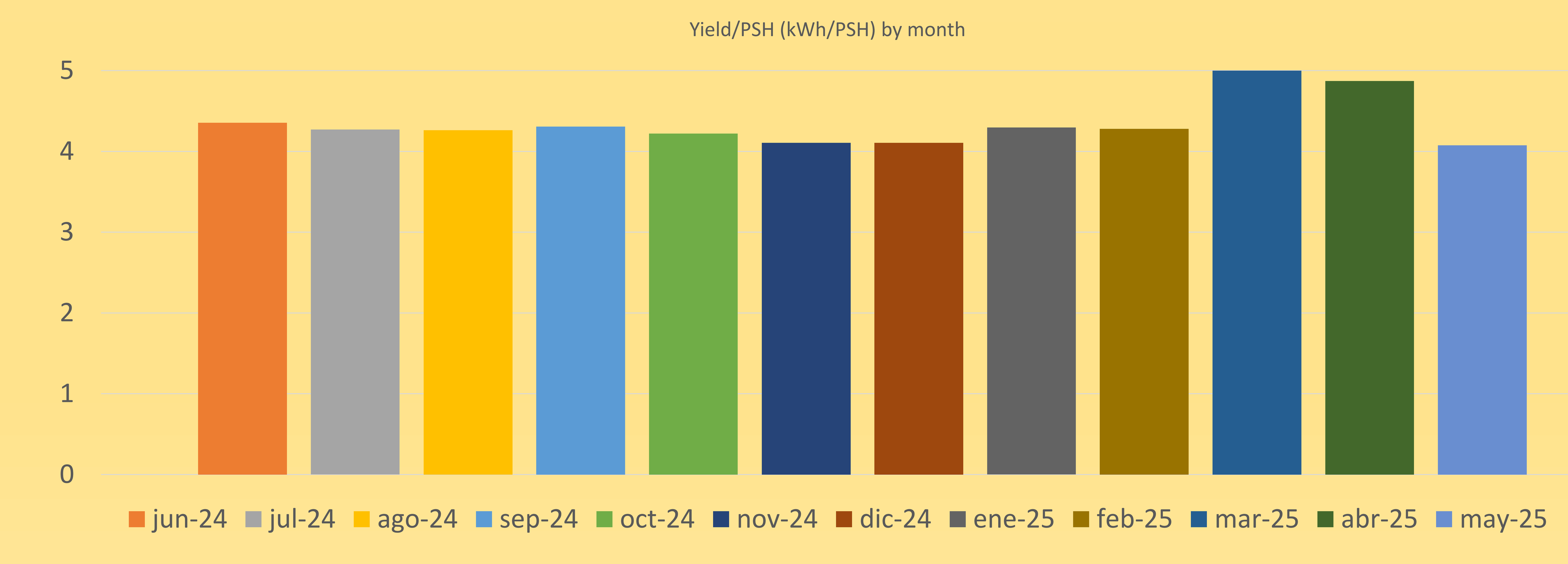

Figure 8: *Yield per peak sun hour, monthly average, from June 2024 to May 2025.*

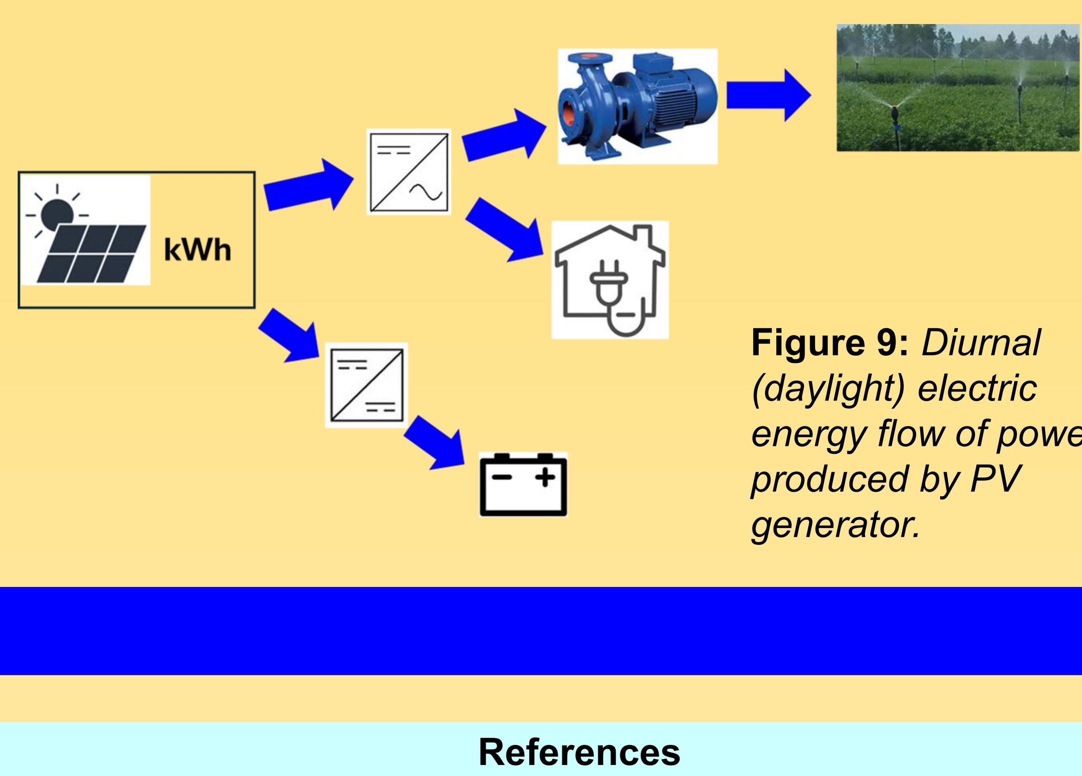

Figure 9: *Diurnal (daylight) electric energy flow of power produced by PV generator.*

Conclusions

- *Diffuse irradiance plays a major role in vertical bifacial PV systems.*
- *A vertical system presents the question of radiation to be taken into account. In this work, we considered that radiation should be the sum of that captured on both sides, but applying a bifaciality coefficient.*
- *More research is needed on outdoor characterization of bifaciality, specially for vertical bifacial systems.*

4DV.1.22. Topic: 4DV.1: Agrivoltaics Approaches, Experiences, Results / Integrated and Innovative PV Applications

References

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Acknowledgements

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