Agrivoltaics demonstrator experimentation

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PROGRAMME DE RECHERCHE FRANCE 2030 SYSTÈMES ÉNERGÉTIQUES & ÉNERGIES RENOUVELABLES

AgriPV Enhance Resilience

Error in power output modelling of a PV module in an agrivoltaic installation : horizontal position vs backtracking

Introduction (1)

The need to address growing water, food, and renewable energies, challenges has led to agrivoltaics, a photovoltaic (PV) application, to continue to gain importance since it increases food production while reducing water usage for farming and generates energy. There are studies showing that the best environment for crops to grow is simultaneousy ideal for PV power generation and that the combined land use is more productive than using land solely fro crop growth. Bifacial modules are uniquely positioned to contribute to the development of this field since they absorb irradiance from both sides of the panel, a variable that is impacted by the soil and which is affected by plant growth. Due to the lengthy growth cycles of crop, modelling is an essential tool to study the impact of crop presence in the energy production of a PV installation. An important challenge of today is adapting existing models for these new conditions or developing new ones.

Installation (2)

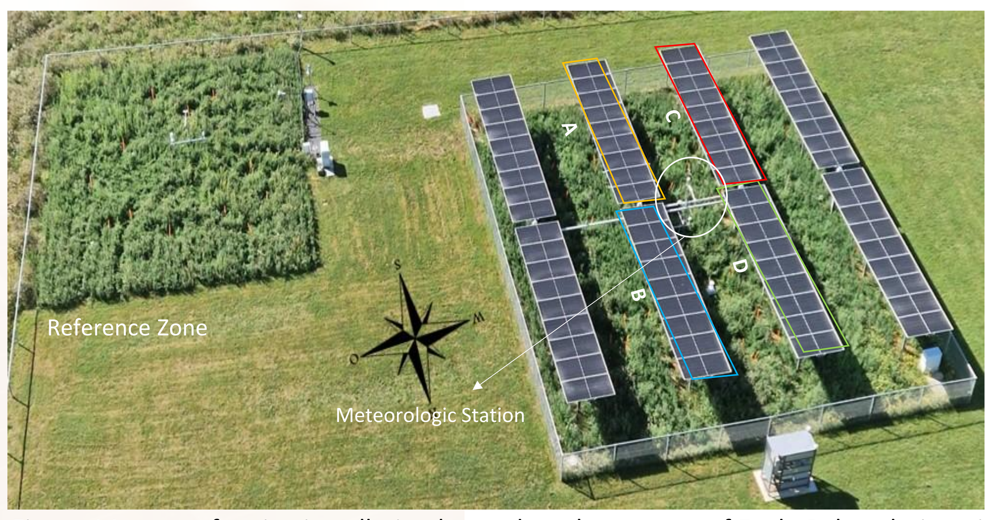

Figure 1 Layout of agripv installation located on the campus of Ecole Polytechnique in Palaiseau, France.

- North-South orientation with single-axis tracking (East-West)
- 72 TOPCon half-cell bifacial modules (555 Wp, 560 Wp, 565 Wp)
- 36 modules equipped with individual optimizers
- 4 inverters (1 per row)
- Meteorological variables: wind, air temperature, precipitation, among others

Methodology (3)

- 4 c-Si reference cells on module A8 (2 front/2 back)
- 4 temperature probes (2 on A8)

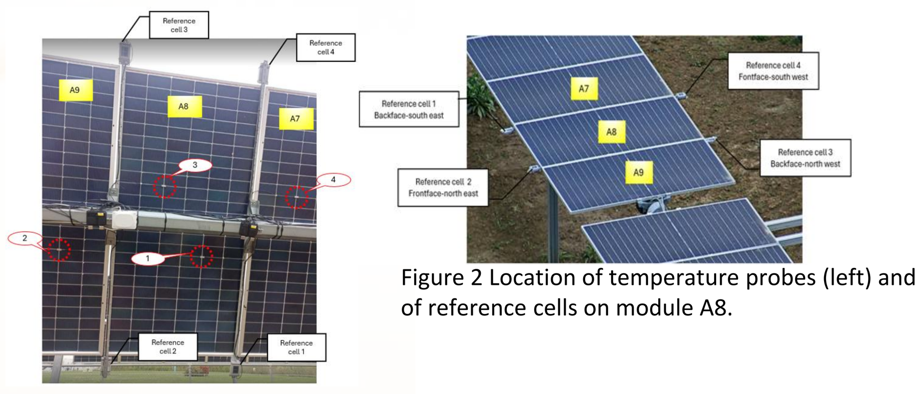

Figure 2 Location of temperature probes (left) and of reference cells on module A8.

- 2 periods of PV tracking: fixed horizontal and backtracking

Figure 3 Photos of installation at two different periods of tracking: horizontal (left) and backtracking (right).

- 3 alfalfa cycles:
  - June 11th – August 29th 2024
  - August 30th – November 19th 2024
  - March 1st – May 27th 2025

Models (4)

$$G_{eff} = POA_{front} + (POA_{back} * \varphi_{Pmax}) \quad (1)$$

$$T_F = T_a + \frac{POA}{U_0 + U_1 * WS} \quad (2)$$

$$T_S = POA * \exp(a + b * WS) * T_a \quad (3)$$

$$T_{PVS} = T_a + \frac{\alpha\, POA\,(1-\eta)}{U_0 + U_1 * WS} \quad (4)$$

$$P_{DC} = \frac{POA}{1000} P_{STC}(1 + \gamma(T_m - T_{STC})) \quad (5)$$

POA: plane-of-array irradiance
Φ: bifaciality factor
T_a: air temperature
U_0: heat loss factor
U_1: heat loss factor influenced by wind
WS: wind speed
a,b: parameters dependent on module construction, materials, and mounting
α: absorption coefficient
η: module efficiency
P_{STC}: power output at STC
γ: power temperature coefficient
T_m: measured module temperature
T_{STC}: module temperature at Standard Test Conditions

Results (5)

I)

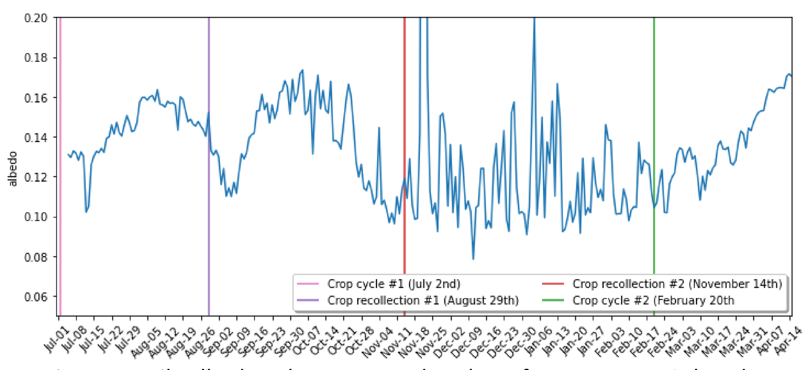

Figure 4 Daily albedo value measured at the reference zone. Colored lines correspond to start and recollection dates of alfalfa cycles.

July 16th 2024

August 3rd 2024

November 22nd 2024

Figure 4 shows the daily variation of the albedo measured at the reference zone, shown in Figure 1.
The growth of alfalfa between July and August, shown to the left, contributed to an increase of 3% of the albedo, from 0.13 to 0.16. A values of 0.2 is typically used in the literature for grass.
A short period of snow in November 2024 led to an albedo of up to 0,5 due to the higher reflected irradiance.

II)

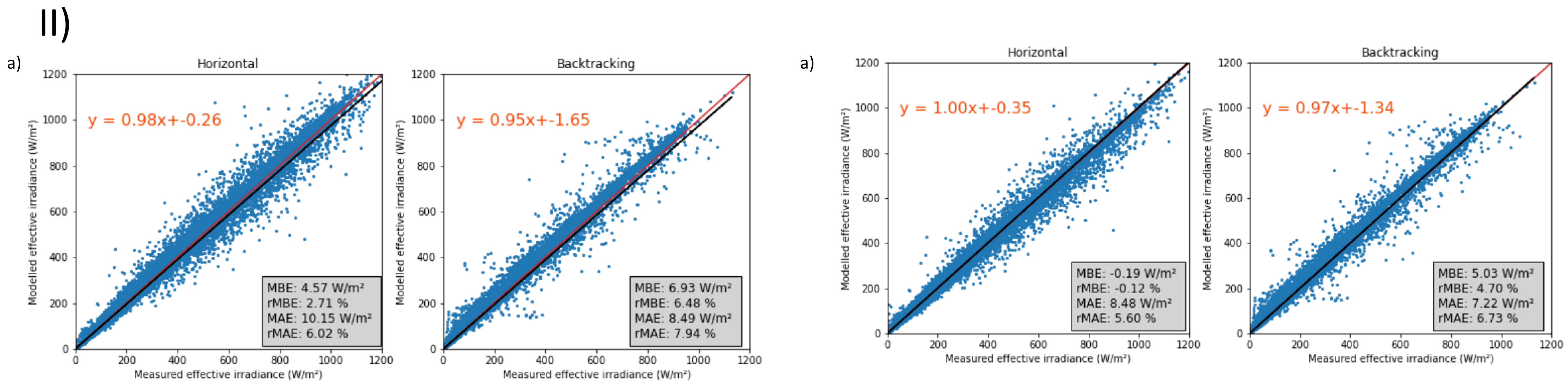

Figure 5 Comparison between modelled and measured effective irradiance calculated with eq. 1. a) was calculated using a fixed albedo of 0.2 (value typically used for grass) for both horizontal and bactracking periods. On b) the real albedo at a 5-min time step was used, for both periods as well.

In Figure 5 it can be seen that using a measured albedo instead of a fixed value when modelling the front and back POA received by a module can help decrease the relative mean bias error (rMBE) when calculating the effective irradiance. It can be reduced by 2.83 % in horizontal position and 1.78 % when in backtracking mode. This will impact the error when modelling the power output since the main contribution comes from irradiance.

III)

	MBE (°C)	MAE (°C)
Faiman	3.43	3.64
SANDIA	3.30	3.55
PVSyst	1.98	5.32
Faiman	3.03	3.15
SANDIA	3.19	3.32
PVSyst	2.07	2.37

Table 1 MBE and mean absolute error (MAE) between modelled and measured module temperature of A8. Rows in light blue correspond to the period in horizontal position and those in darker blue correspond to the backtracking period.

Table 1 shows the results for the « Faiman », « SANDIA », and « PVSyst » models which are expressed by eqs. 2-4, respectively. It is shown the PVSyst cell model proves to be the best regardless of the period, although better for the horizontal period. Despite a small overestimation for the horizontal period, it could be partially due to the fact that evapotranspiration from the crop will cool the module and the models do not take this into account. These initial results indicate that despite the models not being developed for bifacial modules, nor moving modules, they are adequate for a first approximation.

Table 2 shows that in a horizontal position, an error of less than 10% can be achieved when using eq. 5 whether using own measurements or modelled ones calculated with the real albedo. However, for the backtracking period, the rMBE using own measurements only increases by 2.15% but when using those modelled with real albedo it increases by 6.72 %. Although this increase is related to the result presented in section II, it must also be considered that this model was not developed for bifacial modules but for monofacial ones. Although adequate as a first approximation, other models must be explored.

	MBE (W)	rMBE (%)	MAE (W)	rMAE (%)
Horizontal	15.88	8.70	16.99	9.32
	21.10	11.50	21.44	11.69
	14.70	8.51	15.29	8.85
Backtracking	17.86	10.65	18.59	11.09
	29.15	17.32	32.07	19.28
	25.63	15.23	25.91	15.40

Table 2 Summary of error metrics between modelled and measured power output of module A8 using eq. 5. Different effective irradiances were used for input: measured, modelled using a fixed albedo, and modelled using the real albedo.

Conclusions (6)

The compounding effect on modelization errors of having own measurements at an installation has been shown.
The presence of crops can cause an increase of almost 3% in albedo, depending on whether it's in a fixed position or tracking mode, which will in turn impact the irradiance and power output modelizations. It can also have a cooling effect on modules that needs to be considered.
Despite the adequacy of existing irradiance, module temperature and power output models, the development of new models that take into account the new variables present in the installation is necessary in order to further improve estimations.

Acknowledgements

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