Power modeling of a bifacial single-axis tracker module in an agrivoltaic installation considering various bifacial irradiances and module temperatures

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According to the Mediterranean IPCC [1], the Euro-Mediterranean area is one key region where action is needed to address water, food, and energy demand. For this reason, agrivoltaics is a photovoltaic (PV) application that has gained importance since it increases food production while reducing water usage for farming combined with energy generation. Studies such as [2] show the best environment for crops to grow is simultaneously ideal for PV power generation, while the results in [3] indicate that the combined land use is more productive than using the land solely for crops.

Bifacial modules are uniquely equipped to improve the energy generation of an agrivoltaic installation. However, their performance characterization and modelling is complex due to the variety of factors that can influence their energy production as explained in [4].

The present work focuses on the results of a step-by-step modelling chain starting with the tilt angle of a single module in backtracking mode, followed by the incident front and back irradiance, module temperature, and finally its DC power output. The impact on power estimation of using various bifacial irradiances and module temperatures is analyzed. The results were validated with on-site measurements from May 2024 to June 2025 during which the test module changed from a horizontal position to backtracking mode.

The module under study, hereafter test module, is a TOPCon bifacial half-cell panel with a North-South orientation and 1-axis of tracking (East-West). It is equipped with 4 irradiance c-Si reference cells, each located on a corner, with 2 upward and 2 downward facing, and 2 temperature probes. It is also equipped with an optimizer, thus rendering its measurements independent. The test module is part of a larger installation of 72 panels located in Palaiseau, France, shown in Fig. 1.

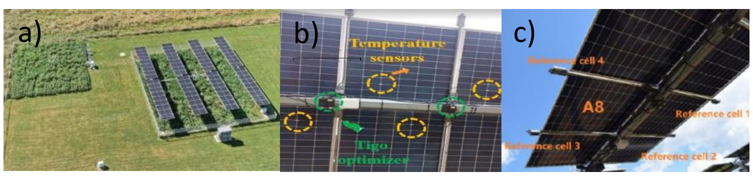

Figure 1 a) Layout of agrivoltaic installation showing the reference zone where the growth of plants is undisturbed and the PV module zone. b) Location of temperature probes and optimizer in test module. c) Location of upward and downfacing reference cells installed on test module.

First, the optimal tilt angle between rows to minimize self-shading at every moment of the day was found by varying the ground coverage ratio (GCR). Second, with the previously obtained tilt angles and the View Factor model [5], the front and back irradiance received by the test module were computed, both with a fixed albedo of 0.2 and a value calculated from on-site measurements. Utilizing those, the bifacial irradiance (G_{eff}) was computed using both measured and modelled irradiances. Following this, three different temperature models (Faiman, Sandia, PVSyst) [6-8] were used to estimate the module's temperature making use of the aforementioned bifacial irradiances. Finally, said module temperatures and bifacial irradiances were used to estimate the power output of the test module. All modelling results were validated with on-site measurements.

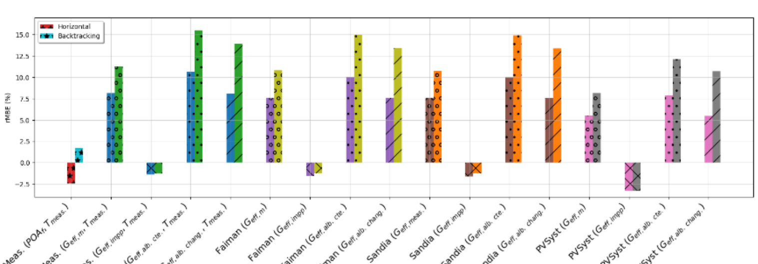

Figure 2 Relative mean bias error between modelled and measured power output. In parenthesis are indicated what bifacial irradiance and module temperature was used for the calculation.

Fig. 2 presents the relative mean bias error between modelled and measured power output. It shows that calculating the bifacial irradiance from the module's Impp measurement leads to the best result because the irradiance is what the module really perceives. It also shows that when using modeled irradiances, using the on-site albedo is more adequate than choosing a fixed one. Furthermore, when using a modeled temperature, utilizing on-site measurements leads to lower errors.

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