

Benchmarking PASE Backward Ray Casting Light Model with `bifacial_radiance` and Experimental Data

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1. Introduction

Properly modelling light pattern dynamics underneath photovoltaic (PV) modules is one of the key challenges in agrivoltaics modelling to assess agricultural yields. Currently, tools like NREL's `bifacial_radiance` [1] are already used to assess the performance of bifacial PV systems using ray tracing algorithm. However, there is a lack of an efficient open-source tool to model not only light reaching PV panels but also crop light interception in agrivoltaic systems. The Digital Energy and Agriculture Lab (DEAL) has initiated the Python Agrivoltaic Simulation Environment (PASE), an open-source Python framework to model PV and agricultural productions of most types of agrivoltaic systems. The ray casting-based light model developed in PASE has already been presented in [2]. As the productivity of an agrivoltaic facility should be modelled over multiple years to integrate the inter-annual variability of agricultural yield [3], efforts have been made in the development to have fast computations by avoiding calculation repetitions and allowing different levels of precision and resolution depending on the user needs. This work aims to compare the results of the light model that has been developed and integrated into PASE with experimental data and a `bifacial_radiance` model.

2. Material and methods

Irradiance data have been collected from 10th to 27th August 2023 on a SigueSol agrivoltaic prototype located in Werbomont, Belgium (latitude: 50.376 and longitude: 5.677). A pyranometer was in full sun conditions, and another was in agrivoltaic conditions. The latter was located below the centre of a PV table with a gap of 56 cm between panels. The experimental set-up is shown in Figure 1a. Geometric parameters have been measured on site and are used in the simulations performed by PASE (Figure 1b) and `bifacial_radiance` to construct the scene. Virtual sensors are used as specific points of interest in simulations to reproduce the agrivoltaic pyranometer. Both simulation tools use the irradiance data in full sun conditions at a quarter hour time step as an input for the light decomposition.



Figure 1. SigueSol agrivoltaic prototype and experimental set up with full sun condition pyranometer in purple and agrivoltaic pyranometer in red (a) and experimental set up reproduced in PASE (b).

3. Results and discussion

Figure 2 presents the irradiance reaching the full sun and agrivoltaic in situ pyranometers as well as both virtual sensors on the 10th of August, a day of clear sky conditions and on the 19th of August, a cloudy day. The figure highlights good results for both tools with RMSE of respectively 90.1 and 45.2 W/m² for PASE and bifacial_radiance on the 10th of August and 33.1 and 14.6 W/m² on the 19th of August. The main limitation on accuracy, especially regarding the small irradiance peak shifts, may arise from a lack of precision in the in situ geometric parameters measurement. In further comparisons with experimental campaigns, the geometric features of the scene should be measured very precisely. Unlike bifacial_radiance, the current PASE light model slightly overestimates diffuse irradiance when PV panels are casting a shadow on the digital sensor on the 10th of August. Indeed, PASE and bifacial_radiance do not use the same light decomposition models.

Considering daily irradiation, which is the main input of crop models and is therefore an important metric, PASE and bifacial_radiance present respectively an error of 2.4 % and 11.3 % on the 10th and 0.5 % and 1.0 % on the 19th of August. As far as the whole period of measurements is concerned, PASE is making an error of 1.0 % and bifacial_radiance an error of 0.5 % on the total irradiation of the period. These results present a first validation and give good confidence in the light model of PASE as an input for the spatialized crop models implemented in the tool. However, further validations could be made on datasets from different agrivoltaic geometries and periods of the year.

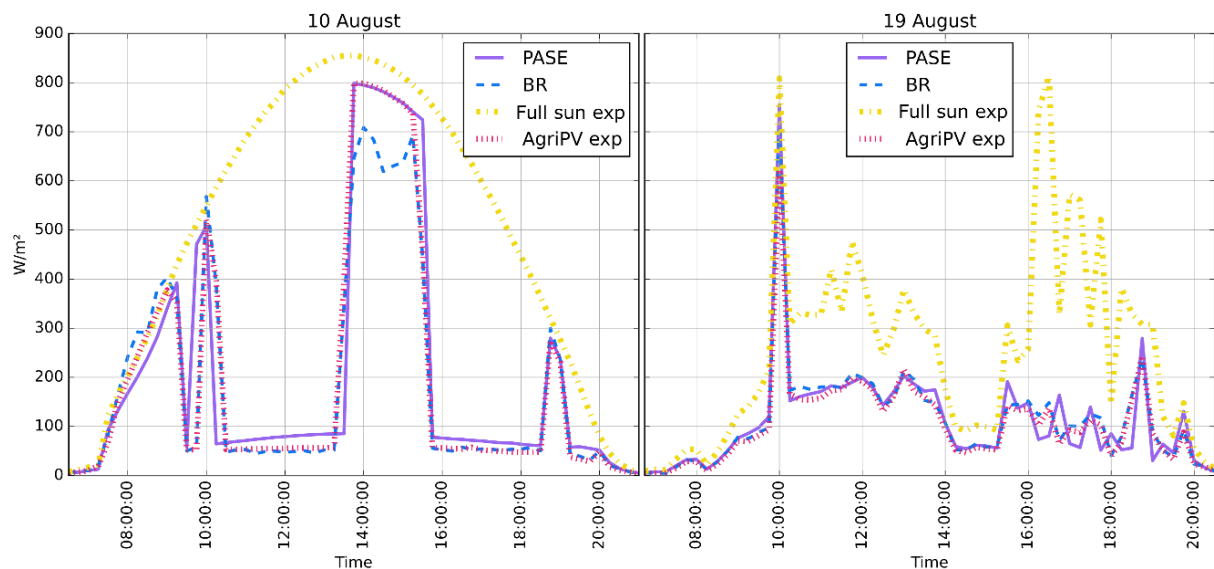


Figure 2. Comparison between experimental and simulation data with PASE and bifacial_radiance (BR) on a clear sky day (10th August) and a cloudy day (19th August).

4. References

1. S.A. Pelaez and C. Deline, “bifacial_radiance: a python package for modeling bifacial solar photovoltaic systems,” *J. Open Source Softw.*, 5(50) (2020), doi: <https://doi.org/10.21105/joss.01865>
2. R. Bruhwiler, et al., “Vertical agrivoltaics and its potential for electricity production and agricultural water demand: A case study in the area of Chanco, Chile,” *Sustain. Energy Technol. Assess.*, vol 60 (2023), doi: <https://doi.org/10.1016/j.seta.2023.103425>
3. C. Dupraz, “Assessment of the ground coverage ratio of agrivoltaic systems as a proxy for potential crop productivity,” *Agroforest. Syst.* (2023), doi: <https://doi.org/10.1007/s10457-023-00906-3>