SUNLIGHT HOURS AS A GUIDE: ENHANCING CROP SELECTION IN AGRIVOLTAIC FIELDS

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Abstract

In agricultural regions, agrivoltaic systems (AVS) represent a promising solution to optimize land use by integrating food production with solar energy generation. This study presents a visual and analytical approach to evaluate sunlight availability beneath photovoltaic (PV) modules, using a case study conducted at the Solar Energy Research Laboratory Fotovoltaica/UFSC in Florianópolis, Brazil (27°S). Simulations were performed in SketchUp® using the SunHours plugin to analyze the spatial and temporal distribution of sunlight across planting beds. Results indicate that average daily sunlight under the AVS ranges from 4 to 5 hours, compared to 9 to 10 hours in open-sky conditions, aligning well with the optimal light requirements for the selected crop, lettuce (*Lactuca sativa*). The shading created by PV modules can reduce thermal stress and support stable crop productivity, highlighting the potential of AVS to balance agricultural and energy objectives. The proposed methodology offers a practical decision-support tool for crop selection, system configuration, and tracker operation strategies. For this project, continuous field monitoring will further assist in refining tracker operation, correlating sunlight availability with actual crop performance and energy yield, reinforcing the integration of renewable energy with sustainable agriculture.

Keywords: Agrivoltaic systems (AVS), Photovoltaic Systems, Sunlight hours, Shading, Shade-tolerant crops.

1. Introduction

The rising global energy demand, coupled with the pursuit of more sustainable agricultural practices to mitigate environmental impacts, has driven the adoption of photovoltaic (PV) systems within agriculture – an approach known as agrivoltaics. Agrivoltaic systems (AVS) integrate solar energy generation with agricultural production on the same land area, enabling synergistic benefits. This dual use of land not only enhances land-use efficiency but can also support agricultural productivity while increasing the share of renewable energy generation. AVS can contribute to the promotion of sustainable agriculture by reducing crop exposure to excessive solar radiation (Zahrawi, A., Aly, A., 2024), a factor of particular importance in regions characterized by high solar incidence. Many cultivated crops are susceptible to climatic stresses – such as elevated temperatures and excessive irradiance – which can affect both yield and quality, ultimately leading to reduced agricultural productivity and economic losses. In the Brazilian context, the implementation of AVS can be advantageous due to the country's strong agricultural sector (Moura, 2024). Combined with the high availability of solar radiation throughout the year, this makes Brazil well-suited for integrating PV systems into agriculture. A significant portion of rural productivity in Brazil is derived from family farming, where agricultural activity often represents the primary or sole source of income (IBGE, 2019), and the adoption of AVS can offer substantial benefits.

The configuration and layout of photovoltaic modules directly influence the levels of solar radiation, temperature, and humidity within the cultivated area, thereby affecting photosynthesis, plant morphology, and crop yield. Furthermore, the partial shading provided by PV panels can contribute to the creation of a favorable microclimate for certain crops, reducing heat stress and optimizing plant growth (Barron-Gafford, G.A., Pavao-Zuckerman, M.A., Minor, R.L., et al., 2019). Field studies indicate that strategically designed shading can reduce excessive solar radiation while improving both physiological and yield performance. In

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the case of *Vigna radiata* (mung bean), the temporal and spatial distribution of sunlight was found to play a decisive role in crop development and productivity (Ukwu et al., 2025). Research on grapevines has also indicated that microclimatic variations created by the PV structures alter photomorphogenesis and yield components according to local climate conditions and the spatial arrangement of the modules (Magarelli et al., 2025). Additionally, recent multidisciplinary reviews emphasize that these changes caused using PV modules over agriculture generate new microenvironments in which light availability and quality beneath the panels become decisive factors for determining the most suitable species and cultivars for each agrivoltaic configuration (Sturchio et al., 2024; Asa'a, 2024). Experiments with tomatoes grown under agrivoltaic systems demonstrate that moderate shading can maintain marketable yields while improving nitrogen-use efficiency, highlighting the potential of cover fraction adjustments as a management strategy (Dal Prà et al., 2025; Mohammedi et al., 2023). Meta-analyses reveal that the relationship between reduced irradiance and yield is non-linear and species-dependent: some crops tolerate limited light reductions without significant productivity losses, while others are highly sensitive. Consequently, integrating effective light hours into crop-selection criteria is essential, supported by experimental analyses tailored to each plant and shading level (Laub et al., 2022).

Modeling studies simulating the spatial distribution of irradiance in agrivoltaic systems, including greenhouse structures, further illustrate how light heterogeneity influences water demand and growth uniformity, offering a quantitative basis for using sunlight hours as a decision-making tool in crop management (Torrente et al., 2024; Chen et al., 2024). Managing daylight availability thus has systemic implications for the simultaneous optimization of energy, food, and water resources, as well as for local environmental impacts. Regional assessments show that adapting crop combinations to local irradiance regimes can maximize these benefits, promoting resource efficiency and sustainability (Randle-Boggis et al., 2025). Meanwhile, research on soil biodiversity and microfaunal dynamics highlights the importance of incorporating environmental indicators into the design and management of AVS, as soil communities are strongly affected by spatial variability and maintenance practices (Leroy et al., 2025). Finally, Solar trackers technologies and semitransparent PV modules have emerged as promising solutions to balance light allocation between electricity generation and crop requirements. When combined with irradiance modeling and field observations, these technologies enable more precise control of usable daylight hours, aligning light availability with the physiological needs of selected crops (Andreev et al., 2025; Yano, 2025; Padilla et al., 2022).

In this context, the present study proposes a visual and analytical tool to evaluate sunlight availability beneath PV modules in agrivoltaic systems, recognizing that PV-induced shading can alter sunlight duration and, consequently, affect agricultural productivity. By quantifying the spatial and temporal distribution of solar exposure in an AVS case study, the tool aims to support crop planning decisions based on sunlight suitability. Ultimately, this approach seeks to foster the adoption of AVS by aligning solar energy generation with optimized agricultural management.

2. Case study

The case study was conducted in the Solar Energy Research Laboratory Fotovoltaica/UFSC in Florianópolis, Brazil (27°S latitude). The AVS under analysis has a total installed capacity of 108 kWp, divided into seven subsystems. It comprises a bifacial fixed array with four rows, two vertically mounted bifacial systems, and eight solar trackers – four with conventional bifacial modules and four with semitransparent bifacial modules – specific for AVS. Additionally, there is a control area without PV coverage, for comparative analysis. Figure 1 shows the 3D model of the AVS with the respective installed capacity in each array.

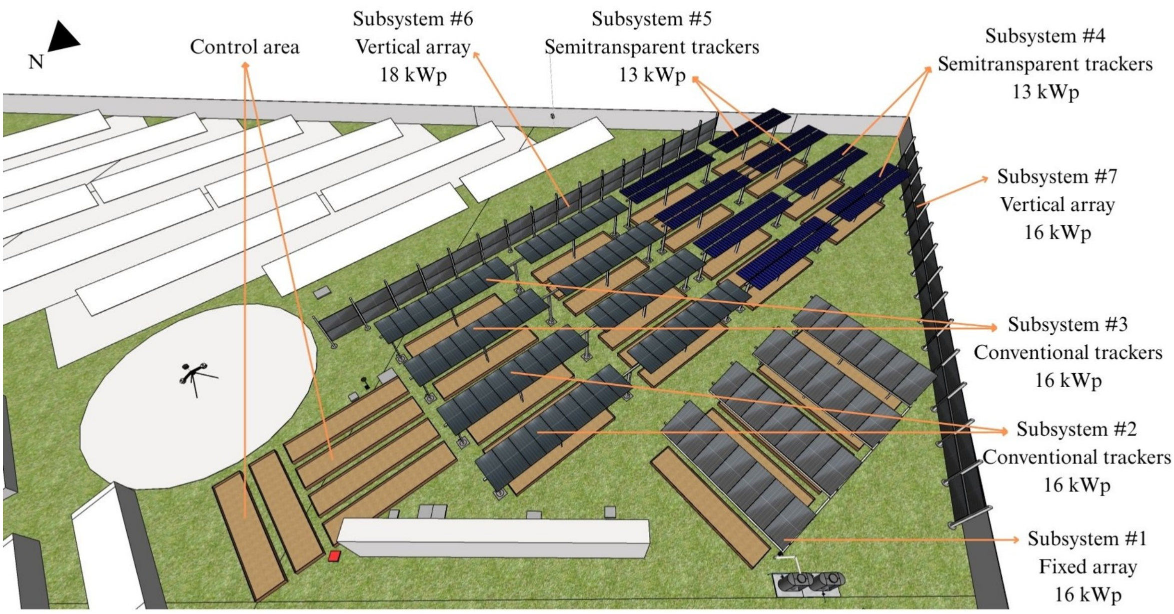

Figure 1: 3D model of the agrivoltaic system used as the case study, located in Florianópolis, Brazil (27°S latitude).

The project was inaugurated on October 14th, 2025, with the construction operations fully completed. Figure 2 shows an aerial view of the complete constructed AVS. It is equipped with sensors dedicated to both agricultural and PV monitoring, enabling a comprehensive assessment of crop development and energy performance. The data collected by these sensors will be used to optimize the operation of the solar trackers to favor agricultural activity, adjusting their positioning based on the specific needs of the crops throughout different growth stages.

Figure 2: Aerial view of the agrivoltaic system used as the case study, located in Florianópolis, Brazil (27°S latitude)

Agricultural cultivation is conducted in 37 planting beds, each measuring 7.5 m × 1.5 m. A plastic liner layer is placed between the wooden framed base of the beds and the planting substrate, with holes for irrigation drainage. Each bed contains 96 lettuce (*Lactuca sativa*) seedlings. Lettuce is characterized by rapid growth and low energy demand (Bantis et al., 2018; Zhang et al., 2018). Therefore, the choice of lettuce as the reference crop was based on compatibility with shaded environments, low daily sunlight requirements, and a short production cycle. Although literature offers varying recommendations on its ideal photoperiod, it is generally accepted that lettuce requires approximately 5 to 6 hours of direct sunlight per day (EOS Data Analytics, 2025) and performs optimally at temperatures from 20°C to 25°C, withstanding temperatures up to 29°C under proper agronomic management. The project includes an irrigation system specifically designed for the layout of the planting beds, in which fertigation provides the necessary nutrients to meet the physiological requirements of lettuce.

Before planting the crops, in June 2025, a test bed without PV modules above it was established to determine the most suitable planting substrate for the project (Figure 3). This configuration represented the control area of the future AVS. Three substrate types were evaluated over a 35-day cultivation period, during which lettuce growth was closely monitored. After harvesting, an additional performance analysis was conducted (Figure 4), considering both growth behavior throughout cultivation and final yield. The substrate used for the lettuce in the center of Figure 4 was selected, as it achieved similar growth performance to the substrate with higher organic matter content (lettuce on the left in Figure 4) but showed a much lower incidence of weeds. The chosen substrate – a slightly clay-like yet well-aerated mixture produced by a specialized supplier – was composed of carbonized rice husks and peat soil, supplemented with mineral fertilizer, and demonstrated strong support for crop development.

Figure 3: Test bed without PV modules, representing the control area of the future AVS, used to evaluate different planting substrates prior to crop installation.

Figure 4: Performance analysis of the test bed without PV modules, used to evaluate lettuce growth under different substrates during and after the 35-day cultivation period.

3. Methodology

A simulation was conducted using SketchUp® (TRIMBLE, 2024) to demonstrate the application of a visual and analytical tool for assessing the impact of PV module installation on sunlight availability for crops, and consequently, on agricultural productivity. In the case study simulation, the PV modules were positioned in the stow orientation due to a limitation of the software, which does not support the modeling of tracking systems. To evaluate the spatial and temporal distribution of solar irradiance over the planting areas, the SunHours (HALL, 2025) plugin for SketchUp® was employed. This tool calculates direct solar exposure by generating a grid across the surfaces of interest and simulating sunlight incidence over a defined period. Hourly data for all months of a year were simulated to compare the results with the crop-specific daylight requirement. The resulting data were exported in CSV format and analyzed to assess the suitability of the planting areas for cultivation under AVS conditions.

The SketchUp® software was selected for this project due to its ability to import three-dimensional models and its direct integration with the SunHours plugin. This integration enables the accurate representation of photovoltaic structures and surrounding urban elements while allowing the export of hourly solar exposure data in CSV format for quantitative analysis. The combination of 3D modeling and solar simulation transforms geometric information into practical insights that support agricultural planning – particularly the spatial and temporal distribution of sunlight over crops. This approach reduces dependence on field measurements and enables the evaluation of expected sunlight availability prior to construction.

The choice of software was therefore pragmatic, prioritizing geometric accuracy, intuitive modeling of surrounding features that influence shading, and the ability to generate solar radiation graphs for assessing ground-level solar incidence. Although SketchUp® does not support the direct modeling of dynamic tracking systems, the modules were positioned in an east–west orientation to approximate their stow configuration. Despite this limitation, the main objective of the simulation was to analyze the local influence of environmental surroundings on the crops. Consequently, the static representation proved sufficient for identifying shadow patterns produced by buildings, vegetation, and the configuration of the PV modules themselves, making SketchUp® the most suitable tool for the study's purpose. Other software tools, such as System Advisor Model® (SAM) (NREL, 2025a) and Byfacial radiance® (NREL, 2025b), were also considered; however, they do not support the modeling of surrounding or neighboring elements, which was a crucial requirement for this case study because the total of sunlight hours is influenced by the surroundings of the area.

By incorporating neighboring buildings, vegetation, and terrain variations in the 3D model, it was possible to evaluate whether each planting bed receives adequate daily sunlight for the selected crop. The study enabled a detailed spatial assessment of sunlight distribution on the ground, producing data that can guide both crop selection and future strategies for tracker operation during field testing and dynamic adjustment phases.

4. Results

Figures 5 and 6 illustrate the sunlight hour analysis for two distinct months: February, representing the period of highest solar incidence, and July, the period of lowest incidence. Figure 5 shows the results without PV modules, while Figure 6 presents the conditions with PV modules installed.

The average daily availability of direct sunlight in the planting areas without PV modules ranges from 9 to 10 hours. Under the agrivoltaic system (AVS), this value decreases to 4 to 5 hours, which aligns well with the optimal daily sunlight requirement for lettuce growth, typically between 5 and 6 hours. The control areas of the AVS (without PV modules) receive more than 6 hours of direct sunlight per day (9–10 hours, the same as the non-shaded scenario), which, without proper crop management, may increase the risk of thermal stress and yield reduction, The opaque modules had a significantly lower average number of sun hours than the semi-transparent modules, which got more sunlight hours, because of the space among cells. Thus, the AVS configuration provides a level of shading that can be beneficial for lettuce cultivation. The seasonal variation in shadow projection may also affect microclimatic conditions at the plot edges over time, possibly affecting localized temperature and irradiance patterns and hence management requirements at those edges.

Additionally, local temperature data reinforce these findings: July, with an average of 21 °C, offers favorable climatic conditions for lettuce growth, while February, with a higher average temperature of 28 °C (Climate-Data.org, 2025), demands more careful management but still allows for viable cultivation. Overall, the results indicate that lettuce is a highly suitable crop for cultivation under the specific AVS conditions evaluated in this case study.

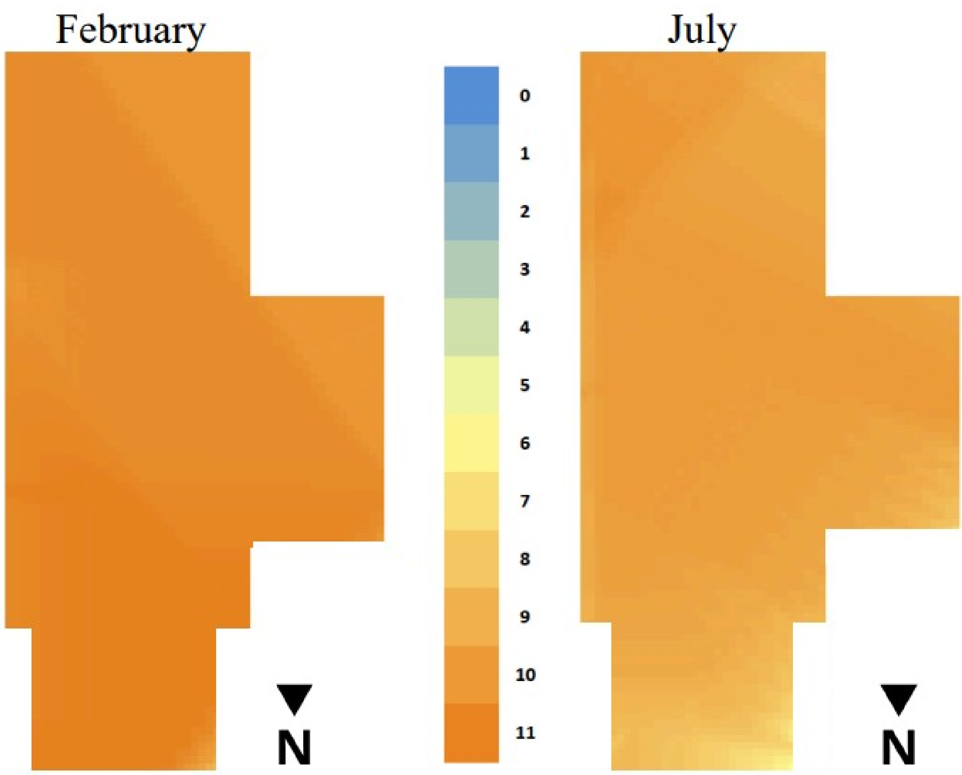

Figure 5: Average daily sunlight hours for the months of February (left) and July (right) without PV modules.

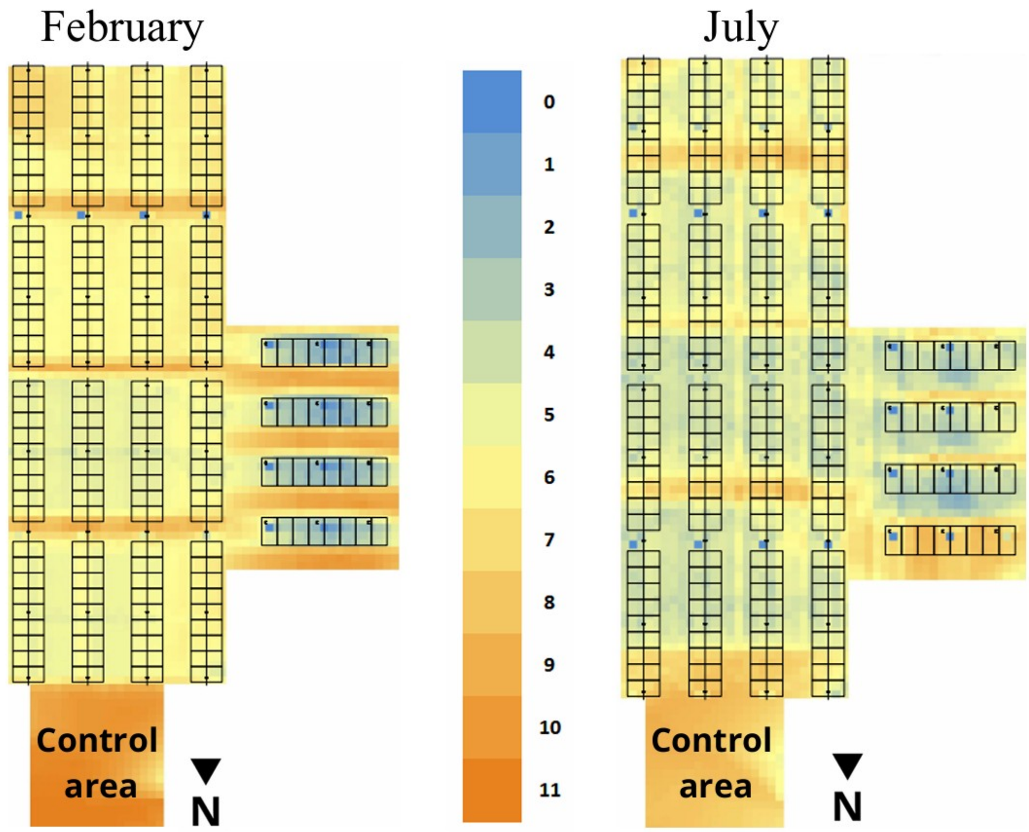

Figure 6: Average daily sunlight hours for the months of February (left) and July (right) in the AVS case study.

5. Conclusions

This study presented a visual and analytical approach to assess sunlight availability in an agrivoltaic system (AVS) through a case study conducted at the Solar Energy Research Laboratory Fotovoltaica/UFSC in Florianópolis, Brazil. By combining three-dimensional modeling with solar exposure simulation, it was possible to quantify the spatial and temporal distribution of sunlight over the planting beds, providing valuable insights for agricultural planning under PV structures.

The results demonstrated that the implementation of PV modules significantly alters sunlight distribution, reducing the average daily exposure from 9-10 hours in open-sky conditions to 4-5 hours under the AVS. This reduction aligns closely with the optimal light requirements of lettuce (*Lactuca sativa*), confirming its suitability for cultivation in partially shaded environments. Furthermore, the shading created by the PV modules can mitigate excessive radiation and thermal stress, contributing to improved crop resilience and promoting more stable agricultural productivity throughout the year.

The findings emphasize that agrivoltaic systems, when properly designed and managed, can simultaneously enhance energy generation and support sustainable agricultural practices. The proposed methodology can serve as a decision-support tool for crop selection, system design, and tracker operation strategies in future AVS implementations. For this project, continuous field monitoring will play a key role in supporting and refining tracker operation strategies, enabling real-time adjustments to optimize conditions for crop development. Future work will focus on validating the simulated results through this ongoing monitoring, correlating sunlight availability with actual crop performance and energy yield.

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