AgriVoltaics World Conference 2024
PV System Technologies
https://doi.org/10.52825/agripv.v3i.1394

Published: 26 May 2025

South-Oriented PV Trackers: A Solution for Tree Plantations?

Jean-Baptiste Pasquier[1,*], Jules Chéron[1], and Farida Amichi[1]

[1]Ombrea, Aix-en-Provence, France

*Correspondence: Jean-Baptiste Pasquier, pasquierjb@gmail.com

Abstract. Single-axis trackers in AgriVoltaics (APV) systems traditionally face East-West (E-W) to track the sun's path. This study investigates the viability of North-South (N-S) oriented trackers for optimising irradiance distribution in tree plantations. Using a modelling framework and meteorological data from Aix-en-Provence, France, we demonstrate that N-S trackers create distinct shading patterns on the ground that shift throughout the year due to varying solar zenith angles. By strategically positioning photovoltaic (PV) panels relative to tree canopies, our simulations show potential for minimising shading on sun-loving crops like apricot trees, crucial for maintaining photosynthesis levels. We propose innovative tracking algorithms to mitigate shading effects during different seasons, preserving both electrical output and agricultural productivity. Our simulations indicate that N-S trackers offer comparable electricity production to E-W configurations in sun-tracking mode and outperform fixed arrays-oriented South, with minimal losses in irradiance during critical growth periods. Additionally, N-S trackers show promise in reducing soil evaporation, which could enhance water balance in agricultural settings. Future research employing 3D modelling and integrated PV-crop simulations is recommended to optimise design parameters and assess the Land Equivalent Ratio (LER) for further validation.

Keywords: Agronomic Tracking, Irradiance Modelling, Single-Axis Trackers, Agrivoltaics, Perennial Crops

1. Introduction

Single-axis trackers are increasingly popular in APV applications. In the United States alone, there are 292 APV sites with a total installed capacity of 7,596 MW according to the NREL InSPIRE "Agrivoltaics Map". Within orchards, trackers are typically oriented East-West (E-W) with overhead structures. This configuration causes significant shading on the canopies, often justified by the need for crop protection [1].

In APV settings, overhead trackers are sometimes operated with an agronomic algorithm that positions the panels in anti-tracking mode during specific times of the year for agronomic reasons. For instance, Valle et al. tested anti-tracking in the morning hours [2] in a lettuce field in Montpellier, France. However, to avoid significant losses in electrical production, sun tracking is applied during most of the year, making this approach suitable only for shade-tolerant crops.

Using our modelling framework, we compare irradiance patterns and electrical production between traditional E-W overhead arrays and North-South (N-S) arrays with identical panel height and density. Our study demonstrates that with a smart tracking algorithm, N-S arrays can optimise both agronomic and electrical outcomes for sun-loving crops, potentially offering a land efficient solution for APV in Mediterranean orchards.

2. Materials and methods

We developed a modelling framework that couples an irradiance, a PV yield and a crop model.

2.1 Irradiance Model

Our model uses an analytical method for computing the irradiance on a shaded surface [3] from the Global Horizontal and Diffuse Horizontal irradiance. Panels are modelled as 2D polygons impacting both components on a horizontal plane beneath them:

- Direct Component: At each time step, we project polygons onto a horizontal plane using the 3D sun array. Projected polygons are then rasterized on a 2D grid.
- Diffuse Component: We apply a 3D extension of the 2D infinite shed formula [4]. Computation is done for each panel tilt, and we assume isotropic diffuse light distribution for computational efficiency.

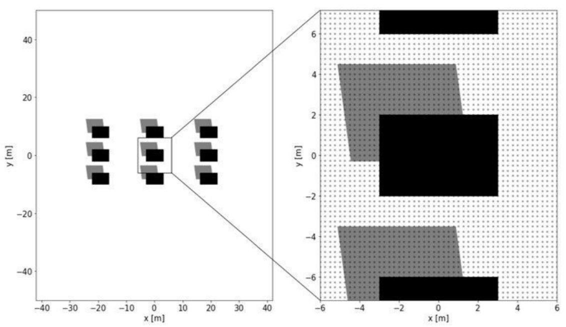

***Figure 1**. Polygon clipping (Direct)*

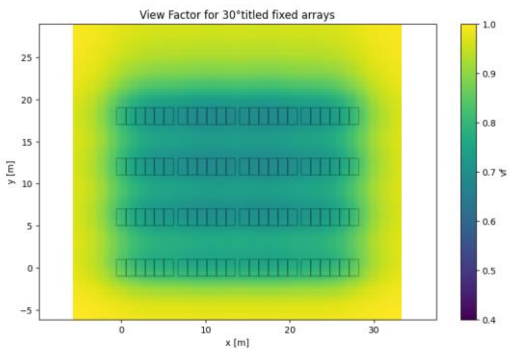

***Figure 2.** View Factor: Share of light intercepted (Diffuse)*

With the projected polygons and the view factor estimate, the estimated irradiance on a given point (x, y) is:

$$Irr(x,y,t) = GHI(t) \cdot S_{01}(x,y,t) + DHI(t) \cdot VF(x,y,t) \quad (1)$$

With:

- $Irr(x,y,t)$: Irradiance at location (x, y)
- $GHI(t)$: Global Horizontal Irradiance
- $S_{01}(x,y,t)$: Binary indicator for shaded locations (0 for shaded, 1 for unshaded)
- $DHI(t)$: Diffuse Horizontal Irradiance
- $VF(x,y,t)$: View Factor (ranging from 0 to 1) at location (x, y)

Irradiance maps are computed in relative terms through the ratio between the sum of irradiance for each timestep and point and the sum of unshaded Global Horizontal Irradiance (GHI) for a given period.

$$\frac{\sum \quad Irr(x,y,t) * \Delta t}{GHI(t) * \ \Delta t} \quad (2)$$

2.2 Irradiance Model

PV production is simulated using the Pvlib library [5] with a 120kWp PV plant of bifacial panels coupled with a 100kWp inverter. Row-to-row shading losses are calculated by fitting an infinite shed factor model with the design parameters. The PV models considered, as named in the pvlib library, are:

Table 1. *pvlib models*

clearsky_model	ineichen
transposition_model	haydavies
solar_position_method	nrel_numpy
airmass_model	kastenyoung1989
dc_model	cec
ac_model	sandia_inverter
aoi_model	sapm_aoi_loss
spectral_model	no losses
temperature_model	pvsyst
losses_model	pvwatts

Yearly power outputs are expressed as specific yields (in kWh/kWp/year) to allow for comparison with different designs and locations.

2.3 Crop Model

Tree canopies are modelled as horizontal disks with specific diameters and heights. Crop height is chosen to be representative of the height where the crop has the maximum number of leaves and therefore with maximum photosynthesis.

2.4 Study parameters

The economic and agronomic feasibility of south-oriented PV trackers are evaluated in a potential apricot (or similar tree) orchard in Aix-en-Provence, France. PV and irradiance simulations are performed using Typical Meteorological Year (TMY) weather data extracted from PVGIS. All simulations are conducted with an hourly time step and a spatial resolution of 50 cm. The crops and PV geometric parameters are provided in the following table:

Table 2. *Study parameters*

Crop Parameters		**PV Parameters**	
Height	2.5m	Panel height	4m
Diameter	3m	Panel length	2.2m
Inter-row spacing	6m	Pitch	6m
		GCR	38%
		Tilt angle	+/- 90°

3. Results

3.1 Irradiance patterns

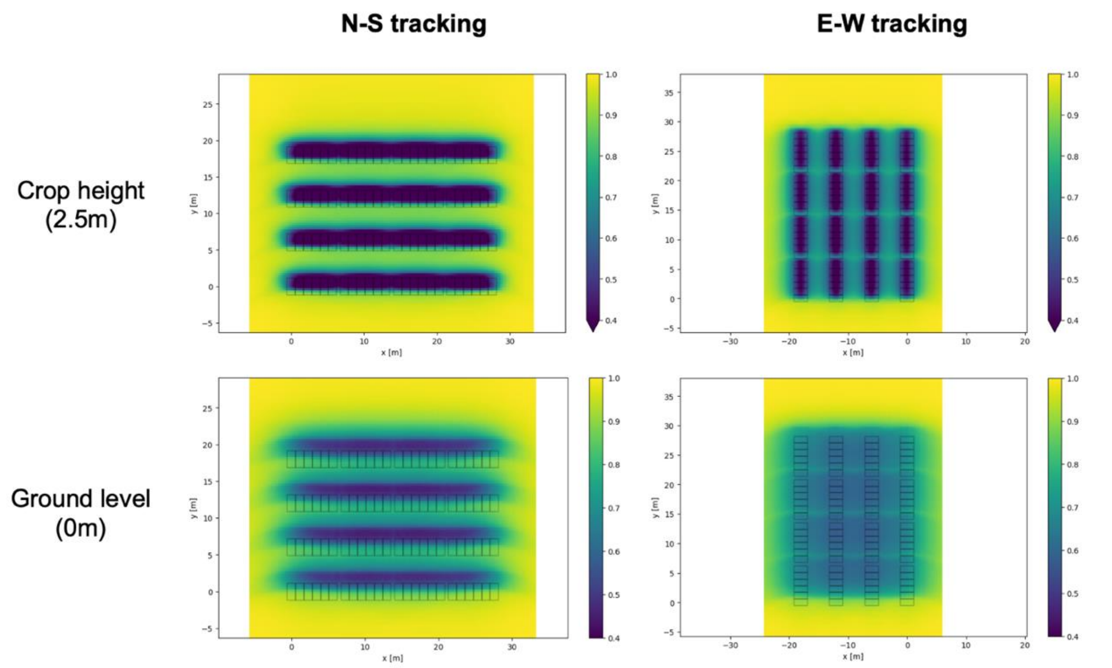

Figure 3. *Irradiance patterns under N-S and E-W trackers at crop (2.5m) and ground level (0m)*

Our modelling framework allows us to compute irradiance reduction maps under the panels. The above maps show the irradiance patterns when applying a backtracking algorithm (that maximises electricity production) throughout the growing season (March-October). E-W tracking results in a uniform reduction of irradiance under the panels, while N-S tracking creates distinctive shading bands. Bands are more pronounced when the panels are closer to the canopy. Uniform patterns could be suitable for continuous crops like cereals to avoid maturity disparities. For orchards, N-S tracking patterns could be leveraged to maximise light interception at the canopy level.

Here, we present different strategies to capitalise on these heterogeneous patterns: a design strategy involving panel shifting, and two tracking algorithms, an agronomic monthly tracking algorithm and a “no shade” tracking algorithm.

3.2 Shifting the panels

With irradiance mapping throughout the growing season, it is possible to optimise the positioning of panels relative to the trees. With the chosen design parameters, the optimal position to maximize light received by the canopies is to shift the panels 2.2 meters north of the crop rows. In practice, because PV poles are positioned within tree rows to facilitate agricultural work, shifting the panels out of the crop rows is feasible only if structural components that can support the panels, such as cables or stays, link the poles together. This linkage is common in elevated structures for mechanical reasons (wind resistance).

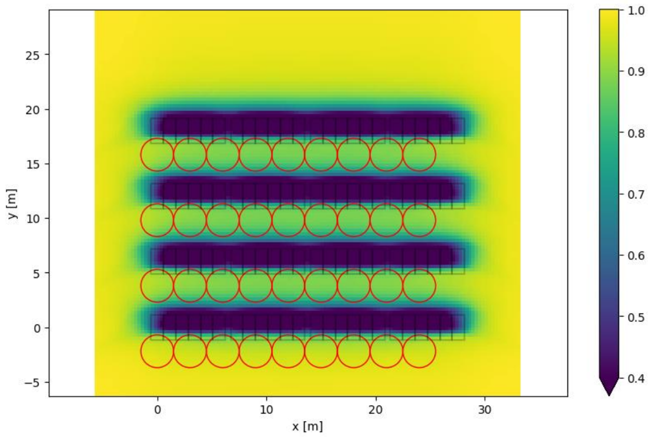

Figure 4. *Optimal positioning of the panels with crops represented as red circles*

3.3 Agronomic tracking

Setting the optimal panel position is an efficient strategy that can also be applied to fixed arrays. However, by analysing irradiance maps on a monthly time scale (Figure 5), we demonstrate that during winter months, the shadowing bands are larger and overlap with the canopies due to the sun's lower zenith and elevation angles. In contrast, closer to the summer solstice, the shadowing bands are narrower, and their positions remain relatively stable from April to August. In addition to the panel positioning, we propose two different tracking algorithms designed to maximize light reaching the canopy.

3.3.1 Monthly anti-tracking

To maximize sunlight reaching the plants and avoid shading during key phenological stages, we propose the following binary tracking algorithm:

Table 3. *Monthly tracking algorithm*

Months	Tracking algorithm
January, November, December	Sun tracking (unless leaves are still present)
March, September, October	Anti-tracking
April, May, June, July, August	Sun tracking

During winter months, as deciduous trees lose their leaves, shading does not impact photosynthesis, allowing for the use of a regular tracking algorithm. However, in March, September, and October, when apricot trees still have leaves, an anti-tracking algorithm is applied to avoid shadowing the canopies. This strategy must be tailored to specific crops and locations, utilizing detailed irradiance maps and agronomic knowledge of shading impacts during different phenological phases.

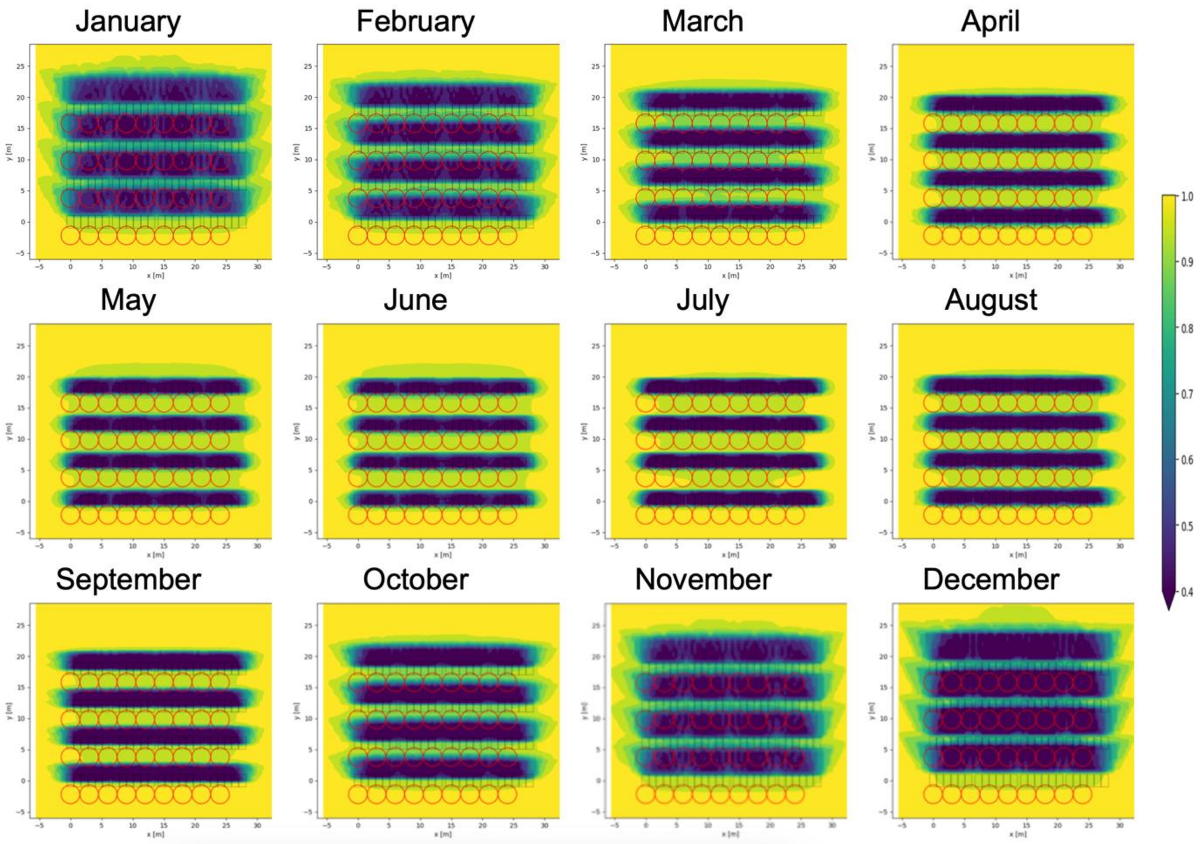

Figure 5. *Monthly irradiance maps with a Sun Tracking algorithm*

3.3.2 “No shade” tracking algorithm

With a binary monthly tracking algorithm (tracking and anti-tracking), there are moments where:

- The panels will shade the plants during the tracking months. This will especially occur at sunrise and sunset when the sun elevation is low, and the projected shadow is large.
- The panels could produce more energy without shading the plants during the anti-tracking months. These situations arise if the center of the shading bands falls between the canopies and an anti-tracking algorithm is applied.

To take advantage of the 90° continuous tilt range between tracking and anti-tracking, we propose a “no shade” tracking algorithm that:

- Applies anti-tracking if the shadow centre falls on the crop disks (Figure 8)
- Find the closest tilt to sun tracking that does not shade the disks if the shadow centre does not fall on the crop disks (Figure 6 and Figure 7)

This approach maximizes energy production while ensuring the plants are not shaded.

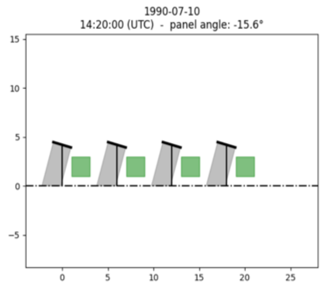

Figure 6. *Tracking*

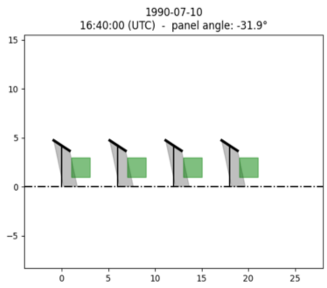

Figure 7. *Partial tracking*

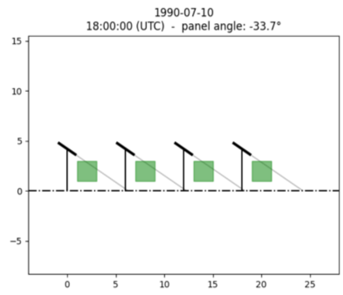

Figure 8. *Anti-tracking*

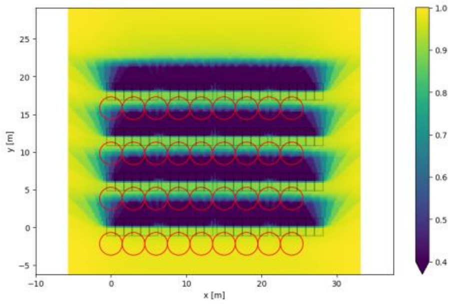

Figure 9. *October pattern with tracking algorithm*

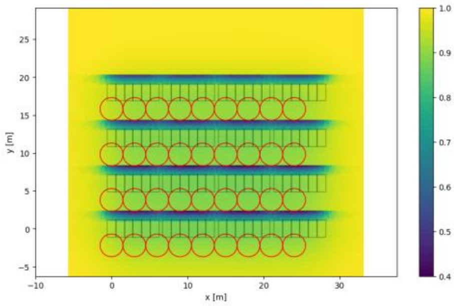

Figure 10. *October pattern with "no shade" algorithm*

3.4 Comparing strategies

The strategies have different results in terms of irradiance reduction on canopies and on electrical production. The reference scenario is the E-W sun-tracking where crops are positioned in between panel rows for minimal shading. Then, in all south oriented scenarios, crops are positioned in the optimal 2.2m position relative to the panel and only the technology and tracking algorithm varies

Table 4. *PV yield and irradiance reduction table*

PV Azimuth	Technology	Tracking algorithm	PV Yield (kWh/kWp/year)	PV Yield (%)	Irradiance Loss (disk centre)	Irradiance Loss (disk edge)
90° (E-W)	Tracker	Backtracking	1992	100%	32%	30%
180° (South 30°)	Fixed Array	-	1786	90%	11%	25%
180° (N-S)	Tracker	Backtracking	1874	94%	12%	26%
180° (N-S)	Tracker	Monthly track / anti-track	1307	66%	8%	15%
180° (N-S)	Tracker	“No Shade”	1619	81%	8%	9%

While E-W tracking is optimal for energy production, it significantly reduces irradiance on crop canopies, which we believe can greatly impact crop yield and phenological development. In contrast, the 'no shade' algorithm reduces energy production by 19% but minimises shading on the crops. In this last scenario, there is still some irradiance reduction (8%-9%) caused by the reduced diffuse irradiance available under the panels (view factor)

3.5 Water savings

A potential agronomic benefit of south-oriented arrays, which primarily shade the space between tree rows, is the reduction of soil evaporation. This can help limit water stress and reduce irrigation needs. With the 'no shade' algorithm, reduced irradiance causes the reference evapotranspiration (ET0) to drop by up to 38.6% in the shading bands during the growing season.

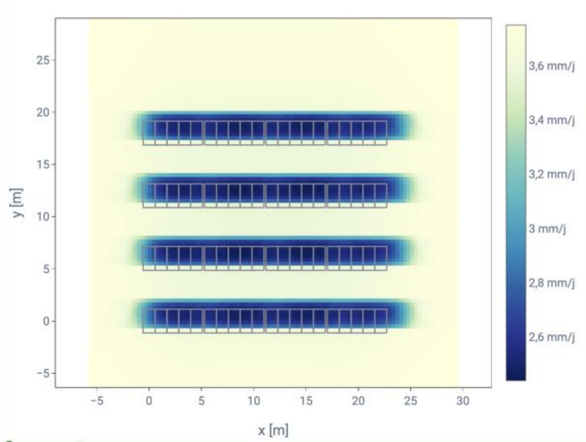

Figure 11. *Referenced evapotranspiration for the "no shade" algorithm*

4. Discussion

4.1 Economic Considerations

The main limitation for the widespread adoption of south-oriented overhead trackers is likely their economic feasibility. The additional structural costs for elevated structures are high, leading to limited adoption of such designs outside of high-value crops. While lowering the panel height could be an option if the crop positions allow it, this approach may cause shading on the PV arrays, thereby reducing electrical production [6]. Additionally, the increased use of motors for agronomic tracking can result in higher maintenance costs. Lower electricity production due to agronomic tracking further impacts the economic viability of these projects. Well-positioned south-oriented fixed arrays might offer a good compromise between reduced costs and minimal irradiance reduction on canopies. However, more studies are needed to assess the impact of light reduction during key phenological phases.

To determine which crops are best suited for this solution, two primary limitations must be considered. First, crop rows must be oriented from east to west to fully utilize the distinct shading bands created by south-oriented structures. Second, significant row spacing is necessary to maximize inter-row shading, which explains the focus on trees in this study. However, crops with large spacing, such as berries or cucurbits, could also be considered. Olive trees are a promising candidate in Mediterranean areas due to their large spacing and substantial surface area, which could allow for economies of scale. Nevertheless, further research is needed to evaluate the impact of shading during the winter dormancy period, as they are evergreen species. Additionally, water savings need to be considered for a comprehensive economic analysis.

4.2 Modelling limits

In this study, the irradiance model did not consider the supporting structures, such as poles, which can cause significant additional shading on the plants. Additionally, our disk model oversimplifies crops by only considering absorbed light on a horizontal plane. Although incorporating 3D models would increase complexity, they could more accurately evaluate the impact of these simplifications on certain crops. Further work is ongoing with Functional–Structural Plant Models (FSPMs) [7]. These models often use ray-tracing numerical simulations to assess light interception on complex shapes. Moreover, other micro-climate impacts of PV arrays, such as effects on wind and temperature, should also be considered.

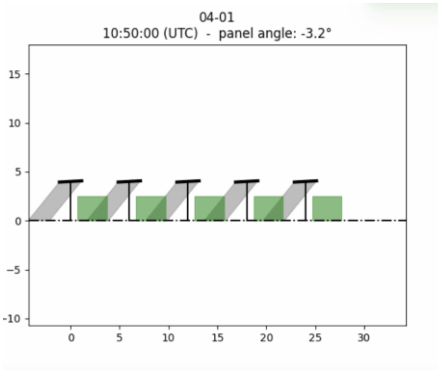

Figure 12. *Side shading is neglected in this study*

This study only considered the loss of irradiance at different points on the canopies to estimate the potential impact on plants. Estimating the impact on crop production, both in terms of quantity and quality, requires further studies and experiments. Ongoing work includes utilizing the STICS crop model to evaluate shading impacts on crop yields for certain species [8] and compute Land Equivalent Ratios (LER) to further compare different design and tracking strategies.

Position and intensity of the shading significantly varies with the considered location and design parameters. A parametric study is necessary to evaluate the sensitivity of parameters on the findings.

5. Conclusion

This study demonstrates the potential benefits of North-South (N-S) oriented PV trackers for AgriPV systems, particularly for sun-loving tree crops. Our analysis shows that N-S arrays, coupled with a smart tracking algorithm, can effectively balance the dual goals of maximizing electrical output and minimising crop shading.

While East-West (E-W) trackers provide uniform shading, suitable for continuous crops like cereals, they are less effective for discontinuous crops such as orchards, where excessive shading can reduce productivity. N-S arrays create distinct shading patterns that can be leveraged to optimise both sunlight availability for crops and energy production. By adjusting plant positions, implementing anti-tracking algorithms, or using a "no shade" strategy, N-S trackers can offer a tailored solution for sun-loving trees.

Further research is needed to refine these models and validate findings in real-world settings. Future studies should consider structural impacts, cost implications, and more advanced crop models to fully understand shading effects on plant growth and yield.

Data availability statement

The data on which this study is based is available upon request.

Author contributions

Jean-Baptiste Pasquier: Conceptualisation, Methodology, Software, Writing - Original Draft

Jules Chéron: Conceptualisation, Methodology, Software

Farida Amichi: Conceptualisation

Competing interests

The authors declare that they have no competing interests.

References

[1] G. Lopez, J. Chopard, S. Persello, P. Juillion, V. Lesniak, G. Vercambre, ... & D. Fumey, "Agrivoltaic systems: an innovative technique to protect fruit trees from climate change," in XXXI International Horticultural Congress (IHC2022): International Symposium on Innovative Perennial Crops Management 1366, Aug. 2022, pp. 173–186, doi: 10.17660/ActaHortic.2023.1366.20.
[2] B. Valle *et al.*, "Increasing the total productivity of a land by combining mobile photovoltaic panels and food crops," *Appl Energy*, 2017, doi: 10.1016/j.apenergy.2017.09.113.
[3] V. Quaschning and R. Hanitsch, "Irradiance calculation on shaded surfaces," *Solar Energy*, vol. 62, no. 5, pp. 369–375, May 1998, doi: 10.1016/S0038-092X(98)00018-8.
[4] M. A. Mikofski, R. Darawali, M. Hamer, A. Neubert, and J. Newmiller, "Bifacial Performance Modeling in Large Arrays," *Conference Record of the IEEE Photovoltaic Specialists Conference*, pp. 1282–1287, Jun. 2019, doi: 10.1109/PVSC40753.2019.8980572.
[5] W. F. Holmgren, C. W. Hansen, and M. A. Mikofski, "pvlib python: a python package for modeling solar energy systems," *J Open Source Softw*, vol. 3, no. 29, p. 884, Sep. 2018, doi: 10.21105/JOSS.00884.
[6] F. J. Casares de la Torre, M. Varo-Martinez, R. López-Luque, J. Ramírez-Faz, and L. M. Fernández-Ahumada, "Design and analysis of a tracking / backtracking strategy for PV plants with horizontal trackers after their conversion to agrivoltaic plants," *Renew Energy*, vol. 187, pp. 537–550, 2022, doi: 10.1016/j.renene.2022.01.081.
[7] E. Daoud, J. Cheron, J.-B. Pasquier, "Integrating functional–structural plant models for accurate simulation of shade heterogeneity effects on intercepted light and leaf temperature," in Poster presented at Agrivoltaics 2024, Denver, USA, 2024.
[8] E. Perez, B. Tiffon-Terrade, P. Souquet, J.-B. Pasquier, "Agrivoltaics design assessment through dual modelling of electricity production and agronomic outputs," in Poster presented at Agrivoltaics 2024, Denver, USA, 2024.