Comparing PAR Calculation Methods for Tracker and Vertical Agrivoltaic Arrays

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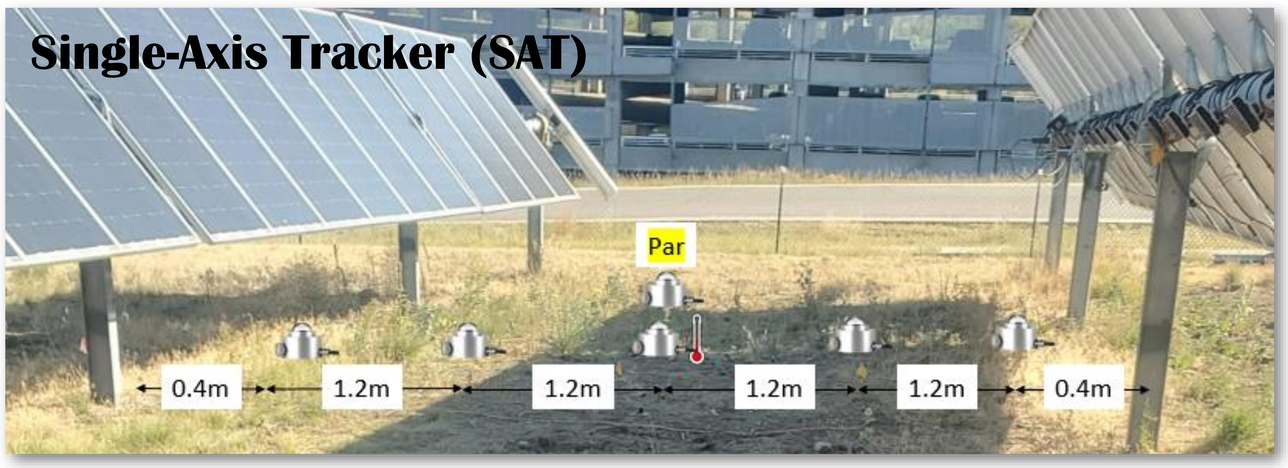
INTRODUCTION

Availability of sunlight is crucial for plant growth. Light and shade distribution vary by geographic location and panel configuration in PV Arrays. Thus, characterizing the spatial distribution of irradiance and photosynthetically active radiation (PAR) at ground level important for determining crop geometry in an agrivoltaic system is crucial. Furthermore, PAR calculation using irradiance is reliable in an open-sky condition, but it is unclear whether the same can be done in the partial shade in an agrivoltaic setting.

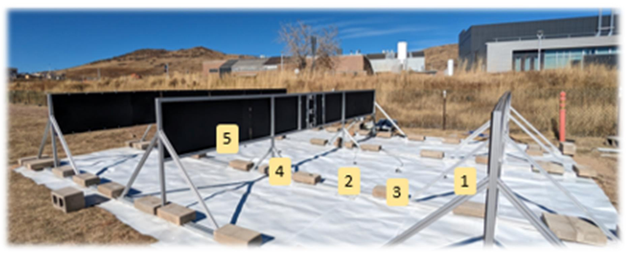
This project evaluates the accuracy of NREL's open-source raytracer *bifacial_irradiance* for ground irradiance modeling, and characterize the relationship between modeled irradiance and PAR in an agrivoltaic setting

Ground-Irradiance in PV Arrays Data

Golden, CO



75kW tracking array with common utility-scale configuration: 1.5 m hub-height, pitch of 5.7m. Site has had sections of crops, pollinator habitat and pasture since 2022, as well as seasonal for comparison.



Vertical Test-bed

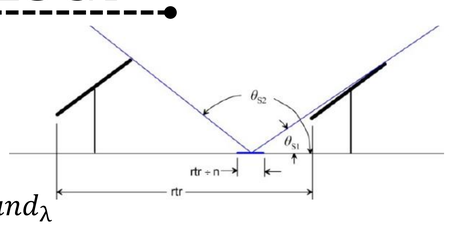
Testbed representing a 2/3rd scaled-dwn PV array of 5 modules in 1-up landscape at a clearance height of 1m and pitch of 5 m.

Vertical and ground irradiance dataset available at
https://data.nrel.gov/submissions/254

METHODOLOGY

$$PAR = \int_{400}^{700} GHI_{\lambda}$$

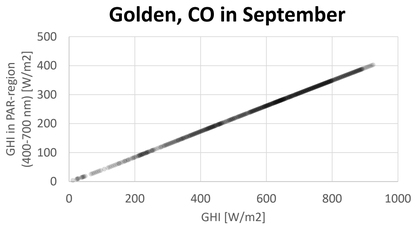
$$PAR_{PV} = \int_{400}^{700} Gground_{\lambda}$$



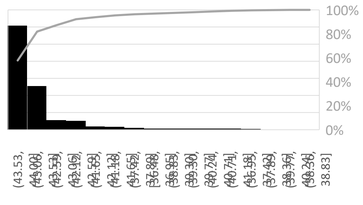
***P*hotosyntetically *A*ctive *R*adiation** (PAR) *is the solar radiation between* 400 *to* 700*nm. PAR represents* 43% *of the standard AM* 1.5 *spectrum.*
Irradiance in the ground is composed from both direct and diffuse light, but in PV arrays the quantities of each changes depending on the position in the ground and the time of day based on the sun and the trackers movements.

➢ **SMARTS can model clear-sky spectral irradiances**

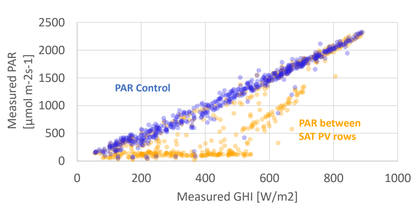
Modeled PAR for ideal GHI in Golden, CO in September



PAR represents 43% of GHI for ideal clear-sky conditions,



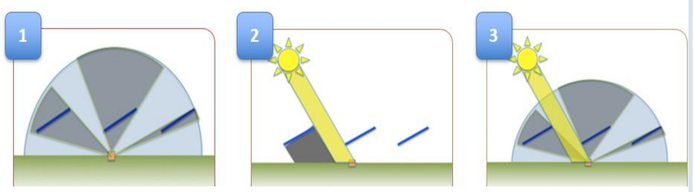
Field measured PAR's relationship to GHI is not as linear. But inside the array, it varies even more



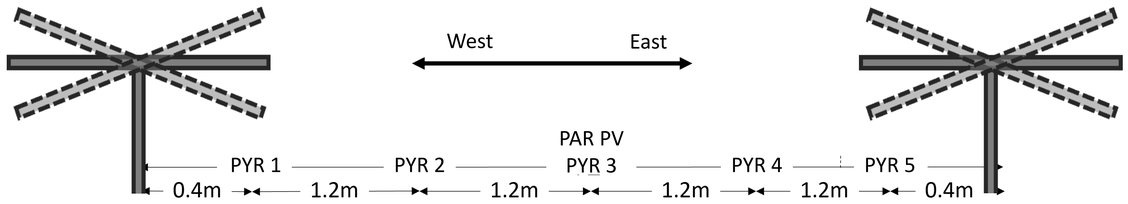
➢ **Optical models can help calculate irradiance in the ground between arrays**

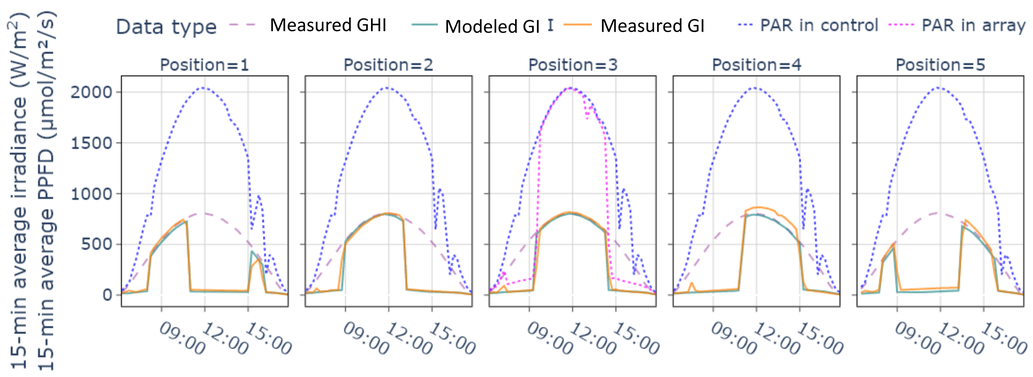
$$Gground_{\lambda,t} = \alpha\ cos\theta\ x\ G_{DNI_{\lambda},t} + \beta\ G_{DHI_{\lambda,t}}$$

Where α *is* 0 *or* 1 *depending if hte ground section is shaded or not, and* β is the amount of sky not obstructed by the PV panels at each timestep.



RESULTS

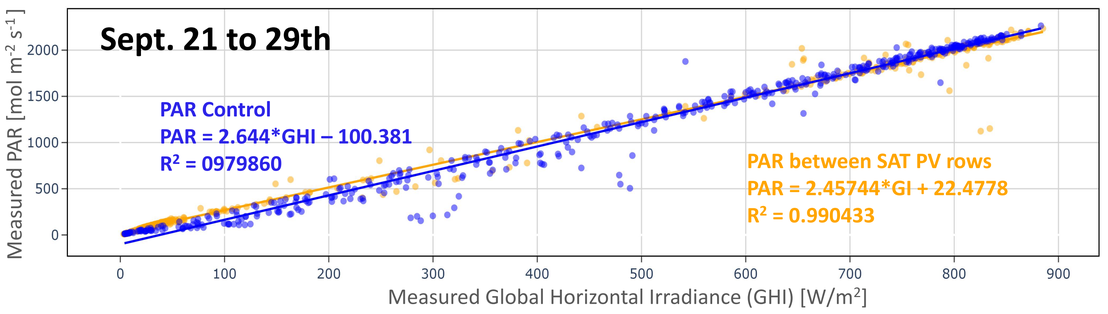




GHI and Ground Irradiance (GI) measurements for September 26, a clear-sky day. The pyranometer (PYR) in Position 3 experiences no shading at midday, with corresponding PAR values showing good agreement. Ground Irradiance at the different sensors exhibits variations due to tracker shadows, which shift throughout the day. Modeled versus measured GI also has good agreement, except for sensor 4, where a correction factor was applied to address a systematic error observed.

	SENSOR				
Position	**1**	**2**	**3**	**4**	**5**
MBD [%]	4.4	3.4	1.8	4.1	15.1
MBDAbs	8.3	9.7	6.3	11.4	25.9
RMSE [%]	20.4	17.4	15.9	12.6	31.2
RMSE Abs	38.6	48.8	55.5	34.7	53.6

The table shows Mean Bias Deviation (MBD) for September 26. MBD is higher for sensors in shaded areas, while crop-bed sensors align well with expected simulation uncertainties and fall within sensor accuracy limits.



The relationship between measured PAR and GI in the PV array differs from PAR and GHI in the control area but follows a linear regression. For this sensor position, the similarity is sufficient that uncertainties in irradiance models overshadow potential improvements from more complex crop model calculations, but more data is needed to determine for positions that experience more shadowing during peak hours of the day.

Conclusions and Next Steps

- Irradiance modeling offers a practical alternative to direct measurements suitable for agrivoltaics modeling
- Initial results show minimal difference between irradiance and PAR in the center of the array under clear-sky conditions. However, this may not apply to more shaded crop-beds. Since crop models typically use daily averages, the impact of this deviation may be minimal, but further data and modeling are needed to fully assess its significance.
- Future efforts will focus on refining simplified models using SMARTS and ground irradiance data, incorporating shade analysis and alternative methods for calculating spectral characteristics and sky view factors. These improvements aim to reduce uncertainties and enhance the reliability of models for predicting crop performance in agrivoltaic systems.

ACKNOWLEDGEMENTS

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