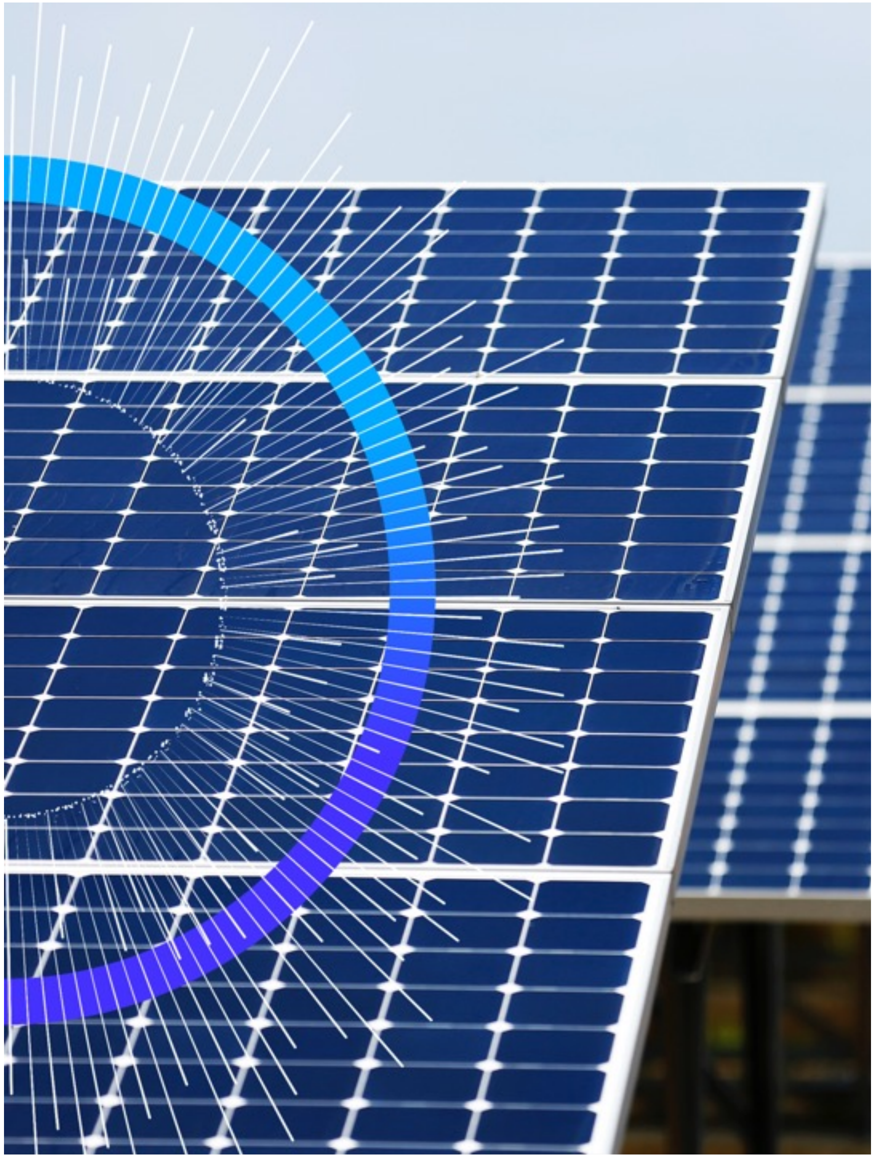


PVPMC 2023 Workshop
Salt Lake City, Utah, USA

TotalEnergies

SolarOPS: A versatile PV system simulation software

Antonios Florakis[1,2], Fadi Bourarach[1], Erwann Houzay[1], Nils-Peter Harder[1], Issam Smaine[1], Arthur Poquet[1], Alexandre Buzy-Debat[1,3], Soufiane Ait-Tilat[1,3], Julien Chapon[1], Pierre Biver[1], Tatiana Chugonova[1], Arttu Tuomiranta[1] and Gilles Poulain[1]

[1]TotalEnergies OneTech, Solar R&D
[2]Advanced Solar Energy Technologies Consulting BV
[3] Capgemini Consulting

Disclaimer and Copyright Reservation

Definition – TotalEnergies / Company

The entities in which TotalEnergies SE directly or indirectly holds an interest are separate and independent legal entities. The terms "TotalEnergies", "TotalEnergies company" and "Company" used in this document are used to refer to TotalEnergies SE and its affiliates included in the scope of consolidation. Similarly, the terms "we", "us", "our" may also be used to refer to these entities or their employees.
It cannot be inferred from the use of these expressions that TotalEnergies SE or any of its affiliates is involved in the business or management of any other company of the TotalEnergies company.

Copyright

All rights are reserved and all material in this presentation may not be reproduced without the express written permission of TotalEnergies.

Disclaimer

This presentation may include forward-looking statement within the meaning of the Private Securities Litigation Reform Act of 1995 with respect to the financial condition, results of operations, business, strategy and plans of TotalEnergies that are subject to risk factors and uncertainties caused by changes in, without limitation, technological development and innovation, supply sources, legal framework, market conditions, political or economic events.

TotalEnergies does not assume any obligation to update publicly any forward-looking statement, whether as a result of new information, future events or otherwise. Further information on factors which could affect the company's financial results is provided in documents filed by TotalEnergies with the French Autorité des Marchés Financiers and the US Securities and Exchange Commission.

Accordingly, no reliance may be placed on the accuracy or correctness of any such statements.

TotalEnergies and Renewables

TotalEnergies' gradual transition to Low-Carbon Energy generation (solar and wind) →
35 GW in 2025 and 100 GW in 2030 →
Ambition to be among the world's top five producers of renewable electricity

GROSS INSTALLED CAPACITY FOR RENEWABLES AT END-2022

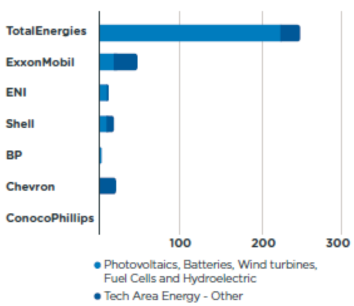
In MW

	Wind turbines	Photovoltaic	Other³	TOTAL
Europe	1,936	991	134	3,061
Oceania	20	325	8	354
Americas	2,426	3,307	62	5,796
Asia	492	6,871	0	7,363
Africa	0	239	15	254
Total	4,875	11,734	219	16,829

Strong focus on renewables R&D:

TOP INNOVATORS

Number of patent families published[1] 2019 - 2022



1. Source : Top innovator according to Cipher – https://cipher.ai/insights/energy-transition-oil-and-gas/.

Power R&D

4 Programs covering the entire electricity value chain

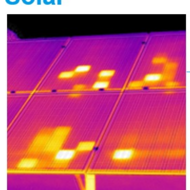
Wind

Develop leading solution for floating offshore wind Whilst ensuring acceptability of all our development

Hybrid & Storage

Combine renewable energies and storage to fast track the decarbonization of TotalEnergies' assets

Solar

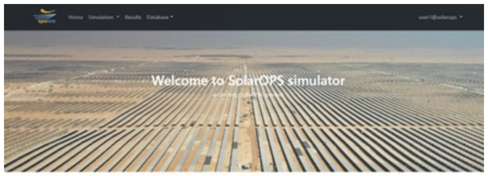


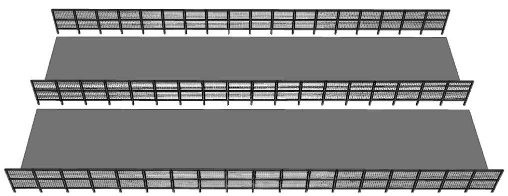
Develop solutions to accelerate solar energy deployment, improve assets efficiency

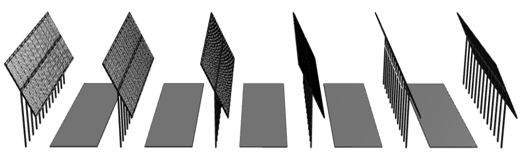
Distributed Energy Resources (DER)

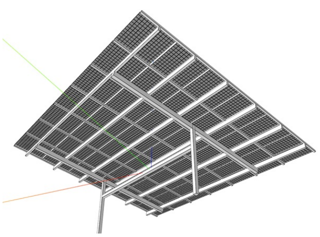
Increase TotalEnergies capacity to aggregate, optimize and evaluate multiple DER streams in multiple markets to create value and decarbonize

SolarOPS at a Glance









An internally developed PV performance simulation tool that is used complementarily with PVsyst to:

- Address complex scenarios where PVsyst has limitations
- Offer increased predictive accuracy & component optimization
- Interconnect with other internally developed frameworks for large-scale optimization

Background and key technical specifications

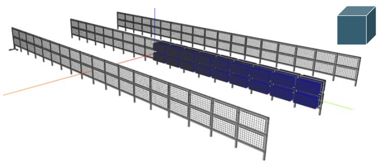
- Python-based
- Making use of radically redesigned libraries from the PVPMC community and Radiance [1-4]
- Accessible via a dedicated webapp (internal access only)
- Deployed on Azure Cloud and - in some cases - on TotalEnergies' HPC infrastructure
- **Flexibility:** users can opt either for the rigorous Ray Tracing (RT) or the fast PVsyst-like View Factor (VF) optical models
- **Development on demand:** tailored development based on requests from internal stakeholders
- **Confidence:** Continuous validation using meteo & performance data from TotalEnergies' pilot sites

Intended use and indicative use cases

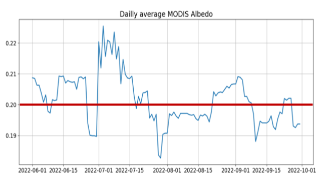
- Only for internal usage within TotalEnergies' Solar R&D and selected internal stakeholders
  - Support TotalEnergies' Solar R&D activities (including PhD students)
  - Conduct studies on demand for specific technical problems
- Multiple use cases, including (Agrivoltaics, High-albedo materials; design optimization, carports…)

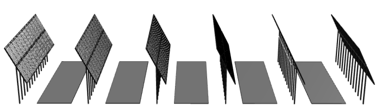
[1] W. F. Holmgren et al.,. "pvlib python: a python package for modeling solar energy systems," *Journal of Open Source Software*, 3(29), P. 884, (2018).
[2] B. Marion, et al, "A Practical Irradiance Model for Bifacial PV Modules," *44th IEEE PVSC* , pp. 1537-1542, (2017).
[3] S. A. Pelaez, and C. Deline, "bifacial_radiance: a python package for modeling bifacial solar photovoltaic systems," *Journal of Open Source Software*, 5(50), p. 1865, (2020)
[4] G. W. Larson, and R. A. Shakespeare, "Rendering with Radiance: The Art and Science of Lighting Visualization", San Francisco:(1998)

SolarOPS Key Features

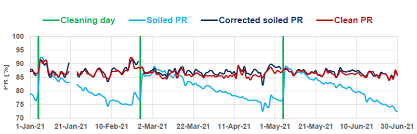


3 modes of operation:
View Factor (VF)
RT – Linescan
RT – Gridscan @ cell level

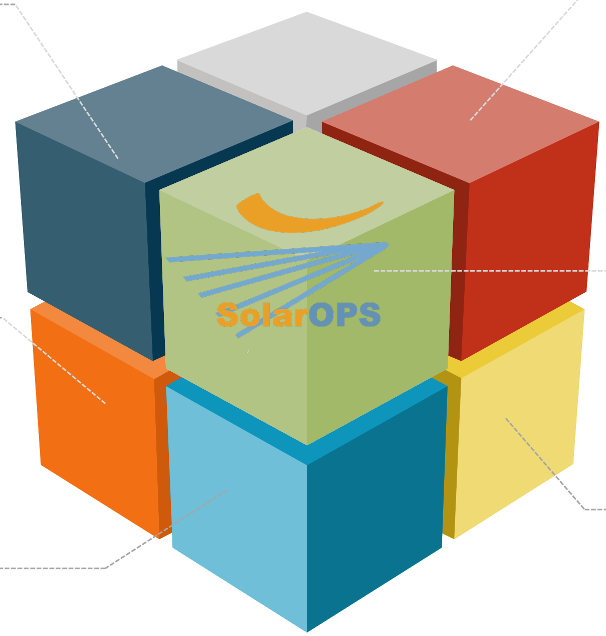




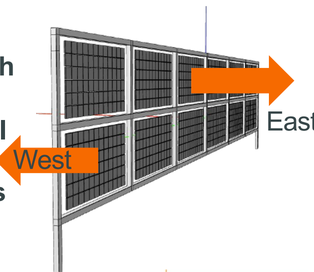
Albedo inclusion via time series (MODIS)
Spatially resolved albedo for VF & RT



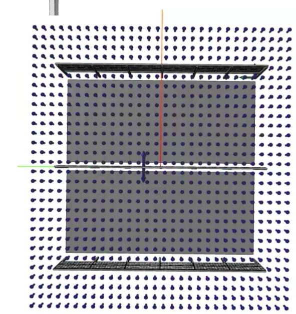
Soiling definition:
Time series
Cleaning schedule



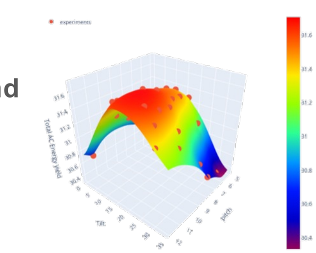
Bi-Directional high bifaciality – particularly useful for Vertically Mounted modules



Ground irradiance distribution mapping for AgriPV applications

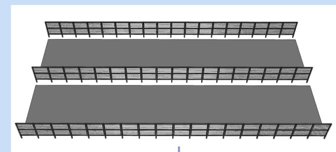
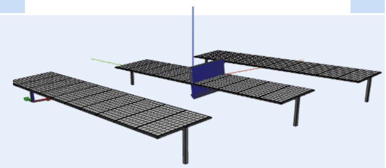
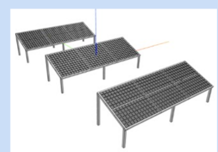


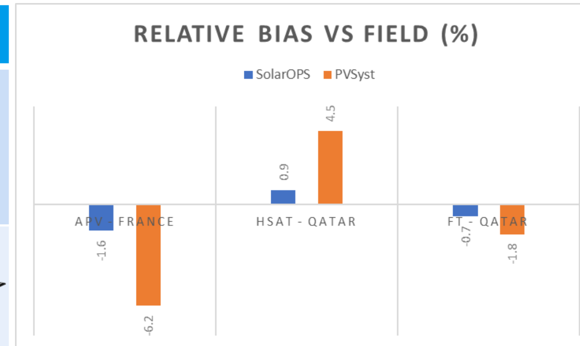
Automation of design optimization and uncertainty propagation

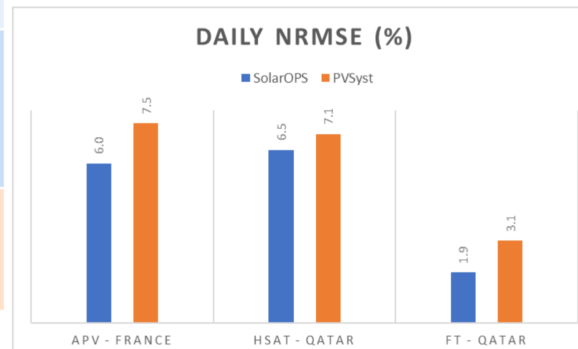


Validation

Continuous validation vs field data from **TotalEnergies' pilot sites**

	Location	Specification	Period	Site	SolarOPS structure
	Valpuiseaux, France	APV, Vertical, Bifacial,Next2Sun (7.0kWp)	3 Months in 2023		
RT	QEERI, Qatar	HSAT, Bifacial (4.1kWp)	3 Months in 2023		
	QEERI, Qatar	FT, Bifacial (2.6kWp)	6 Months in 2022		
VF	Various locations	UPP size (10-200MWp): Mono & Bifi	SolarOPS VF for UPP yields similar results with PVsyst due to similar models; Several other comparative cases showed max delta of 1%		

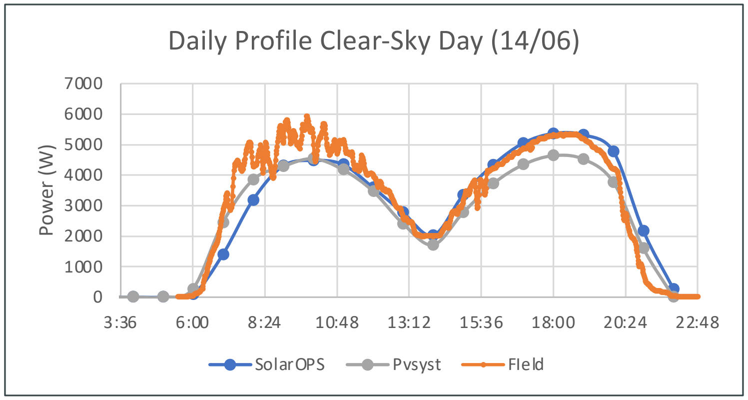




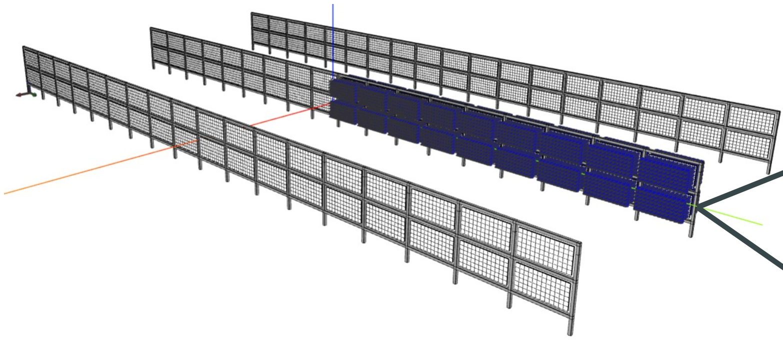
- SolarOPS RT outperforms PVsyst for small installations (edge effects, soiling and albedo as timeseries, detailed racking configuration)
- SolarOPS VF yields similar results to PVsyst
- More pronounced difference in APV/Vertical → high sensitivity from ground albedo

Use Case: PV Production in Agrivoltaic Systems

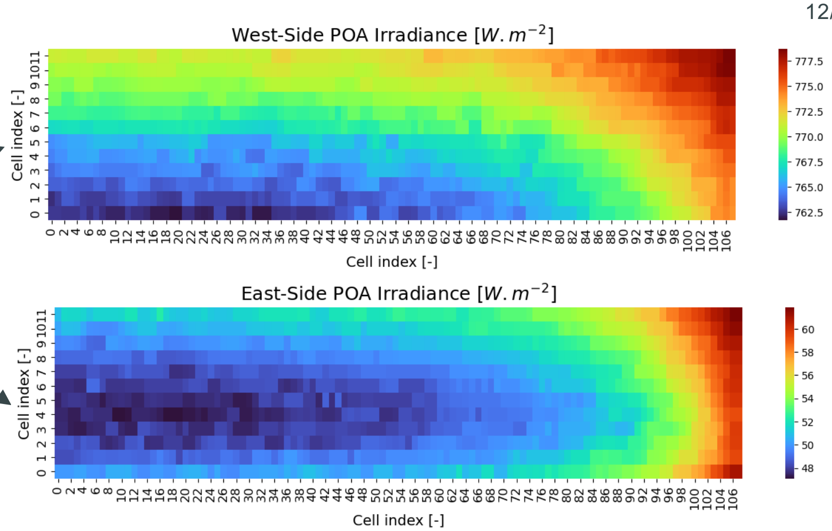
- **Motivation:** Combine PV energy generation and crop production by embedding PV systems on agricultural land
- **Use case:** Vertically mounted Next2Sun [1] systems installed within the crops. Highly sensitive to crop reflectivity → varies significantly throughout the crop growth cycle
- **Methodology:** Use ray tracing to include the detailed structure; add zones of different albedo (crops and no crops); potentially use albedo as time series; two RT strategies: linescan vs gridscan [2]



Hourly DC production comparison for a clear-sky day



West (top) and East (bottom) side POA irradiance for 12/06/2022, 18h30

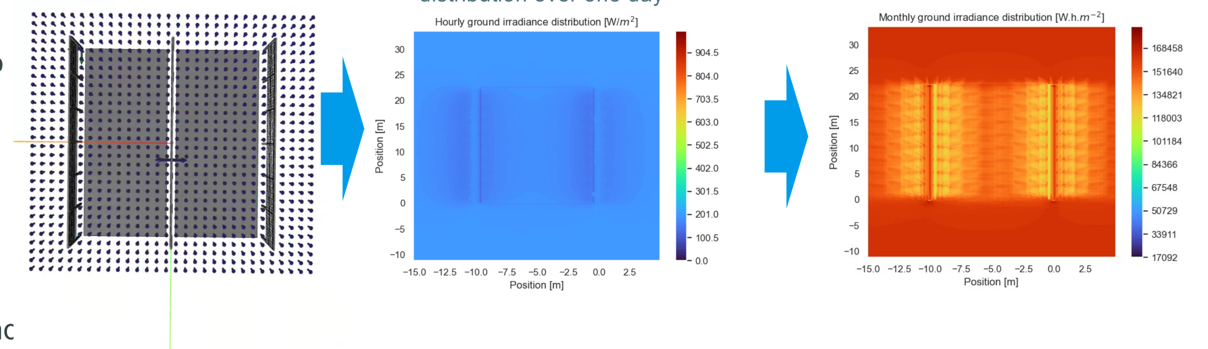


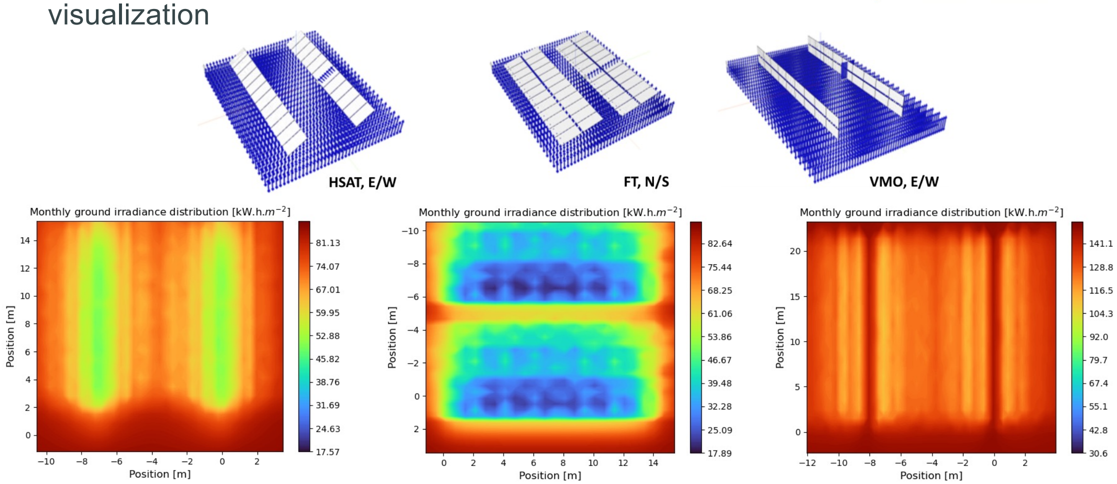
[1] https://next2sun.com/en/
[2] A. Poquet et al., "Vertical Agrivoltaic System – On-Site Measurement and Prediction of the Influence of Crops Albedo on Photovoltaic Energy Yield", oral presentation at Agrivoltaics 2023, Daegu, South Korea, on April 12-14, 2023.

Use Case: Ground Shading Distribution

- **Motivation:** PV modules affect the irradiance distribution on the ground → affect the available PAR* for plants photosynthesis
- **Use case:** Assess ground shading patterns due to different PV technologies (vertically mounted, HSAT, and FT) and different geometric configurations for different locations
- **Methodology:** Estimation of ground irradiance distribution by using Ray Tracing → Ground irradiance distribution files for each hourly time stamp → Post-processing for aggregation and visualization

Sensor placement (top view) | Hourly ground irradiance distribution over one day | Monthly ground irradiation distribution





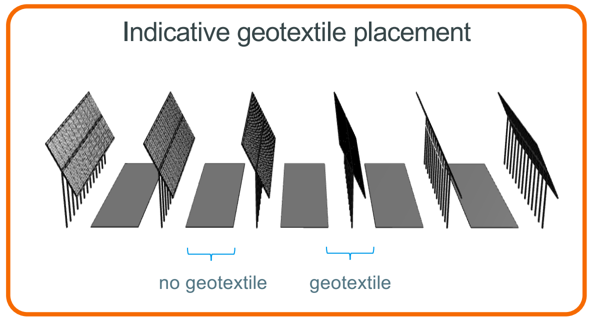
Final outcome:

- Monthly ground irradiation distribution can help farmers to optimally place the crops based on the available light for photosynthesis
- Obtain insights on the impact of different configurations on shading patterns

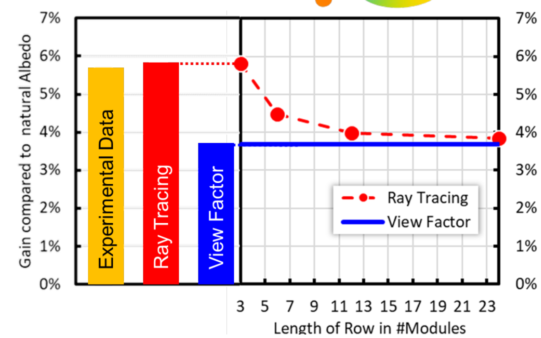
**Photosynthetically Active Radiation*

Use Case: Bifacial Gain Enhancement via Geotextiles

- **Motivation:** Enhance bifacial gain by using high-albedo geotextiles
- **Use case:** optimization of the placement and width of the geotextile under various scenarios (HSAT vs FT, geotextile type, soiling, etc.)
- **Methodology:** A new VF-based algorithm developed to include different zones of albedo → validation vs RT and field data → VF-based approach allows for much faster simulations with the same level of accuracy for UPPs

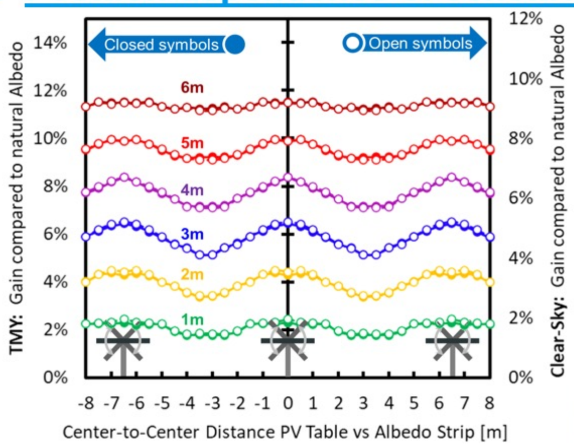


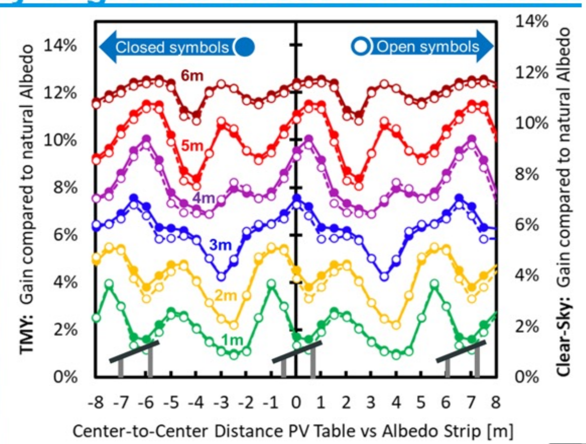
Scene visualization via SolarOPS; white areas represent areas with geotextile, grey areas with native albedo



Left: Measured and simulated energy yield gain from artificial ground albedo improvement for a FT system. Right: VF-based simulation converges with more accurate RT for long module rows typical of UPP installations

Tracking ← Position dependence of sensitivity to ground albedo enhancement → Fixed Tilt



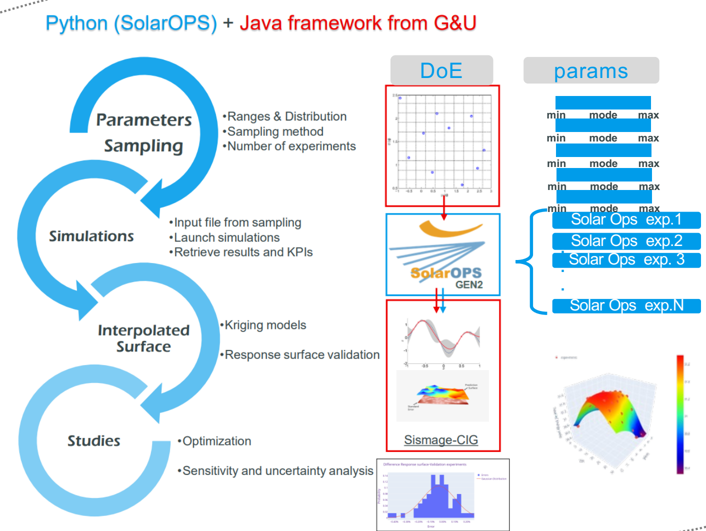


For more information refer to oral presentation "Position dependence of the performance gain by selective ground albedo enhancement for bifacial installations" in the upcoming IEEE PVSC 2023

Use Case: optimization & uncertainty propagation

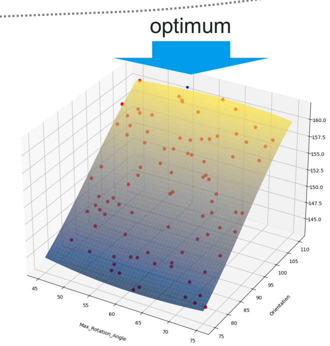
- **Motivation:**
  - Reduce the time for design optimization of a powerplant, by means of statistical approaches and automation.
  - Detailed estimation of the uncertainty based on the propagation of the uncertainties on the inputs
- **Use case**: Design optimization for different KPIs and propagation of uncertainties
- **Methodology**: Create a workflow that combines SolarOPS with an advanced statistical framework developed in oil reservoir exploration projects. Two step approach: 1. optimization 2. uncertainties propagation estimate

Workflow



Potential outputs

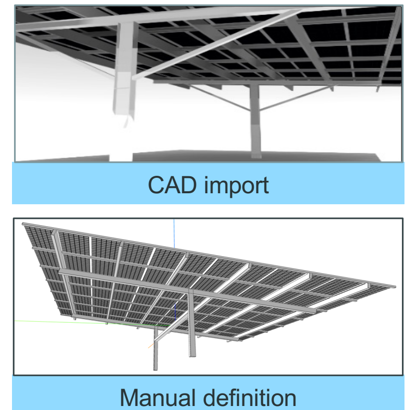
- Ranking of the optimal scenarios based on different KPIs (i.e. AC production, LCOE etc.)
- Pareto diagrams showing the impact of the individual parameters on the targeted KPI
- Probability distribution of the targeted KPI based on the uncertainty propagation framework.



Use Case: Carports and Component Optimization

- **Motivation:** Estimation of the bifacial gain for Carports equipped with Bifacial Modules
- **Use case:** Bifacial carport in Vichy, France; Seasonality and cars create a temporally and spatially inhomogeneous light distribution
- **Methodology:** Use RT. Two different ways to introduce the structure (programmatic and via CAD) → follow a similar approach to that of NREL [1]. Initial focus on the optical part.

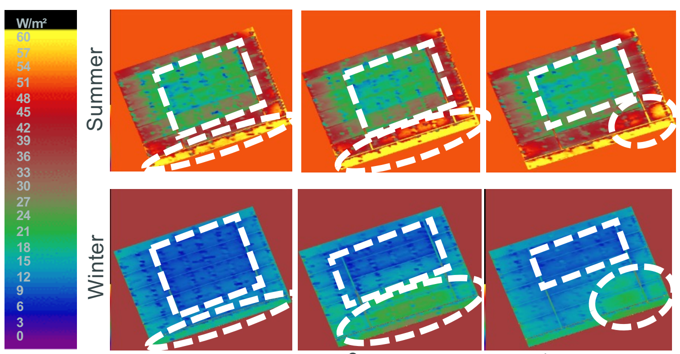
Carport in Vichy, France



Carport digital twin depiction via CAD (top) and programmatic inclusion (bottom)

Hourly snapshots of the Impact of various factors on the rear POA irradiance; Left: different number of cars and seasonality impact; right: impact of the distance between adjacent carports

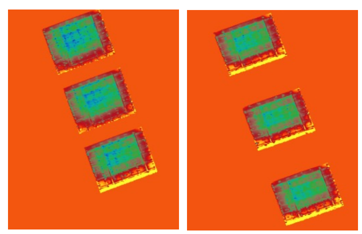
Preliminary results



No car

3 cars
50% reflectance

1 cars
50% reflectance



3 carports
15m pitch

3 carports
20m pitch

[1] https://github.com/NREL/bifacial_radiance/blob/main/docs/tutorials/5%20-%20Bifacial%20Carports%20and%20Canopies.ipynb

Outlook and perspective work

SolarOPS : PV system performance simulation software, developed internally at TotalEnergies, for the modeling of complex cases, in conjunction with PVsyst

- RT and VF optical modeling available - New features to address internal requests	Leverages TotalEnergies' pilot sites for the validation	SolarOPS RT: increased predictive accuracy vs PVsyst for small installations; SolarOPS VF: similar results with PVsyst for UPP-sized installations	Different use cases (agrivoltaics, bifacial gain enhancements via geotextiles, carports, etc.)

Perspective work:

- Increase flexibility (model uneven terrain, automated inclusion of CAD files, etc.)
- Expand the validation for more test sites for a larger variety of conditions / configurations
- Explore various strategies to minimize run-time for RT
- Targeted enhancements on the thermal-electrical part

TotalEnergies
Sustainability Report

TotalEnergies

OneTech
SOLAR
R&D PROGRAM