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Analysis and Reduction of Uncertainties in Yield Assessments of Large-Scale Bifacial PV Projects

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Agenda

1. Introduction
2. Results
3. Summary

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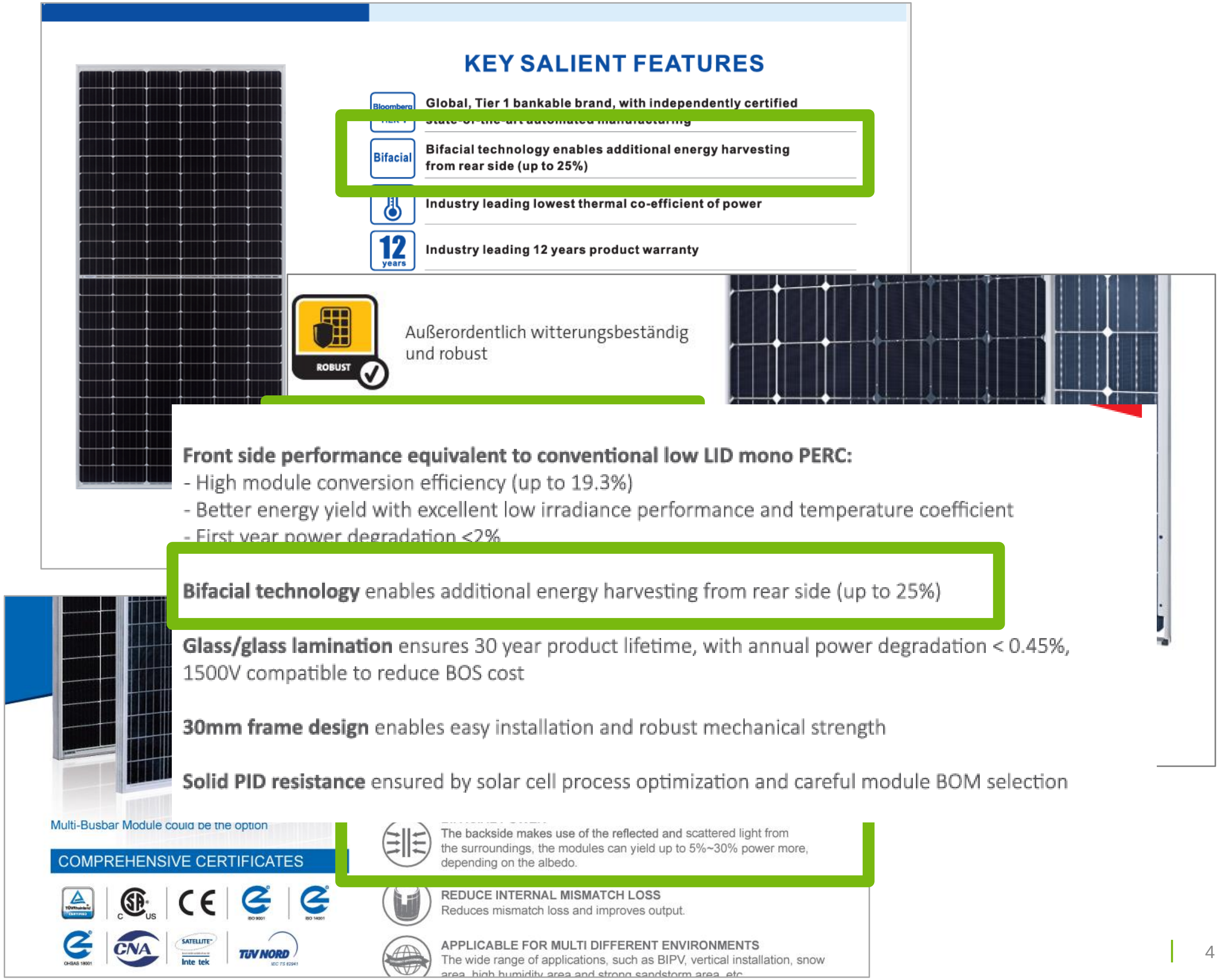
Introduction

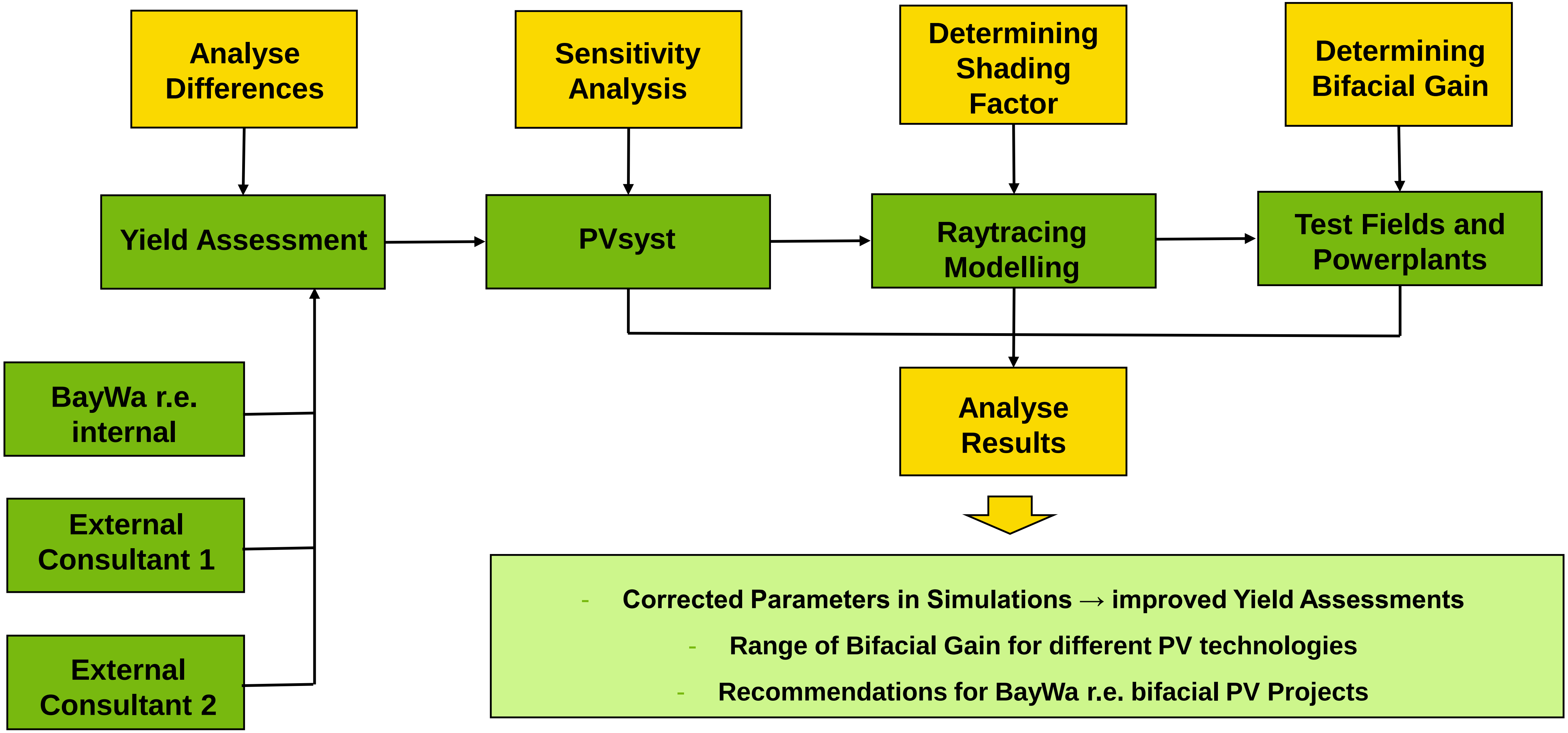
Motivation

What is the actual bifacial gain on System level in simulation and operation for large-scale projects?



Research Structure

[1] [2] [3]



[1] PVsyst Software. https://www.pvsyst.com/
[2] Ayala Pelaez and Deline, (2020). bifacial_radiance: a python package for modeling bifacial solar photovoltaic systems. Journal of Open Source Software, 5(50), 1865, https://doi.org/10.21105/joss.01865
[3] Ward Larson, G. & Shakespeare, R., 1998. Rendering with Radiance: The Art and Science of Lighting Visualization. San Francisco: Morgan Kaufmann Publishers, Inc.

Bifacial Gain [4,5]

Optical Bifacial gain BG_{opt} :

$$BG_{opt} = G_{rear}/G_{front} \; [\,]$$

With G_{rear} *: Irradiation rear side [kWh/m²]*

Module Bifacial gain BG_{mod} :

$$BG_{mod} = \varphi * BG_{opt} \; [\,]$$

$$With\ Module\ Bifaciality\ \varphi$$

System Bifacial gain BG_{sys} :

$$BG_{sys} = E_{rear}/E_{front} = (E_{bifa} - E_{mono})/E_{mono} \; [\,]$$

With E: Energy output bifacial modules and monofacial modules [kWh]

- **Consultants** do **not always** express the **bifacial gain** based on the **same definition** and do not state clearly which definition they used -> makes comparison difficult

[4] J. S. Stein, C. Reise, J. B. Castro, G. Friesen, G. Mauger, E. Urrejola, and M. Wang, “Bifacial Photovoltaic Modules and Systems: Experience and Results from International Research and Pilot Applications,” Report IEA-PVPS T13-14, 2021.

[5] D. Valencia and P. Berthelemy, *PV Modules: Bifacial technology: Global Optimization of Integrated Photovoltaic System for Low Electricity Cost*.

Methodology of Analysing field-measured Data

Comparison Method

- Comparison of the normalized energy output of monofacial and bifacial modules [6]

$$BG_{sys} = \frac{(E_{bifa}/P_{max,bifa} - E_{mono}/P_{max,mono})}{E_{mono}/P_{max,mono}} \, [\,]$$

With E: Energy output bifacial modules and monofacial modules [kWh]

Irradiance Method

- With two pyranometers, the irradiance received by the rear side and the irradiance received by the front side in the orientation of the array are measured [4]

$$BG_{opt} = G_{rear}/G_{front} \, [\,]$$

With G_{rear} : Irradiation rear side [kWh/m^2]

[4] J. S. Stein, C. Reise, J. B. Castro, G. Friesen, G. Mauger, E. Urrejola, and M. Wang, "Bifacial Photovoltaic Modules and Systems: Experience and Results from International Research and Pilot Applications," Report IEA-PVPS T13-14, 2021.

[6] Internal BayWa r.e. Document, "Quantifying the Field-Measure Bifacial Gain"

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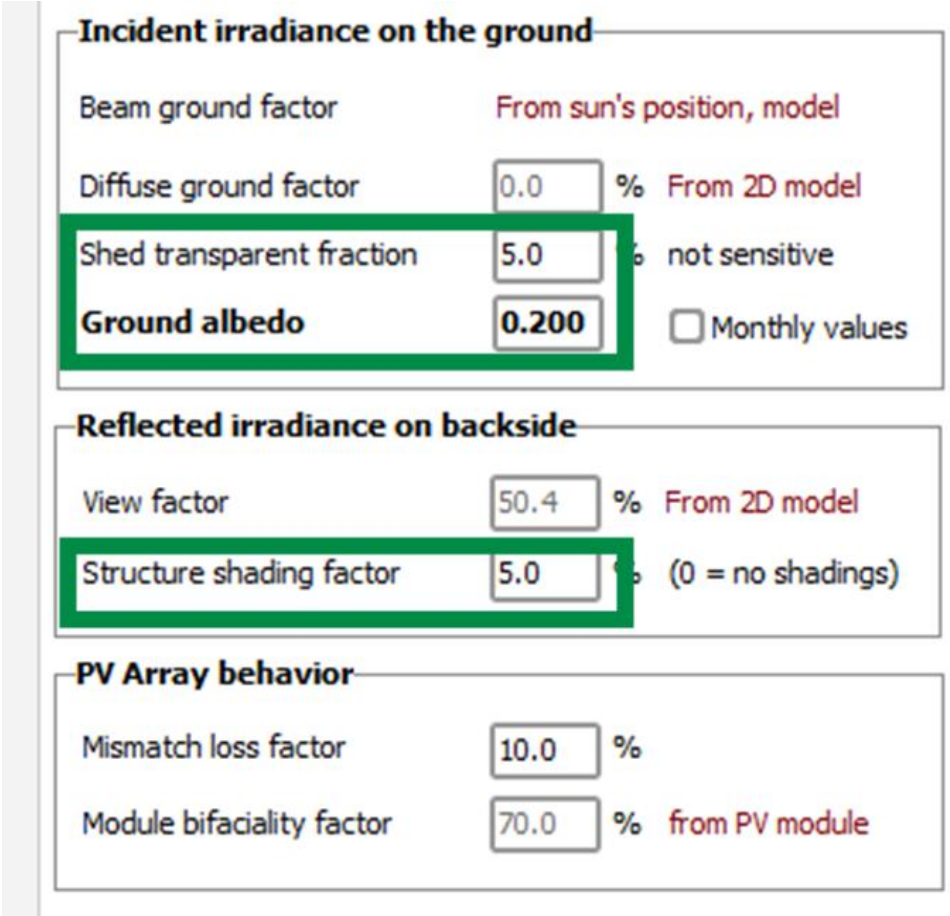
Results

Yield Assessment Analysis

Parameters to determine bifacial gain



Parameter	External Consultant 1	External Consultant 2	BayWa r.e.
Albedo	20%	20%	15% - 25%
Structure Shading Factor	20% - 25% (Fixed Tilt) 5% - 7.5% (Tracker)	5%	5% - 6%
Shed Transparent Fraction	?	2% - 8%	5%

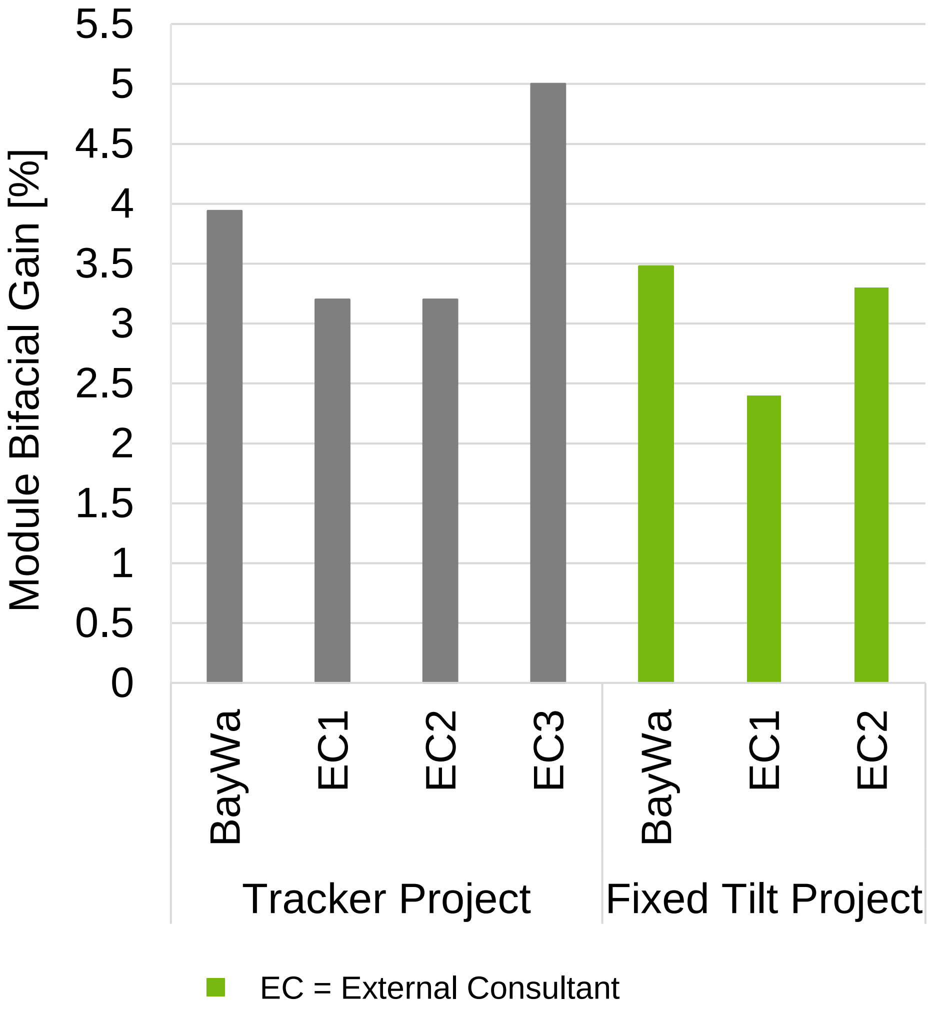
[1] PVsyst Software. https://www.pvsyst.com/

Yield Assessment Analysis

Deviations in the Assessment of bifacial gain for Tracker and Fixed Tilt projects

Tracker Module BG:

range of 2.2% - 6.0%

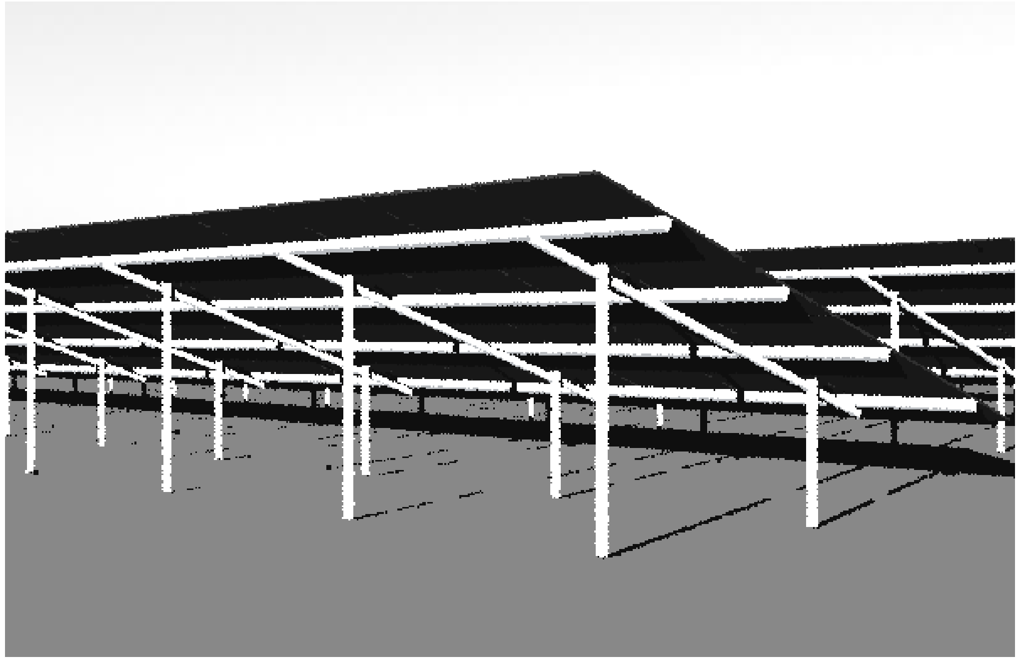


Fixed Tilt Module BG:

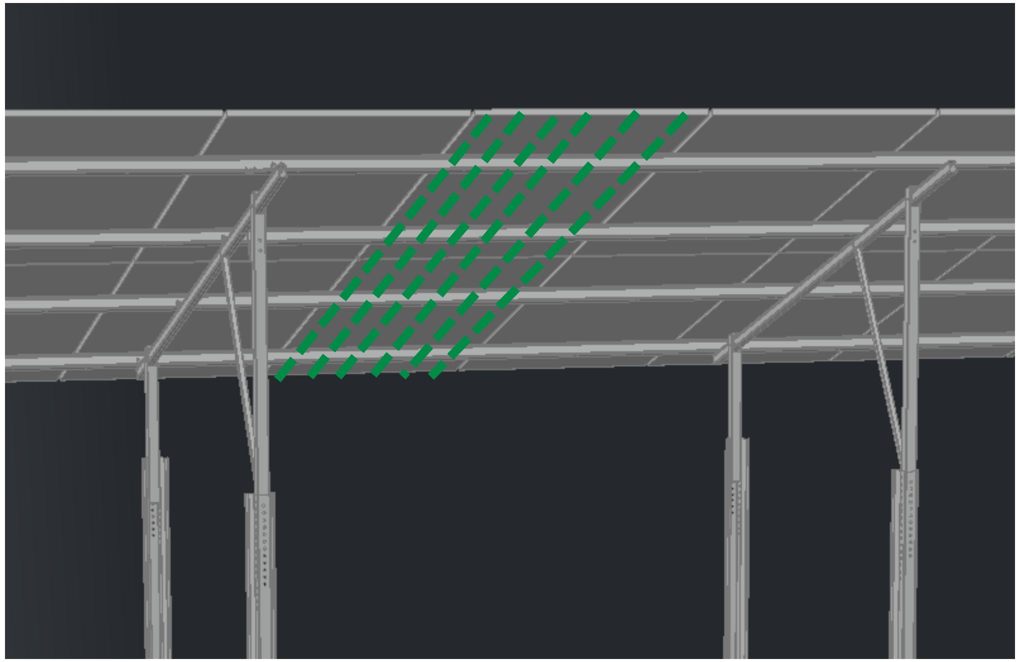
range of 0.7% - 4.5%

Simulatons

Shading Factor Analysis



- Rendering picture



- AutoCAD drawing with sensor placement

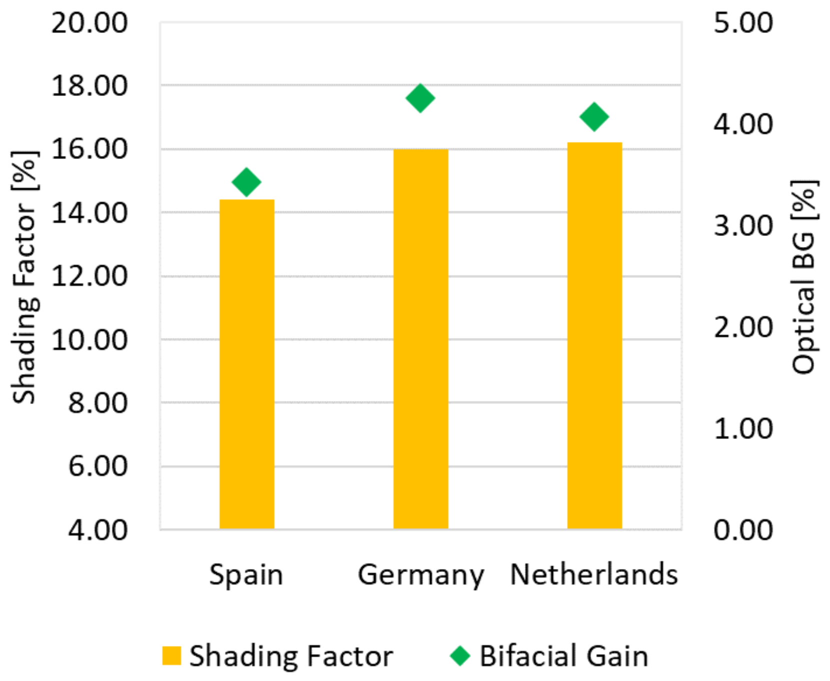
$$SF\,[\%] = \frac{\sum_{n=0}^{N} G_{rear,without\ substructure} - \sum_{n=0}^{N} G_{rear,with\ substructure}}{\sum_{n=0}^{N} G_{rear,without\ substructure}} * 100 \quad [7]$$

[7] C. Zhao, J. Xiao, Y. Yu, and J.-N. Jaubert, “Accurate shading factor and mismatch loss analysis of bifacial HSAT systems through ray-tracing modeling,” *Solar Energy Advances*, vol. 1, p. 100004, 2021.

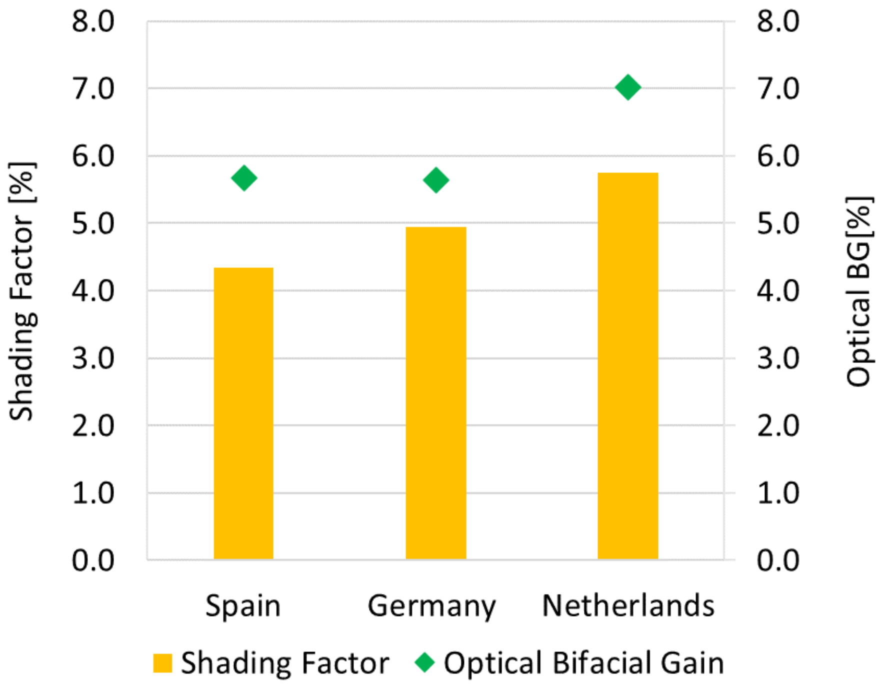
Simulatons

Shading Factor Analysis

Fixed Tilt



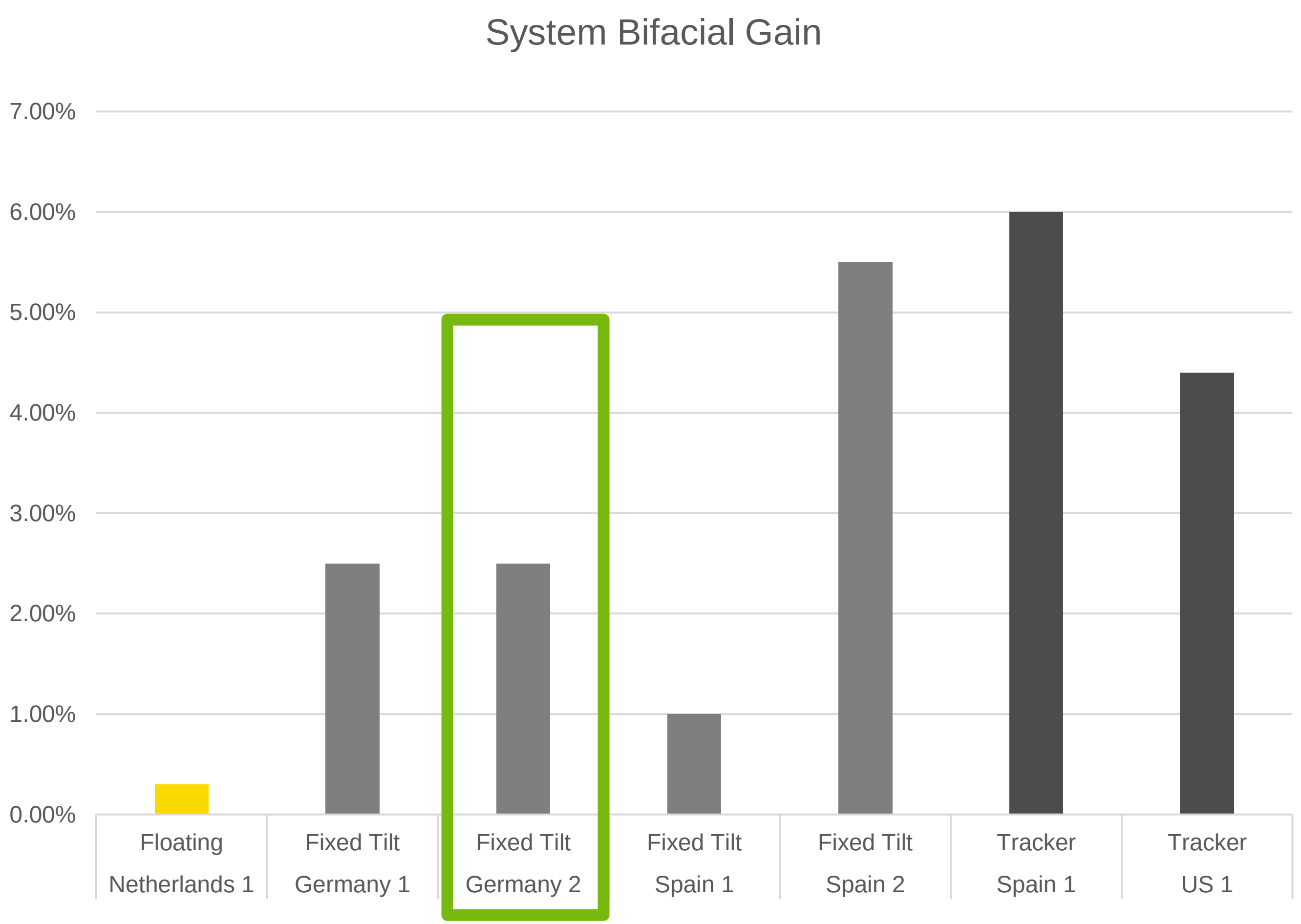
Tracker

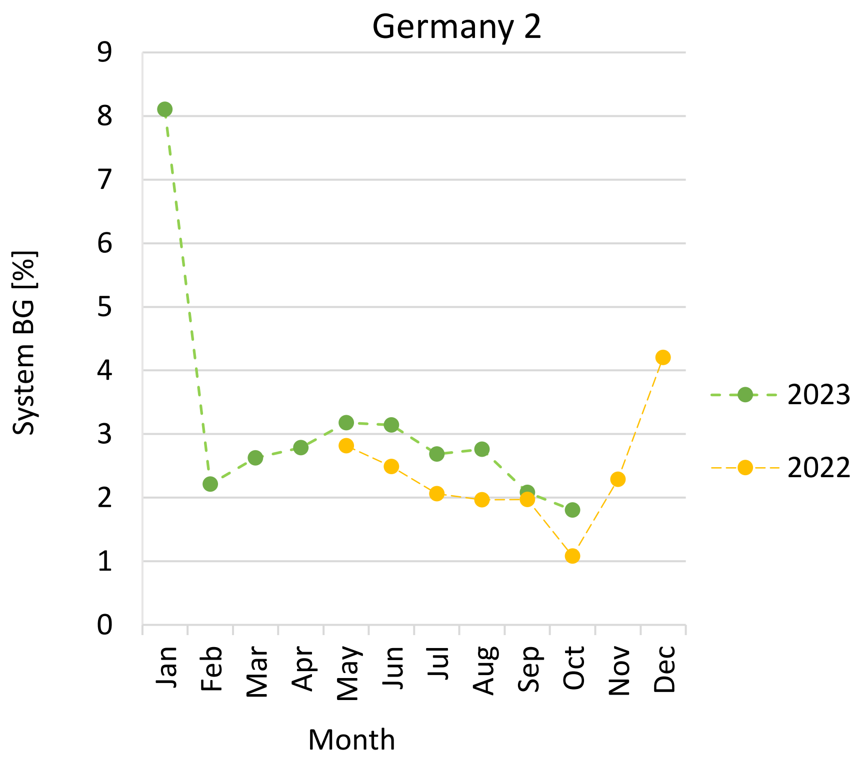


- Shading Factor increases slightly with increasing latitude

Powerplant Analysis

Analysing Test Fields and Power Plants – Results





- High peaks in winter: snow → high albedo
- Average system bifacial gain Germany 2: 2.5%

Powerplant Analysis

Analysing Test Fields and Power Plants – Irradiance Method

- Front side simulation very accurate
- Rear side simulation below measurements
- Reasons:
  - Albedo is not exact
  - Measurement Uncertainty
  - Placement of pyranometer not favorable

Optical Bifacial Gain	Pyranometer Rear Side	PVsyst
Spain 1 (Fixed Tilt)	7.5%	5.6%
Spain 1 (Tracker)	10.6%	8.4%
US 1 (Tracker)	9%	7.2%

Proposed Correction Factors

Parameter	BayWa r.e.	External Consultant 1	External Consultant 2	Correction
Albedo	15% - 25%	20%	20%	Site Specific
Structure Shading Factor Fixed Tilt	5%	20% -25%	5%	15%
Structure Shading Factor Tracking	5%	5% - 7.5%	5% - 6%	4.5%
Shed Transparent Fraction	5%	?	2% - 8%	5% (Calculation Tool for new modules)

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Summary

Summary

System Bifacial Gain for Different Technologies

Floating E-W
~0.3%

Fixed tilt
1.0% - 4.0%

Agri Fixed Tilt
3.5% - 5.0%

Tracking
4.0% - 6.0%

Agri Tracking
6.0% - 7.3%

Summary

Outcomes

- Communicate and discuss research results with **third parties** (crucial point for PR guarantee)
- Equip new plants with **albedometers and pyranometers** or **reference cells** on **multiple positions** of the module to **verify** simulated **parameters and albedo values**
- Adapt developed tools and methods to changes in standard system

Outlook

- New large-scale bifacial plants go into operation within this and next year → verify results of this research
- Topcon modules are integrated within the next year → higher bifaciality

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References

[1] PVsyst Software. https://www.pvsyst.com/

[2] Ayala Pelaez and Deline, (2020). bifacial_radiance: a python package for modeling bifacial solar photovoltaic systems. Journal of Open Source Software, 5(50), 1865, https://doi.org/10.21105/joss.01865

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