Decoupling performance gains of Silicon Hetero-Junction bifacial modules

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1 Context and goals

- As SHJ cells and bifacial modules become more prominent in PV markets[1], it is increasingly relevant to have robust performance comparisons with industry standards, evaluating their potential gains and advantages.
- This contribution compares three commercial technologies, focusing on bifacial vs. monofacial applications and SHJ vs. PERC solar cells
- The goal is to decouple the contributions to increased energy yields and performance (bifaciality and temperature coefficients).

Reproducible data analysis pipelines

Comparative analysis of PV technologies

Proposals for improved monitoring guidelines

2 Experimental

- Five modules: 2 bifacial SHJ, 2 monofacial SHJ, and 1 PERC monofacial.
- Installed at 15° tilt and 175° orientation (South-facing).
- Aluminum mounting racks at 0.1 m from the gravel-covered rooftop.
- Data retrieved: module-level I-V curve at 180 sec. timesteps, back-surface module temperature, GHI, DHI, rear-irradiance.

Table I. Nameplate STC characteristics of the modules (Mo=Monofacial, Bi=Bifacial).

ID	P_0 [W_p]	I_{sc} [A]	V_{oc} [V]	γ [%/°C]
SHJ-Bi-1	380	53.4	9.17	-0.25
SHJ-Bi-2	380	40.6	10.4	-0.25
SHJ-Mo-1	380	53.4	9.17	-0.25
SHJ-Mo-2	380	53.4	9.17	-0.25
PERC-Mo	330	53.4	9.17	-0.37

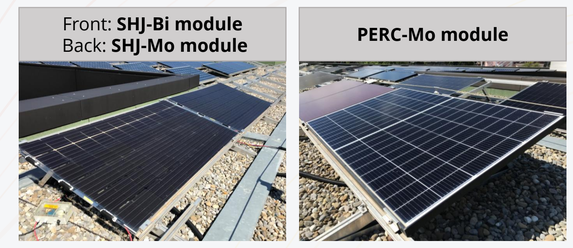

Fig. 1: Photographs of the outdoor test facility and monitored modules.

3 Results

3.1 | Performance analysis

- Clear-sky daily profile comparison of performance metrics, based on the IEC 61724-1 guidelines.
- Decoupling bifacial & cell technology effects on specific power:
  - **+ 6.1 %** w/ bifaciality
  - **+ 1.7 %** w/ SHJ
- Between Jan. 2021 – Jul. 2022:
  - **7.2%** energy yield bifacial gain.
  - **1.5%** yield gain due to SHJ TC.
  - PR gain of **~5%** between bifacial and monofacial SHJ modules and **~1%** for SHJ over PERC.
- Remaining **~2.2%** gains with PR'_{bi} (temperature and rear irradiance corrected), with higher gains observed for low sun angles.

Proposal for **angular-dependent PR**

- Better I_{sc} performance and lower degradation rates for the bifacial vs. monofacial SHJ modules linked to increased irradiance reaching cells[3].

Rear-irradiance components:
Sky diffuse + reflected + direct rear
+ G-G optical gains at low sun angles

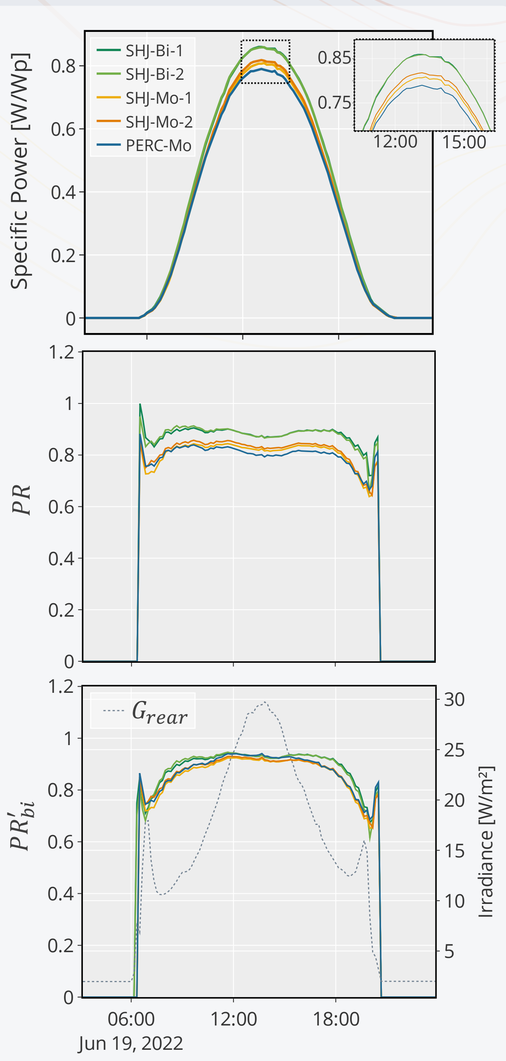

Fig. 2: Quantifying bifacial and SHJ gains using the daily production profile during a clear-sky day, for the specific power, performance ratio (PR) and corrected PR'_{bi} with measured rear irradiance.

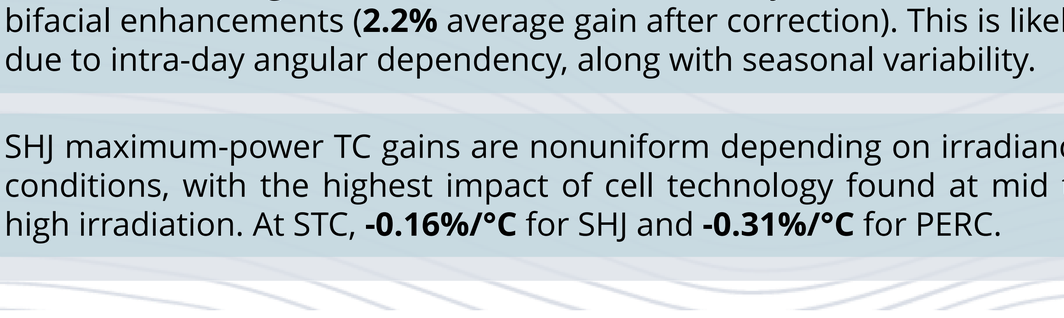

Fig. 3: Normalised performance rates of the DC power and I-V parameters for the studied modules. V_{oc} seems to degrade more for SHJ modules[4].

3.2 | Temperature coefficient (TC) variability

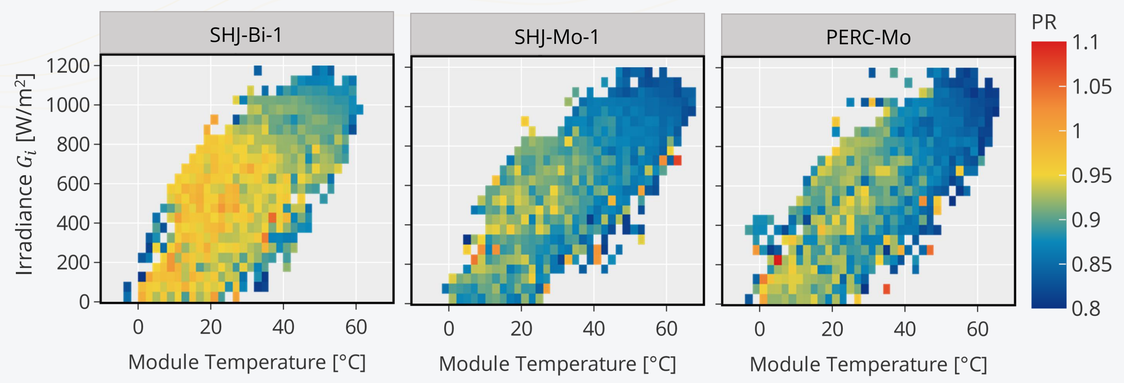

Fig. 4: Performance ratio heatmaps of the irradiance vs. module temperature relationship. The PR is averaged over intervals of 50 W/m² for irradiance and 2°C for temperature.

- Bifaciality offers the most gains in performance, especially in mid to low light conditions.
- Lower PR at high irradiance and temperature values for PERC cells: **+2.5%** for monofacial SHJ at module temperature ≥ 55°C due to better TC.

Method for TC variability analysis[2]

1. Filter at different irradiance levels (5% tolerance)
2. Filter outlier PR values (e.g. shading)
3. Linear regression of DC Power vs. module temperature

- SHJ solar cells have better field-based TCs at STC, with all four SHJ modules converging to **-0.16 %/°C**, while PERC is estimated at **-0.31 %/°C**.
- TCs only diverge for the different cell technologies for mid to high irradiance values, confirming the nonuniform temperature behaviours.

TCs are often considered **uniform** in PV modelling tools, which could lead to errors and uncertainties.

Table II. TC variability with irradiance.

G_i [W/m²]	γ [%/°C] SHJ	PERC
200	-0.11	-0.15
300	-0.16	-0.12
400	-0.9	-0.07
500	-0.13	-0.21
600	-0.10	-0.22
700	-0.15	-0.28
800	-0.20	-0.34
1000	-0.16	-0.31

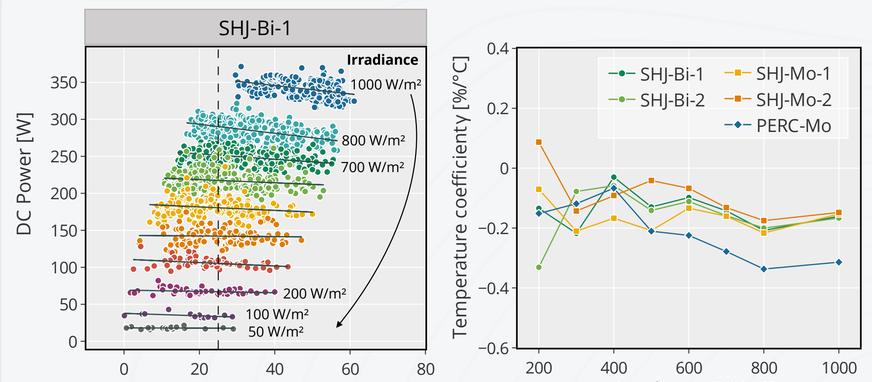

Fig. 5: Left: module power vs. temperature relationship, with irradiance level filtering. Right: Irradiance dependence of the temperature coefficients.

3.3 | Soiling detection

- Bifacial modules outperform by **~2.2%** on average, although geometric factors likely lead to seasonal variations.
- PR'_{bi} is identified as a viable indicator for extreme soiling events detection.

March 2022 **Sahara dust cloud** visible as PR loss.

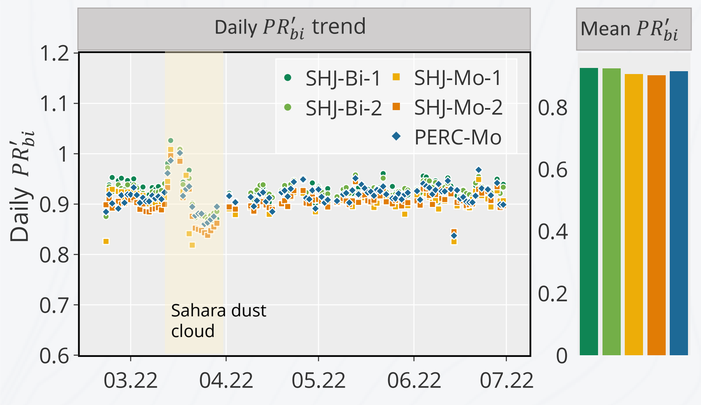

Fig. 6: Left: daily PR'_{bi} trends. Right: average PR over period.

4 Conclusion

The standard, non-corrected PR is a valuable metric to quantify bifacial and cell technology gains. Overall, bifaciality improves the PR by at least **5%** when comparing the bifacial and monofacial SHJ modules.

Overall energy bifacial energy yield gain of **7.2%** over monofacial modules.

The IEC 61724-1 guidelines for PR corrections may not account for all bifacial enhancements (**2.2%** average gain after correction). This is likely due to intra-day angular dependency, along with seasonal variability.

SHJ maximum-power TC gains are nonuniform depending on irradiance conditions, with the highest impact of cell technology found at mid to high irradiation. At STC, **-0.16%/°C** for SHJ and **-0.31%/°C** for PERC.

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