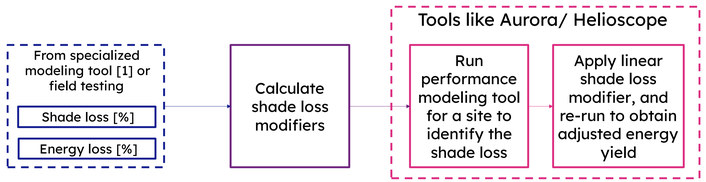
A methodology to capture technology and market-specific shading behavior in common industry performance modeling tools

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Introduction

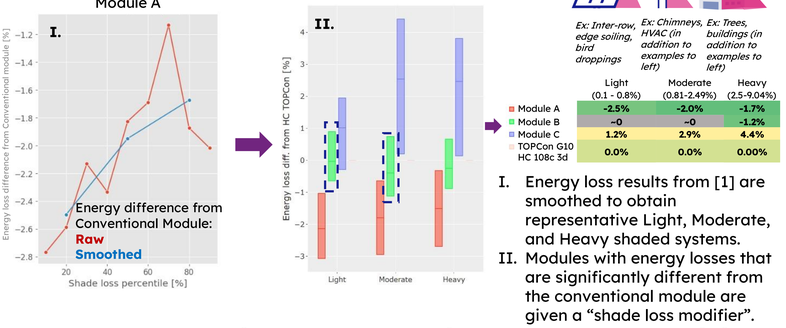
Technology-specific shading loss differences can increase annual energy yield by 0.5-3% across DG market segments [1]. Common tools like Helioscope and Aurora offer a detailed and user-friendly approach to estimate system level irradiance loss. These shading models often capture circuit design effects at the sub-module level for conventional half cut modules; however electrical effects like (low) reverse breakdown voltage and fill factor are not typically captured. We present a method to use pre-calculated "shade loss modifiers" to better capture these effects.

Methodology using linear modifiers



At different levels of shade loss, calculate the energy yield gain for specific module from Conventional module

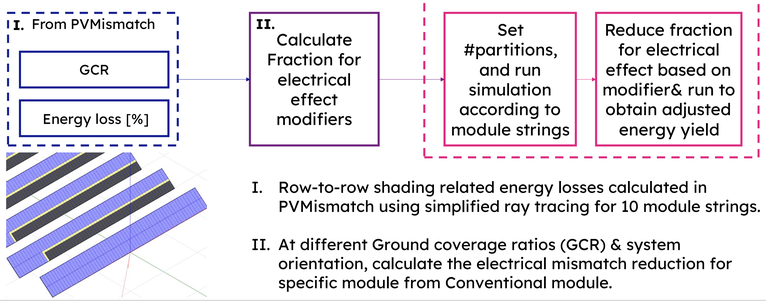
How are shade loss modifiers calculated?



	Light (0.1 - 0.8%)	Moderate (0.81-2.49%)	Heavy (2.5-9.04%)
Module A	-2.5%	-2.0%	-1.7%
Module B	~0	~0	-1.2%
Module C	1.2%	2.9%	4.4%
TOPCon G10 HC 108c 3d	0.0%	0.0%	0.00%

I. Energy loss results from [1] are smoothed to obtain representative Light, Moderate, and Heavy shaded systems.
II. Modules with energy losses that are significantly different from the conventional module are given a "shade loss modifier".

PVsyst's "fraction for electrical effect" modifiers



I. Row-to-row shading related energy losses calculated in PVMismatch using simplified ray tracing for 10 module strings.

II. At different Ground coverage ratios (GCR) & system orientation, calculate the electrical mismatch reduction for specific module from Conventional module.

References

1. An Updated Modeling Framework for Technology and Market Specific Shading Impacts on Annual Energy Yield, K. Balasubramanian, A. R. Hoffman, PVPMC Workshop 2024, Salt Lake City.
2. pvlib python: 2023 project update, K. Anderson, C. Hansen, W. Holmgren, A. Jensen, M. Mikofski, A. Driesse, Journal of Open-Source Software, 8(92), 5994, (2023).
3. V_PVMismatch: Vectorized version of SunPower's PVMismatch using dynamic programming.

Shade loss modifiers can improve accuracy by capturing up to 3% DG energy yield gain for modules with low V_{RB} when using common performance modeling tools.

See Step 2 in Example 1

Landscape	Residential Rooftops: Module-level MPPT Light (0.1 - 0.8%)	Moderate (0.81-2.49%)	Heavy (2.5-9.04%)	Residential Rooftops: String inverters Light (0.1 - 0.8%)	Moderate (0.81-2.49%)	Heavy (2.5-9.04%)	Commercial Rooftops: String inverters Light (0.10 - 0.55%)	Moderate (0.56-1.23%)	Heavy (1.24-8%)
A	-0.3%	~0	~0	-1.5%	-0.7%	-0.6%	-0.2%	-0.3%	-0.8%
B	-0.9%	-0.6%	-0.4%	-2.5%	-2.0%	-1.7%	-0.5%	-0.9%	-1.2%
C	-0.9%	~0	~0	-3.1%	-1.8%	-0.5%	-0.3%	-1.0%	-2.3%
D	-0.2%	-0.1%	-0.8%	~0	~0	-1.2%	-0.3%	-0.8%	-1.6%
E	0.6%	2.1%	5.3%	1.2%	2.9%	4.4%	1.0%	1.4%	-0.2%

Portrait							
A	-0.1%	~0	~0	-1.7%	-1.7%	~0	A: IBC 5" 112c 2D
B	-0.9%	-1.0%	~0	-2.9%	-3.1%	-0.5%	B: IBC G10 54c 3D
C	0.1%	~0	~0	-2.5%	-2.3%	-1.4%	C: IBC G10 HC 108c 3D
D	~0	~0	~0	~0	~0	~0	D: TopCon Shingled
E	-0.2%	-0.8%	-2.2%	-0.6%	-1.5%	-2.5%	E: Horizontal Circuit 4D

- Negative value = **advantage** (less loss) & positive value = **disadvantage**.
- IBC modules use Maxeon's low V_{RB} technology.
- **Not all xBCs have the same performance.**

Utility Power Plants (GFT systems)

Modifiers for IBC G10 HC from Conventional module

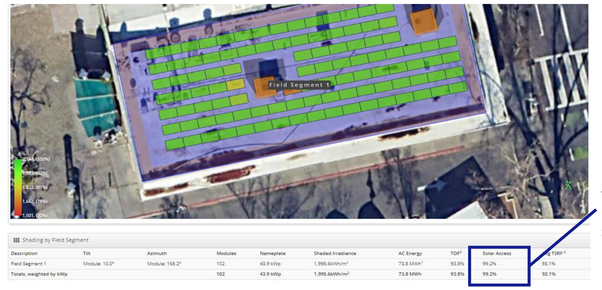
See Step 1 in Example 2

1P Tilt [deg]	Electrical effect modifiers GCR 0.4	0.5	0.6	Linear shade modifiers GCR 0.4	0.5	0.6
25	-9%	-11%	-10%	0.0%	-0.1%	-0.2%
35	-6%	-7%	-7%	-0.1%	-0.2%	-0.3%
40	-5%	-8%	-5%	-0.1%	-0.2%	-0.3%

- Four typical US locations modeled, system is oriented South, and only row-to-row shading modeled.

Modules with low V_{RB} often have better energy yield, especially with string inverters and high GCR & tilt GFT systems

Example 1: Linear modifiers in Helioscope



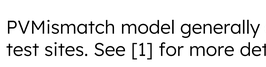
Step 1

Solar Access Identify the shade loss (-0.8%)

Step 2

1. Identify module orientation to use suitable table.
2. Identify system electrical design (Module-level MPPT or string inverter).
3. Locate module technology installed in the system.
4. Select shade loss range based on shade loss at site.
5. Select the corresponding shade loss modifier to be entered into Helioscope to account for module technology differences in shading (0.3%).

Step 3



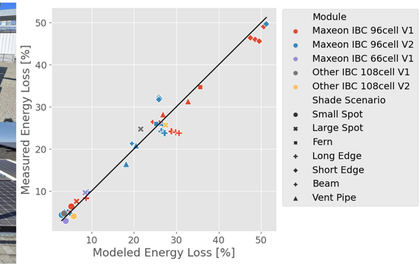
Apply the appropriate linear shade loss modifier in the soiling conditions. Subtract the shade loss modifier (0.3%) from baseline soiling loss (e.g., 2%). Simulation can now be re-run to obtain adjusted energy yield.

Example 2: PVsyst Electrical effect modifiers

1. For module technology, identify the system orientation & GCR to use the appropriate fraction for electrical effect modifier for the site.
2. Select "According to module strings" option.
3. Select "Fast (table)" option.
4. Reduce fraction for electrical effect by specified electrical effect modifier in the table (11%).

Model Validation





PVMismatch model generally agrees well with experiments conducted at our field test sites. See [1] for more details.

Contact Maxeon for specific use-cases!

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