HELIOSOLVE

PV Simulation & Yield Analysis Platform

Technical Validation Report

Heliosolve PV Simulation Engine

Bifacial SAT Field Validation — NREL SRRL BEST Plant, Golden CO

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EXECUTIVE SUMMARY

EXECUTIVE SUMMARY AT A GLANCE

HelioSolve's bifacial solar-simulation engine matched real-world measurements at the NREL Bifacial Experimental Single-Axis Tracking (BEST) research plant in Golden, Colorado, to within -0.34% **on the front and** $+1.50\%$ **on the back of the panels** over a full year of operation. That is the simulation-side share of the modelling uncertainty contributing to the industry's documented $\sim$**8% energy-yield-forecast gap** [3, 5, 6].

- **What was tested**: HelioSolve modelled the entire array of the BEST research plant using twelve months of measured weather and reference-instrument data distributed with the publicly-released Ovaitt et al. dataset [2].
- **What we found**: Modelled front-side sunlight on the panels matched the measured reference to within -0.34%, and modelled back-side sunlight to within $+1.50\%$ — in line with the peer-reviewed bifacial-validation literature [11, 12].
- **Why it matters**: Modelling the back side of bifacial panels is one of the documented sources of forecast uncertainty contributing to the $\sim$8% industry gap. Tighter modelling on this side addresses one of several contributors to lender uncertainty [7]; operational, financial, and degradation contributors lie outside this report.

Scope: one site, one year. Multi-site and multi-year validation is the next step before production-grade certification.

Table 1: Annual front- and back-side sunlight bias on the BEST research plant, twelve-month validation window. See the methodology appendix for term definitions.

Channel	HelioSolve Bias
Front-side sunlight (annual, vs. on-plant reference sensor)	-0.34%
Back-side sunlight (annual, vs. on-plant reference sensor)	$+1.50\%$

Bias = annual integrated difference between modelled and measured sunlight reaching the panel surface, expressed as a percentage of the measured value. Reference instruments are individually calibrated sensors named on the published BEST plant.

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WHY THIS MATTERS

Modern U.S. utility-scale solar plants commissioned after 2015 produce roughly **8% less energy** on a weather-adjusted basis than their pre-construction forecasts had predicted [3, 5]. Lawrence Berkeley National Laboratory has separately documented plant-level capacity-factor distributions and degradation patterns across more than 31 GW of installed capacity [6]. The gap has multiple drivers — soiling, availability, degradation, EPC quality, weather inputs, and modelling. This report addresses the **modelling** share, specifically for bifacial single-axis-tracking plants (i.e., plants where the panels rotate east-to-west to follow the sun and produce energy from sunlight hitting both their front and back):

- **The 8% shortfall is real and measured**: In its 2025 update, kWh Analytics reports an 8.6% mean shortfall across 34,000 system-months of operating data [3, 5].
- **It feeds straight into project finance**: Higher modelling uncertainty widens the gap between best-case and worst-case revenue forecasts, which can depress lender debt-service-coverage margins [7].
- **Bifacial-tracking plants add an extra source of uncertainty**: The back side of the panels picks up sunlight reflected off the ground and from neighbouring rows, which is harder to model than the simple front-side calculation. This is one of several documented contributors to the overall gap.

This report focuses on that bifacial-tracking case, and on a single question: can a simulation engine match what calibrated reference instruments actually measured on a real plant, over a full year? The answer, on this case, is yes — front sunlight to within -0.34% and rear sunlight to within $+1.50\%$.

WHAT WE VALIDATED

HelioSolve is a physics-based simulation engine that estimates how much sunlight reaches the front and back of solar panels under real-world weather, geometry and tracker-angle conditions. The engine's internals are proprietary; what is published here is the input dataset, the output metrics, and the comparison against on-plant measurements.

The validation reference is the **NREL Bifacial Experimental Single-Axis Tracking (BEST) research plant**, operated by the U.S. National Renewable Energy Laboratory in Golden, Colorado. The plant is purpose-built for this kind of comparison: across a 200-module single-axis-tracking array, multiple modules carry calibrated reference sensors that measure the sunlight on both the front and back of the panel. A full year of those measurements has been released as a public open-access dataset by Ovaitt et al. [2]; the same plant is the subject of a peer-reviewed system-level validation by Deline et al. in *IEEE Journal of Photovoltaics* (2024) [1].

Why this is the right benchmark

- **Outdoor measurements across a full year** of changing weather and seasons — not a clear-sky idealisation.
- **Reference instruments are individually calibrated and named in the published paper**, so

anyone can reproduce the comparison module-for-module.

- **The dataset is public**: weather and irradiance inputs are distributed with the paper database, eliminating any uncertainty about which inputs HelioSolve was given.

> **The Investor View:** For bifacial-tracking plants, the back-side sunlight estimate is one of the largest discretionary modelling choices in the simulation chain — different commercial tools use different methods and disagree by one to two percentage points of annual yield on the same plant [12]. A validation that pins this number against measured ground-truth removes one element of forecast uncertainty that lenders see as discretionary.

THE RESULT

Over a full year of operation on the BEST research plant, HelioSolve's modelled sunlight on the panels matched the on-plant measured reference to within -0.34% on the front side and $+1.50\%$ on the back side (Table 2, Figure 1). No post-hoc tuning was applied to the measured data.

These numbers sit in the same precision band as the peer-reviewed bifacial-validation literature: Riedel-Lyngskær et al. (2020) report that across the available bifacial codes, agreement on annual yield between simulators and measurements is typically of order one-to-two percentage points [12]. The peer-reviewed system-level validation of the same plant by Deline et al. (2024) [1] provides operating context and establishes the plant as a reference for this kind of work.

Table 2: Annual front- and back-side sunlight bias on the BEST research plant. Twelve-month validation window. No values rescaled or normalised.

Channel	HelioSolve Bias
Front-side sunlight (annual, vs. on-plant reference sensor)	-0.34%
Back-side sunlight (annual, vs. on-plant reference sensor)	$+1.50\%$

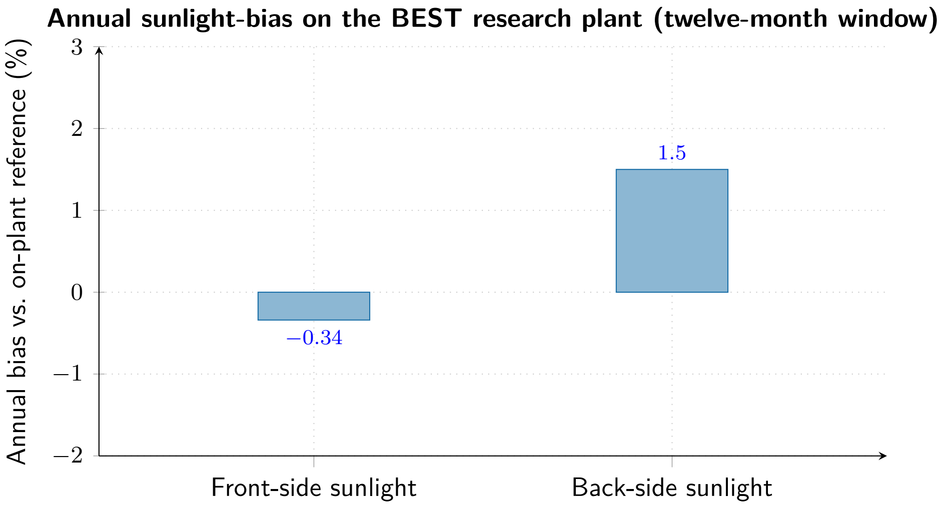

Figure 1: Annual sunlight bias on the BEST research plant against the on-plant calibrated reference sensors, twelve-month validation window. Closer to zero is better.

WHAT THIS CHANGES FOR PROJECT FINANCE

Tighter modelling on the back side of bifacial-tracking panels addresses one element of the forecast-uncertainty budget that lenders use to size debt and equity returns. Pacudan (2016) documents the link between resource-estimation uncertainty and project-finance metrics — the narrower the modelled distribution of plant output, the better the debt-service-coverage ratio and net present value of the asset [7]. The operational gap between forecasts and realized generation reported by kWh Analytics [3, 5] and Bolinger et al. [6] captures the full mix of modelling, soiling, availability, degradation and weather drivers; this report addresses only the modelling component, on one site.

What this validation is, and isn't: It is evidence that the simulation side of a bifacial-tracking forecast can be made tighter on a real plant against measured ground-truth. It is *not* a closed business case for any specific asset. We do not, in this document, quantify the project-level NPV or DSCR impact of any individual project; that requires a project-by-project analysis using the client's own capital-stack assumptions.

SCOPE, LIMITATIONS, AND THE NEXT STEP

This validation covers **one site** (the NREL BEST plant in Golden, Colorado) over a **twelve-month window** drawn from the public Ovaitt et al. dataset [2]. Before the engine can be considered generally validated for production-grade forecasting, the same exercise needs to be repeated on additional sites, additional years, and additional bifacial-module technologies. That is the next phase of work.

Request a pilot / technical review

Asset owners, lenders, and developers are invited to benchmark their own bifacial-tracking simulation assumptions against a HelioSolve simulation under matched inputs.

Request a pilot / technical review

Contact the HelioSolve team to schedule an independent audit of your bifacial or tracking project's yield projections.

contact@heliosolve.com

APPENDIX A — METHODOLOGY AND DEFINITIONS

Glossary

- **Front-side / back-side sunlight** (in the technical literature, "plane-of-array irradiance" or POA, front and rear): the actual sunlight reaching the front and back surfaces of a solar panel after accounting for the panel's tilt, the sun's position, and any shading.
- **Bifacial panel**: a solar panel that produces electricity from sunlight hitting both its front and its back surface.
- **Single-axis tracking (SAT)**: panel-mounting system in which the panels rotate during the day around a horizontal north–south axis to follow the sun east-to-west.
- **Annual bias**: the difference between the simulated value and the measured reference value, integrated over the twelve-month validation window, expressed as a percentage of the measured total. A bias of -0.34% means the simulation is 0.34% *below* the measured total over the year.
- **Calibrated reference sensor** (technical: "broadband pyranometer"): a meteorological-grade instrument that measures the total sunlight on a surface and is individually calibrated against a reference standard.
- **Albedo**: the fraction of sunlight reflected from the ground in front of and beneath the panels. Affects how much sunlight reaches the back side of bifacial panels.
- **P50 / P90 / P99**: probabilistic forecast percentiles. P50 is the median (best-estimate) annual production; P90 is the level of production that is exceeded with 90% probability (used by lenders as a worst-case sizing metric).
- **DSCR**: Debt-Service Coverage Ratio — the ratio of a project's operating cash flow to its debt service. A higher DSCR means more headroom against under-performance.

Two well-known sources of modelling error in commercial PV simulators

- **Simplified thermal assumptions**: Many tools assume a constant "heat-loss factor" that ignores wind speed. Wind-driven cooling is a first-order driver of cell temperature and therefore efficiency, as documented in the Sandia Array Performance Model [9].
- **Bifacial back-side modelling**: Riedel-Lyngskær et al. (2020) report annual bifacial-yield agreement of order one-to-two percentage points across the available bifacial codes against measured monthly data on single-axis-tracking systems [12], with substantially higher hourly errors during fast-changing tracker angles.

Sensitivity to snow and high-reflectance conditions

Deline et al. (2024) observe that simulator-based weekly weather-correction error on the BEST plant can reach 6–7% during weeks with snow on the ground (which dramatically increases the reflected sunlight on the back of the panels), while measurement-based methods stay below 2% under the same conditions [1]. This is a known limitation of any simulator that drives back-side sunlight from a single albedo input. The annual numbers in this report use the on-plant measured albedo time series available with the public dataset [2].

What was filtered out

Night-time hours and sensor-outage rows (encoded as zero values in the public dataset) are excluded from the annual integrations. The full filtering rules are those documented with the public dataset.

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