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PlantPredict v12 PV Simulation Software Review

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TABLE OF CONTENTS

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2 EXECUTIVE SUMMARY

2.1 REVIEW SCOPE

Terabase Energy Inc. (the "Client") engaged Solphi Engineering PLLC ("Solphi Engineering") to conduct an Independent Engineering review of the PlantPredict version 12 PV Simulation Software ("PlantPredict"). Solphi Engineering has reviewed previous Independent Engineering (IE) reports from version 3 and 4 of PlantPredict, the PlantPredict software documentation, and recent literature in the field of PV performance modeling. Solphi Engineering's review process has also included regular meetings with PlantPredict team members to raise questions and seek clarifications where it is necessary to understand the operation and functionality within PlantPredict.

2.2 PV PERFORMANCE MODELING AND SOFTWARE

PlantPredict PV simulation software has been available for commercial use since 2016. Initial versions of PlantPredict were reviewed by several Independent Engineering service providers to assess the accuracy and capability of the tool to be relied on by PV performance engineers. These review scopes generally covered a review of PlantPredict methodology, benchmarking against an industry accepted PV simulation software (PVsyst), and a review of a validation study against real world systems.

Since the issuance of these reports in 2016 and 2017, PlantPredict and PVsyst have evolved to meet the increasingly complex needs of the PV industry.

Modern PV simulation software should be capable of simulating performance of bifacial modules, arrays installed on complex and undulating terrain, large varieties of tracker angle algorithms, and be able to execute simulations at sub-hourly intervals.

Increasingly, operations and asset management teams are also looking for PV simulation software that can smoothly transition from a pre-construction model of plant performance to a real-time operating model comparing expected and actual performance.

Academic and industry working groups have also undertaken comprehensive efforts in the past decade to develop independent assessments of PV simulation software as well as PV performance engineering practices. These studies have identified that robust and transparent documentation is an important feature of high-quality PV simulation software and suggest that user interfaces that facilitate quality control and mitigate the possibility of user error are likely as important as the core modeling algorithms.

2.3 PlantPredict v12 Summary

PlantPredict v12 Stable was released on October 23, 2025 and included a substantive new feature for importing and analyzing 3D shading scenes.

PlantPredict maintains a detailed repository of past release notes from v3 to v12. Solphi Engineering has summarized several notable updates within this report, however the release notes on the PlantPredict website should be consulted as the authoritative record.

2.4 Model Review

Solphi Engineering completed a detailed review of the PlantPredict *Models & Algorithms* documentation on their website and reviewed numerous questions with the PlantPredict engineering team. Solphi Engineering found the documentation to be clear and comprehensive, and found no material deficiencies in the methodology.

2.5 PVsyst Simulation Comparison

Solphi Engineering performed a simulation comparison between PlantPredict and PVsyst. In total, 20 simulations were run using both software tools across three representative project locations. Desert Rock, Nevada was used as a location to leverage nearby high-quality ground-based sub-hourly weather data. Desert Rock also benefits from the presence of flat desert topography near more complex undulating terrain. Jaen, Spain was used as a representative location in Europe with complex terrain and a non-trivial horizon line. Wellington, Australia was selected to represent a Southern hemisphere project location in an area of New South Wales that has seen significant utility scale solar construction.

Across all simulations, average absolute differences in Inverter output energy between PVsyst and PlantPredict were found to be less than 0.5%, with individual simulations all less than 1.0%. Solphi Engineering considers these differences to be well within expected modeling uncertainty, as well as within the variations documented between a survey of seven reputable PV simulation software providers published by Deville et al. and the PV Performance Modeling Collaborative (PVPMC) [1].

2.6 Notes on Validation

The original commercially available PlantPredict version (3.x) was validated against real-world operating systems. Solphi Engineering notes that validation against operating systems was not part of this scope of work but notes that such a validation exercise would be beneficial to directly assess the accuracy of the latest PlantPredict versions in simulating real-world plant performance.

2.7 CONCLUSION

Solphi Engineering considers PlantPredict PV simulation software to be aligned with industry best practices and has demonstrated that the model engine can reproduce results within an acceptable tolerance compared to PVsyst.

Solphi Engineering considers the clear and comprehensive documentation provided by PlantPredict to be an asset for its use in the development, design, and financing of PV systems.

Solphi Engineering considers the PlantPredict user interface simple to navigate, and notes numerous features facilitate user quality control efforts which should help reduce user input errors.

While Solphi Engineering's review did not cover assessments of PlantPredict using operational data, Solphi Engineering considers the available PlantPredict features to be beneficial for the integration of PlantPredict within operational performance assessment workflows. Solphi Engineering considers PlantPredict's ability to efficiently simulate a 1GW+ tracker system with a 3D scene to be beneficial, particularly as modern PV plant sizes continue to increase.

3 PV PERFORMANCE MODELING AND SOFTWARE

PlantPredict PV simulation software (versions 3.X and to a limited extent version 4.5) were evaluated by four Independent Engineering service providers between 2016 and 2017, assessing PlantPredict's acceptability as a PV simulation software tool, and making direct comparisons against PVsyst as a well-established and frequently used tool for bankable underwriting of solar project financing. A decade later, PV simulation software has evolved substantially with more market entrants, greater functionality within tools, and a greater need to address unique conditions more prevalent in actual project design and construction (e.g. bifacial modules, complex terrain, terrain-aware backtracking).

In parallel with these developments within PV simulation software tools, industry and academic efforts have been underway to develop methods to compare the differences across these tools and provide greater confidence to solar industry stakeholders that these tools can be relied upon to develop acceptable confidence in the software model outputs.

In this section, Solphi Engineering summarizes key capabilities expected of PV simulation software tools that would not have been commonplace in 2016, reviews the latest industry findings with respect to PV simulation software tool benchmarking and assessment, and summarizes the capabilities of PlantPredict's software when viewed through this broad lens.

3.1 PV SIMULATION SOFTWARE CAPABILITY

Modern PV simulation software must address several design realities as well as fundamental PV modeling concerns that were not well understood or broadly available a decade ago. Solphi Engineering has identified the following as most relevant:

- *Bifacial modules* – This technology is now commonplace and has captured a significant market share compared with monofacial technology for utility scale projects based on Solphi Engineering's experience in the US market. Simulating the performance of bifacial modules adds significant complexity to PV simulation software as the transposition of irradiance to the rear-side of the module requires additional steps and can potentially demand tradeoffs between geometric accuracy and computational efficiency.

- *Complex terrain* – historically the solar industry (particularly in the US market) focused development of projects in areas with relatively flat terrain. As the costs of solar have continued to decline, solar development has expanded globally and increasingly projects are being constructed on more challenging plots of land with undulating terrain. Complex terrain creates additional demands for PV simulation software providers as simplifying assumptions (e.g. assumptions that a representative PV tracker could characterize the average irradiance incident on the entire array) may result in greater error as terrain complexity results in greater deviations of tilt angle and azimuth between individual module tables within an array.

- *Sub-hourly modeling* – Significant literature has been published since 2016 related to modeling errors introduced by simulating PV performance at the traditional 1-hour time step. These modeling errors are more pronounced when the PV systems being simulated utilize higher DC/AC ratios. As the cost of PV modules has continued to decline relative to overall project installation costs, typical industry specifications for DC/AC ratios have increased. Real-world operation of PV systems with high DC/AC ratios includes sub-hourly clipping events that can be missed when modeling at 1-hour intervals [2].

- *Tracker angle schedules* – Single-axis-tracker (SAT) technology has increasingly dominated PV systems design, particularly for utility scale projects located in the US market. While SAT projects were common in 2016, these technologies have continued to evolve to address various market needs. Modern trackers implement safety stow mechanisms for high wind events, as well as hail events, and some tracker technologies now enable individual tracker row control to optimize performance when installed over uneven terrain. Conventional backtracking schedules (where the array of trackers operate under a single schedule assuming flat terrain to prevent self-shading) do not always represent the real-world operating conditions of modern SAT PV systems.

- *Pre-construction model continuity with post-construction Operations and Asset Management* – historically PV systems were modeled before construction using the best tools and software available for estimating the energy production that could be expected from the plant. These pre-construction models were relied upon by developers, owners, and lenders to make commercial decisions. Once projects reached commercial operation, it was typical that Operations and Asset Management service providers would utilize different tools, Key-Performance-Indicators (KPIs), and often simplified internal models to compare actual performance to “expected” performance. The dislocation between the pre-construction model and the operational model were in part attributed to the computational costs and complexity associated with running a pre-construction model on an ongoing basis with real-world operating data. Industry and academia have flagged the benefits of reconciling pre-construction PV performance models with operational models [3]. As computational capacity has increased over the last decade, it has also become easier to consider evaluating ongoing operational data using the pre-construction performance model. Increasingly, stakeholders within the industry are looking for PV simulation software solutions that can facilitate the use of these complex performance models within ongoing operations and asset management performance monitoring activities.

Modern PV simulation software is expected to accurately simulate the performance of bifacial modules, installed on complex and uneven terrain, at sub-hourly time steps, and with the ability to integrate complex modern tracker angle schedules. Increasingly, stakeholders are also looking for PV simulation software with the ability to integrate with ongoing operations and asset management performance monitoring.

3.2 BLIND MODELING COMPARISONS

The PV Performance Modeling Collaborative (PVPMC) is organized through Sandia National Laboratories to facilitate "a collaborative group of photovoltaic (PV) professionals… interested in improving the accuracy and technical rigor of PV performance models and analyses" [4]. In recent years, PVPMC has organized detailed studies to independently evaluate features within PV modeling software [1] as well as to independently evaluate PV performance modeling professionals against their peers to determine the accuracy and sources of error typical within industry-generated PV performance simulations [5][6].

Solphi Engineering has participated as a voluntary industry contributor to the PVPMC Blind Modeling Comparison initiative, which invited individual PV performance modeling professionals to submit their simulation results for comparison. Solphi Engineering did not participate in the PVPMC Photovoltaic Modeling Software Blind Performance Assessment, which was limited to software providers submitting their results for comparison.

These studies are helpful in framing the evaluation of specific PV simulation software and further highlight key sensitivities that are within the control of the PV simulation software as well as those that are subject to the skills, knowledge, and professionalism of the user of the software (the modeler).

3.2.1 PVPMC Photovoltaic Modeling Software Blind Performance Assessment

Deville et al. [1] developed a blind performance assessment methodology and solicited submissions from seven commercially used PV software tools: 3E SynaptiQ, PlantPredict, PVsyst, RatedPower, SAM, SolarFarmer, and SolarGIS Evaluate. Each software participant was given input information for two real-world projects and invited to submit their simulation results for comparison. Deville et al. were then able to compare the simulated performance from the software providers against the real-world operating data from the two systems. This study will be referred to in this report as the "PVPMC software study".

The PVPMC software study covered a lab scale (15.4kW) system in Albuquerque, NM as well as a small utility scale (14.5 MW) system in Germany.

It is notable in the context of this report that the study results were based on PlantPredict version 11 and PVsyst version 7.4.

The PVPMC software study covered the following comparison of features: weather and irradiance features, DC system modeling features, AC system modeling features, and derates and losses.

3.2.1.1 Weather and irradiance features

The PVPMC software study results highlighted that even when software tools utilized the same nominal transposition model (e.g. Perez) the simulated Plane of Array (POA) irradiance residuals across the software providers were non-trivial. The PVPMC software study reported that the four tools using the Perez 1990 transposition model with generic coefficients simulated POA irradiance differences as high as 62 W/m^2 on clear sky days and as high as 123 W/m^2 on days with variable irradiance conditions and reported median POA irradiance residuals ranging from -14.65 W/m^2 to +6.06 W/m^2. The PVPMC software study highlighted that the insolation bias errors for the software tools evaluated did not exceed +/-2.5%. The software study authors noted these bias errors are comparable to typical measurement uncertainty of pyranometers used to collect the measured data which the software was being compared against. The PVPMC software study concluded that more detailed accounting of the full transposition model chain is necessary to be able to reliably reproduce how a given software operates (i.e. specifying that a model uses the Perez transposition with generic 1990 coefficients is insufficient).

Solphi Engineering's interpretation of these findings is that software providers should provide robust documentation of their transposition model implementation to facilitate modeling decisions by the users, as well as to enable effective review of simulation results. Solphi Engineering notes that PlantPredict provides clear and comprehensive details of its implementation of decomposition and transposition models within the *Models & Algorithms* documentation published on PlantPredict's website.

3.2.1.2 DC system modeling features

The PVPMC software study provided a detailed comparison table of software provider features for Module and DC system performance. PlantPredict v11 was notable in accepting multiple module data formats, providing multiple options for Incidence Angle Modifier models, module temperature models, and backtracking algorithms and features. It was noted that PlantPredict v11 did not provide a transient temperature model option, with only the System Advisor Model (SAM) providing this capability as of the date of the PVPMC software study. The PVPMC software study presented representative plots of modeled module temperature vs. measured module temperature as well as normalized performance ratios across two example days.

Solphi Engineering concluded that the PVPMC software study results indicate PlantPredict has a robust DC system modeling feature set when compared to its peers, and that the temperature and performance ratio plots indicate PlantPredict can perform well against its peers in these areas.

3.2.1.3 AC system modeling features

The PVPMC software study provided a detailed comparison table of software provider features for Inverter and AC system performance. PlantPredict v11 was notable in accepting multiple inverter data formats and allowing time series inputs for Grid limitation. Inverter efficiency results were plotted for each software provider compared to measured data from the project located in Germany. The results demonstrated that PlantPredict had a median difference of 0.16%, which was lower than the mean absolute median difference across the seven software providers of 0.23%.

Solphi Engineering considers these results to indicate that AC system modeling capabilities across software providers were very similar, with minor differences in modeling features for Grid limitation and reactive power.

3.2.1.4 Derates and Losses

The PVPMC software study provided a detailed comparison table of software provider default derates and loss models. Tool capability between providers was generally consistent across the large list of features evaluated. Software specific total derates were reported based on the blind modeling submissions, and results were normalized for differences in the selected derates as these were user selected and not reflective of the underlying capability of the tools themselves. Results were plotted to report Annual Energy Error at both the lab-scale and utility-scale systems. Individual software provider results were presented as deviations from the mean results across all providers with the intention of providing a relative (not absolute) comparison.

Solphi Engineering considers the PVPMC software study results to indicate that PlantPredict performed well for modeling both the lab-scale and utility-scale system's annual energy production.

3.2.2 PVPMC Blind Modeling Comparison

Deville et al. developed a blind performance assessment methodology and solicited submissions from 35 participants and 15 countries (including Solphi Engineering). This 2023 study built off an earlier Blind performance assessment conducted by Theristis et al. in 2021 [7]. Across the 2021 and 2023 studies (referred to in this report as the PVPMC 2021 study and the PVPMC 2023 study respectively), participants were given input information for two real-world projects and invited to submit their simulation results for comparison. The study authors were then able to compare the simulated results from the PV performance modeling professionals against real-world operating data from the two systems.

The PVPMC 2021 study covered lab scale systems in Albuquerque, NM (3.9kW and 3.3kW) as well as lab scale systems in Roskilde, Denmark (~26kW). The PVPMC 2023 study covered a lab scale (15.4kW) system in Albuquerque, NM as well as a small utility scale (14.5 MW) system in Germany.

As a PVPMC 2023 study participant, Solphi Engineering has reviewed and received pre-print drafts of the manuscript by Deville et al. which summarizes the final analysis of these blind modeling comparisons. It is expected these results will be published sometime in the second half of 2026.

As the final manuscript is not publicly available as of the issuance of this report, Solphi Engineering will discuss preliminary findings presented by Deville et al. at the 2024 and 2026 PVPMC workshops.

Participants were able to use their PV simulation software of choice, and it was reported that PlantPredict, PVsyst, SAM, and other tools were used by the participants.

The PVPMC 2023 study covered many elements of the participant simulation methodologies, and evaluated results for model accuracy for POA irradiance, module temperature, inverter clipping, and shading. Solphi Engineering would encourage a review of the source reports as well as the upcoming publication for a detailed breakdown of the findings.

The critical takeaways that expand from the findings of the PVPMC Software study are those that relate to user error. The presentations and interim reports highlight large variations in derate factors between participants and user errors that lead to material uncertainties (for example in the selection of temperature coefficients). Theristis et al. concluded from the 2021 study that “modeler skill at understanding, choosing, and using the models and their parameter correctly, and accumulated experience observing various derate mechanisms in operational systems seems to be more important than the PV model itself” [7].

Solphi Engineering therefore considers it important to evaluate the user interface and feature elements within a given PV simulation software in addition to assessing the underlying physical models used and the replicability of results against benchmark providers.

3.3 PlantPredict Software Capability

Solphi Engineering considers PlantPredict to be a capable PV simulation software in the context of the modern demands detailed in Section 3. PlantPredict allows for sub-hourly modeling, with the ability to simulate bifacial systems over complex terrain with complex tracker schedules. While Solphi Engineering’s evaluation did not include assessments of operational data using PlantPredict, PlantPredict does offer API integration. The API, coupled with the ability to simulate at sub-hourly intervals with time series tracker schedules is considered by Solphi Engineering to be a positive for the integration of PlantPredict within operational performance assessment workflows.

4 PLANTPREDICT V12

4.1 v12 Summary

PlantPredict v12 Stable was released on October 23, 2025 and included a substantive new feature for importing and analyzing 3D shading scenes.

4.1.1 Version evolution summary

PlantPredict maintains a detailed repository of past release notes from v3 to v12. For an exhaustive list of changes, refer to PlantPredict's website. Solphi Engineering has highlighted several notable changes and refinements since v3 based on Solphi Engineering's review of the Release Notes:

- v5 introduced several module single diode model related items, including expanding the boundaries for the Recombination Parameter and the Diode Ideality Factor in the module file, and adding error messages to improve user quality checks.
- v6 introduced the 2D view-factor for bifacial modeling capability
- v7 updated simple linear shading capability with an electrical shading estimation function
- 3D object shading was first introduced in v8, and a slope-aware transposition (along with slope aware backtracking) were added in v10
- v9 implemented a new calculation for diffuse IAM losses, following published work by Marion et al. and v11 introduced a Physical IAM model
- The Perez transposition was aligned with pvlib [8] in v11 to take non-pressure corrected airmass into account instead of pressure corrected airmass
- The Perez coefficient set also became user selectable in v11, and users were given the ability to select circumsolar treatment as direct or diffuse.
- v11 added Diffuse (irradiance) optimization, and v12 added wind stow
- v11 replaced the PlantPredict inverter efficiency model with the Sandia Inverter Efficiency Model
- PlantPredict v11 added the ability to select the NOCT model for the module temperature model.
- v12 introduced a step fractional electrical shading model to better represent non-linear step changes in electrical shading of modules

4.1.2 User Interface and feature elements

As noted in the PVPMC studies, user errors can easily exceed methodological differences between specific PV simulation software tools. Solphi Engineering has extensive experience using PVsyst, PlantPredict, as well as other modeling tools such as the System Advisor Model (SAM). Solphi Engineering finds the user interface simple to navigate, and highlights the following elements that facilitate user quality control:

- PlantPredict provides warnings during interim steps of the set-up and execution of predictions to assist users and mitigate errors. Some warnings are cautionary and will allow the user to proceed, while others will prevent the simulation from proceeding.

- PlantPredict provides expandable context windows for many user inputs directly at the data entry point in the Graphical User Interface (GUI). These provide quick references for users as they execute the workflow.

- PlantPredict provides a Prediction Status for each simulation which encourages users to adopt an engineering style approval workflow. A prediction status can be marked as Draft-Private, Draft-Shared, Analysis, Bid, Contract, Development, As Built, Warranty, Archived, or String-Sizing. When downloading prediction results, PlantPredict provides a warning if the prediction has not been set to a read-only status and exported results will be watermarked as a draft. This functionality encourages review cycles before exporting results.

4.2 Model Review

Solphi Engineering completed a detailed review of the PlantPredict *Models & Algorithms* documentation published on their website. Overall, Solphi Engineering found the documentation to be clear and comprehensive. The following sections provide a high-level summary of notable elements of the PlantPredict model and material findings from Solphi Engineering's review. This summary is not a substitute for reading the source documentation from PlantPredict.

4.2.1 Solar Position/Geometry

Critical to all PV simulation software is the determination of the sun relative to the PV module plane(s). The mathematical formulations for determining this relative position have been well documented for many decades and are generally not an area where PV simulation software providers are expected to differ materially. PlantPredict uses the National Lab of the Rockies (f.k.a. National Renewable Energy Laboratory) Solar Position Algorithm (SPA) as detailed in the technical report by Reda & Andreas 2004 [9]. PlantPredict's documentation details several simplifications made which PlantPredict describes as minor. The documentation provided by PlantPredict on their website appeared clear and comprehensive from Solphi Engineering's review.

Solphi Engineering notes that previous Independent Engineering reports of PlantPredict v3.x found the solar position and geometry methodology employed by PlantPredict to be acceptable. Based on a review of release notes from v3.x to v12.x Solphi Engineering is unaware of any changes to the solar position and geometry calculations that would result in a degradation of software accuracy since those previous Independent Engineering reports were published.

4.2.2 Module Orientation/Angle

For tracker systems, PV simulation software must model the module orientation and angle as it tracks the sun across the sky. PlantPredict provides a wide array of tracking models including: true-tracking, backtracking, terrain-aware backtracking, diffuse optimization, wind stow, and user-specified time series tracking angle schedules. This discussion focuses on Single-Axis-Tracker (SAT) applications.

True-tracking: Uses a tracking algorithm that rotates the modules to minimize the sun angle of incidence. The modules attempt to point towards the sun at all times within the tracking plane.

Backtracking: Modifies the true-tracking algorithm to prevent self-shading assuming a flat (or uniformly sloped) installation. When the sun position in the morning and afternoon is low enough that the true-tracking angle would cause tracker rows to shade one another, the actual tracker angle is reduced until row-to-row shading is no longer present.

Terrain-aware backtracking: Backtracking at the individual tracker level. This tracking algorithm is meant to avoid row-to-row shading accounting for the local terrain and adjacent trackers geometry. This assumes the tracker is capable of individual tracker control, and that the topography of the trackers is known to a reasonable approximation.

Diffuse Optimization (or Irradiance Optimization): Modifies the tracking algorithm to optimize POA irradiance. This is most commonly utilized under diffuse (cloudy) conditions where an angle that captures a larger view-factor of the sky may be optimal compared to a typical tracking algorithm that follows the expected position of the sun during clear sky conditions.

Wind stow: Moves the trackers into a safe stow position based on wind gust speed.

PlantPredict documentation describes implementing a tracker algorithm hierarchy where the higher priority algorithm overrides lower priority algorithms. Wind stow is given the highest priority, followed by diffuse optimization, backtracking, and true-tracking. As of v12, Terrain-aware backtracking cannot be utilized with irradiance optimization and wind stow. Solphi Engineering understands that PlantPredict is actively working on v13 which plans to include the ability to handle tracker algorithm hierarchy when using terrain-aware backtracking.

User-specified time series tracking angle schedules: Users can upload time series tracking angles schedules to bypass default tracking algorithms. These schedules can be set at the DC field level, or when the 3D scene is enabled at the tracker level.

Solphi Engineering reviewed the PlantPredict documentation detailing the models and algorithms employed for module orientation and angle and found them to be clear, comprehensive, and in general conformance with industry standards.

In Solphi Engineering's review of direct comparisons between PlantPredict and PVsyst across various project locations, no material discrepancies were identified with respect to true-tracking or backtracking angles.

Solphi Engineering notes that wind stow, diffuse optimization, and terrain-aware backtracking methodologies are often developed by tracker providers as proprietary models making it more difficult to validate PV simulation software models against actual plant data. Solphi Engineering considers it a positive that PlantPredict offers API integration with ArrayTechnologies for wind stow and diffuse optimization, as well as the ability for users to upload their own time series tracker angles schedules.

In reviewing the PlantPredict documentation for terrain-aware backtracking, Solphi Engineering noted that the algorithm assumes the tracker azimuth is North-South oriented. In correspondence with PlantPredict, Solphi Engineering was advised that the user can run terrain-aware backtracking with non-zero tracker azimuths (off the N-S azimuth). If users do so, additional uncertainty will be introduced which is difficult to quantify. Solphi Engineering recommended to PlantPredict to provide a warning to users in the event they proceed with modeling a terrain-aware backtracking system with an azimuth not aligned N-S.

Solphi Engineering also noted that the PlantPredict terrain-aware backtracking algorithm documentation details a tradeoff in the determination of the local cross-axis slope angle (a parameter calculated within the terrain-aware backtracking calculation procedure). The documentation notes that the most conservative methodology would eliminate shading entirely but result in more significant transposition losses. The documentation concludes that "empirical testing has shown [the implemented cross-axis slope angle calculation methodology] provides the best balance between shade mitigation and energy capture". Solphi Engineering requested if there were sources or citations available and was advised that this tradeoff was determined based on internal PlantPredict testing.

4.2.3 Transposition (2D and 3D)

For PV simulations that use a weather file with Ground Horizontal Irradiance (GHI) as the input, PlantPredict provides decomposition model options including the Erbs model, Reindl model, and DIRINT model.

These decomposition models break out Diffuse Horizontal Irradiance (DHI) and Direct Normal Irradiance (DNI) from GHI, which is a necessary step to allow for the execution of the transposition steps to determine Plane of Array (POA) irradiance. This decomposition step is not required in the event the user supplies a weather file with

GHI and DHI. When these are supplied in the weather file, DNI is calculated by PlantPredict using the closure equation[1]. If the weather file has GHI, DHI, and DNI available the user has the option to use these directly.

In reviewing the decomposition model documentation, Solphi Engineering noted that the upper clearness index threshold was specified as 0.83 which was a modification from the original published model value of 0.78 and was not supported with a citation. PlantPredict updated their documentation to provide a citation to Lave et al. (2014) which details this adjustment.

Solphi Engineering also noted that the DIRINT decomposition documentation indicates that the DIRINT correction coefficient calculation does not use precipitable water as a parameter. While it is understood that the DIRINT model has a set of coefficients when precipitable water is not available, if precipitable water is available in the weather file it would be beneficial to allow the user to implement the coefficients that were developed with this additional parameter. PlantPredict indicated that they would consider providing this capability in a future update to the software.

In the event the weather file supplies POA irradiance as the input, PlantPredict documentation indicates that the GTI-DIRINT algorithm is used to reverse-decompose GHI, DNI, and DHI.

Transposition in PlantPredict can be completed using the Hay-Davies model, or the Perez Model using a 2-dimensional geometry (e.g. uniform tilt and azimuth assuming a uniform slope). When users enable a 3D site-level scene within the project model, transposition is automatically completed using the pvlib[2] [8] implementation of the Perez transposition model to calculate POA irradiance for each tracker "bay[3]".

Solphi Engineering reviewed the PlantPredict transposition documentation in detail and considers the documentation clear and comprehensive. The 3D transposition process is complex, and the PlantPredict documentation should be reviewed for the comprehensive explanation. It is notable that to manage computational complexity, the 3D transposition calculates a weighted 3D-corrected global POA irradiance value for each time step by averaging bay-by-bay results and weighting the results by bay length. This allows the POA irradiance value passed through the model to reflect the variation across the array but does not carry bay-level POA irradiance through each step of the modeling process.

In Solphi Engineering's review of direct comparisons between PlantPredict and PVsyst across various project locations, no material discrepancies were identified with respect to Plane of Array irradiance transposed using the Perez model with generic coefficients.

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[1] See the PlantPredict *Horizontal Irradiance Components Pre-Processing* documentation on the PlantPredict website for further details.

[2] pvlib is described as a "community developed toolbox that provides a set of functions and classes for simulating the performance of photovoltaic energy systems and accomplishing related tasks".

[3] In PlantPredict, a bay is defined as a section of Single Axis Tracker corresponding to one torque tube segment, where all modules in the bay share the same tilt angle and follow the same rotation angle.

4.2.4 Bifacial Model

PlantPredict calculates the rear-side irradiance required for modeling bifacial PV modules using the 2D view factor model developed by Marion et al. [10] As noted in the *PVPMC Photovoltaic Modeling Software Blind Performance Assessment* [1], this model is also used by the System Advisor Model (SAM). The bifacial model is based on an assumed infinite array on flat terrain and calculates the sky view factor of the rear-side as well as ground shading across 100 discrete intervals. Irradiance on the rear-side of the module is calculated at six intervals across the module (as rear-irradiance is not spatially uniform). Once rear-side irradiance is calculated, a total effective POA irradiance is calculated as the sum of the front-side POA irradiance and the product of the rear-side POA irradiance and the module bifaciality factor.

4.2.5 Optical Losses

PlantPredict provides multiple models for calculating optical losses (Incidence Angle Modifier losses) associated with light reflecting off the module glass. These models include the ASHRAE model, Sandia model, Physical model, and a custom cubic spline model referred to in the user interface as the “Tabular IAM” option. The custom cubic splice model requires an Incidence Angle Modifier (IAM) table to be provided within the module file and the cubic spline interpolation allows PlantPredict to estimate the IAM response across all necessary angles.

4.2.6 PV Cell Temperature

PlantPredict allows the user to select one of three PV cell temperature models or provide measured back-of-module surface temperature data from a time series file. The Heat Balance model (referred to by Deville et al. as the PVsyst model), the Sandia model, and the NOCT-SAM model are well documented in the literature. Solphi Engineering notes that PlantPredict does not currently offer a transient temperature model.

4.2.7 Module IV Curve

PlantPredict calculates the module’s current-voltage (IV) curve using the Single Diode Model (referred to by Deville et al. as the PVsyst SDM model). The 5-parameter or 7-parameter model is used depending on the definitions and data provided in the module file. The PVsyst SDM was the most frequently implemented model for software providers referenced in the *PVPMC Photovoltaic Modeling Software Blind Performance Assessment*.

4.2.8 DC Ohmic Losses

PlantPredict calculates DC Ohmic losses to capture resistive power loss from DC cabling in the PV system. This loss is calculated based on operating current using Ohms law (Ohmic Loss = I^2R). PlantPredict translates a user-specified DC Ohmic loss percentage value (defined at the nominal operating point) into a series resistance at the module level. This methodology effectively integrates the DC cabling resistance into the IV curve for the system.

4.2.9 Other DC Losses

PlantPredict allows for additional DC derates to be applied based on user specifications including: DC Degradation losses, module mismatch, Light-Induced Degradation, Module Quality Factor, DC health, rear-side module mismatch, rear-side shading.

4.2.10 Inverter Efficiency

As of version 11, PlantPredict uses the Sandia Polynomial Model for inverter efficiency curves unless the inverter file has fewer than three inverter efficiency curves available (in which case the Bilinear interpolation model is used). PlantPredict release notes for version 11 indicated that the Bilinear model resulted in inverter efficiency curves that were too steep, resulting in more efficiency losses. Solphi Engineering notes that inverter efficiency curves using the method employed in v11 appeared to be in good agreement when compared to other PV simulation software providers in the Deville et al. study.

4.2.11 AC Ohmic Losses

These are referred to as AC Collection losses in the PlantPredict documentation. As of v12 these losses are calculated quadratically proportional with Ohms law (Ohmic Loss = I^2R). The user input AC loss percentage at full system power is multiplied by the square of AC output power divided by the nameplate AC power.

4.2.12 Auxiliary Losses

PlantPredict provides options for the user to specify auxiliary loads associated with tracker motor operation, data acquisition system loads, and inverter cooling loads. These losses are applied to the AC power before transformer losses.

4.2.13 Transformer Losses

PlantPredict allows the user to include transformer losses within the simulation. The calculation of transformer loss includes no-load losses which are independent of system power and full-load losses which are proportional to the square of current per Ohms law.

4.2.14 Gen-tie Losses

PlantPredict enables users to specify a transmission line loss by inputting a gen-tie line length, a cable resistance value, and the number of conductors per phase. Based on these inputs, PlantPredict calculates a total gen-tie line resistance value and applies Ohms law to calculate the gen-tie losses.

4.2.15 Power Factor

PlantPredict allows the user to specify an Inverter Design Derate as a representative power factor specification for each inverter. This is defined as the ratio of the inverter real output power and the inverter apparent power rating.

PlantPredict documentation indicates that this value is used to estimate the higher current on the gen-tie line associated with off-unity Power Factor operation. This higher current results in higher gen-tie line losses.

Solphi Engineering notes that it is common for PV plants to rely on the reactive power capabilities of inverters (both for distribution-connected projects and transmission-connected projects). Solphi Engineering understands that the AC collection losses do not account for off-unity Power Factor operation, which would result in an underestimation of AC collection losses in the event the inverters are required to operate at a non-unity Power Factor.

4.2.16 Availability

PlantPredict provides a user input for an availability loss, applied as a percentage deduction to the final output power of the system.

4.2.17 Grid Limit

PlantPredict allows the user to define a grid limit that will curtail any power exceeding the defined limit. This can either be a constant fixed power limit, or a time series schedule which defines the limit per time step. The user can also disable the grid limit function if not applicable.

4.2.18 Model Conclusion

Based on a detailed review of the PlantPredict documentation, Solphi Engineering considers the PlantPredict PV simulation software to be aligned with industry best practices. Solphi Engineering considers the clear and comprehensive documentation provided by PlantPredict to be an asset for its use in the development, design, and financing of PV systems.

5 PVSYST SIMULATION COMPARISON

PlantPredict engaged several Independent Engineers in 2016 and 2017 to benchmark v3.x and v4.x of the PlantPredict software against PVsyst software. The overall findings from these IE reviews were that PlantPredict appeared to be a capable PV simulation software tool with performance consistent with industry expectations for bankability.

Solphi Engineering was engaged to complete an updated comparison between PlantPredict and PVsyst based on the evolution of both tools since the original IE reports were issued. Solphi Engineering ran a variety of simulations using PlantPredict version 12.24.0, 12.25.0, and 12.26.0[4] as well as PVsyst version 8.1.1 and 8.1.2.

Simulations were run at three representative site locations: Desert Rock, Nevada in the United States; Jaén, Jaén, Spain; and Wellington, New South Wales, Australia.

Each project location included simulations of bifacial crystalline silicon modules installed on Single-Axis-Trackers (SAT) using the backtracking algorithm, CdTe modules installed on Single-Axis-Trackers using the true-tracking algorithm, and bifacial crystalline silicon modules installed on a fixed-tilt racking system.

As PVsyst released version 8.1.0 during Solphi Engineering's execution of the review scope, which integrated the capability for PVsyst to natively simulate at sub-hourly time steps for the first time, the Desert Rock location was used to compare sub-hourly simulation performance using SURFRAD ground station data from the SURFRAD [11] Desert Rock location.

Other minor variations studied included an assessment of the Jaén located fixed-tilt system with an imported horizon line (as this project location had a non-trivial horizon line), a simulation of the Jaén location with a lower 1.2 DC/AC ratio to compare results when inverter clipping was not significant, a simulation with a complex topography and 3D scene at Desert Rock, and CdTe simulations with and without spectral correction included.

A full table of simulations variations is included for reference on the next page (Table 1 & Table 2).

[4] Solphi Engineering understands that PlantPredict's versioning policy is to keep the prediction engine fixed between major version numbers (e.g. v11, v12) so v12.24.0, v12.25.0, and v12.26.0 should all produce replicable results for the same inputs.

PROJ NO	VARIANT NO	SUB-VARIANT	PROJECT SITE NAME	LAT	LONG	REGION	MODULE TYPE	TRACKER TYPE	TRACKER MODE	DC/AC RATIO	HORIZON LINE	DC (MW)	AC (MW)	TIMESTEP	WEATHER FILE TYPE	WEATHER FILE	SHADE SCENE?	DC LOSSES	SPECTRAL CORR
1	A	1	JAEN	37.84	-3.79	EU	BIFI PERC	SAT (1P)	BACKTRACK	1.4	NONE	10.0	7.14	HOURLY	TMY	NSRDB	N	N	N
1	A	2	JAEN	37.84	-3.79	EU	BIFI PERC	SAT (1P)	BACKTRACK	1.2	NONE	8.6	7.14	HOURLY	TMY	NSRDB	N	N	N
1	B	1	JAEN	37.84	-3.79	EU	FS (CdTe)	SAT (1P)	TRUE TRACK	1.4	NONE	10.0	7.14	HOURLY	TMY	NSRDB	N	N	N
1	B	2	JAEN	37.84	-3.79	EU	FS (CdTe)	SAT (1P)	TRUE TRACK	1.4	NONE	10.0	7.14	HOURLY	TMY	NSRDB	N	N	Y
1	C	1	JAEN	37.84	-3.79	EU	BIFI PERC	FIXED	N/A	1.4	NONE	10.0	7.14	HOURLY	TMY	NSRDB	N	N	N
1	C	2	JAEN	37.84	-3.79	EU	BIFI PERC	FIXED	N/A	1.4	INCLUDED	10.0	7.14	HOURLY	TMY	NSRDB	N	N	N
2	A	1	DESERT ROCK	36.65	-116.04	USA	BIFI PERC	SAT (1P)	BACKTRACK	1.4	NONE	10.0	7.14	HOURLY	TMY	NSRDB	N	N	N
2	A	1B	DESERT ROCK	36.65	-116.04	USA	BIFI PERC	SAT (1P)	BACKTRACK	1.4	NONE	10.0	7.14	1 MIN	2018	SURFRAD	N	N	N
2	A	1C	DESERT ROCK	36.65	-116.04	USA	BIFI PERC	SAT (1P)	BACKTRACK	1.4	NONE	10.0	7.14	HOURLY	2018	SURFRAD	N	N	N
2	A	2	DESERT ROCK	36.65	-116.04	USA	BIFI PERC	SAT (1P)	BACKTRACK	1.4	NONE	10.0	7.14	HOURLY	TMY	NSRDB	Y	N	N
2	A	3	DESERT ROCK	36.65	-116.04	USA	BIFI PERC	SAT (1P)	BACKTRACK	1.4	NONE	10.0	7.14	HOURLY	TMY	NSRDB	Y	N	N
2	A	4	DESERT ROCK	36.65	-116.04	USA	BIFI PERC	SAT (1P)	BACKTRACK	1.4	NONE	10.0	7.14	HOURLY	TMY	NSRDB	Y	N	N
2	B	1	DESERT ROCK	36.65	-116.04	USA	FS (CdTe)	SAT (1P)	TRUE TRACK	1.4	NONE	10.0	7.14	HOURLY	TMY	NSRDB	N	N	N
2	B	2	DESERT ROCK	36.65	-116.04	USA	FS (CdTe)	SAT (1P)	TRUE TRACK	1.4	NONE	10.0	7.14	HOURLY	TMY	NSRDB	N	N	Y
2	C	1	DESERT ROCK	36.65	-116.04	USA	BIFI PERC	FIXED	N/A	1.4	NONE	10.0	7.14	HOURLY	TMY	NSRDB	N	N	N
4	A	1	WELLINGTON	-32.51	148.95	AUS	BIFI PERC	SAT (1P)	BACKTRACK	1.4	NONE	10.0	7.14	HOURLY	TMY	NSRDB	N	N	N
4	B	1	WELLINGTON	-32.51	148.95	AUS	FS (CdTe)	SAT (1P)	TRUE TRACK	1.4	NONE	10.0	7.14	HOURLY	TMY	NSRDB	N	N	N
4	B	2	WELLINGTON	-32.51	148.95	AUS	FS (CdTe)	SAT (1P)	TRUE TRACK	1.4	NONE	10.0	7.14	HOURLY	TMY	NSRDB	N	N	Y
4	C	1	WELLINGTON	-32.51	148.95	AUS	BIFI PERC	FIXED	N/A	1.4	NONE	10.0	7.14	HOURLY	TMY	NSRDB	N	N	N
4	D	1	WELLINGTON	-32.51	148.95	AUS	BIFI PERC	FIXED	N/A	1.4	NONE	10.0	7.14	HOURLY	TMY	NSRDB	N	Y	N

Table 1: Simulation scenario summary table

SCENARIO	SITE	PVSYST GlobInc (MWh/m²)	PP Global POAI (MWh/m²)	Δ POA pair %	PP 3D Corrected (MWh/m²)	Δ POA pair w/ 3D %	PVSYST EArrMPP (MWh)	PP DC Power at MPP (MWh)	Δ DC MPP %	PVSYST EOutInv (MWh)	PP Total AC Power from Inv (MWh)	Δ AC Inv %
1A1	JAEN	2.373	2.374	0.06%	2.374	0.06%	22,010	22,198	0.85%	19,791	19,974	0.93%
1A2	JAEN	2.373	2.374	0.06%	2.374	0.06%	18,893	19,054	0.85%	18,208	18,382	0.96%
1B1	JAEN	2.537	2.522	-0.58%	2.522	-0.58%	21,291	21,380	0.42%	19,388	19,482	0.49%
1B2	JAEN	2.537	2.522	-0.58%	2.522	-0.58%	21,355	21,443	0.41%	19,338	19,441	0.53%
1C1	JAEN	2.056	2.056	0.01%	2.056	0.01%	19,137	19,004	-0.69%	17,592	17,569	-0.13%
1C2	JAEN	2.056	2.056	0.01%	2.056	0.01%	19,060	18,990	-0.37%	17,519	17,555	0.21%
2A1	DESERT ROCK	2.815	2.813	-0.06%	2.813	-0.06%	26,114	26,228	0.44%	22,765	22,890	0.55%
2A1B	DESERT ROCK	2.741	2.735	-0.22%	2.735	-0.22%	25,508	25,570	0.24%	22,151	22,265	0.51%
2A1C	DESERT ROCK	2.745	2.742	-0.10%	2.742	-0.10%	25,557	25,664	0.42%	22,471	22,588	0.52%
2A2	DESERT ROCK	2.834	2.813	-0.73%	2.829	-0.17%	26,103	25,864	-0.92%	22,656	22,500	-0.69%
2A3	DESERT ROCK	2.905	2.813	-3.14%	2.882	-0.80%	24,879	24,571	-1.24%	21,617	21,512	-0.49%
2A4	DESERT ROCK	2.905	2.822	-2.84%	2.891	-0.48%	24,879	24,624	-1.03%	21,617	21,558	-0.28%
2B1	DESERT ROCK	3.065	3.061	-0.11%	3.061	-0.11%	25,536	25,549	0.05%	22,576	22,624	0.21%
2B2	DESERT ROCK	3.065	3.061	-0.11%	3.061	-0.11%	25,153	25,179	0.10%	22,324	22,373	0.22%
2C1	DESERT ROCK	2.407	2.407	-0.01%	2.407	-0.01%	22,416	22,220	-0.87%	20,030	19,983	-0.24%
4A1	WELLINGTON	2.514	2.515	0.02%	2.515	0.02%	23,509	23,665	0.66%	20,694	20,851	0.76%
4B1	WELLINGTON	2.726	2.727	0.02%	2.727	0.02%	22,812	22,915	0.45%	20,344	20,449	0.52%
4B2	WELLINGTON	2.726	2.727	0.02%	2.727	0.02%	22,887	22,976	0.39%	20,294	20,396	0.50%
4C1	WELLINGTON	2.166	2.166	0.00%	2.166	0.00%	20,318	20,150	-0.83%	18,363	18,324	-0.21%
4D1	WELLINGTON	2.166	2.166	0.00%	2.166	0.00%	19,440	19,282	-0.81%	17,959	17,912	-0.26%

Table 2: Simulation results summary table

In total, 20 simulations variants were conducted using PlantPredict and PVsyst for comparison as shown on Table 1. A summary table of annual AC Inverter output energy is provided for all simulation variants in Table 2. AC Inverter output energy was selected as the comparison variable as Solphi Engineering's experience is that it is common for Independent Engineers and PV performance modelers to apply AC to POI derates in post-processing.

In addition to comparing annual results for AC Inverter output energy, Solphi Engineering reviewed representative daily plots of POA irradiance, DC MPP array power, and AC Inverter output power on clear days, partly cloudy days, and cloudy days. Based on reviewing these plots for all variants, a sample of representative plots and discussion have been provided to illustrate Solphi Engineering's findings from the simulation comparison.

5.1 Scenario 1B1 & 1B2 – JAEN – CdTe – SAT – Spectral Correction ON/OFF

In this scenario, a comparison of results is made with spectral correction off, and spectral correction on for the CdTe First Solar module system. The spectral correction coefficients were selected based on the two-variable model within PlantPredict, and the "CdTe FirstSolar Series 4-2 and later" coefficient set within PVsyst. Review of the documentation for both software tools indicate the same coefficients are used.

Side by side comparisons of a cloudy day and a clear sky day for Scenario 1B1 (spectral correction off) and Scenario 1B2 (spectral correction on) indicates visually very little discrepancy in results between PlantPredict and PVsyst:

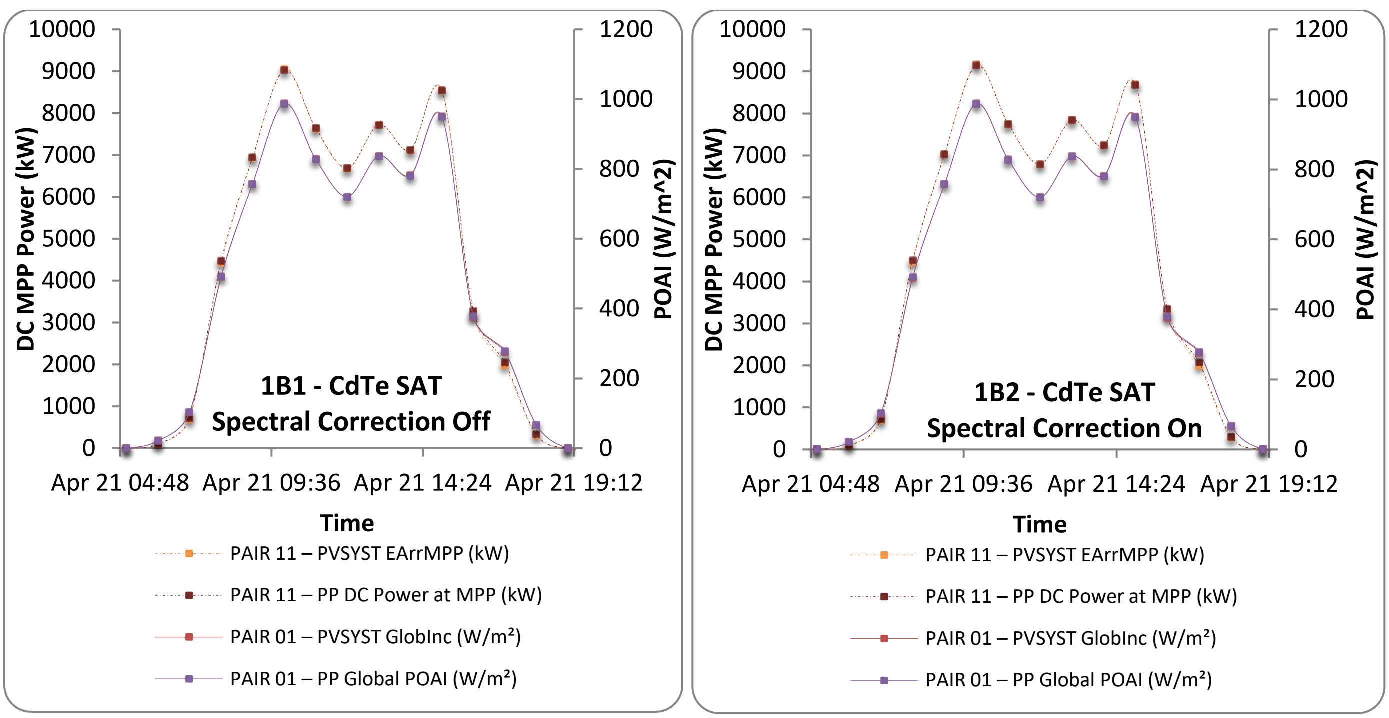


Figure 1- Plots of Plane of Array Irradiance (POAI) and DC Maximum Power Point Power on a cloudy day (with spectral correction off on the left plot and on for the right plot).

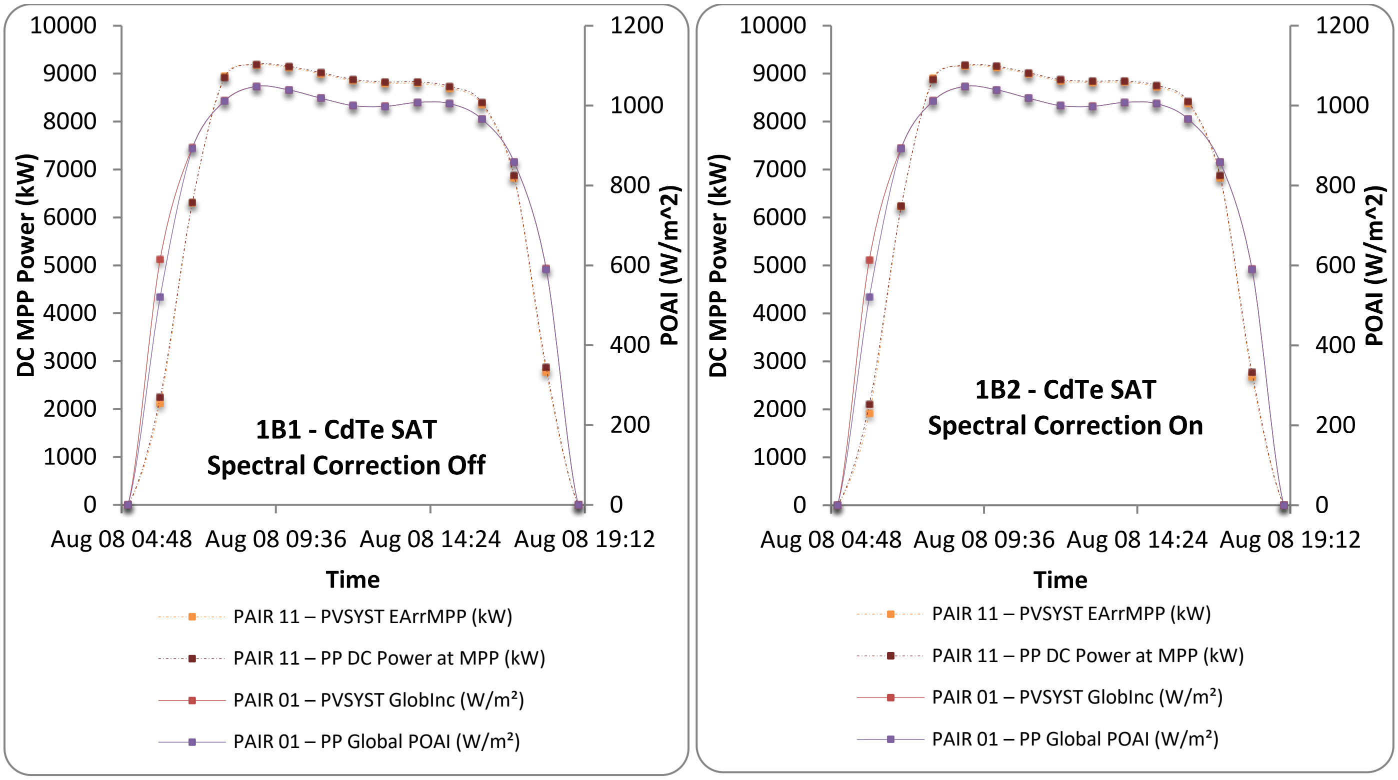


Figure 2- Plots of POA irradiance and DC Maximum Power Point Power on a clear day (with spectral correction off on the left plot and on for the right plot).

When Solphi Engineering compared the total DC MPP array energy per day, as well as annually, it was observed that the percent change between PVsyst with and without spectral correction, and PlantPredict with and without spectral correction are closely aligned:

PERIOD	TOOL	1B1 DC MPP Energy (MWh)	1B2 DC MPP Energy (MWh)	% Delta
CLOUDY	PlantPredict	64.64	65.49	1.31%
CLOUDY	PVsyst	64.36	65.26	1.40%
CLEAR	PlantPredict	98.24	97.94	-0.31%
CLEAR	PVsyst	97.77	97.41	-0.38%
Annual	PlantPredict	21,380	21,443	0.29%
Annual	PVsyst	21,291	21,355	0.30%

Table 3 - Comparison of Scenario 1B1 and 1B2 DC MPP Energy across different daily sky conditions, as well as annual results

5.2 SCENARIO 1C1 & 1C2 – JAEN – BIFACIAL – FIXED – HORIZON LINE IMPORT

The Jaén, Spain project location included a non-trivial horizon line as it is located in the mountainous region of Andalusia. This scenario comparison evaluated results between PlantPredict and PVsyst when a horizon line is imported into the energy simulation. It was noted in some of the 2016/17 IE reports that PVsyst and PlantPredict took notably different approaches to calculating horizon shading (far shading).

PERIOD	TOOL	1C1 DC MPP Energy (MWh) – no horizon line	1C2 DC MPP Energy (MWh) – with horizon line	% Delta
Annual	PlantPredict	19,004	18,990	-0.08%
Annual	PVsyst	19,137	19,060	-0.40%
30-Dec	PlantPredict	44.69	44.43	-0.57%
30-Dec	PVsyst	46.36	45.22	-2.44%

Table 4 - Annual DC MPP Energy and total energy on a clear day (December 30th) with and without a horizon line imported. Scenario 1C2 includes a horizon line, whereas no horizon line was imported in Scenario 1C1.

Annual result comparisons align with comparisons of a clear sky day on December 30th, PVsyst determines a more significant loss due to the horizon line than PlantPredict. Solphi Engineering reviewed PVsyst release notes highlighting some corrections to how the horizon (far shading) calculations were performed within PVsyst. Solphi Engineering understands that the PlantPredict horizon shading calculation accounts for direct (beam) shading but not diffuse shading. It would be expected that the lack of diffuse horizon shading would be most pronounced in instances where the sun path is behind the array (a common occurrence at sunrise and sunset at higher latitude project locations like Jaén). The results appear generally consistent with this scenario, where diffuse POA irradiance dominates and PlantPredict would not capture diffuse horizon shading. PlantPredict has indicated to Solphi Engineering that they plan to include the effect of horizon shading on diffuse irradiance in a future v13 release.

5.3 SCENARIO 2A1B & 2A1C – DESERT ROCK – BIFACIAL – SAT – SURFRAD DATA

All other scenarios studied used TMY files from the National Solar Radiation Database (NSRDB). For Scenario 2A1B and 2A1C ground station data from the SURFRAD Desert Rock location was downloaded for an example year. The year 2018 was selected based on high data completeness (>99.8% for all required input variables), with a simple data filling procedure for the ~0.2% of missing data[5]. Scenario 2A1B used the 1-minute native SURFRAD resolution weather data. Scenario 2A1C used the same data, converted to 1-hour time steps.

[5] For the small number of data points with missing data, data was filled using linear interpolation between data gaps for weather data: temperature, relative humidity, pressure, and wind speed (including across the largest gap of 7.7 hours). For irradiance variables: GHI, DNI, DHI, short gaps less than 5 minutes were filled by linear interpolation and a single large data gap of 7.7 hours was filled using hourly NSRDB data for 2018. The impact to the overall simulation for this rudimentary correction is expected to be minimal, however individual day results were not plotted on the large data gap date (March 29) as this day's results are not real sub-hourly data.

Annual metrics for Scenario 2A1B suggest strong agreement between the PlantPredict and PVsyst simulations at the 1-minute time step as summarized in Table 5:

SCENARIO 2A1B – 1-minute time step				
PERIOD	Metric	PVsyst	PlantPredict	Delta %
Annual	POAI (kWh/m^2)	2,741	2,735	-0.2%
Annual	DC MPP Energy (MWh)	25,508	25,570	0.2%
Annual	Inverter Output Energy (MWh)	22,151	22,265	0.5%

Table 5 - Annual sub-hourly simulation results at Desert Rock using 2018 SURFRAD data

As another method of comparing the results, a 1:1 plot of PVsyst Inverter output power and PlantPredict Inverter output power for each 1-minute time step over the year was compared in Figure 3. A regression line fit through the data suggests good agreement with an R^2 value of 0.9997 and a slope of 0.9914.

Reviewing the same annual metrics for Scenario 2A1C with hourly data in Table 6, agreement remains strong between both PV simulation software simulations. Solphi Engineering notes that the PlantPredict POA irradiance is unchanged between 1-minute simulations and 1-hour simulations, whereas the PVsyst POA irradiance increases slightly at the hourly time step. Solphi Engineering understands that the recent PVsyst capability to model at sub-hourly time steps has been coupled with updated Perez transposition coefficients tuned for sub-hourly applications [12]. This suggests hourly and sub-hourly simulations in PVsyst may be based on slightly different transposition calculations resulting in this small discrepancy.

SCENARIO 2A1C – 1-hour time step				
PERIOD	Metric	PVsyst	PlantPredict	Delta %
Annual	POAI (kWh/m^2)	2,745	2,742	-0.1%
Annual	DC MPP Energy (MWh)	25,557	25,664	0.4%
Annual	Inverter Output Energy (MWh)	22,471	22,588	0.5%

Table 6 - Annual hourly simulation results at Desert Rock using 2018 SURFRAD data

The hourly 1:1 plot of PVsyst Inverter output power and PlantPredict Inverter output power shown in Figure 4 has a slightly improved R^2 value of 0.9999 and a slope of 1.0012. It is unclear if differences in transposition coefficients between sub-hourly and hourly simulations in PVsyst contribute to the regression fit differences over these two time steps, or if these small differences are a product of the overall smoothing effect of the 1-hour time step.

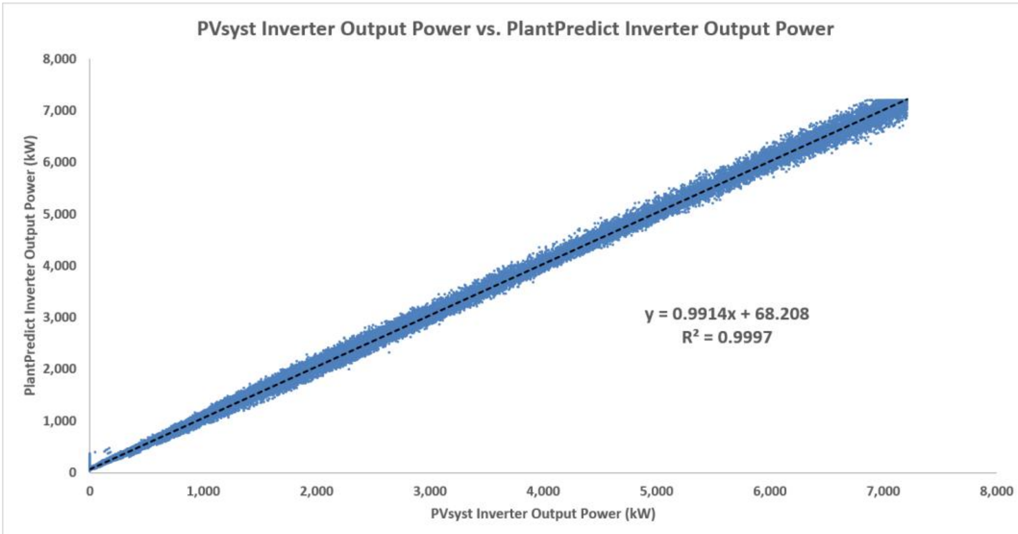


Figure 3 – 1:1 plot of Scenario 2A1B Inverter output power from PVsyst and PlantPredict showing strong correlation for the 1-minute data sub-hourly simulations.

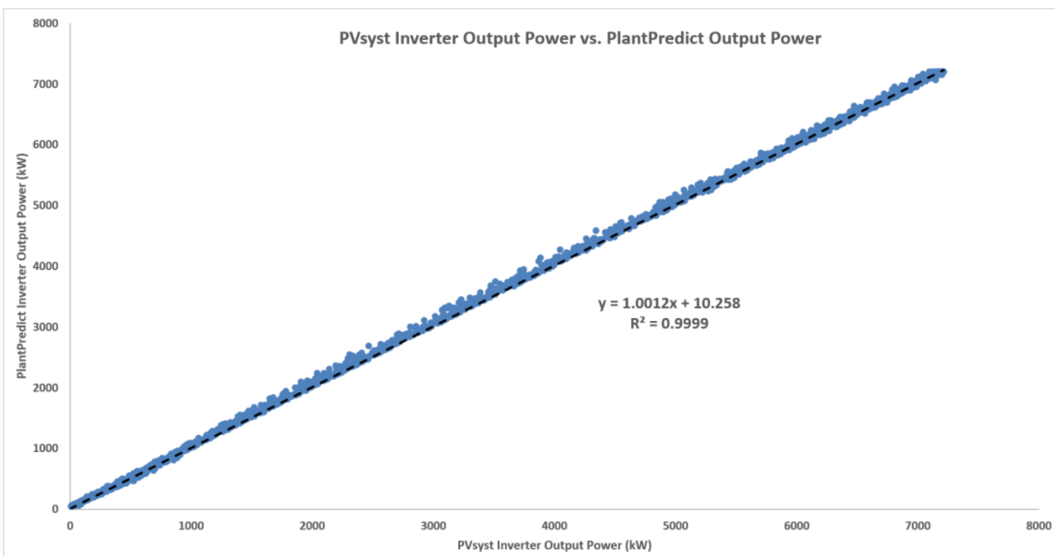


Figure 4 - 1:1 plot of Scenario 2A1C Inverter output power from PVsyst and PlantPredict showing strong correlation for the hourly simulations.

5.4 Scenario 2A3 & 2A4 – DESERT ROCK – Bifacial – SAT – Complex Terrain

Desert Rock was an interesting project location, not only because of the availability of nearby SURFRAD 1-minute ground station weather data, but also due to a stark contrast between flat desert terrain and nearby complex topography. Solphi Engineering constructed an array using the PlantPredict "Build on the Map" feature which creates an array of trackers that follow the topography of the terrain.

An isometric view of the PlantPredict model is shown in Figure 5, along with a heat map view. This model was exported as a PV Collada (PVC) file and imported into PVsyst. The PVsyst import isometric view is shown in Figure 6.

Solphi Engineering notes that attempts to develop a large-scale scenario comparison using a 3D scene of a 1GW system were not practical given limitations within PVsyst to manage 3D scenes of this size. Solphi Engineering found PlantPredict capable of generating a 1GW 3D scene and running the full simulation calculation process. Replicating the same within PVsyst was not found to be achievable with our workstation hardware. PVsyst online documentation notes that "shed construction may be unfeasible with a very big number of rows (say, more than several hundreds)".

Scenario 2A3 compared PlantPredict and PVsyst results based on standard backtracking with this complex 3D scene. It would be expected that this type of terrain would lead to row-to-row shading from trackers that are following a standard backtracking algorithm (which assumes flat terrain in the case of PVsyst or uniformly sloped terrain in the case of PlantPredict). In this scenario, electrical shading losses would also be anticipated.

The modules were configured in a single-module-in-portrait configuration, and the module specified has a half-cell construction. In PlantPredict, Solphi Engineering specified the Direct Shading calculation for the 3D scene as "Step Fractional Electrical Shading" with 2 steps per bay (to reflect the module half-cell design). In PVsyst, tracker partitioning was defined with 2 rectangles wide, and 28 rectangles in length (consistent with the 28 module long tracker rows constructed in the original PVC file). Electrical effect was set to 100% in PVsyst, an equivalent modifier is not provided in PlantPredict.

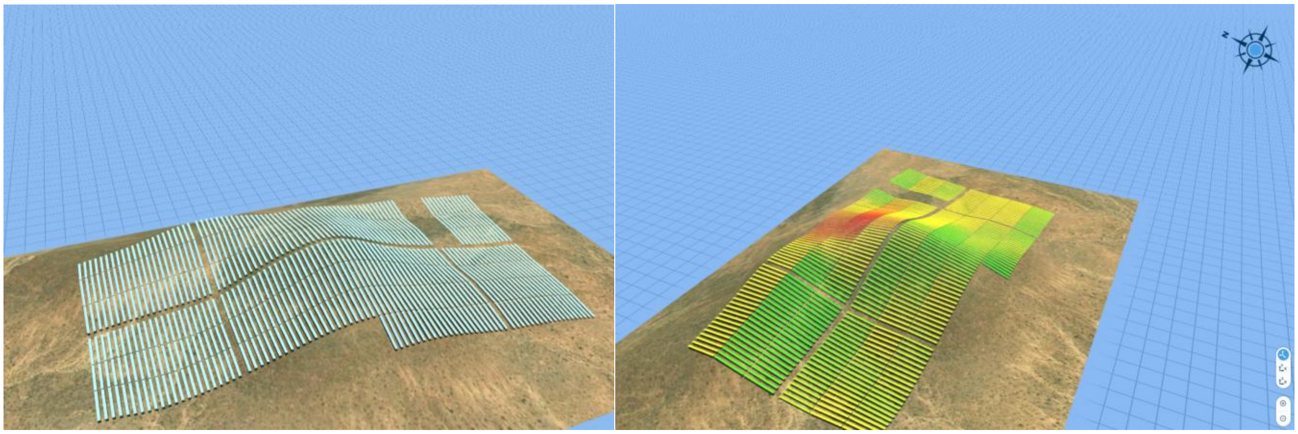


Figure 5 - Isometric view of Desert Rock complex 3D scene, constructed via PlantPredict's "Build on Map" feature as well as a heat map view showing distribution of POAI impact. Red areas indicate relative reductions in POAI and green areas indicate relative increases in POAI. The heat map suggests on average more of the array is sloped southwards than northwards.

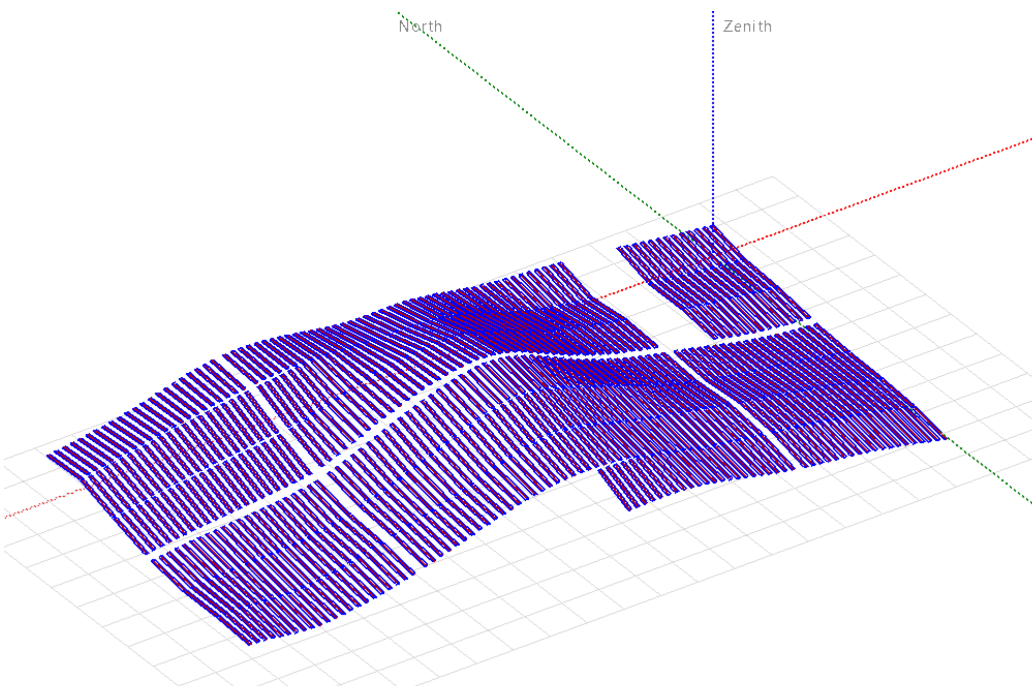


Figure 6 - Isometric view of the Desert Rock complex 3D scene, imported as a PVC file into PVsyst from PlantPredict

One observation from Scenario 2A3 is that PlantPredict reports a Global POA irradiance before any 3D correction, as well as the 3D-corrected POA irradiance. PVsyst provides GlobInc as the POA irradiance transposed based on the representative tracker configuration.

Plots comparing PVsyst GlobInc and PlantPredict 3D-Corrected POA irradiance are provided for cloudy, partly cloudy, and clear days in both summer and winter months in Figure 7. Plot axes have been compressed to provide a clearer picture of the differences. It appears that the largest differences in POA irradiance occur in winter months, regardless of if conditions are clear or diffuse.

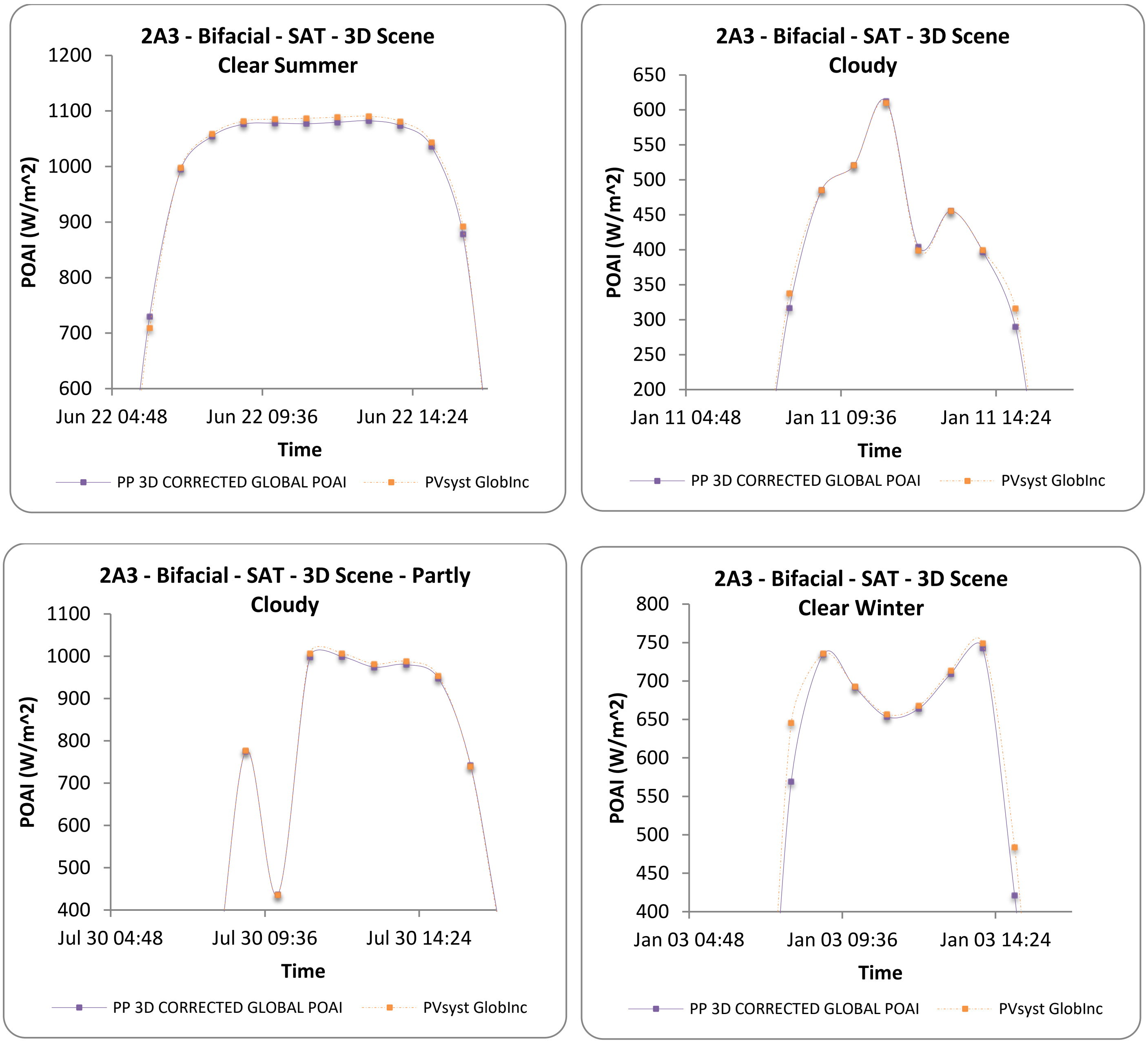


Figure 7 - Zoomed in plots of PVsyst and PlantPredict POA irradiance on clear summer, cloudy, partly cloudy, and clear winter days

Results are summarised in Table 7 below for total daily POA irradiance and annual POA irradiance values for Scenario 2A3.

PERIOD	2A3 – PVsyst POAI	2A3 PlantPredict - 3D POAI	% Delta (PVsyst-PP 3D POAI)
CLOUDY	3.58	3.53	-1.4%
PARTLY CLOUDY	7.77	7.80	0.4%
CLEAR (SUMMER)	11.91	11.91	0.0%
CLEAR (WINTER)	5.45	5.28	-3.2%
ANNUAL	2,905	2,882	-0.8%

Table 7- Scenario 2A3 daily and annual POAI totals (all values in units of kWh/m^2).

A single plot of the same clear winter day is provided in Figure 8 comparing PVsyst and PlantPredict DC MPP system power. The DC power at Maximum Power Point for both software tools incorporates 3D shading and electrical effect. As summarized in Table 8, PlantPredict DC MPP Energy is substantially lower in clear sky conditions and on an annual basis. For clear sky conditions where beam irradiance dominates, the PlantPredict 3D shading and electrical loss methodology appears to result in greater losses than PVsyst in this example.

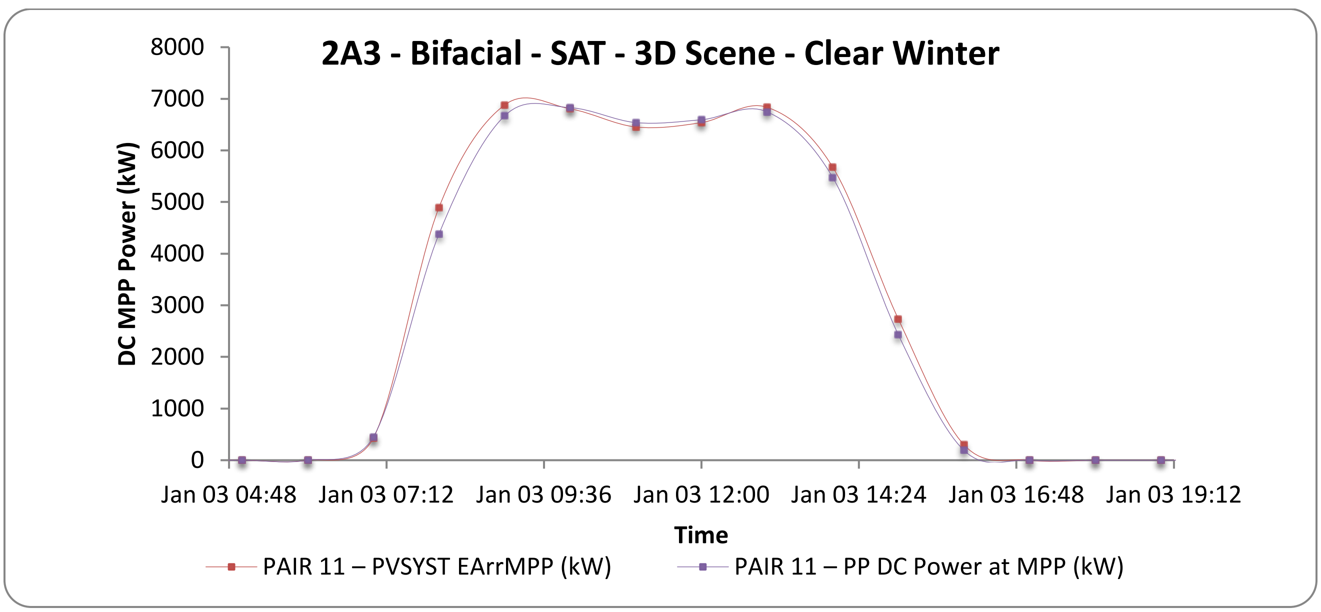


Figure 8 - Comparison of DC MPP Power on a clear winter day between PVsyst and PlantPredict

PERIOD	2A3 – PVsyst - DC MPP Energy (MWh)	2A3 - PlantPredict DC MPP Energy (MWh)	% Delta (PVsyst-PlantPredict)
CLOUDY	32.30	32.88	1.8%
PARTLY CLOUDY	66.86	66.83	0.0%
CLEAR (SUMMER)	100.52	98.60	-1.9%
CLEAR (WINTER)	47.55	46.31	-2.6%
ANNUAL	24,879	24,571	-1.2%

Table 8- Scenario 2A3 daily and annual DC MPP Energy totals

To isolate the possible effects of tracker algorithms on the results of Scenario 2A3, the PVsyst backtracking angle time series schedule was fed back into PlantPredict for Scenario 2A4. In 2A3 and 2A4 the PVsyst results are the same, but the PlantPredict results in 2A4 use the PVsyst tracker angles.

Table 9 indicates that overall, the PlantPredict 3D-corrected POA irradiance was brought closer to PVsyst POA irradiance values when using the PVsyst tracker angle schedule. Table 10 also shows that while this closer POA irradiance alignment improved agreement in annual DC MPP Energy by a similar amount, individual daily totals continued to show >2% disagreement on certain days.

In some conditions PlantPredict results are greater than PVsyst, and in some conditions they are less. Isolating the fundamental drivers of this behavior is challenging given the complexity of the 3D scene. Based on the annual results, it appears that this variance acts as a noise signal, with annual differences in DC MPP Energy of ~1.0% suggesting non-trivial differences between the two software tools but also well within model variations quoted by Deville et al.

PERIOD	2A4 - PVsyst POAI	2A4 - PlantPredict 3D CORR POAI	% Delta (PVsyst-PlantPredict)
CLOUDY	3.58	3.59	0.3%
PARTLY CLOUDY	7.82	7.78	-0.5%
CLEAR (SUMMER)	11.91	11.83	-0.7%
CLEAR (WINTER)	5.45	5.42	-0.6%
ANNUAL	2,905	2,891	-0.5%

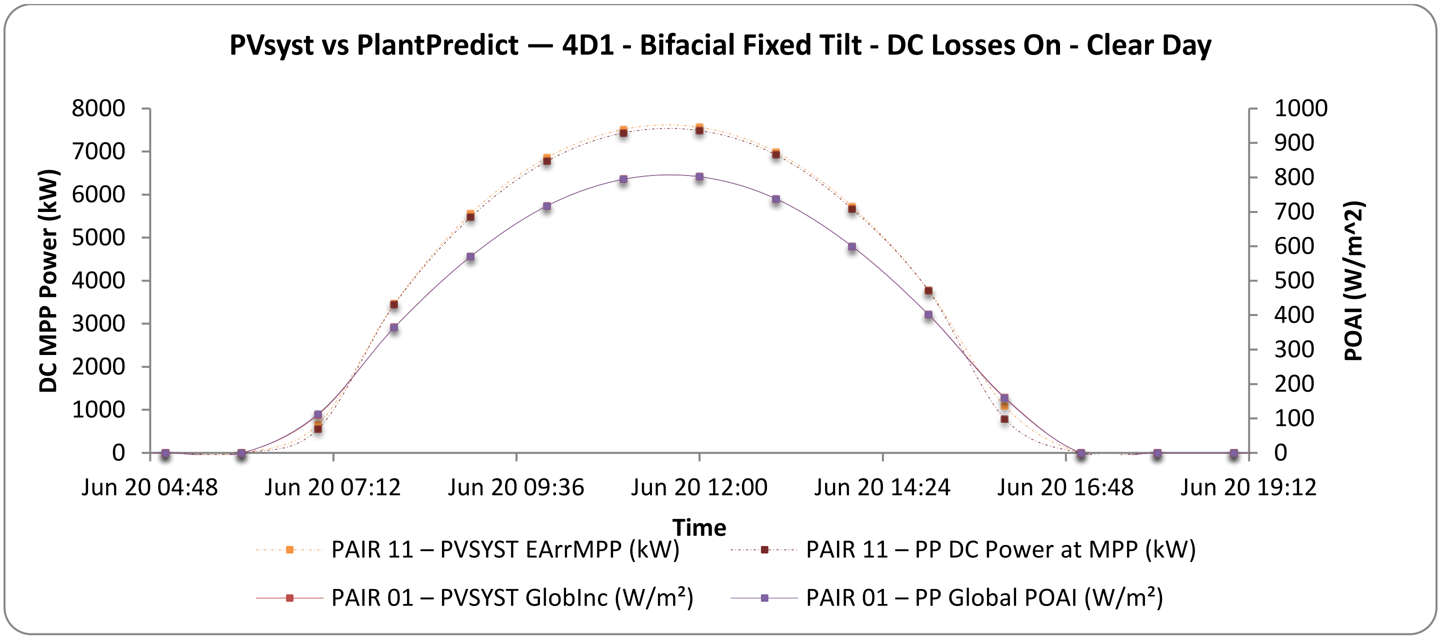
Table 9- Scenario 2A4 daily and annual POAI totals (all values in units of kWh/m^2).

PERIOD	2A4 - PVsyst DC MPP Energy (MWh)	2A4 - PlantPredict DC MPP Energy (MWh)	% Delta (PVsyst-PlantPredict)
CLOUDY	32.30	33.17	2.6%
PARTLY CLOUDY	66.86	66.79	-0.1%
CLEAR (SUMMER)	100.52	98.31	-2.2%
CLEAR (WINTER)	47.55	46.98	-1.2%
ANNUAL	24,879	24,624	-1.0%

Table 10- Scenario 2A4 daily and annual DC MPP Energy totals

5.5 Scenario 4C1 & 4D1– WELLINGTON – Bifacial – Fixed – DC Losses on/off

In this scenario, a comparison of results is made with DC losses not included, and with DC losses turned on. This included a 1.5% Light Induced Degradation loss assumption, a -0.4% Module Quality Loss (gain with negative sign), a 1.2% Mismatch loss assumption, a 1.5% DC Ohmic loss at STC assumption, and a 1.0% soiling loss assumption.



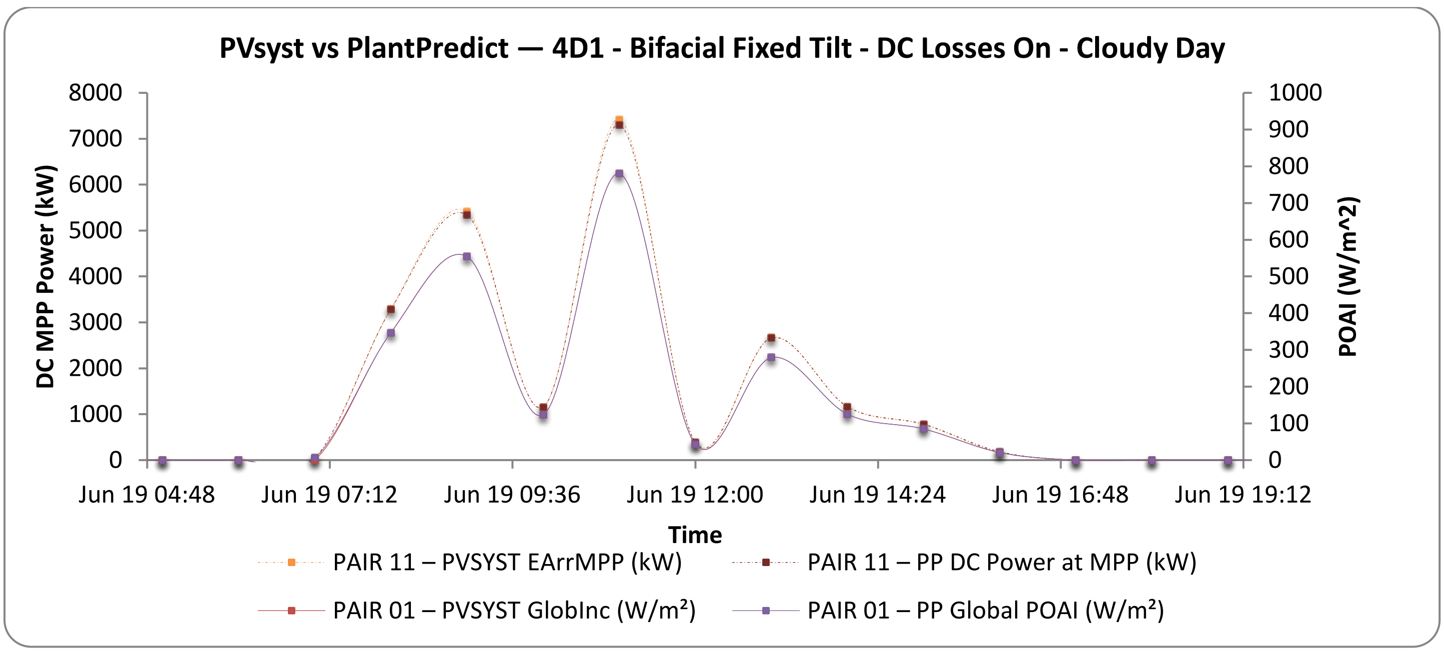


Figure 9 - Full scale clear day and partly cloudy day plots of POA irradiance and DC MPP Power with DC losses included. These plots demonstrate reasonable alignment between PlantPredict and PVsyst even with DC losses included.

PERIOD	4C1 - PVsyst DC MPP Energy (MWh)	4D1 - PVsyst DC MPP Energy (MWh)	4C1 - PlantPredict DC MPP Energy (MWh)	4D1 - PlantPredict DC MPP Energy (MWh)	% Delta (PVsyst 4C1 - 4D1)	% Delta (PlantPredict 4C1 - 4D1)
CLOUDY	23.3	22.4	23.2	22.3	4.0%	4.0%
CLEAR	51.3	49.2	50.4	48.3	4.3%	4.3%
ANNUAL	20,318	19,440	20,150	19,282	4.5%	4.5%

Table 11 - Daily and annual total DC MPP Energy for PVsyst and PlantPredict with DC losses off and DC losses on, as well as the calculated percent difference between the off and on scenarios for PVsyst and PlantPredict. Both software simulation tools capture the same relative difference within two significant figures.

Reviewing daily and annual totals for DC MPP Array energy for the scenario with DC losses off and DC losses on as presented in Table 11, it appears the relative change in DC MPP Array energy is nearly identical between PlantPredict and PVsyst in the studied scenario. Plots of POA irradiance and DC MPP Array power are also provided for clear and partly cloudy days in Figure *9*, which demonstrate reasonable alignment between the PlantPredict and PVsyst simulations.

Solphi Engineering notes that if comparing DC Ohmic loss as an output variable per time step between PVsyst and PlantPredict, you will observe a significant difference in results in instances where the inverter is clipping as demonstrated in Figure 10. Solphi Engineering understands this to be a result of PlantPredict calculating the DC Ohmic losses based on the clipped DC operating current, whereas PVsyst calculates the loss based on unclipped DC current. Given Scenario 4C1 and 4D1 show extremely small differences in both DC MPP Array Energy and Annual AC Inverter output energy it is reasonable to conclude that the agreement between PlantPredict and PVsyst is not materially impacted by the introduction of DC loss derate inputs.

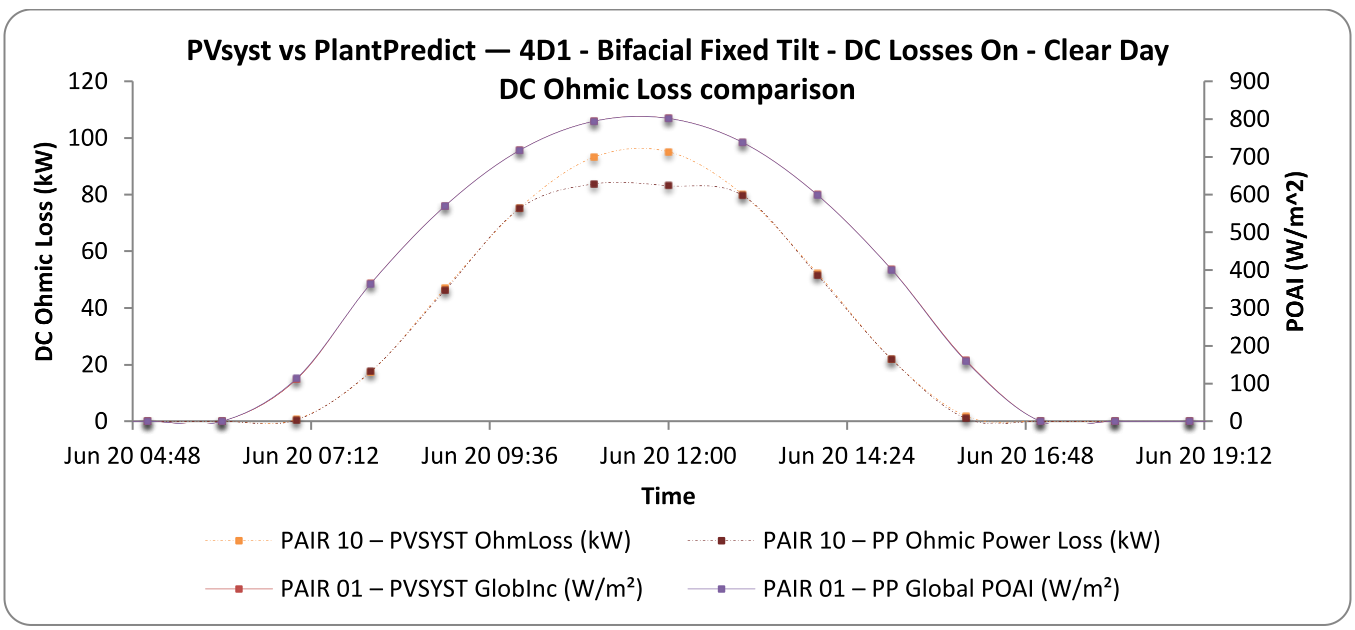


Figure 10 - Scenario 4D1 comparing PVsyst and PlantPredict output variables for DC Ohmic Loss (kW) on a clear day. At peak sun-hours where clipping is required, PVsyst reports a lower DC Ohmic loss than PlantPredict.

5.6 SIMULATION RESULTS CONCLUSION

Across all simulations, average absolute differences in Inverter output energy between PVsyst and PlantPredict were found to be less than 0.5%, with individual simulations all less than 1.0%. Solphi Engineering considers these differences to be well within expected modeling uncertainty, as well as within the variations documented between a survey of seven reputable PV simulation software providers published by Deville et al. and the PV Performance Modeling Collaborative (PVPMC).

Solphi Engineering concluded that the PlantPredict model engine can reproduce results within an acceptable tolerance compared to PVsyst.

6 NOTES ON VALIDATION

The original 2016/17 Independent Engineering studies included a review of a validation study prepared internally by First Solar comparing simulated PlantPredict results against 20 operating utility scale systems using First Solar CdTe modules. Generally, the IE reviews of this validation effort were positive and suggested that future work planned for PlantPredict at that time would be expected to improve the results further.

Solphi Engineering's scope has not included validation of PlantPredict simulations against operating data. While the benchmarking exercise against PVsyst is valuable given the broad acceptance within the solar industry of PVsyst as a reputable PV simulation tool, validation against real-world operating data is an important mechanism for quantifying the software uncertainty against "ground-truth". Solphi Engineering notes that PlantPredict v11 was tested against real world operating data in the study by Deville et al., but nevertheless would encourage all PV simulation software providers to provide validation studies against real world operating data.

7 CONCLUSION

Solphi Engineering considers PlantPredict PV simulation software to be aligned with industry best practices and has demonstrated that the model engine can reproduce results within an acceptable tolerance compared to PVsyst.

Solphi Engineering considers the clear and comprehensive documentation provided by PlantPredict to be an asset for its use in the development, design, and financing of PV systems.

Solphi Engineering considers the PlantPredict user interface simple to navigate, and notes that the inclusion of warnings, expandable context windows adjacent to key user inputs, and the use of a Prediction Status workflow, all facilitate user quality control efforts. Solphi Engineering considers these features particularly important given user input errors can result in greater discrepancies than the choice of PV simulation software.

While Solphi Engineering's review did not cover assessments of PlantPredict using operational data, Solphi Engineering considers the availability of a PlantPredict API coupled with the ability to simulate at sub-hourly intervals and using tracker angle time series data to be a positive for the integration of PlantPredict within operational performance assessment workflows. Solphi Engineering considers PlantPredict's ability to efficiently simulate a 1GW+ tracker system with a 3D scene to be beneficial, particularly as modern PV plant sizes continue to increase.

8 CITATIONS

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