FINAL

PLANT PREDICT INDEPENDENT ENGINEER REPORT

BLACK & VEATCH PROJECT NO. 193462

PREPARED FOR

First Solar, LLC

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1 Executive Summary

1.1 INTRODUCTION

First Solar LLC (First Solar) engaged Black & Veatch Management Consulting LLC (Black & Veatch) to conduct a technical assessment of First Solar's PlantPredict solar photovoltaic (PV) simulation software. Black & Veatch evaluated the PlantPredict model in the following manner:

- Reviewed the algorithms used in PlantPredict through a comparative study of the algorithms used in PVsyst. PVsyst is a PC software package for the study, sizing, simulation and data analysis of complete PV systems that is widely used in the PV industry. Black & Veatch relied on publicly available literature for this task.
- Compared the PlantPredict generated energy forecast of a particular project to the PVsyst generated energy output of the same project using the same input parameters. The comparative analysis was performed for three cases that were determined by Black & Veatch.
- Black & Veatch reviewed and opined on a peer-reviewed paper (13) published by First Solar that compares the output of PlantPredict to the output of PVsyst for fifty one cases. Black & Veatch reviewed the data used for a sample of ten cases.
- Black & Veatch reviewed a benchmarking analysis conducted by the First Solar based on operational data. Black & Veatch conducted a detailed review of the benchmarking methodology for a single project. Black & Veatch also conducted spot checks on ten projects to ensure that the methodology was applied consistently.

This report summarizes the analysis done by Black & Veatch and provides Black & Veatch's opinions and conclusions based on that analysis.

1.2 KEY FINDINGS

1. On the basis of Black & Veatch's review of PlantPredict and the documents made available at the time of this Report, Black & Veatch believes that PlantPredict should be able to model the fundamental aspects of solar PV energy production.
2. Black & Veatch is of the opinion that many of the algorithms presented in PlantPredict are similar to those in PVsyst. The algorithms selected for implementation in PlantPredict are used across the industry and offer spectral modeling capability that may result in more accurate energy predictions than those of PVsyst.
3. Black & Veatch modeled the energy output at four different sites using PlantPredict and PVsyst. Black & Veatch used identical input parameters and compared the results provided by PlantPredict and PVsyst. The four sites were chosen to represent different climates and irradiance characteristics. Black & Veatch found that the differences in annual energy output calculated by PlantPredict and PVsyst differed from -0.1 to +0.5 percent.
4. Black & Veatch is of the opinion that paper "Accuracy of Energy Assessments in Utility Scale PV Power Plant using PlantPredict" (13) provides an objective comparison of the energy forecast results calculated by PlantPredict and PVsyst. The results indicate that PlantPredict's and

PVsyst's energy forecasts differ, on average, by 0.13 percent with a standard deviation of 0.52 percent.

5. Black & Veatch reviewed the benchmarking analysis report provided by First Solar (11) which compared the energy output predictions of PlantPredict to the measured energy for twenty one projects representing nearly 1GW of modules. The results in (11) indicated that PlantPredict's average prediction accuracy at the energy meter was -0.41 percent (slight underprediction) with a standard deviation of 2.01 percent. Black & Veatch's analysis included a detailed review of the benchmarking approach for a single project. Black & Veatch also spot checked the data filtering and the adjustment process and verified key PlantPredict inputs for ten projects to ensure that the approach was consistent.

2 Review of PlantPredict Algorithm

The following section discusses Black & Veatch's analysis of the PlantPredict algorithms.

2.1 OVERVIEW

Black & Veatch reviewed the algorithms behind the energy calculations within PlantPredict, as described in the document "PlantPredict Algorithm Requirements"[1] provided by First Solar. Black & Veatch compared the PlantPredict algorithms to the algorithms used in analogous modeling stages within PVsyst. In this comparison Black & Veatch used publicly available information on PVsyst. In some cases, the algorithm documentation was not published by PVsyst. Each algorithm is discussed below.

2.2 SOLAR POSITION

PlantPredict incorporates the Solar Position Algorithm (SPA) described in the NREL technical report entitled "Solar Position Algorithm for Solar Radiation Applications" (1). Black & Veatch understands that the algorithm calculates the solar position in terms of the solar zenith angle and the solar azimuth angle with the required inputs being latitude, longitude, elevation, coordinated universal time (UTC), and the difference between the earth rotation time and terrestrial time, which is referred to as Δt. Black & Veatch understands that the algorithm has an uncertainty of +/-0.0003° in the period from the year -2000 to 6000 (1).

PVsyst utilizes a simpler version of the SPA. The PVsyst Help files (16) state that the accuracy of the SPA is "some few arc minutes" indicating the uncertainty is greater than +/-0.01°.

2.3 TILT ANGLE

PlantPredict supports three types of PV system orientations: fixed tilt, seasonal tilt and horizontal axis tracking. PVsyst provides the following additional PV system orientation options: vertical axis tracking, two-axis tracking and tracking sun-shields. In Black & Veatch's experience, systems with vertical axis tracking, two-axis tracking and tracking sun-shields are not as prevalent as the fixed tilt and horizontal axis tracking systems.

Black & Veatch understands that for horizontal axis tracking PlantPredict implements the equations provided in the NREL technical report titled "Rotation Angle for the Optimum Tracking of One-Axis Trackers" (7). The outputs of this algorithm include the rotation angle of the tracker and the relationship between the rotation angle and the PV system's tilt and azimuth angles. PlantPredict uses these values to calculate the incidence angle of light on the PV system's modules. PlantPredict also incorporates a backtracking algorithm and tracker limitation.

Black & Veatch was not able to identify publicly available information on the tracking algorithm used in PVsyst.

[1] Filename: *"PlantPredict Algorithms 11-Aug-2016.pdf"*, provided by Client

2.4 IRRADIANCE

2.4.1 Direct Normal and Diffuse Irradiance

PlantPredict allows the use of three models for calculating direct normal irradiance and diffuse irradiance for datasets that do not include the diffuse and direct normal irradiance: Reindl (17), Erbs (2) and DIRINT (15). PVsyst currently only offers the Erbs model.

2.4.2 Transposition

PlantPredict provides the option to use the Hay-Davies (3), and Perez (14) models for calculating the irradiance in the plane of the array. PVsyst also provides the option to use these two models.

2.5 OPTICAL LOSSES

2.5.1 Direct Beam Horizon Shading

In determining the shading factor that modifies the beam component of the irradiance, PlantPredict requires the user to provide the horizon profile as pairs of horizon azimuth and elevation angles. The shading factor has a value between 0 and 1 depending on whether or not the horizon is above the sun elevation. If the horizon is above the sun elevation PlantPredict estimates the amount of time the sun is obscured to determine the horizon shading factor.

PVsyst applies a similar algorithm, where shadings are as described by the horizon line. However, for any given time the beam component is either “on” or “off” which differs from PlantPredict’s more granular shading factor.

2.5.2 Near Direct Shadings

Both PlantPredict and PVsyst incorporate geometric shading calculations to produce the near direct beam shading factors. Black & Veatch is of the opinion that the PlantPredict and PVsyst algorithms appear to be very similar, if not identical. PlantPredict references (19), and (12).

2.5.3 Near Diffuse Shadings

PlantPredict incorporates an “isotropic dome” model, dependent only on tilt angle, collector width, and row spacing. Shading factors are solved for five spherical wedges, based on the ratio of the total diffuse sunlight available in the sphere to the amount of sunlight blocked by an adjacent PV module. PlantPredict calculates the diffuse incident angle modifier (IAM) value as part of the diffuse shading calculation.

PVsyst also assumes an isotropic diffuse sky model, and integrates a shading factor over all sky directions. The shading factor is based only on system geometry and is independent of the position of the sun. PVsyst computes the shading factors for fixed-tilt and tracking PV systems differently. In the case of tracking PV systems, a shading table is computed for various orientations and then each simulation step is interpolated. Black & Veatch was not able to find publicly available information that describes PVsyst’ s integration approach with the same detail as the PlantPredict algorithm.

However, both the PVsyst and the PlantPredict integration algorithms appear to be based on similar computation principles.

2.5.4 Soiling

Both PlantPredict and PVsyst apply monthly soiling percentages directly to the direct and diffuse irradiance values. In both cases the user inputs the monthly soiling percentages.

2.5.5 Reflection and Refraction (Incidence Angle)

PlantPredict offers the following options for computing the IAM: the Sandia incidence angle coefficients (4), ASHRAE formula using B0 coefficient (18), or user-defined tabular data which is then interpolated using a cubic spline approach.

IAM is calculated in the diffuse shading algorithm; from the documentation it seems the calculation always uses the ASHRAE formula. PVsyst offers the user the choice of using either the ASHRAE formula using B0 coefficient or user-defined tabular data which is then interpolated. PVsyst does not specify the interpolation method.

2.5.6 Spectral Correction

PlantPredict offers several methods to adjust the PV module nameplate power to take into account the difference between the spectrum of the solar simulator used to measure the PV module power output and the actual outdoor spectrum at the site where the simulation is being performed.

The default option in PlantPredict is the two-variable Pwat and air mass model (6) developed by First Solar to apply accurate adjustments to any module technology. PlantPredict also offers the use of the:

- Sandia polynomial method (4) which has historically been used for crystalline silicon modules, as it is a function of air mass only.
- one-variable precipitable water (Pwat) method developed by First Solar (10) to describe the spectral behavior of First Solar’s CdTe modules.

The PlantPredict user may also “override” the spectral correction models and input monthly values in a manner similar to First Solar’s spectral correction workaround method for PVsyst.

PVsyst only offers the use of the Sandia polynomial method when calculating spectral correction.

2.6 DC ARRAY BEHAVIOR

2.6.1 Module Temperature

PlantPredict provides two options for calculating the module temperature: the Sandia model (5) and the static heat balance model (9). PVsyst utilizes the heat balance model.

2.6.2 Module IV Curve

PlantPredict utilizes the “one-diode” model (9) which is an equivalent electrical circuit model of the PV module as a single diode. PlantPredict incorporates module-specific “one-diode” parameters into a Module File. PVsyst also uses a “one-diode” model and integrates the module-specific parameters into a PAN file. PlantPredict offers a tool for conversion of a PVsyst PAN file to a PlantPredict Module File.

2.6.3 Mismatch

PlantPredict models the output energy losses due to the mismatch of module electrical parameters as an empirical constant. PVsyst takes a similar approach. However, PVsyst offers a "detailed computation" option that estimates the energy losses due to module mismatch from the knowledge of actual module electrical parameters. Black & Veatch utilizes this feature whenever module flash test data is available in order to reduce the uncertainty in this loss parameter.

2.6.4 DC Wiring

PlantPredict addresses the ohmic losses in the PV system's DC wiring as a user-specified percentage at standard test conditions (STC). PlantPredict uses this input to calculate a bulk resistance value that is used to compute the power available at the inverter terminals. Black & Veatch is of the opinion that this approach is similar to that taken by PVsyst. However, PVsyst also provides the option to estimate the DC wiring loss from the DC cabling information.

2.6.5 Module Power Degradation

PlantPredict provides three options for incorporating the module power degradation rate into the system performance simulation: DC Linear, AC Linear, and AC stepped.

PVsyst does not provide an option to apply the module degradation on the DC side of the system. Black & Veatch is of the opinion that DC linear degradation better represents the effects of module power degradation on system performance.

PVsyst includes considerations for non-uniformity in module characteristics that could lead to higher mismatch losses over time. PlantPredict currently does not include these considerations.

2.7 AC SUBSYSTEM LOSSES

2.7.1 Elevation and Temperature Derate

PlantPredict allows the user to input elevation and temperature-dependent inverter output values either directly or through the inverter file specification. The user may enter as many temperature points as they like. PlantPredict linearly interpolates the inverter maximum power output based on this data.

PVsyst provides linear interpolation of the inverter power as a function of temperature, and only allows three points to be input. Black & Veatch is not aware of any elevation correction in PVsyst.

Black & Veatch considers that linear interpolation is an effective approach to inverter derating when temperature or elevation output dependencies are known.

2.7.2 Array Bias

Both PlantPredict and PVsyst use similar approaches to adjust the array current along the array IV curve in order to maximize the array power output and stay within the inverter's maximum power point (MPP) tracking window. The PlantPredict and PVsyst algorithms resemble actual inverter MPP tracking, where the DC voltage is controlled via switching frequencies to change the inverter current input and subsequently the power output.

2.7.3 Inverter Efficiency

Both PlantPredict and PVsyst estimate the inverter efficiency using power and voltage values and efficiency tables provided in the inverter specifications. PlantPredict does not limit the number of points on each curve or number of voltage curves. PVsyst allows a maximum of three different curves with up to eight points each.

2.7.4 Array and Auxiliary (Aux) Losses

PlantPredict allows the user to input power loads for inverter cooling, tracker motors (applied during daylight hours only), and aux loads such as the Supervisory Control and Data Acquisition (SCADA) system and lighting (applied during all hours of the day). These loads are input in watts, and simply subtracted from the inverter power output.

PVsyst accounts for inverter loads in the inverter file definition, and also has an option to input losses in proportion to the inverter power output. PVsyst allows the user to manually input non-inverter night time losses. PVsyst does not provide the option to model tracker motor power consumption.

2.7.5 Transformer Losses

Both PlantPredict and PVsyst calculate transformer losses based on user-input no-load and full-load loss fractions, as well as the transformer rating and AC power output. PlantPredict provides a single formula to calculate the transformer losses, and references an ABB Electrical Transmission and Distribution Reference (8). PVsyst calculates the no-load and variable load losses with two simple calculations. Black & Veatch did not find a reference for these calculations. Both PlantPredict and PVsyst take the same input variables and produce very similar loss factors given identical inputs.

2.7.6 AC Collection System Losses

PlantPredict applies a user-input, flat-rate loss when the power output is greater than zero. Black & Veatch believes that this is an effective approach to calculating AC collection system losses.

PVsyst allows the user to input a loss to be applied at the "inverter to injection point" for each sub-array. This requires the input of two of the following three variables: wire length, wire size, or loss fraction. Black & Veatch did not find publicly available information that explains how the loss is applied in PVsyst.

2.7.7 System Transmission Line Losses

PlantPredict calculates transmission line ohmic power losses using the line voltage, length, resistivity, and the number of connectors per phase. PVsyst does not appear to explicitly model transmission line losses.

2.8 AVAILABILITY LOSS

Availability is modeled in PlantPredict as a constant power output loss for all time steps. An availability coefficient is input by the user, and applied at the transformer and transmission line output.

In PVsyst, the availability loss is modeled through user-specified outage periods. These periods may be manually set by the user, or random periods can be chosen to meet the target availability.

Black & Veatch understands that availability losses are modeled in different ways throughout the solar industry and that both the PlantPredict and PVsyst approaches are used.

2.9 PLANT OUTPUT CONTROL

Both PlantPredict and PVsyst allow for power limitations to be set at the plant level. PlantPredict utilizes a calculation that caps the output at the specified level.

PVsyst offers a limit that is applied at the inverter or the plant levels. Black & Veatch was unable to find publicly available information that describes the PVsyst algorithm.

2.10 CONCLUSIONS

Many of the algorithms presented in PlantPredict are similar to those in PVsyst. Black & Veatch believes that PlantPredict should be able to model the fundamental aspects of solar PV energy production. Black & Veatch notes the following differences between PlantPredict and PVsyst:

- PlantPredict utilizes a more detailed solar position algorithm than PVsyst.
- PlantPredict offers a more detailed horizon shading computation than PV syst. Black & Veatch is of the opinion that this is a positive feature.
- PlantPredict offers advanced spectral correction algorithms that are particularly useful in modeling CdTe modules. PVsyst does not incorporate comparable spectral correction algorithms.
- PlantPredict does not consider the non-linear electrical effects of shading on crystalline-Si and thin film modules. PVsyst does allow for these effects in its calculations.
- PlantPredict takes into account inverter performance de-rating due to elevation, whereas PVsyst does not. PlantPredict also allows for greater curve definition.
- PlantPredict allows for the modeling of tracker motor power consumption, whereas PVsyst does not.
- PlantPredict allows for more detailed modeling of system AC-side losses and configurations than PVsyst.
- PlantPredict allows for the application of the module power degradation values on the system DC side (DC linear degradation) whereas PVsyst does not provide this option. Black & Veatch is of the opinion that DC linear degradation better represents the effects of module power degradation on plant performance.

Black & Veatch is of the opinion that the algorithms selected for implementation in PlantPredict are used throughout the industry and offer spectral modeling capability that may result in more accurate energy predictions than PVsyst.

3 Analysis of PlantPredict Performance

3.1 ANALYSIS AND RESULTS

Black & Veatch modeled the energy output at four different sites using PlantPredict and PVsyst with identical input parameters and compared the results provided by both tools. The project sites, input data, design parameters, and model settings were chosen by Black & Veatch, with no input provided by First Solar.

The four sites were chosen to represent different climates and irradiance characteristics, in an attempt to test PlantPredict and PVsyst in different environments. Black & Veatch selected a diverse range of resource data sets, equipment, module mounting and configuration, row spacing, inverter loading ratios, and losses (ohmic losses, transformer losses, power factor). Single inverter "blocks" as well as larger arrays were modeled. Some characteristics of the selected sites are summarized in Table 3-1.

Table 3-1 Characteristics of Sites Selected

SITE #	LOCATION	MODULE MOUNTING TYPE	MODULE TYPE	ILR[1]	GCR
Site 1	Lancaster, CA	Horizontal Tracking (+/-45°)	Poly-Si	1.34	0.35
Site 2	St. Paul, NC	Fixed Tilt (20°)	Poly-Si	1.4	0.55
Site 3	Chennai, India	Horizontal Tracking (+/- 60°)	CdTe	1.25	0.4
Site 4	Al Jawf, Saudi Arabia	Fixed Tilt (30°)	CdTe	1.1	0.55

[1]ILR: Inverter Loading Ratio, a.k.a. DC/AC Ratio.

Identical input parameters and model settings were applied to PlantPredict and PVsyst for each site. Black & Veatch performed all of the computation within the software and no post-processing was conducted on the outputs of either PlantPredict or PVsyst. For the models that incorporated First Solar CdTe modules, spectral adjustments were made using First Solar's spreadsheet method for adjusting module losses in PVsyst. These losses were then input into PlantPredict using the "monthly override" option for spectral loss to provide an even comparison.[2]

The differences in annual energy output calculated by PlantPredict and PVsyst ranged from -0.1 to +0.5 percent. Table 3-2 summarizes the simulation results.

[2] *Filename: "PD-5-423EX.xlsx",* Provided by Client.

Table 3-2 Annual Energy Estimate Comparison

SITE #	LOCATION	PLANTPREDICT (MWH/YR)	PVSYST (MWH/YR)	DIFFERENCE (PERCENT)
Site 1	Lancaster, CA	6,273	6,269	-0.06
Site 2	St. Paul, NC	4,393	4,404	0.25
Site 3	Chennai, India	247,000	248,217	0.49
Site 4	Al Jawf, Saudi Arabia	215,540	215,386	-0.07

Black & Veatch observed differences in the reporting conventions between PlantPredict and PVsyst. For example, PlantPredict presents each plane of array (POA) loss, i.e., shading, soiling, IAM, and spectral shift relative to the POA magnitude prior to any of those losses. However, PVsyst presents each of these losses relative to the sequential energy output after the prior “upstream” loss.

Losses that are directly input by the user, e.g. DC and AC ohmic losses, module mismatch, and module quality are reported using different conventions. PlantPredict reports such DC losses as a percentage of the power at 25°C and operating effective irradiance. AC ohmic losses are reported as a percentage of inverter output power. This can result in reported loss factors that differ slightly from what was input. PVsyst reports the values exactly as they were input by the user.

Black & Veatch also noted the following differences between PlantPredict and PVsyst:

- **Electrical Shading Effect**: Electrical shading effects account for partial shading of polycrystalline modules according to cell and bypass diode configuration. PlantPredict currently does not model electrical shading effects. First Solar has indicated that they intend to incorporate electrical shading effects in a future PlantPredict release. PVsyst does incorporate electrical shading losses in PV array modeling. Black & Veatch has not independently verified the accuracy of PVsyst’s electrical shading algorithms. However, the method used by PVsyst to model electrical shading losses seems sound. This loss is typically of second or third order impact on plant output.
- **Near Shadings**: PlantPredict models plant layouts down to the single inverter level, and multiple fields can be modeled with different configurations of row spacing, tracking behaviors, and equipment types. PVsyst utilizes a three dimensional (3-D) shading scene construction, which allows for detailed plant layouts. However, some configurations need to be aggregated as multiple variants. This is the case when there are multiple row spacing values. As noted above, PVsyst does model electrical shading effects, and through the 3-D shading scene modules can be partitioned by row to perform a detailed calculation of this loss.
- **Tracker Settings**: Black & Veatch noticed slightly larger differences (on the order of ~0.25 percent) in modeled annual energy when “True Tracking” mode was chosen in PlantPredict and backtracking was left un-checked in PVsyst, as compared to when backtracking was selected on both platforms. The transposition factors calculated by the two platforms are equivalent with and without backtracking. The difference in energy appears to be due primarily to IAM and near shading losses. This is apparently due to the difference in the algorithms used by PVsyst and PlantPredict to calculate these losses. Black & Veatch notes that the IAM and near shading losses

would be greater in magnitude without backtracking, and a larger difference between the two platforms could be expected.

3.2 CONCLUSIONS

Black & Veatch modeled the energy output at four different sites using PlantPredict and PVsyst using identical input parameters and compared the results provided by both tools. The four sites were chosen to represent different climates and irradiance characteristics, in attempt to test PlantPredict and PVsyst in different environments. Black & Veatch found that the annual energy outputs calculated by PlantPredict and PVsyst differed from -0.1 to +0.5 percent.

4 Review of Research Paper Published By First Solar

Black & Veatch reviewed the First Solar paper "Accuracy of Energy Assessments in Utility Scale PV Power Plant using PlantPredict" (13) which forecasts the energy output for over fifty different projects using PlantPredict and PVsyst and compares the outcomes. The results from First Solar's paper indicated that PlantPredict predicted, on average, 0.13 percent more energy than PVsyst with a standard deviation of 0.52 percent. Black & Veatch reviewed the inputs, assumptions, and methodology used by First Solar for calculating the energy forecast in ten of the projects. A high-level description of the projects reviewed by Black & Veatch is shown in Table 4-1.

Table 4-1 Project Description

SITE #	REGION	MODULE MOUNTING TYPE	MODULE MAKE	INVERTER MAKE
Site 1	South Africa	Horizontal Tracking	FS Series 4	SMA
Site 2	Brazil	Horizontal Tracking	FS Series 4	GE
Site 3	Australia	Fixed Tilt	FS Series 3	SMA
Site 4	Philippines	Fixed Tilt	FS Series 4	SMA
Site 5	Chile	Horizontal Tracking	FS Series 3	SMA
Site 6	Jordan	Horizontal Tracking	FS Series 3	SMA
Site 7	Southwest US	Fixed Tilt	FS Series 3	GE
Site 8	Southwest US	Fixed Tilt	FS Series 3	SMA
Site 9	Midwest US	Fixed Tilt	FS Series 4	SMA
Site 10	Mexico	Horizontal Tracking	FS Series 4	SMA

For each project, First Solar provided the following documents:

- PlantPredict "Inputs and Assumptions Summary" output file (.pdf)
- PlantPredict "Plant Summary" output file (.pdf)
- PlantPredict "Plant Summary" spreadsheet output file (.xlsx)
- PVsyst report (.pdf)
- PVsyst project files (.prj, .vc*, .met, .pan, .ond,.hor, etc.)
- PVsyst post-processing spreadsheet (.xlsx)

First Solar also provided the "Master List" spreadsheet that contained the main inputs used in each project calculation and the results of the energy outputs calculated by PlantPredict and PVsyst.

The information provided by First Solar allowed Black & Veatch to conduct a detailed comparison of the following project input parameters:

- Location
- Irradiance (GHI, DHI)
- Tracking vs. Fixed Tilt
- Tilt and orientation
- Module configuration
- Elevation
- Inverter specification
- Inverter derating
- DC Project capacity
- AC Project capacity
- Weather File
- Mismatch loss
- Module quality loss
- Spectral loss
- Ohmic loss

- Row spacing
- Backtracking strategy
- Module specification
- String size
- Transposition model
- Soiling loss
- Thermal loss model
- Far shadings
- Transformer loss
- Transmission line loss
- Power factor
- POI capacity limit

Black & Veatch compared the energy outputs and net losses throughout the different modeling stages.

For each calculation, Black & Veatch reviewed all of the data used in the PlantPredict and PVsyst calculations to confirm that identical settings were used in both cases. In the PVsyst simulations, First Solar performed a majority of the AC-side losses in a post-processing spreadsheet. In the PlantPredict simulations these losses were modeled within the platform. Black & Veatch confirmed that any post-processing performed on the PVsyst results was consistent with those elements of the PlantPredict modeling parameters. In a few cases, small discrepancies were found. In these cases First Solar revised the modeling and provided updated results. Black & Veatch is of the opinion that the revisions to the modeling had little impact on the average energy output and standard deviation of the error in the energy output for the projects.

As noted in (13) advanced spectral and thermal models which are features of PlantPredict were not used in the analyses, as PVsyst did not have analogous settings or algorithms.

The ten projects evaluated by Black & Veatch employed First Solar CdTe modules. Black & Veatch observed that First Solar used its own methodology to correct for spectral gain and loss in PVsyst. First Solar applied the spectral correction to the module performance calculations. Black & Veatch is of the opinion that First Solar applied the change in module performance due to the spectral correction consistently in both PlantPredict and PVsyst.

4.1 CONCLUSIONS

Black & Veatch is of the opinion that paper “Accuracy of Energy Assessments in Utility Scale PV Power Plant using PlantPredict” (13) provides an objective comparison of the energy forecast results calculated by PlantPredict and PVsyst. The results indicate that PlantPredict’s and PVsyst’s energy forecasts differ, on average, by 0.13 percent with a standard deviation of 0.52 percent.

5 Benchmarking Analysis

5.1 OVERVIEW

Black & Veatch reviewed the benchmarking analysis report provided by First Solar (11) which compared the energy output predictions of PlantPredict to the measured energy for twenty one projects representing nearly 1GW of modules. The results in (11) indicated that PlantPredict's average prediction accuracy at the energy meter was -0.41 percent (slight underprediction) with a standard deviation of 2.01 percent. Black & Veatch's analysis included a detailed review of the benchmarking approach for a single project. Black & Veatch also spot checked the data filtering and the adjustment process and verified key PlantPredict inputs for ten projects to ensure that the approach was consistent.

A high-level description of the projects reviewed by Black & Veatch is shown in Table 5-1.

Table 5-1 Project Description

SITE #	DC MW	COMM ISSION YEAR	MOUN TING TYPE	CLIMATE	COUNTRY	BENCH MARKING START	BENCHMARKING END
3	39	2012	FT	Hot	USA	05/01/12	12/31/15
6	13	2012	FT	Hot	Australia	09/21/12	12/31/15
7	35	2012	HT	Hot	USA	01/01/13	12/31/15
10	36	2013	FT	Hot	USA	07/01/13	12/31/15
14	65	2014	HT	Hot	USA	06/01/14	12/31/15
15	26	2014	HT	Hot	USA	07/01/14	12/31/15
16	31	2014	FT	Hot	USA	10/01/14	12/31/15
18	55	2013	FT	Hot	USA	01/01/14	12/31/15
19	73	2010	FT	Temperate	Canada	10/01/10	12/31/15
21	26	2013	FT	Temperate	Canada	02/01/13	12/31/14

Black & Veatch selected the ten projects in Table 4 because they cover a range of commissioning years, locations and module mounting types.

In the comparative analysis of measured and modeled data for each of the ten projects Black & Veatch reviewed First Solar's project model to understand how well it represented the site conditions and reviewed First Solar's data filtering process.

Black & Veatch evaluated First Solar's project model by comparing the information contained in the sites' as-built drawings to the information used in the model developed in PlantPredict. Black & Veatch evaluated the data filtering process by reviewing of the data filtering methodology, raw data and the code used to implement the process.

Black & Veatch reviewed the following information provided by the First Solar:

- As-built site layouts

- PlantPredict model summaries
- Measured actual data
- Measured data Flags
- Code used for data filtering process
- Sample soiling calculations
- Soiling loss estimates for site 6 and site 16.

5.2 VERIFICATION OF PLANT CHARACTERISTICS

Black & Veatch compared the system characteristics used in the PlantPredict model summaries to the information contained in the site as-built layouts. Table 5-2 shows a tabulation of the same.

Black & Veatch found that the plant characteristics shown in Table 5-2 to be consistent with the information contained in the as-built drawings.

Table 5-2 Plant Characteristics Verification

PLANT CHARACTERISTICS	SITE 3	SITE 6	SITE 7	SITE 10	SITE 14	SITE 15	SITE 16	SITE 18	SITE 19	SITE 21
Total AC Size MWac	30.24	10.37	28.46	28.98	24.39	54.6	23.68	44.8	60	20
Total DC Size MWdc	39.09	12.61	34.91	36.34	26.24	65.33	31.18	53.03	72.93	26.29
DC:AC ratio	1.29	1.22	1.23	1.25	1.08	1.2	1.32	1.18	1.22	1.31
Array Tilt	20°	20°	HT	25	HT	HT	25°	HT	25	25
Array Azimuth	195	0	180	180	180	180	180	180	180	173
Array Row Spacing	4.27	5.18	5.79	4.27	5.49	6.71	4.27	5.03	3.96	5.49

Note: HT-Horizontal Tracking

First Solar stated that the soiling loss for sites 6 and 16 was calculated using the data collected by a soiling monitoring station installed onsite. Black & Veatch found that the soiling losses for sites 6 and 16 used in PlantPredict (Table 5-3) were consistent with the soiling calculations provided by First Solar.

Table 5-3 Soiling Loss Estimates (%) for Site 6 and 16

SITE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
6	0.9	1.1	0.4	0.3	0.1	0.1	0	0.1	0.1	0.1	0.3	0.4
16	0.1	0	0.3	0.4	0.4	0.8	0.6	1.5	1.7	2.3	0	0.1

5.3 DATA FILTERING AND MODEL ADJUSTMENT PROCESS REVIEW

From the review of (11) Black & Veatch understands that First Solar applied the following data filters when calculating the plant energy forecasts

- **Limit Filter**: Values that were not within predefined bounds were excluded.

- **Dead Sensor filter**: Values that were "stuck" were identified and excluded.
- **Statistical Outlier Filter**: In cases where at least six sensor readings were available, deviations from the median values were identified and excluded.
- **Pairwise Filter -** In cases where at least three sensor readings were available the deviations from the average values were identified and excluded.
- **Erratic Jumping Filter**: Instances of erratic changes were identified and excluded.
- **No Confidence Filter**: Instances where the limit, dead, or jump filters were triggered several times within any 15-minute period were identified and excluded.
- **Pyranometer Drift Check**: Periods with gradual drift indicating that the sensors were falling out of calibration and/or displaced from the correct orientation were identified and excluded.
- **Manual Sensor Filtering**: Any additional discrepancies identified through visual inspection were manually excluded.
- **Snow Filter**: This filter was used to identify periods affected by snow.
- **Manual Time Period Filtering**: Unpredictable events such plant outages or undetected snow cover that were manually identified by an analyst were excluded from the analysis.

Black & Veatch believes that the data filtering criteria employed for the benchmarking analysis appear to be consistent with accepted energy modeling practices.

Black & Veatch understands that First Solar made the following adjustments to the PlantPredict modeled data:

- **Inverter Availability Loss Corrections**: The PlantPredict modeled data was corrected using the actual inverter availability.
- **Inverter Setpoint Corrections**: For projects where curtailment was imposed due to point of interconnection limitation, the operating set point was adjusted manually or by a plant controller. The PlantPredict modeled data was adjusted as per the actual inverter setpoint to account for the imposed curtailment.

Black & Veatch is of the opinion that the PlantPredict model adjustments based on inverter availability and setpoints reflect the actual operating conditions of the project.

Black & Veatch performed a detailed review of the benchmarking methodology for a single project (Site 3) by manually applying the filtering criteria and the model adjustments to the unfiltered and unadjusted data provided by First Solar. The annual mean error[3] calculated by Black & Veatch agreed with the First Solar calculated value. Black & Veatch calculated the annual mean error to be 0.23 percent compared to First Solar's calculated value of 0.22 percent.

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[3] Defined as $\frac{Predicted\ Energy - Measured\ Energy}{Measured\ Energy} * 100\%$ calculated on an annual basis

Through a review of the code and of the pre- and post- filtered data for Site 3, Black & Veatch is of the opinion that First Solar has applied the data filtering and model adjustment in accordance to the methodology provided by the First Solar.

5.4 CONCLUSIONS

In its review of the input values used in the PlantPredict simulation performed by First Solar for ten projects, Black & Veatch found that the input values were consistent with the information contained in the project as-built drawings. Black & Veatch also found consistency between the measured soiling values and those used in the PlantPredict simulation for the two sites reviewed.

Black & Veatch reviewed First Solar's data filtering criteria and is of the opinion that the criteria appears to be consistent with accepted energy modeling practices.

Black & Veatch performed a detailed review of the data filtering and PlantPredict model adjustment process for a single project. Through a review of the code used to filter the data and the review of the data before and after filtering, Black & Veatch is of the opinion that First Solar has used sound methods for data filtering and model adjustment.

6 References

1. Andreas, I. R. (2008). *Solar Position Algorithm for Solar Radiation Applications.* NREL.
2. Erbs. (1982). Estimation of the diffuse radiation fraction for hourly, daily and monthly- average global. *Solar Energy, 28*, 293-302.
3. Hay, J., & Davies, J. (1980). Calculations of the solar radiation incident on an inclined surface. *Proc. of First Canadian Solar Radiation Data Workshop*, 59.
4. King, D., Boyson, E., & Kratochvil, J. (2004). *Photovoltaic Array Performance Model.* Sandia National Laboratories.
5. King, D., Kratochvil, J., & Boyson, W. (1997). *Photovoltaic Array Performance Model.* Sandia National Laboratories.
6. Lee, M., & Panchula, A. (n.d.). Spectral Correction for Photovoltaic Module Performance Based on Air Mass and Precipitable Water. 43rd IEEE Photovoltaic Specialists Conference.
7. Marion, W., & Dobos, A. (2013). *Rotation Angle for the Optimum Tracking of One-Axis Trackers.* NREL.
8. McCann, L. (n.d.). *ABB Electrical Transmission and Distribution Reference.*
9. Mermoud, A. (2005). *Conception et dimensionnement de systèmes photovoltaïques : Introduction des modules PV.*
10. Nelson, L., Frichtl, M., & Panchula, A. (2013). Changes in Cadmium Telluride System Performacen due to Spectrum. *IEEE Journal of Phovoltaics Vol 3*.
11. Ngan, L., Passow, K., & Lee, M. (2016). *PlantPredict Performance Model Fleet Benchmarking for 2013 Energy Prediction Guidance parameters.*
12. Nguyen, & Duc, D. (2008). *Modeling and Reconfiguration of solar Photovoltaic Arrays Under Non-Uniform Shadow Conditions.* Northeastern University.
13. Passow, K., Ngan, L., Litmann, B., Lee, M., & Panchula, A. (n.d.). *Accuracy of Energy Assessments in Utility Scale PV Power Plant using PlantPredict.*
14. Perez, R., Ineichen, P., Seals, R., Michalsky, J., & Stewart, R. (1990). Modeling Daylight Availability and Irradiance Component from Direct and Global Irradiance. *Solar Energy 44, no 5*, 271-289.
15. Perez, R., Ineichen, P., Maxwell, E., Seals, R., & Zelenka, A. (1992). Dynamic Global-to-Direct Irradiance Conversion. *ASHRAE Transactions-Research Series*, 354-369.
16. PVsyst. (2016). *PVsyst 6 Help*. Retrieved from http://files.pvsyst.com/help/
17. Reindl, D. T, Beckman, W., & Duffi, J. (1990). Diffuse Fraction Corrections. *Solar Energy Vol. 45, No. 1*, 1-7.
18. Souka, A., & Safwat, H. (1966). Determination of the Optimum Orientations for the Double Exposure Flat-Plate Collector and Its Reflections. *Solar Energy Vol. 10*, 170-174.
19. Weinstock, D., & Appelbaum, J. (2004). Optimal solar Field Design of Stationary Collectors. *Journal of Solar Energy Engineering*, 905.