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Technical Performance and Probabilistic Energy Yield Assessment of a 620 MWp Bifacial Grid-Connected Photovoltaic Power Plant in an Area Located in the Eastern Part of the Absheron Peninsula of Azerbaijan

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Article

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Abstract

This study audits the energy balance, geometric inputs, performance indicators and exceedance-yield calculation of a 620 MWp DC / 477.5 MWac bifacial photovoltaic plant proposed for the eastern Absheron Peninsula. The source is a single PVsyst V8.0.12 simulation (VC1, 23 June 2025), rather than measured plant operation. Simulated first-year grid-injected energy is 886.81 GWh (1,430 kWh/kWp), with conventional PR of 89.95% and reported bifacial PR of 83.89%. Under an explicitly assumed normal distribution and illustrative 4.39% combined relative standard deviation, conditional P90 and P95 estimates are approximately 837.0 and 822.8 GWh. The review distinguishes active module width from shed width, tests the internal arithmetic of the exceedance estimates, and identifies the input evidence needed before the forecast can support investment decisions. Independent weather validation, manufacturer-specific uncertainty evidence and confirmation of as-built electrical design remain outstanding.

Highlights

• Simulated first-year grid-injected energy: 886.81 GWh/year.

• Specific production: 1,430 kWh/kWp/year.

• Annual performance ratio: 89.95%.

• Net bifacial irradiance gain: 9.2%.

• P90 annual production estimate: 836.9 GWh/year.

1. Introduction and Project Context

The project considered in this study is a large-scale, grid-connected photovoltaic power plant proposed for development in an area located in the eastern part of the Absheron Peninsula of Azerbaijan. The plant is modelled with a nominal DC capacity of 620.0 MWp and an AC inverter capacity of 477.5 MWac. It is designed as a bifacial, ground-mounted installation connected to the national medium-voltage grid.

The objective of the simulation review is to estimate long-term annual energy production, quantify the principal loss mechanisms affecting the theoretical output, and establish probabilistic production indicators relevant to financial modelling and bankability review. The analysis uses the PVsyst V8.0.12 simulation reference VC1, dated 23 June 2025, with a 5 m pitch and unlimited-sheds configuration.

1.1 Headline Simulation Results

- Annual energy injected into the grid: 886.81 GWh/year.
- Specific production: 1,430 kWh/kWp/year.

- Performance ratio (PR): 89.95%.
- Bifacial performance ratio: 83.89%.
- P90 annual production: 836.9 GWh/year.
- P95 annual production: 822.9 GWh/year.

2. Site and Meteorological Conditions

The modelled site is located in the eastern part of the Absheron Peninsula of Azerbaijan, at latitude 40.33° N and longitude 50.31° E, with an altitude of -35 m above sea level. The below-sea-level elevation is consistent with the low-lying coastal plain of the Absheron region. The simulation uses the UTC+4 time zone.

Meteorological data were taken from Meteonorm 8.2 for the 1986-2000 climatological reference period. Satellite-derived irradiance data were applied at 100% weighting to produce the synthetic hourly dataset used in the PVsyst simulation. The annual global horizontal irradiation is 1,428.1 kWh/m². Ground albedo was set at 0.20, which is a critical input for rear-side irradiance estimation in the bifacial model.

Table 1. Monthly irradiation and ambient temperature used in the simulation

Month	GlobHor (kWh/m²)	DiffHor (kWh/m²)	T_Amb (°C)
January	57.8	33.54	4.55
February	65.2	39.24	4.36
March	106.2	63.80	7.43
April	140.3	85.16	11.74
May	185.1	95.43	18.76
June	202.3	95.58	23.97
July	189.3	98.06	27.52
August	170.5	95.14	27.64
September	125.3	65.85	22.61
October	80.5	52.00	16.87
November	55.3	33.69	10.94
December	50.1	28.79	6.76

The irradiation profile peaks in June and July, with monthly global horizontal irradiation values of 202.3 and 189.3 kWh/m², respectively. These months also coincide with the highest ambient temperatures, which increases thermal derating and slightly lowers the monthly performance ratio during the summer period.

3. System Configuration and Array Design

3.1 Mounting Geometry and Orientation

The plant is modelled using an unlimited-sheds configuration, an appropriate abstraction for a utility-scale solar plant with extensive and repetitive row geometry. The modules are installed at a fixed tilt of 35° and an azimuth of 0°, corresponding to a true south-facing orientation suitable for a northern-hemisphere site at this latitude.

The row pitch is 5.00 m and the sensitive module width is approximately 2.38 m, producing an average ground coverage ratio of approximately 47.6%. The limit profile angle is 24.4°, meaning that mutual row-to-row shading begins below this solar elevation angle. The Perez transposition model was used to convert horizontal irradiation into plane-of-array irradiation under a free-horizon assumption.

3.2 Bifacial System Modelling

Because the selected JKM-645N-66HL4-BDV modules are bifacial, the PVsyst Unlimited Sheds 2D bifacial model was used to quantify rear-side irradiance and its impact on effective collector-plane irradiance. The main bifacial modelling parameters are summarised below.

Table 2. Bifacial model and row-geometry parameters

Parameter	Value
Sheds spacing	5.00 m
Sheds width	2.42 m
Limit profile angle	24.4°
Ground coverage ratio (GCR)	48.4%
Height above ground	1.60 m
Number of sheds modelled	5 units
Ground albedo	0.20
Bifaciality factor	80%
Rear shading factor	5.0%
Rear mismatch loss	10.0%
Shed transparent fraction	0.0%

The 1.60 m mounting height is particularly relevant for bifacial gain because it affects the rear-side view factor and the amount of ground-reflected and sky-diffuse light reaching the back side of the modules.

The simulation reports a net 9.2% uplift in effective irradiance on the collector plane after applying the 80% bifaciality factor and associated rear-side losses.

4. Equipment Specification and Electrical Architecture

4.1 PV Modules

Table 3. PV module specification

Parameter	Value
Manufacturer	Jinkosolar
Model	JKM-645N-66HL4-BDV
Unit nominal power	645 Wp
Number of modules	961,246 units
Array configuration	36,971 strings x 26 modules in series
Total nominal power (STC)	620.0 MWp (620,004 kWp)
Module area	2,596,506 m²
Cell area	2,424,762 m²
Pmpp at 50°C operating condition	575.1 MWp
Vmpp at 50°C	997 V
Impp at 50°C	577,061 A

4.2 Inverters

Table 4. Inverter specification

Parameter	Value
Manufacturer	Sungrow
Model	SG2500-HV-20
Unit nominal AC power	2,500 kWac
Number of inverters	191 units
Total AC power	477,500 kWac (477.5 MWac)
Operating voltage window	800-1,300 V
Max. AC power (>=25°C)	2,750 kWac per unit
DC:AC ratio (Pnom ratio)	1.30

The DC:AC ratio of 1.30 is a deliberate oversizing strategy. It allows the DC array to exceed the nominal inverter AC capacity so that the inverter fleet operates closer to its rated output for more hours of the day. In this simulation, clipping losses remain very limited at approximately 0.1% of array energy, indicating appropriate sizing between the DC generator and the inverter fleet.

4.3 Electrical Balance of Plant

The inverter output is collected at 550 V AC, three-phase, and transmitted through copper cabling consisting of 191 sets of 3 x 2,000 mm² over an average length of 150 m to a medium-voltage transformer. The medium-voltage side operates at 6 kV and is connected to the grid injection point through 3 x 50,000 mm² copper conductors over 311 m. The step-up transformer is rated at 613.8 MVA at STC, with iron losses of 605.84 kVA and copper losses of 6,218.71 kVA at STC.

5. Simulated Annual Energy Balance

The monthly energy balance shows the progression from horizontal irradiation to effective plane-of-array irradiation, array output and final grid-injected energy. The annual grid-injected production is 886.81 GWh, with an annual performance ratio of 0.900 and a bifacial performance ratio of 0.839.

Table 5
Monthly simulated energy balance

Month	GlobHor (kWh/m²)	GlobInc (kWh/m²)	GlobEff (kWh/m²)	EArray (GWh)	E_Grid (GWh)	PR	PRBifi
January	57.8	89.6	83.0	52.05	50.32	0.906	0.872
February	65.2	88.4	82.7	52.40	50.67	0.925	0.878
March	106.2	125.7	117.7	74.84	72.44	0.930	0.868
April	140.3	147.7	137.7	87.38	84.68	0.925	0.856
May	185.1	180.9	169.0	104.99	101.71	0.907	0.835
June	202.3	190.2	177.9	108.94	105.52	0.895	0.821
July	189.3	181.1	169.0	102.42	99.28	0.884	0.812
August	170.5	176.5	165.1	99.29	96.24	0.879	0.814
September	125.3	145.1	135.9	82.39	79.79	0.887	0.829
October	80.5	100.5	94.0	57.93	56.03	0.899	0.844
November	55.3	81.0	75.0	46.37	44.81	0.892	0.854
December	50.1	83.4	75.4	46.88	45.30	0.876	0.847
Year total / average	1,428.1	1,590.1	1,482.4	915.86	886.81	0.900	0.839

The plant maintains a high performance ratio throughout the year, ranging from 0.876 in December to 0.930 in March. The seasonal decline during July and August is mainly associated with higher ambient temperatures and the corresponding increase in module operating temperature.

6. Bifacial Gain and Loss Mechanisms

The bifacial model calculates annual ground-incident irradiance of 683 kWh/m² across an effective ground area of 5,364,682 m². Starting from this ground-incident irradiance, the model applies albedo, rear-side view factor, diffuse sky contribution, direct beam contribution, rear-side shading, and rear mismatch losses. The resulting rear-side irradiance is 136 kWh/m²/year, contributing a net 9.2% gain in global effective irradiance on the collector plane.

The detailed loss cascade shows how the annual horizontal solar resource is converted into final grid-injected energy. The most important losses include front-side near shading, soiling, angle-of-incidence effects, temperature derating, mismatch, inverter losses, AC wiring losses and transformer losses.

Table 6
Detailed PVsyst loss and gain cascade

Loss / Gain Step	Magnitude	Physical Cause
Global horizontal irradiation	1,428 kWh/m²/year	Baseline solar resource
Global incident in collector plane	+ 11.3%	Gain from 35° tilt compared with a horizontal plane
Near-shading irradiance loss	-3.4%	Mutual row-to-row shading between sheds
Soiling loss factor	-2.0%	Dust and dirt accumulation on module surfaces
IAM factor on global	-2.0%	Angle-of-incidence optical reflection losses
Ground reflection on front side	+ 0.4%	Albedo contribution on the front side
Ground reflection loss on rear side	-80.0%	Only the reflected fraction is available due to ground albedo
View factor for rear side	-62.7%	Geometric visibility of the ground from the rear side
Sky diffuse on rear side	+ 35.7%	Diffuse sky contribution to rear-side irradiance
Beam effective on rear side	+ 0.4%	Direct beam component reaching the rear side
Shading loss on rear side	-5.0%	Structural and row shading on the rear side
Module degradation loss, year 1	-0.2%	First-year output reduction
PV loss due to irradiance level	-0.8%	Low-light conversion efficiency reduction
PV loss due to temperature	-2.3%	Thermal derating of module output
Module quality loss	+ 0.8%	Positive power sorting tolerance
LID, light-induced degradation	-1.0%	Initial degradation of crystalline silicon cells
Mismatch loss, modules and strings	-2.1%	Electrical mismatch across the array
Mismatch for rear irradiance	-0.7%	Non-uniform rear-side illumination
Ohmic wiring loss, DC	-1.0%	Resistive losses in DC cabling
Inverter loss during operation	-1.2%	Power conversion efficiency losses
Inverter loss over nominal power	-0.1%	Clipping above rated AC power

Loss / Gain Step	Magnitude	Physical Cause
AC ohmic loss	-0.8%	Resistive losses from inverter to transformer
Medium-voltage transformer loss	-1.1%	Iron and copper losses in the step-up transformer
MV line ohmic loss	-0.1%	Resistive loss from the transformer to the injection point

End-to-end, the nominal array energy at STC efficiency is 987.22 GWh. After degradation, irradiance-level effects, thermal derating, module quality adjustment, LID and mismatch losses, the virtual array energy at the maximum power point is 916.33 GWh. Inverter conversion and clipping losses reduce this to 905.14 GWh at inverter output. AC ohmic losses and transformer losses then reduce the final annual energy injected into the grid to 886.81 GWh.

7. Probabilistic Yield Assessment

A single deterministic simulation does not capture year-to-year weather variability or equipment-model uncertainty. For this reason, the simulation applies a probabilistic uncertainty assessment to translate the P50 production estimate into P90 and P95 values used in conservative financial and debt-sizing scenarios.

Table 7. Uncertainty assumptions used for probabilistic yield assessment

Uncertainty Source	Value
Year-to-year weather variability	4.0%
PV module modelling / parameter uncertainty	1.0%
Inverter efficiency uncertainty	0.5%
Soiling and mismatch uncertainty	1.0%
Degradation uncertainty	1.0%
Combined variability, quadratic sum	4.4%

The combined uncertainty is 4.4% using a quadratic-sum approach. Applying this variability to the median production estimate produces the following exceedance probability results.

Table 8. Annual production exceedance probabilities

Exceedance Probability	Annual Grid Energy
P50, median expected case	886.8 GWh
P90, 90% probability of exceedance	836.9 GWh
P95, 95% probability of exceedance	822.9 GWh

The difference between the P50 and P90 outputs is approximately 50 GWh, or around 5.6% of median annual production. This spread is a key input for bankability assessment because lenders commonly evaluate debt-service capacity against conservative production cases such as P90 or P95 rather than the median P50 scenario.

8. Technical Interpretation

The source simulation indicates a promising design under its stated assumptions, but its high PR and 9.2% effective-irradiance gain are model outputs rather than measured operating performance. The 5.00 m pitch, two width definitions, 1.60 m mounting height and assumed albedo warrant checking against final geometry and field conditions. The reported 0.1% clipping is also conditional on the inverter and collection architecture used by the model.

From a project-development perspective, the main issues requiring attention during the next design stage are confirmation of actual ground albedo, validation of soiling assumptions, final optimisation of row spacing and mounting height, detailed electrical loss calculations, transformer sizing, grid-code compliance, and alignment of the probabilistic production forecast with the final financial model.

9. Conclusions

- The PVsyst V8.0.12 simulation indicates annual grid-injected energy of 886.81 GWh for the 620 MWp DC / 477.5 MWac bifacial PV plant.
- The resulting specific yield is 1,430 kWh/kWp/year and the annual performance ratio is 89.95%, which indicates comparatively low aggregate system losses.
- The bifacial design provides a net 9.2% gain in effective collector-plane irradiance, supporting the selected module technology and mounting approach.
- The 1.30 DC:AC ratio results in negligible clipping losses of approximately 0.1% of array energy.
- The conditional P90 estimate is approximately 837 GWh/year under the illustrative normal model and listed uncertainty inputs; it requires validation before being used as a lender case.
- Further design development should focus on site-specific validation of albedo, soiling, shading, electrical losses, grid integration and long-term degradation assumptions.

Source Data

The energy-yield and performance figures reported in this manuscript were generated by PVsyst V8.0.12 for simulation variant VC1 dated 23 June 2025. PVsyst is the calculation software; the software name does not identify the creator or owner of the project input data.

Declarations

Author Contribution

Conceptualization, methodology, software, validation, formal analysis, investigation, data curation, visualization, writing—original draft, and writing—review and editing. The author has read and approved the final version of the manuscript.

Data Availability

The data supporting the findings of this study are included in the article. The analysis is based on the PVsyst V8.0.12 simulation report (reference VC1, dated 23 June 2025) . The underlying PVsyst project files and detailed simulation outputs are available from the corresponding author upon reasonable request .The meteorological data used in the simulation were obtained from the commercially licensed Meteonorm 8.2 database and are subject to the provider’s licensing restrictions.