

Annex III: Solar Resource and Energy Yield Assessment (SRA)

Solar Resource and Energy Yield Assessment

FOR 120 MW PV POWER PROJECT BY SINDH SOLAR IN DEH HALKANI, SINDH, PAKISTAN

Prepared for:

Sindh Solar Energy Project, Energy Department, Government of Sindh

Bungalow F3, Forum Street, Near the Forum,
Clifton Block 9,
Karachi

Prepared by:

Renewable Resources (Pvt.) Ltd.

1002, 10th Floor, Green Tower,
Jinnah Avenue, Blue Area,
Islamabad.



Reviewed by:

Tractebel Engineering GmbH.

Friedberger Strasse, 173,
61118 Bad Vilbel,
Germany.



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0	13-04-2023	Imran Ahmed Khan	Lucas Martinez Samuel Karres	Samuel Karres	Final

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Annexure 1

- i. **Solar Panel Datasheet (Trina Solar_Vertex_DEG21C.20_EN_2022)**
- ii. **Central Inverter Datasheet (Sungrow_SG2500HV_SG3000HV_EN)**

Abbreviations & Definitions

AM	Air Mass
AEP	Annual Energy Production
EPA	Energy Purchase Agreement
EPC	Engineering, Procurement and Construction
GHI	Global Horizontal Irradiation
GlobInc	Global incident in Collector plane
GOP	Government of Pakistan
EPC	Engineering, Procurement and Construction
GoS	Government of Sindh
IAM	Incident Angle Modifier
IEC	International Electro-technical Commission
IPP	Independent Power Producer
JV	Joint Venture
KE	K-Electric
MoU	Memorandum of Understanding
MPP	Maximum Power Point
NEPRA	National Electric Power Regulatory Authority
O&M	Operation and Maintenance
OEM	Original Equipment Manufacturer
PoE	Probability of Exceedance
Project or First Solar Park	Solar PV project located in Deh Halkani, District West, Karachi, Sindh, Pakistan
PVsyst	PV simulation tool developed by University of Geneva
QCBS process	Quality and Cost Based Selection process
RE2	Renewable Resources (Pvt.) Ltd.
RFP	Request for Proposal
SED	Sindh Energy Department
SSEP	Sindh Solar Energy Project
STC	Standard Test Conditions
TEG	Tractebel Engineering GmbH
ASEL	Artistic Solar Energy (Private) Limited
TA	Transaction Advisor
PBS	Pakistan Bureau of Statistics
T _{amb}	Ambient Temperatures

1 EXECUTIVE SUMMARY

1.1 Background

The Sindh Solar Energy Project (SSEP) falls under the overall ambit of development of Renewable Energy projects in the Province of Sindh through an international standard competitive bidding framework with a wider application to the rest of Pakistan. The Energy Department, Government of Sindh (ED GoS, SED or the Client) received funding from the World Bank Group in the form of a loan to finance the studies related to SSEP. Accordingly, the Client engaged a technical firm to conduct locational and pre-feasibility studies for a 120 MWp project with respect to the identified project Site in Deh Halkani, District West, Karachi, Sindh, Pakistan (First Solar Park or Project) and engaged a reputable legal firm to advise on the legal structuring for the bankability of the Project. Following this procedure, the Client floated an RFP on 8th March 2019 for Transaction Advisory for Utility Scale Solar in the Sindh Province. The Joint Venture (JV) of Bridge Factor (Pvt) Limited from Pakistan and Tractebel Engineering GmbH from Germany was shortlisted as 'Transaction Advisor' for the Project vide letter dated 04th October 2019, following a competitive Quality and Cost based selection process (QCBS). The contract between the Client and the Transaction Advisor ("TA") was signed on 6th December 2019 for this assignment (the Contract). The main objectives of the assignment include:

- 1) Develop the mechanisms of solar park tariff-based competitive bidding and substation-based tariff based competitive bidding using international best practices following World Bank Procurement Regulations while encompassing Pakistan's specific NEPRA Regulations [Phase 1]
- 2) Support the implementation of the first round of solar park tariff-based competitive bidding until the selection of the lowest evaluated responsive bidder(s) and till the financial close of the project [Phase 2]
- 3) depending on the results of Phase 1, support the implementation of a substation-based solar tariff-based competitive bidding (optional under the present contract) [Phase 3]

KE has allied with Sindh Energy Department (SED) and the World Bank to develop a solar park with an aggregate capacity of 350 MW under the ambit of the 'Sindh Solar Energy Project' (SSEP). The objective of SSEP is to increase solar power generation and access to electricity in Sindh Province. The purpose of this tripartite arrangement – formalized today with the signing of a Memorandum of Understanding (MoU) – is to develop and implement sustainable, cost-effective, and competitive utility-scale IPPs in Karachi under a competitive bidding structure.

This tri-partite collaboration is being supported by the World Bank through development financing to the Government of Sindh for the implementation of SSEP. SED will be responsible for conducting relevant project-related studies, implementation of the competitive bidding process, and construction of any public sector infrastructure that is required. The solar IPPs would be constructed and owned by competitively selected private sector developers. Once complete, the power from the project (s) would be inducted into KE's grid via power off-take agreements, enhancing its ability to serve the current and evolving needs of its growing consumer base of 3.2 million.

Tractebel Engineering GmbH (TEG), Bridge Factor Pvt. Ltd (BF), Renewable Resources Pvt. Ltd (RE2), Axis Law Chambers, collectively henceforth referred to as “the Transaction Advisor” has received the legal and technical studies available with the ED-GoS for this Project site. Tractebel Engineering GmbH and Renewable Resources Pvt. Ltd, collectively henceforth referred to as “the Technical Advisor” and Bridge Factor, henceforth referred to as “the Financial Advisor”.

1.2 Solar Resource Assessment

This report has been prepared by Renewable Resources (Pvt.) Ltd and reviewed by Tractebel Engineering GmbH of Germany, for its client, The Energy Department, Government of Sindh. This report presents the solar resource assessment and energy yield estimation prepared for the Project.

The total land area available for survey around 870 acres, but due to obstacles and agricultural land areas, the survey team marked 612 acres consisting of flat terrain with small undulations on the surface. There is no obstruction on project area and its surroundings. The most feasible transportation route of National and Super highway link road then Karachi-Hyderabad M-9 Motorway to Karachi Northern Bypass M-10 can be used for the project transportation during the construction phase. The total length of route is approximately 74.9 km from Karachi Port Qasim to the project site. The Project Company has been allocated land by Government of Sindh (GoS) for the development of the Project.

The project land has small bushes and shrubs, many seasonal streams and slopes in the proposed land area which can be redirected or flattened in the construction phase for safety of the installed structures in that area. The Project site in general has no shading due to terrain or natural objects that can cast shading on PV arrays. The project land area is clear, and the terrain has low to moderate slopes at some points but overall, the elevation profile of the land is smooth. The PV sheds are placed on the assumed levelled area to accommodate the project size of 200 MWp/120MWp based on Fixed and Single Axis tracking system respectively.

The detailed shading analysis is performed through plant modelling in PVsyst for the preliminary layout. The preliminary layout considers the existing land features which upon modelling in PVsyst, casts no significant shading effect due to the available natural and anthropogenic land features.

The preliminary design considered in this report considers various technologies. The best results are attained by the Si - Mono bifacial PV module from Trina solar and central inverter from Sungrow manufacturer. Two types of mounting structures are considered as orientation of PV installation:

- i. Fixed mounting structure with tilt of 22° and azimuth 0°.
- ii. Single Axis (N-S) tracker mounting structure with axis tilt of 0° and rotating Phi limits of -90°/+90°.

The conceptual configuration and major technical characteristics are presented in section 3 of this report.

The solar resource assessment for the Project location is estimated by analysing solar data from different databases that are commonly being used in PV market. Solargis is found to be appropriate solar database for the project location. The annual average solar irradiation on horizontal plane (GHI), estimated at Project location is estimated as 1960 kWh/m². This result is prepared based on 23 years (1999 – 2021) long term time series solar data from Solargis. The standard deviation on annual GHI between mentioned periods is found to be 1.7% of long-term annual average.

The Table 1-1 shows the first-year energy production expected from 200 MWp PV of Fixed Tilt System at 7.5m pitch and 22° tilt orientation which will be available for feeding into the grid. These performances are shown in POE-1 year and POE-10 years scenario.

The results for the best case of fixed tilt system are given below:

Table 1-1: Summary of First Year Production with degradation (Best Case – Fixed Tilt)

		PoE	AEP [MWh/a]
1-year period			
Production [MWh/a]	339,997	50%	339,997
Uncertainty	5.51%	75%	327,373
Standard Deviation [MWh]	18,717	90%	316,011
10-year period			
Production [MWh/a]	339,997	50%	339,997
Uncertainty	5.27%	75%	327,910
Standard Deviation [MWh]	17,920	90%	317,031

The base case scenario is represented by POE-10 years and P50. As a base case, the Project is expected to produce 339,997 MWh during its first year of operation. This corresponds to annual average performance ratio and capacity factor of 80.14% and 19.41% respectively.

The Table 1-2 shows the first-year energy production expected from 120 MWp PV of Single-Axis Tracking System at 7.5m pitch and N – S horizontal axis orientation which will be available for feeding into the grid. These performances are shown in POE-1 year and POE-10 years scenario.

The results for the best case of Single Axis (N-S) tracking system are given below:

Table 1-2: Summary of First Year Production with degradation (Best Case – Single Axis)

		PoE	AEP [MWh/a]
1-year period			
Production [MWh/a]	231,905	50%	231,905
Uncertainty	5.51%	75%	223,294
Standard Deviation [MWh]	12,766	90%	215,544
10-year period			
Production [MWh/a]	231,905	50%	231,905
Uncertainty	5.27%	75%	223,660
Standard Deviation [MWh]	12,223	90%	216,240

The base case scenario is represented by POE-10 years and P50. As a base case, the Project is expected to produce 231,905 MWh during its first year of operation. This corresponds to annual average performance ratio and capacity factor of 80.65% and 22.1% respectively.

The detail loss estimation and energy yield at different Probability of Exceedance (POE) levels are presented in Section 4.5.3 of this report.

2 INTRODUCTION

Sindh Solar Energy Project (SSEP), Energy Department, Government of Sindh (DAE GoS, - the “Project Sponsor”) is intending to build a Solar PV power generation project in Deh Halkani District West, Karachi, located in the Province of Sindh (“the Project”). The Project Sponsor has land allotment from the Government of Sindh (GoS). The Project will be 120 MWp solar PV power project which will be built in the allocated land of 612 acres.

This report has been prepared by Renewable Resources (Pvt.) Ltd (the “Consultant”) and reviewed by Tractebel Engineering GmbH of Germany, for its Client; SSEP, Energy Department, Government of Sindh.

The aim of this report is to prepare the solar resource and energy yield assessment for the Project. In order to achieve the objective, the following assessment were performed and presented in this report:

- General site assessment;
- General plant concept and component configuration;
- Solar resource assessment;
- Energy yield estimation;
- Uncertainty estimation for energy yield; and
- Estimation of PV plant performance at P50, P75, and P90.

General site assessment includes the Consultant’s general site evaluation in respect to its location, transportation access, general land characteristics, assessment of potential shading object and available infrastructures. The detail description and findings for site assessment are presented in Section 3 of this report.

General plant concept included in this report consists of the high-level plant layout, module configuration in strings, module-inverter configurations and typical technical characteristics of Project, that are required to perform an energy yield estimation. Such consideration and concept are presented in Section 4.2 of this report.

The estimation of solar resource at project location is presented in Section 4.3 of the report. This assessment includes the selection of appropriate solar data base and analysis of solar data for the project location based on 23 years historic long-term data. The result of solar data for the Project is presented as Typical Meteorological Year (TMY) data which is used for energy yield estimation.

The energy yield estimations including the method, losses type, assumed/calculated values are presented in Section 4.4 of this report. The annual degradation, uncertainty estimations of calculated energy yield and POE (P50, P75 and P90) estimation are performed and presented in Section 4.5 of this report.

3 SITE ASSESSMENT

Sindh Solar Energy Project (SSEP) is located in Deh Halkani site, District West, Karachi City, Sindh, Pakistan. The overall condition of route via Qasim Port road to the National and Super highway link road then Karachi-Hyderabad M-9 Motorway to Karachi Northern Bypass M10 towards Project site is much better than the other route going through N-5. The total distance is around 74.9 km starting from Port Qasim to the Project site. The Project Company has been allocated with the land by Government of Sindh (GoS) for the development of the Project. The project site has a latitude of 25.029533° N and longitude of 66.993153° E with elevation of around 50 meters.

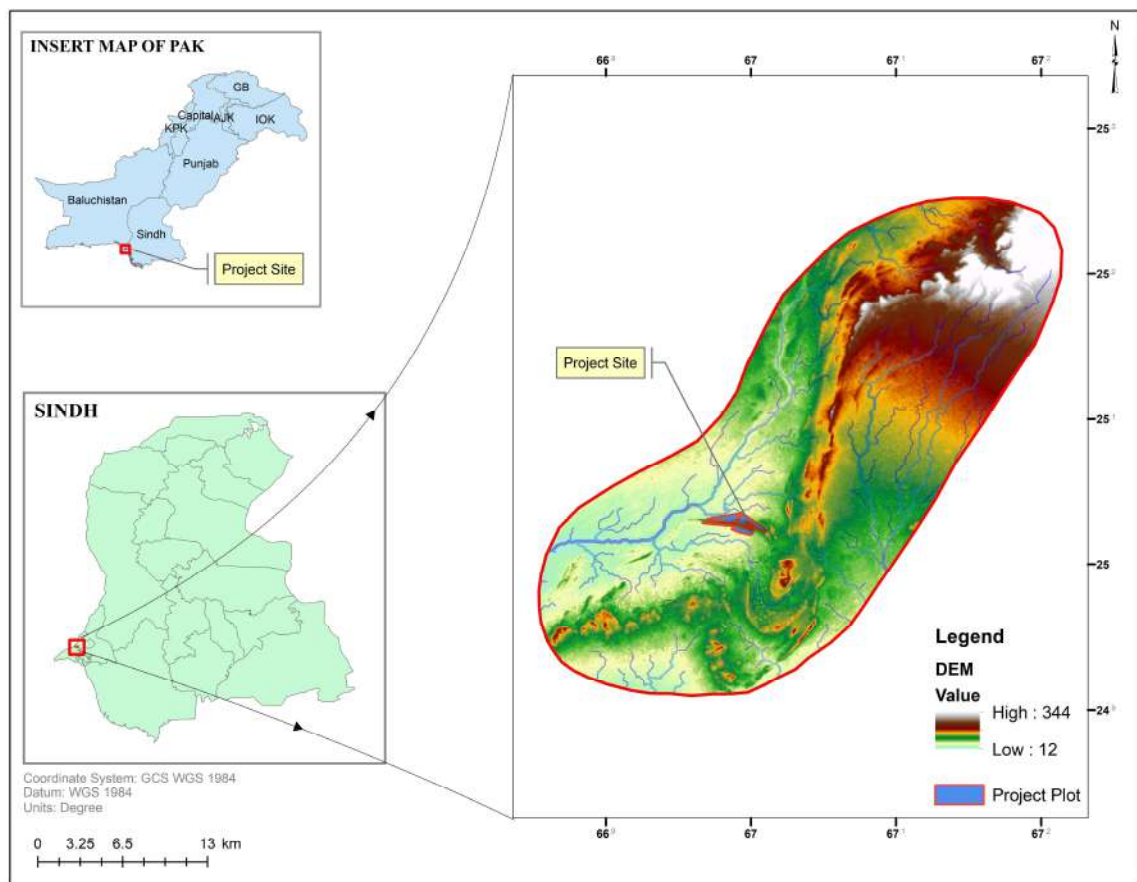


Figure 3-1: Project Site and Nearby Cities

The Consultant performed preliminary site assessment for the energy yield estimation purpose and the results are presented in the following sections.

3.1 Location

The Project site is located at Northern side of the Karachi city in District West near Hazratnabad on Northern Bypass road which is approximately 74.9 km from Port Qasim, Karachi; Pakistan's commercial hub and main port city. The Project site spans across 612 acres of land. According to the information provided by the Client, the land has been leased by the Project Company from Government of Sindh. The access to the site from Port Qasim will be through the National and Super highway link road then Karachi-Hyderabad M-9 Motorway to Karachi Northern Bypass M10 towards Project site. The major section of the track from Karachi to the site is a multi-lane, relatively flat road.

The Project site is surrounded by the small graveyards, chicken sheds, residential area, connecting road, agricultural land, small goths and hills which will neglected while the solar micro-siting and technical study of project area will be done. The Project site has no vegetation consisting of flat terrain with small undulations on the surface. Many small seasonal streams were observed in the proposed land area which can be redirected in the construction phase for safety of the installed structures in the area. The Project location can be seen in Figure 3-2 and Site boundary is shown in Figure 3-3. The boundary coordinates are given in Table 3-1.

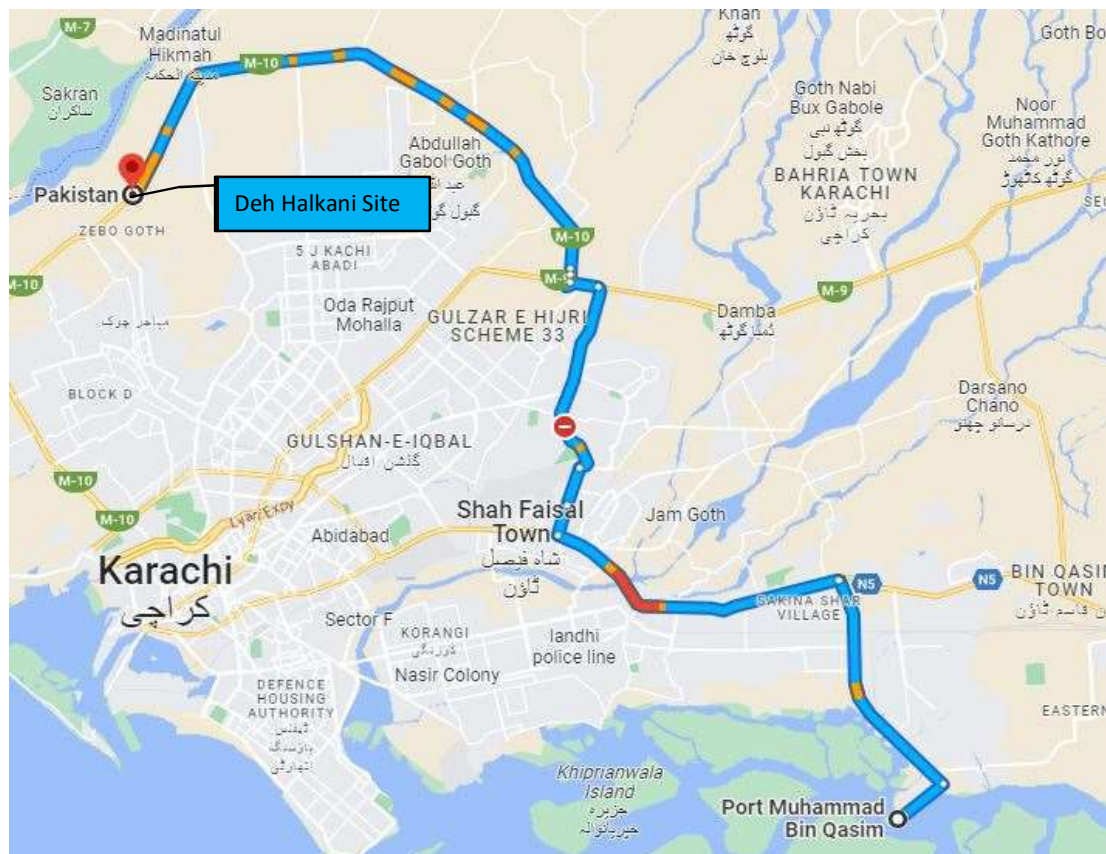


Figure 3-2: Project Location (via Google Map)

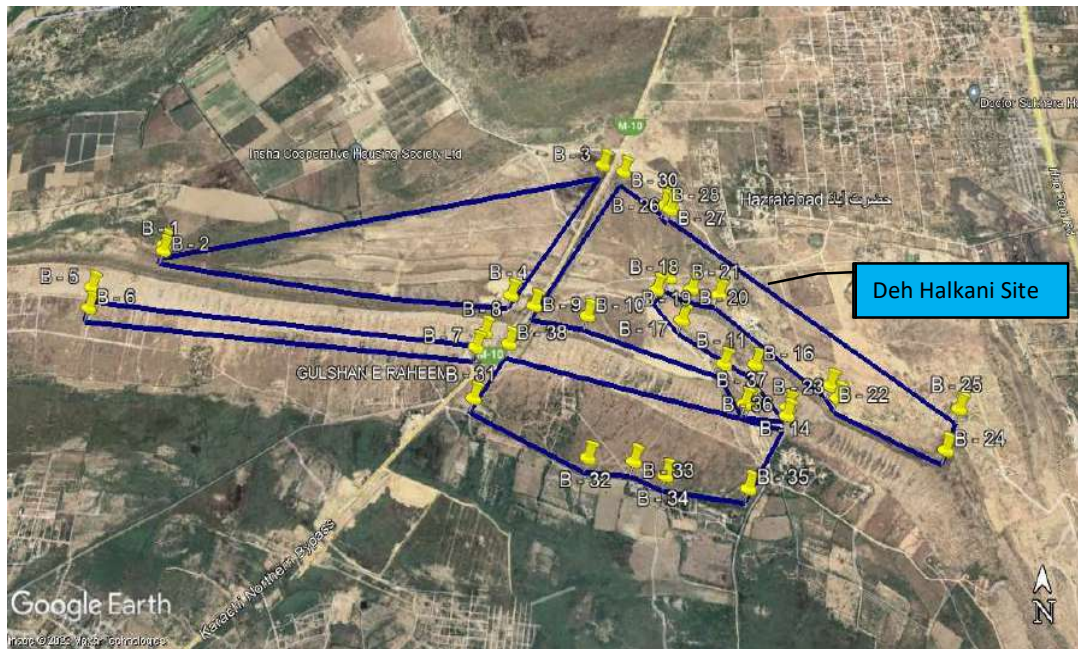


Figure 3-3: Geographical Location of the Project Site and Site Boundary

The Boundary coordinates of the site are as below mentioned in Table 3-1.

Table 3-1: Site Coordinates

Boundary	Latitude/Longitude	Boundary	Latitude/Longitude	Boundary	Latitude/Longitude
1	25° 1'51.49"N	14	25° 1'25.50"N	27	25° 1'59.40"N
	66°58'12.11"E		67° 0'8.67"E		66°59'48.06"E
2	25° 1'52.55"N	15	25° 1'32.11"N	28	25° 1'59.95"N
	66°58'12.05"E		67° 0'3.27"E		66°59'48.43"E
3	25° 2'6.81"N	16	25° 1'39.40"N	29	25° 2'5.52"N
	66°59'36.35"E		66°59'50.32"E		66°59'40.34"E
4	25° 1'43.63"N	17	25° 1'44.48"N	30	25° 1'27.05"N
	66°59'18.66"E		66°59'45.90"E		66°59'11.98"E
5	25° 1'45.09"N	18	25° 1'46.52"N	31	25° 1'17.82"N
	66°57'59.74"E		66°59'48.32"E		66°59'32.57"E
6	25° 1'41.67"N	19	25° 1'44.63"N	32	25° 1'17.29"N
	66°57'59.72"E		66°59'52.39"E		66°59'40.74"E
7	25° 1'35.13"N	20	25° 1'43.72"N	33	25° 1'15.09"N
	66°59'12.26"E		66°59'57.45"E		66°59'46.28"E
8	25° 1'37.48"N	21	25° 1'28.86"N	34	25° 1'13.20"N
	66°59'13.80"E		67° 0'16.64"E		67° 0'0.70"E
9	25° 1'41.84"N	22	25° 1'26.85"N	35	25° 1'24.17"N
	66°59'22.99"E		67° 0'17.71"E		67° 0'8.37"E
10	25° 1'40.12"N	23	25° 1'18.72"N	36	25° 1'25.89"N
	66°59'32.80"E		67° 0'35.74"E		67° 0'0.86"E
11	25° 1'32.18"N	24	25° 1'25.17"N	37	25° 1'35.66"N
	66°59'57.55"E		67° 0'39.42"E		66°59'18.33"E
12	25° 1'26.04"N	25	25° 1'59.17"N		
	67° 0'1.11"E		66°59'49.58"E		
13	25° 1'26.00"N	26	25° 1'58.64"N		
	67° 0'1.80"E		66°59'49.17"E		

The Allotment Letter for the land does not specify the exact boundary co-ordinates. For the purpose of this study, the coordinates have been marked jointly by the representatives of Client and Consultant based on site surveys and judgements. Please refer to Section 4.5.7 for further details about the utilization of land.

3.2 Climate and Conditions

Deh Halkani has an arid climate with hot summers and mild winters. The Summer season persists for the longest period during the year. Deh Halkani also receives the rains from July to September (Monsoon) and experiences a tropical climate encompassing warm winters and hot summers. The humidity levels usually remain high from March to November, while they are very low in winter as the wind direction in winter is north-east. As per weather forecasting website, the warmest month in Deh Halkani is June, with an average high-temperature of 36.0°C and an average low-temperature of 27°C. While winter are dry and cold. The coldest month is January and temperature ranges from average high 26°C to an average low of 12°C. The average rainfall of the district is 145 mm, (ranges from 1 mm to 52 mm) per annum. Deh Halkani has 9.6 hours of sunshine daily on average yearly basis. May has the most sunshine of the year, with an average of 12.8 hrs of sunshine. The month with the least sunshine is August, with an average of 6.75 hrs of sunshine.



Figure 3-4: Average Annual Temperatures of Project Location (in °C)

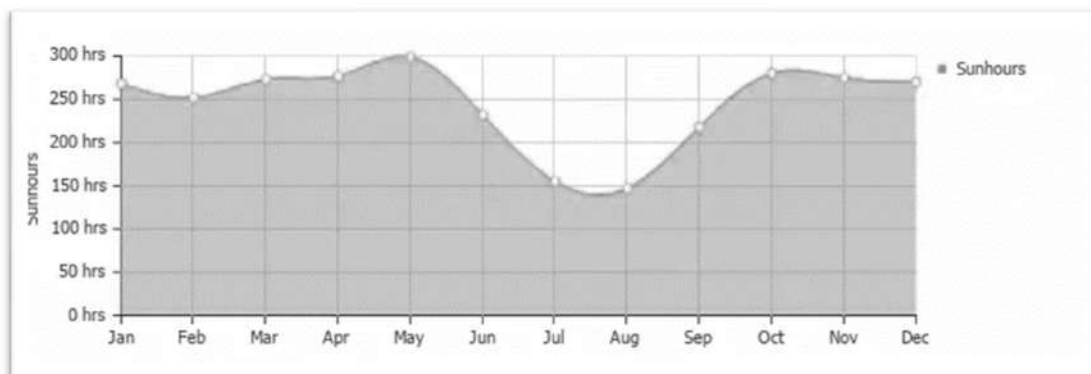


Figure 3-5: Average Monthly Sun hours of Project Location

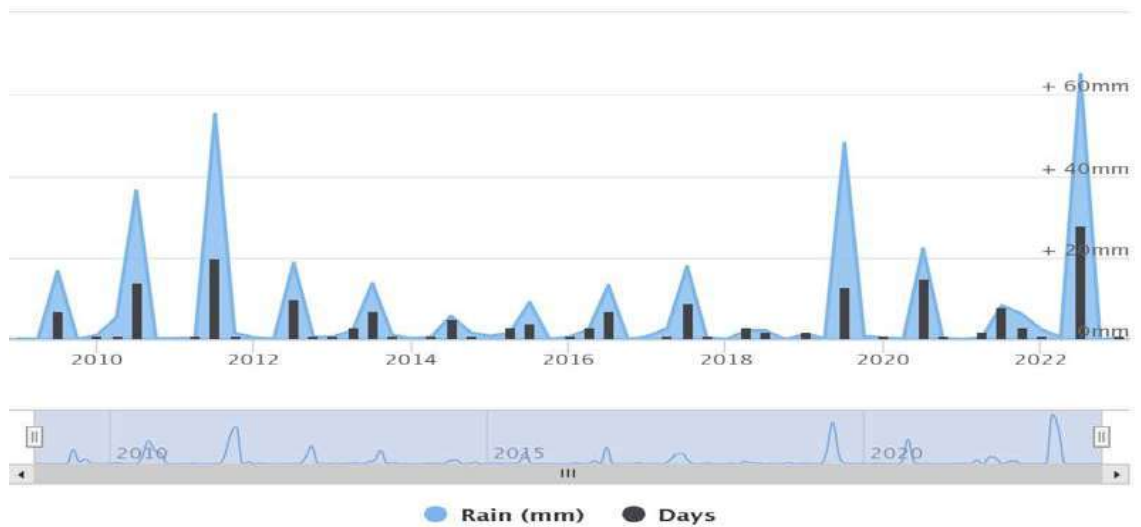


Figure 3-6: Average Yearly Rainfall Chart of Project Location

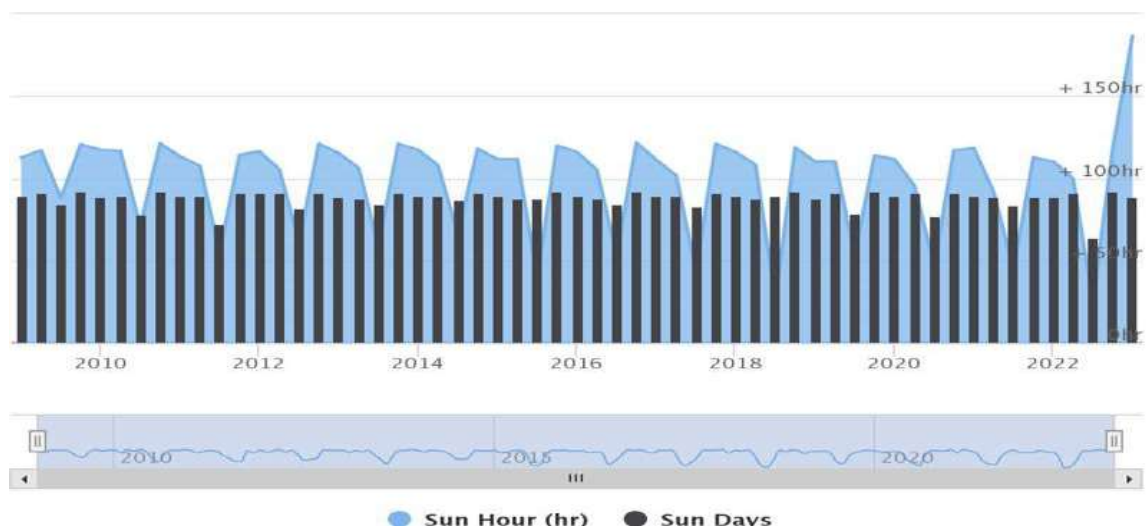


Figure 3-7: Average Yearly Sun Hours of Project Location

3.3 Land Characteristics

The Project site is surrounded by small graveyards, chicken sheds, residential area, connecting road, agricultural land, small goths and hills which will be neglected while the solar micro-siting and technical study of project area will be done. The Project site has no vegetation consisting of flat terrain with small undulations on the surface and no settlements inside project boundary. There is no anthropogenic and natural land use and land cover.

The Project is intended to build in the approximate area of 612 acres. The project site is irregularly shaped and has four (04) sections very close to each other as shown in Figure 3-8. Section 1 is of area 230 acres, Section 2 is of 140 acres, Section 3 is of 195 acres and Section 04 is of 45 acres. The maximum distance between any two sections is 250 m.

Technical arrangements and their implementation in respect of right of way and cable crossings between these 04 sections should be planned and pursued by the successful bidder. The Client may consider extending support with the necessary approvals and permissions (such as for land use) for this interconnectivity within the project. This should be addressed in the RFP with more relevant details and clarity during auction tender process.

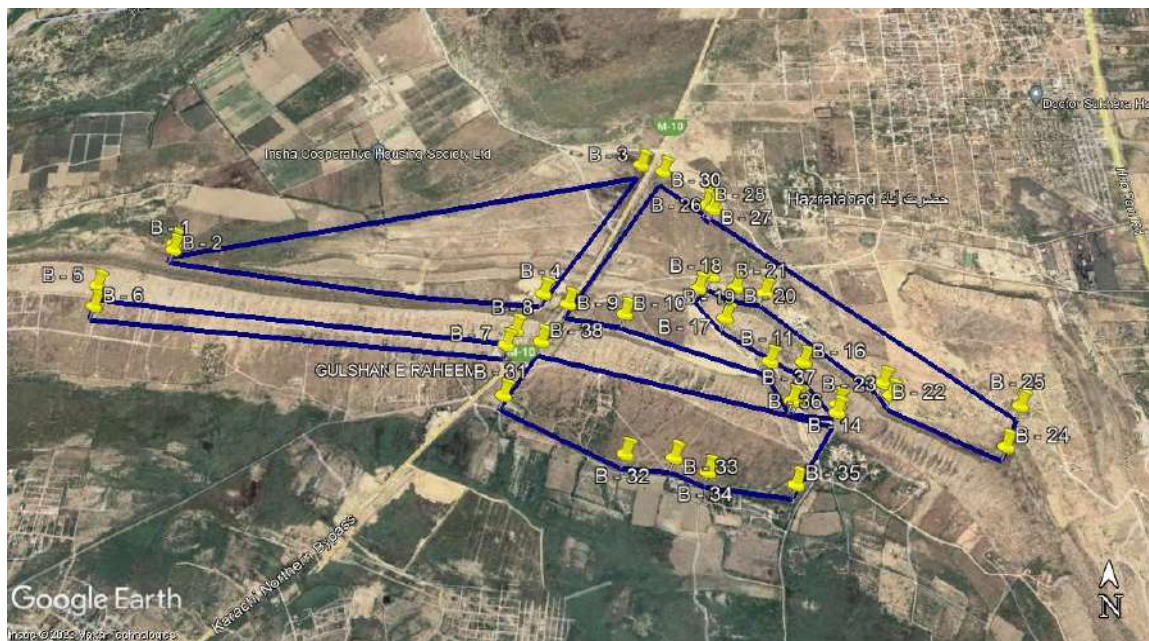


Figure 3-8: Deh Halkani Site Google Earth Imagery

No major horizon shading is expected for the project site. The average slope of the site in West to East direction is 4.0%, while that in North to South direction is 5.1% as seen in the Figure 3-9 and Figure 3-10 respectively.



Figure 3-9: Elevation profile of Project Site W-E



Figure 3-10: Elevation profile of Project Site N-S



Figure 3-11: Panoramic View of West to East Slope Area

3.4 Available Infrastructure

3.4.1 Access Roads

The major road from Karachi to the site is two-way and flat, asphalt road. The Port Qasim being the major port of Pakistan, ideally could be the point of delivery of equipment for the solar PV power plant. While the aerial distance between the Port and the project site is about approximately 45.5 km, the distance by road is approximately 74.9 km. There is no need of access road construction due to location of project is on the main highway. Based on physical inspection, the access to the site appears to be good enough for construction and operation of PV plant. It is expected that the EPC contractor will carry out further detailed investigation on access road during pre-construction assessment.

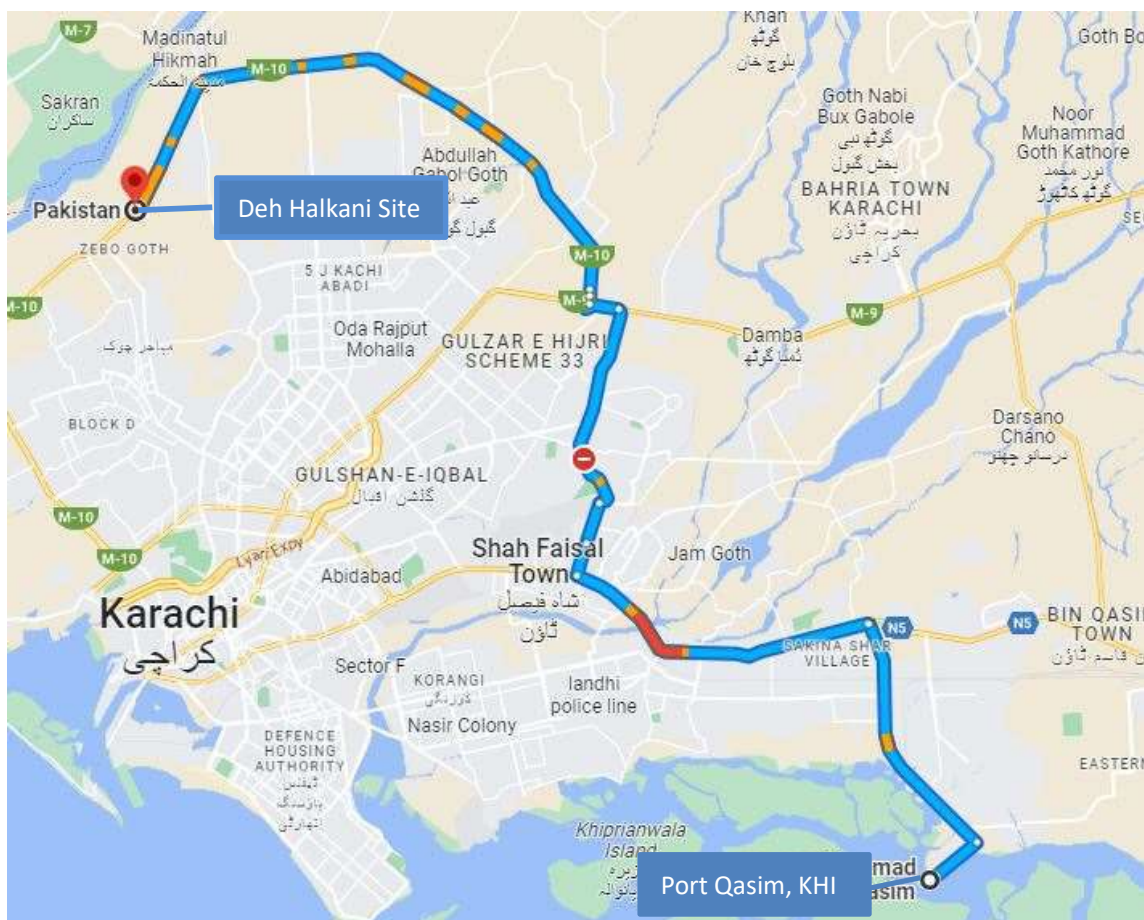


Figure 3-12: Route from Karachi (Port Muhammad Bin Qasim) to Project Site

3.4.2 Geography of the Area

Karachi West District is an administrative district of Karachi Division in Sindh, Pakistan. The district contains mix population including Sindhi, Baloch, Punjabis, Pashtuns and Muhajirs. No single ethnic group form established majority in the district. In 2000, Karachi West District was abolished and divided in to 05 towns namely: Lyari town, Kemari town, SITE town, Baldia town and Orangi town. On 11 July 2011 Sindh Government restored again Karachi West District. In 2020, Kemari District was carved out from Karachi West District. So Kemari town, SITE town and Baldia town ended up being part of Kemari District. Lyari became part of Karachi South district in 2015.

Karachi West District, spreading over an area of 370 km² and population of 2,077,228 as per Census of District population in 2017. The rural population was 160,904 (7.75%) and urban 1,916,324 (92.25%). The literacy rate is 68.29%: 71.27% for males and 65.03% for females. Administrative town in Karachi West is Orangi town which has 13 union councils. Dehs in Karachi West organised by 04 Taluka namely: Mauripur Taluka (9 Dehs), Mangho Pir Taluka (11 Dehs), Orangi Taluka (01 Deh) and Baldia Taluka (02 Dehs).

Project site is located at Deh Halkani and Deh Bund Murad in Mangho Pir Taluka. Population in those areas is around 45,000 as per PBS data of 2017.

3.4.3 Grid Connection

The key components of the solar plant will be PV panels, mounting structure, cabling, inverters, step up transformers and switchgear. PV panels convert the solar radiation into DC electrical energy which then will be converted in to AC energy by inverters. The Project connection point is looping in-out of 220 kV Single Circuit between 220 kV Baldia Substation and 220 kV Surjani Substation of KE network.

The electrical network within the vicinity of the site of the plant will comprises of LV (22/33 kV) and HV (220 kV) lines. A separate electrical and grid interconnection study was conducted by a Third party i.e. Power Planners International (Pvt) Ltd, for the project including Power Quality, Load Flow, Short Circuit and Power Evacuation. The electricity generated by the Project will be directly fed to 220 kV Baldia Grid and 220 kV Surjani Grid station via loop IN – OUT arrangement as pointed out in Grid Interconnection study or as advised by the KE (Power Purchaser).

4 SOLAR RESOURCE AND ENERGY YIELD ASSESSMENT

4.1 Scope of Work

The following scope of work is covered within this section related to solar resource and energy yield assessment:

- General plant concept and component configuration,
- Solar resource assessment,
- Energy yield estimation,
- Uncertainty estimation for energy yield, and
- Estimation of PV plant performance at different Probability of Exceedance (POE) i.e. P50, P75, and P90.

4.2 General Plant Concept and Electrical System

4.2.1 Initial Plant Assessment with Different Solar Technologies

An initial assessment of the technologies has been conducted. Four solar technologies were analysed, including Trina solar (Si-Mono), Trina Solar (Si-Mono Bifacial), Trina Solar (Si-poly), and First solar (Thin-film/Cdte).

Two types of shed design and orientation were considered:

1. Fixed tilt sheds with 2 modules in Y-axis in portrait orientation and 50 modules along X-axis, module spacing of 2 cm at each side. The direction of the modules is due south.
2. Single Axis tracking system with sheds having 2 modules in X-axis in landscape orientation and 50 modules along Y-axis, module spacing of 2 cm at each side. The axis of rotation is horizontal orientated North-South with the modules facing toward the East in the morning and the West in the afternoon.

The Consultant explored the following possible options and performed PVsyst simulation along with each solar technology. Based on PV simulated results, the Consultant recommended and opted the most suitable technology for the case. The PV assessment results are shown in Table 4-1.

Table 4-1: Different PV Technology Yield Assessment and Performance Ratio Comparison

Technology Used	Shed Design	Tilt	Pitch (m)	Performance Ratio PR	Produced Energy MWh/year	Specific prod. kWh/kWp /year	Near Shadings %	Capacity Factor %
	Angle							
Trina (mono)	S/A	+/-90	7.5	77.01	221438	1845	5.68	21.06
Trina (bifacial)	F/T *	22	7.5	80.14	339997	1700	2.52	19.41
	S/A *	+/-90	7.5	80.65	231905	1932	5.68	22.10
Trina (Poly)	F/T	22	7.5	77.18	327440	1637	2.55	18.68
First Solar (Thin film)	F/T	22	7.5	79.20	336000	1667	2.55	19.17
	S/A	+/-90	7.5	78.89	226829	1890	5.68	21.57

*: Selected Case

F/T: Fixed tilt

S/A: Single axis tracking

4.2.2 Plant layout and configuration

A preliminary general layout for 200 MWp Fixed tilt PV system installation is shown in Figure 4-1.

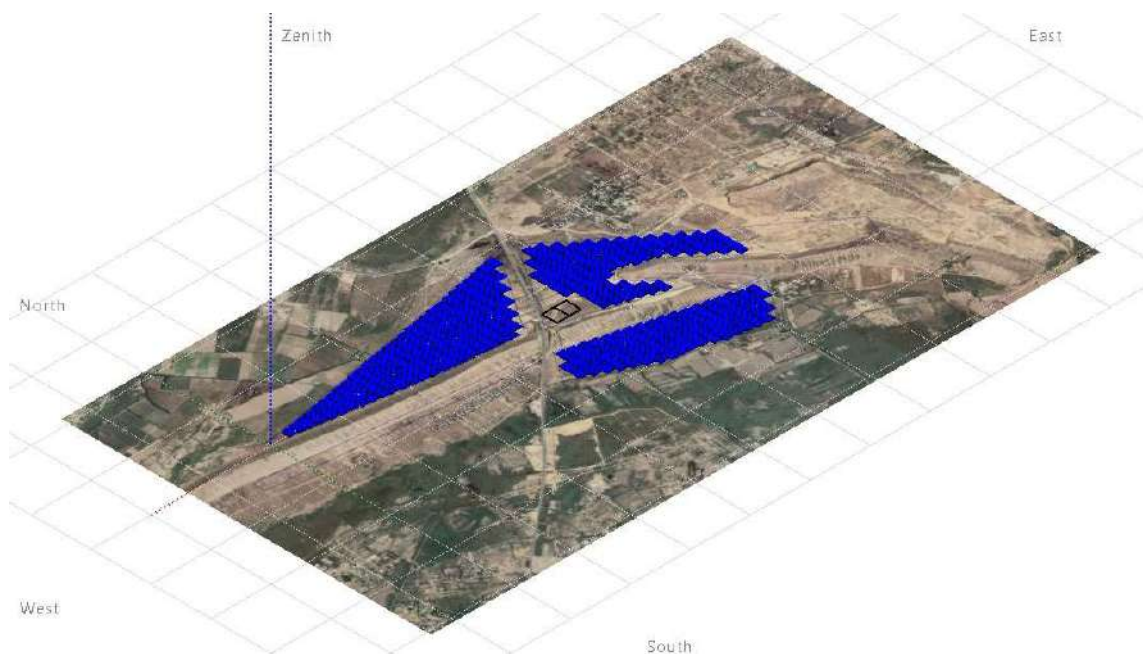


Figure 4-1: Preliminary Plant Layout (Fixed Tilt System)

A preliminary general layout for 120 MWp Single Axis tracking PV system installation is shown in Figure 4-2.

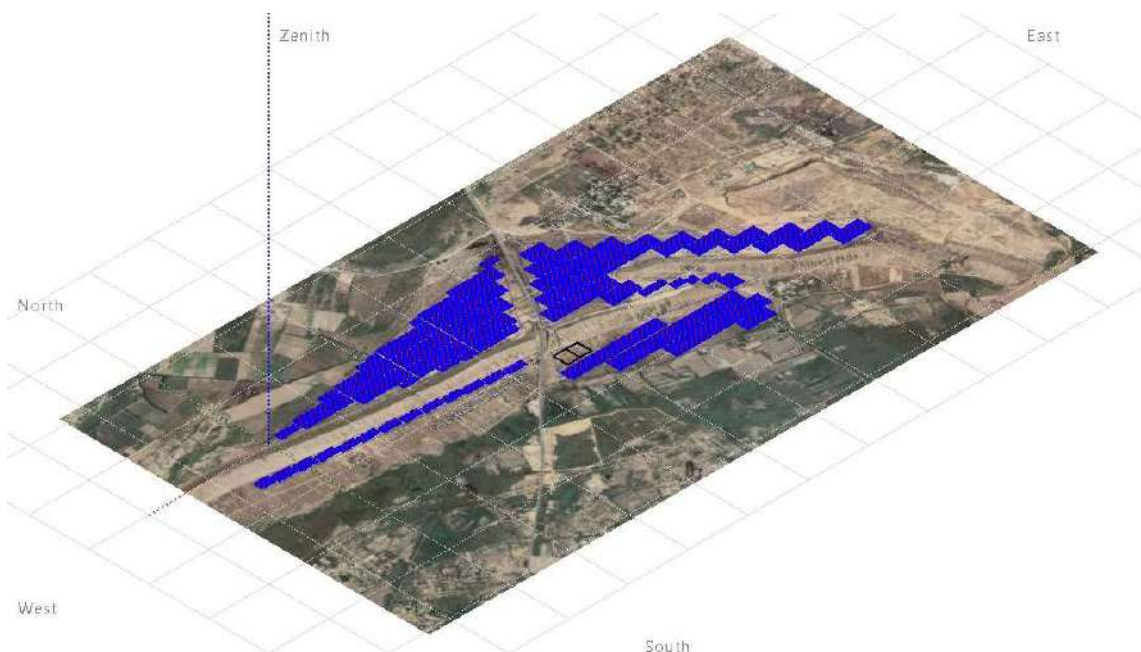


Figure 4-2: Preliminary Plant Layout (Single Axis Tracking System)

The major technical configuration, technical specification of PV modules and inverter considered in general layout concept and energy yield estimation in this report, are shown in Table 4-2 and Table 4-3. The PV module and inverter type considered in this report are selected by the Consultant as no preference was provided by the Project Company. It shall be noted that the final selection of component likely to change at later stage of the project during optimisation of plant design by the bidder.

The complete technical data sheets from OEMs of PV module and Inverter are given as *Annexure 1*.

Table 4-2: Major Technical Characteristics of PV Module

Parameters	Description
Module Model	TSM-650DE21
Manufacturer	Trina Solar
Nominal Power [W]	650
Efficiency [%]	20.96
Power Tolerance [%]	± 1.5
Cell Type	Si-mono Bifacial
Open Circuit Voltage [V]	45.5
Short Circuit Current [A]	18.35
MPP Voltage [V]	37.5
MPP Current [A]	17.36
Power Coefficient of Temperature [-%/C]	-0.34
Nominal Operating Cell Temperature (NOCT)	25
Height X Width X Thickness [mm]	2384 X 1303 X 35

Table 4-3: Inverter Main Characteristics

Parameters	Description
Inverter Model	SG2500HV
Manufacturer	Sungrow
Nominal AC Capacity	2500 kW
Maximum DC Input Power	3500 kWp
MPP voltage Range	800 V – 1300 V
Maximum DC Current	3508 A
Nominal AC Current	2624 A
Maximum Efficiency	0.990
European Efficiency	0.987
Operating Temperature Range	-30°C to +50°C

The Consultant assumed the configuration between PV modules and inverters described in Table 4-4.

Table 4-4: Plant Configuration – PV Module and Inverter

Parameter	Value	
System Type	Fixed Tilt	Single Axis tracking (N-S)
Module Type	Si-Mono (Bifacial) 650Wp	
Inverter Type	SG2500HV - 2500 kW @ 25°C	
Pitch	7.5m	7.5m
Tilt	22 degree*	Variable
Installed Capacity (DC)	200MWp	120MWp
Total Number of Modules	307,692	184,643
Modules per inverter	4,274	4,196
Number of Modules in series	28	29
DC/AC Ratio	1.11	1.09
Number of inverters	72	44
Nominal AC Power of One In- verter [kW]	2500	
Total AC Power [kW]	180,000	110,000

Note:

*The Consultant highlights that 25-degree tilt will be the optimum with regard to amount of irradiation incident on the plane of array. However, considering general layout presented in this report with pitch of 7.5m, it is found that energy yield will be slightly higher (0.1% more) if the panels are tilted 22° instead of 25° to the perfect south. This is because of lower row-row shading. Due to this reason, 22° tilt has been considered for the energy yield estimation in this report.

4.3 Solar Resource Assessment

The solar resource assessment for the Project site is estimated by analysing solar data and accuracy from different databases that are commonly being used in the current PV market. Solar data generated from Solargis at the location of the site, is used as representative data for this project and this corresponds to the annual average solar irradiation on horizontal plane (GHI) to 1960 kWh/m². The blue spot in the Figure 4-3 below shows the site location.

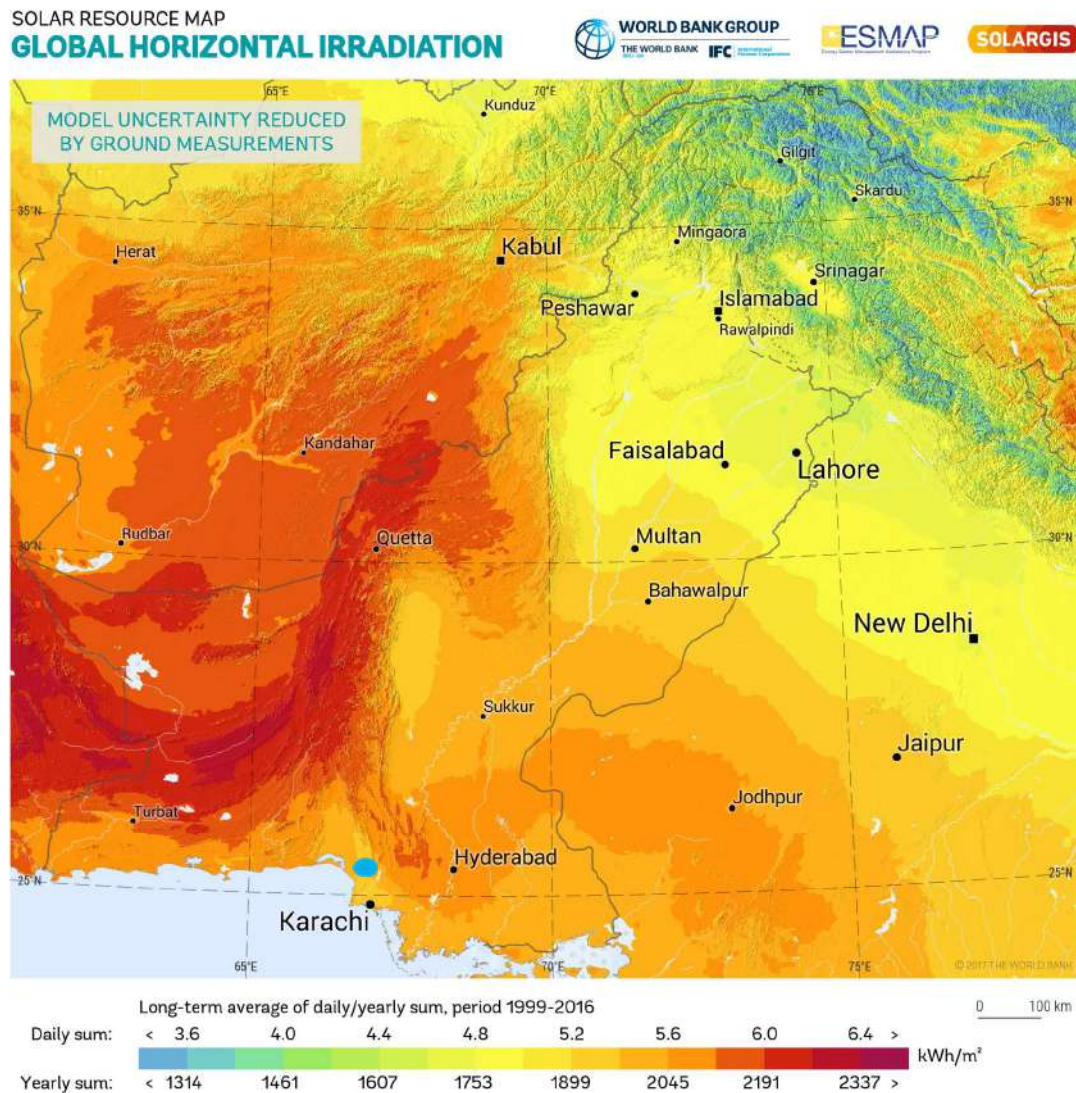


Figure 4-3: GHI Solar Resource Map of Pakistan (source: SolarGIS)

Quality of Solargis data is determined by underlying models, spatial and temporal resolution of atmospheric and meteorological inputs, and their accuracy. Solargis data has been validated at 250+ public and many commercial locations, where high quality measurements were available. Statistics such as bias and RMSD are used for estimation of user's uncertainty. Solargis model demonstrates stable performance globally, and uncertainty lies within the margins. Uncertainty of Solargis GHI and DNI yearly summaries for 80% of observations is within the range of $\pm 4\%$ and $\pm 8\%$ ($\pm 5\%$ and $\pm 10\%$ for 90% of observations), respectively. In complex geographies and extreme cases, uncertainty of GHI and DNI yearly summaries can be as high as $\pm 8\%$ and $\pm 15\%$, respectively.

4.3.1 Solar Data for Project Site

Solar data for the Project site is from SolarGIS database. SolarGIS has provided the Client the time series data 1999-2021 and Typical Meteorological Year (TMY) data for the project location from SolarGIS. The Typical Meteorological Year (TMY) data are generated based on 23 year's time series data, which is used by the Consultant for energy yield estimation.

Table 4-5 shows the monthly GHI, Diffuse Horizontal Irradiation (DHI) and ambient temperature breakdown of TMY at the Project location. Based on the statistics, the annual average GHI at Project location is expected around 1960 kWh/m² and annual average temperature around 26.5°C. Direct Normal Irradiation (DNI) at project location on annual average basis is 1564 kWh/m². The respective annual average Diffuse Horizontal solar Irradiance (DHI) corresponds to 927 kWh/m².

Table 4-5: Typical Meteorological Year GHI, Average DHI and Ambient Temperature

Month	GHI [kWh/m ²]	DHI [kWh/m ²]	Ambient temperature [°C]
January	134	53	19.2
February	149	57	21.7
March	194	75	25.4
April	211	85	28.6
May	218	101	30.3
June	182	104	30.9
July	138	99	29.8
August	134	94	28.8
September	161	86	28.8
October	172	68	28.5
November	138	55	25.2
December	127	50	20.6
Annual	1960	927	26.5

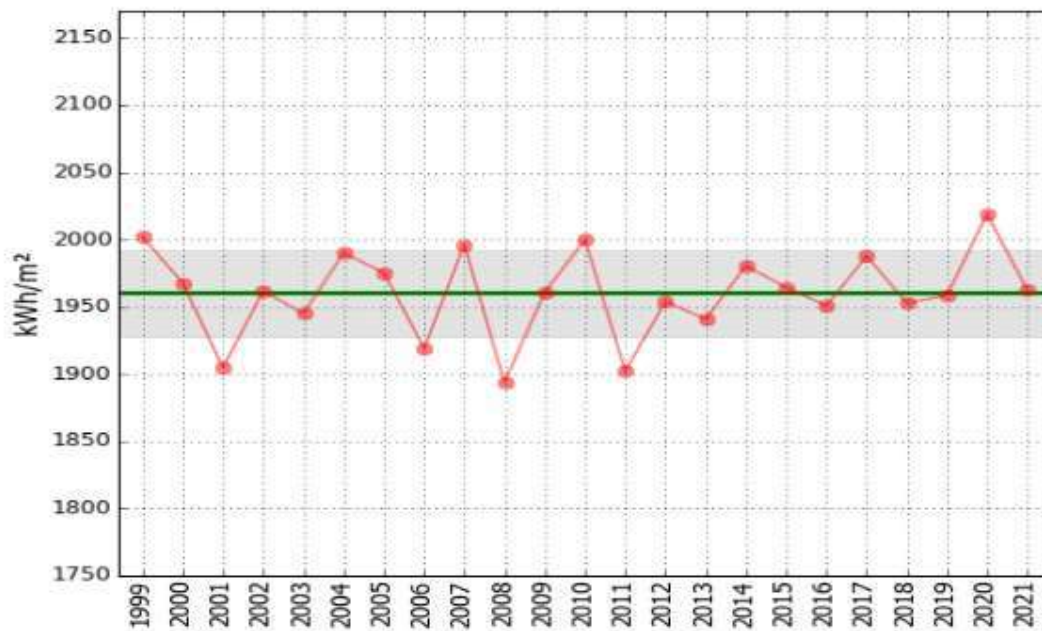


Figure 4-4: GHI Inter-annual Variation with Average line & STDEV band

Figure 4-4 shows the Inter-annual variation on GHI compared to its long-term average for the period between 1999 and 2021. The uncertainty of the annual GHI value, based on the site-adapted SolarGIS data, is estimated to $\pm 2.1\%$. The standard deviation of annual GHI between 1999 & 2021 is estimated as 1.7% of long-term average annual GHI.

In conclusion, the Typical Meteorological Year (on hourly steps) data representing annual average GHI of 1960 kWh/m², annual average DHI of 927 kWh/m², and annual average temperature of 26.5°C are used for energy yield assessment for the Project. The uncertainty on annual average GHI, according to Solargis is $\pm 4.5\%$.

4.4 Energy Yield Estimation

4.4.1 Approach and Methodology

The Consultant used PVsyst 7.3.3 for the plant modelling and estimation of energy yield for the Project considered in this study.

PVsyst stands among one of the most widely used simulation tools in the PV industry for grid connected and stand-alone PV systems. It is developed by the Centre of Energy at the University of Geneva, Switzerland. PVsyst allows for the detailed definition of PV plant including special geometries such as ground slopes, near shading objects, combination of different electrical configuration, etc.

The following technical parameters (for this Project) are required as input in PVsyst for the energy yield estimation:

- Site characteristics (geographical location, land characteristics, slope, shading objects);
- Meteorological data sets (GHI, T_{amb} , Wind Speed);
- Module orientation (tilt, azimuth);
- Technical characteristics of plant component (module, inverter);
- Array configuration (no. of modules per string, no. of strings per inverter);
- Array layout (distance between two rows, width of the row);
- Losses assumptions (soiling, module quality, mismatch losses, cable losses, etc.);

The uncertainties on solar irradiation data are considered based on the information provided along with the solar data. Further uncertainties on assumptions in energy yield calculations are estimated based on the Consultant's experience. The long-term energy yield and Probability of Exceedance on energy yield is calculated by considering estimated uncertainties and annual degradation of the modules.

4.4.2 Major Modelling Input

The meteorological data and technical characteristics of components considered by the Consultant as input for the energy yield estimation is presented in to Table 4-4 and Table 4-5. Any changes to the solar plant configuration and technical characteristics of components, then considered, will have a direct impact on the energy output of the Project.

4.4.3 Modelling of Losses

A description of the losses mechanism in PV system is presented in this section. The described losses outline the significant, non-negligible losses which may pose a risk if the plant is not designed properly.

Albedo

The ground reflectance (also called albedo) is the fraction of solar radiation incident on the ground that is reflected. The Reflected radiation causes reduced radiation on the modules. This value depends upon the type of area. A typical value for grass-covered areas is 20%. Snow-covered areas may have a reflectance as high as 70%. An albedo value of 0.2 is used in calculating the radiation incident on the tilted PV panels, but it has only a modest effect.

Soiling

The soiling factor is a measure of the dimming effect on module due to dust or other precipitation on the module surface. Depending upon the project location, the losses in annual average energy due to soiling varies between 1% and 3% for grid connected solar PV project in semi-urban areas. For the project location in Gadap Town, District Malir based on site visit, an average value of 3% as soiling loss is considered. However, this assumption considers frequent cleaning during operation and maintenance period of the project.

Horizon

The horizon analysis measures the effect on reduction of global solar irradiation at the site due to far shading effect. Based on the site location, there are no far shading objects, hence, the losses due to horizon effect is considered as negligible.

Near Shading

Near Shading are partial shadings which affect only a part of the PV array. This partial shading could be because of closer row to row alignment, surface geometry, external shading objects such as trees, buildings, wind turbines or other objects.

Near shading calculation in PVsyst requires the reconstruction of the exact geometry of the PV field and its environment, in 3D space. The following figure shows the plant modelling (layout) prepared in PVsyst to evaluate near shading losses for array layout considered in this study.

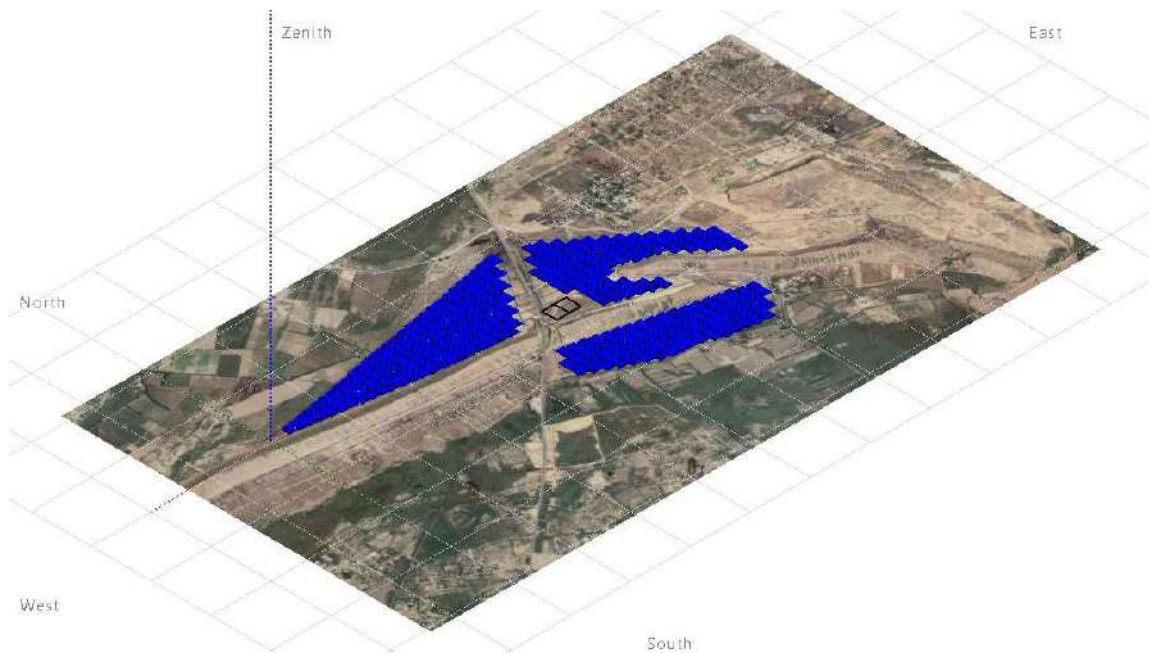


Figure 4-5 PVsyst 3D Modelling of the Project Site

Upon plant modelling with Fixed tilt system, the near shading loss is calculated as 2.52%o (i.e. annual average energy loss) for the general layout prepared for the Project.

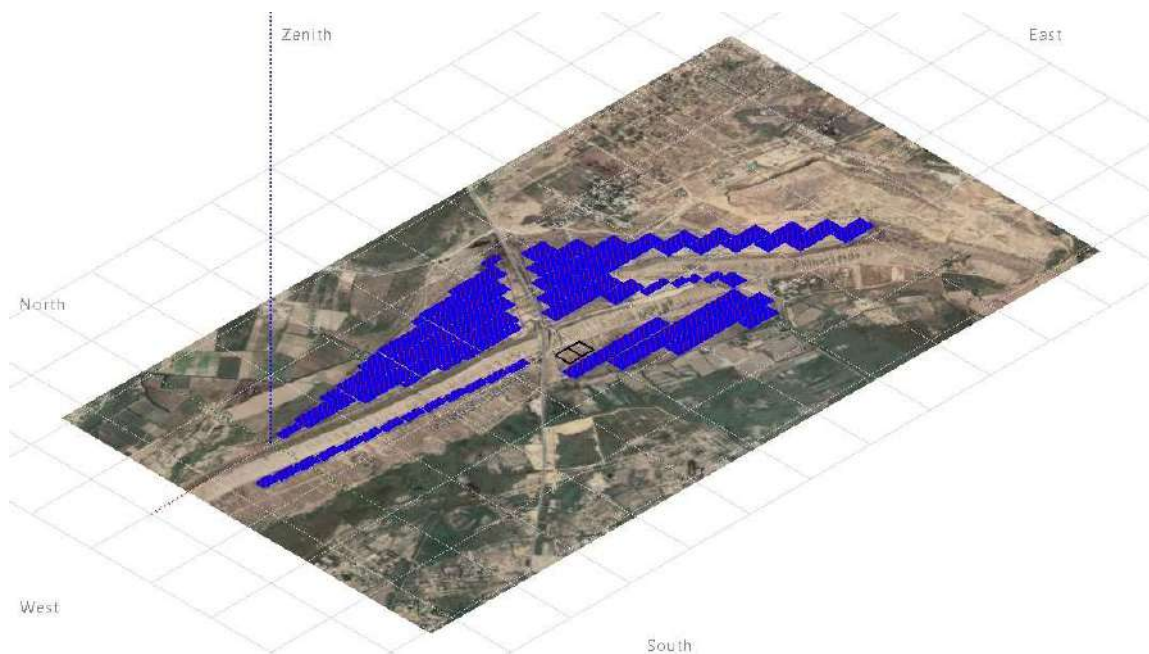


Figure 4-6 PVsyst 3D Modelling of the Project Site

Upon plant modelling with Single-Axis Tracking System, the near shading loss is calculated as 5.68% (i.e. annual average energy loss) for the general layout prepared for the Project.

Losses due to Irradiance Level

Efficiency of Solar module is given at Standard Test Condition (STC). These standards conditions are (1000 W/m², 25°C, AM1.5). Since the irradiation at site is not always 1000 W/m², the efficiency of module also would not stay STC value all the time. There would be changes in efficiency due to plant operation other than STC efficiency. This change is noted in PVsyst by losses due to irradiation. This loss is estimated as 0.49% for Fixed tilt system and 0.29% for Single Axis tracking system in PVsyst.

Losses due to temperature

Losses due to temperature represent is the losses in energy due to array performance in operating conditions other than STC temperature i.e. 25°C cell temperature. The thermal performance of a PV module is defined by a power temperature coefficient of the module [-%/°C]. The higher the absolute value of the temperature coefficient, the higher will be the losses due to temperature.

The modules considered in the concept design has thermal co-efficient on power of -0.34%/°C and this provides the losses due to temperature for Project of about 6.98% for Fixed tilt system and 7.08% for Single Axis tracking system, calculated by the PVsyst.

Ground Reflection on Front side

This represents a contribution of the irradiance reflected by the close ground (between rows), and reaching the front side of the collectors (weighted by the IAM loss, very significant here) calculated in this case by PVsyst simulation as +0.09% for Fixed tilt system and +0.59% for Single Axis tracking system.

This contribution is very low with sheds and trackers systems, but becomes crucial with vertical East-West bifacial systems.

Ground Reflection loss

This is the loss of irradiance due to the reflexion (1 - Albedo), referred to the ground reference area calculated in this case by PVsyst simulation as 80%, in both cases.

View factor for Rear side

Each point of the ground is supposed to receive an irradiance (luminous power) specific to its position on the ground, and the sun's position. After reflexion, this point will re-emit the same power in all directions (isotropic hypothesis, i.e. Lambertian distribution,,) according to the albedo factor.

A part of this power will be intercepted by the rear side of the collectors, the rest is lost (sky). The view factor is the fraction of this interception for each given point.

The total power received by the rear side is the sum of all ground points contributions. This power will result in an irradiance [W/m^2], which is now normalised to the m^2 of collector area. Therefore, it is expressed as Irradiance (and not Power) this view factor is calculated in this case by PVsyst simulation as 50.48% for Fixed tilt system and 76.03% for Single Axis tracking system.

Sky diffuse on the rear side

This is the contribution of the diffuse irradiance, coming directly from the sky and is calculated in this case by PVsyst simulation as +9.65% for Fixed tilt system and +39.84% for Single Axis tracking system.

Shading loss on rear side

The shading loss on rear side is the loss due to the mechanical structures (corresponding to the specified and is calculated in this case by PVsyst simulation as 15%.

Mismatch Losses

Mismatch accounts for manufacturing tolerances that yield PV modules with slightly different current-voltage characteristics. Consequently, when connected together electrically, they do not have exactly similar characteristics, hence losses due to mismatch are expected. Based on default values, the PVsyst simulation results in 2.54% as mismatch loss (including 0.44% for back irradiance) for Fixed tilt system and 2.91% (including 0.81% for back irradiance) for Single Axis tracking system.

DC Cabling Losses

Voltage drop within the PV system DC wiring accounts for system power losses between the modules and inverter. Typical solar grid is based on the combination of series and parallel connections and losses depend on cable type, operating voltage/current, cable length, etc. In general, these losses are typically in the range of 1.0% - 1.5% for similar PV systems (i.e. 1000 V DC system). In this project, by taking the default values the PVsyst Simulation results in 1.5% loss at STC and this corresponds to annual average loss of 1.15% for Fixed tilt system and 1.20% for Single Axis tracking system, at operating condition.

IAM Factor on Global

This refers to the reflection loss. The reflection loss corresponds to weakening of the irradiation really reaching the PV cell's surface with respect to irradiation under normal incidence. In principle, it depends upon the properties of glass surface, positioning of modules, AR coating on glass and location. The overall reflection losses calculated by the PVsyst based on module considered for the Project is 1.85% for Fixed tilt system and 1.02% for Single Axis tracking system.

Light Induced Degradation

LID (Light Induced Degradation for c-Si) refers to the loss of performances of PV modules arising in the first few hours of exposure to the sun, with crystalline modules. For a PV module considered in the preliminary design, the module manufacturer provides 98% of its rated power as power guarantee during first year of operational period. This indicates the degradation of PV modules for first year operation lies a range between 0 – 2.5%. For this project, to be in line with supplier's guarantee, 2% as the losses due to LID is considered in PVsyst modelling, and energy yield estimation calculation.

Module Quality Loss

Module quality loss refers to the deviation between actual module power and nominal power specified in the manufacturer specification. In current PV market, the module manufacturers provide positive tolerance (0/+3% or 0/5 W) on module power. In another words, the manufacturer assures that the actual module power is at least the nameplate power. For the Project with a numbers of PV modules to be installed, some percentage of gain in total installed capacity of the project can be expected. For this project, 0.37% gain is considered as result of the PVsyst simulation, provided that such positive tolerance requirement will be maintained during the procurement.

Auxiliaries Loss

Self-consumption loss refers to the energy that is provided by the PV plant for auxiliary equipment in the plant (e.g. Inverter ventilation, lights, monitoring system and security cameras). Self-consumption value depends upon the final design and final selection of components. In case of this project, the Consultant has assumed the self-consumption loss of 0.53% for Fixed tilt system and 0.58% for Single Axis tracking system, based on assumption that the total auxiliary load will be 400kW for Fixed tilt system and 300kW for Single-Axis Tracker system for whole day.

Inverter Losses

This represents the losses in inverter during conversion of DC to AC energy under real operating conditions. The conversion efficiency of inverter is defined by the European efficiency and maximum efficiency. The European and maximum efficiency of the inverter considered for this project are 98.7% and 99.0% respectively. This leads to annual average loss (efficiency plus over loading) of energy in inverter around 1.23% for Fixed tilt system and 1.18% for Single Axis tracking system, as calculated by the PVsyst Simulation.

Plant Availability

In general, the annual plant availability of fixed PV system lies between 98% and 100%, mainly depending upon the following:

- O&M Operator's response time in case of corrective actions required

- Local availability of maintenance services from major components supplier
- Level of spare parts stocked on site
- Level of maintenance and correction required in the plant

It is the Operator's responsibility to keep the plant running all the times during the year, however, due to some maintenance issues (mainly corrective maintenance) the plant may not run with 100% availability over the year. For this Project, an annual average plant availability factor of 98% is considered in the energy yield estimation.

It shall be noted that unavailability of grid and any curtailment due to the grid is beyond the scope of this assessment. The Consultant believes that provisions for curtailment/failure from grid (if any) will be addressed in Project PPA (Power Purchase Agreement) or agreement with off-taker.

Summary of Losses Estimation

The table below summarizes the estimation of losses value for the Project.

Table 4-6: Losses Estimation Summary

Losses Type	Fixed Tilt	Single Axis	Calculated [C] or Defined [D]
Front Side			
Global Incident in Coll. Plane	+8.2%	+22.2%	C
Near Shading	-2.52%	-5.68%	C
IAM factor on global	-1.85%	-1.02%	C
Soiling losses	-3.0%	-3.0%	D
Ground reflection on front site	+0.09%	+0.59%	C
Back side			
Ground reflection loss	-80%	-80%	C
View factor for rear side	-50.48%	-76.03%	C
Sky diffuse on rear side	+9.65%	+39.84%	C
Shading loss on rear side	-15.0%	-15.0%	D
Both sides			
Module Degradation Loss	-0.45%	-0.45%	D
PV loss due to irradiance level	-0.49%	-0.29%	C
Spectral Correction	-0.0%	+0.0%	D
Losses due to temperature	-6.98%	-7.08%	C
Auxiliaries	-0.53%	-0.58%	D
Module quality loss	+0.37%	+0.37%	D
Light Induced Degradation	-2.0%	-2.0%	D
Module Array Mismatch loss	-2.10%	-2.10%	C
Mismatch for back irradiance	-0.44%	-0.81%	C
Ohmic wiring loss	-1.15%	-1.20%	C
MV Line Ohmic loss& AC Ohmic Loss	-0.10%	-0.08%	C
Medium Voltage Transformer Loss	-1.06%	-1.03%	C
Inverter loss	-1.23%	-1.18%	C
Unavailability loss	-2.10%	-2.03%	C

4.4.4 Energy Yield Results

The table below shows the energy yield estimation results for the Project operation during the first year. The results are mainly presented in terms of annual energy production, specific yield and performance ratio.

Table 4-7: First Year Plant Performance Summary

Parameter	Fixed Tilt	Single Axis
Installed DC Power [kWp]	200,000	120,000
Irradiation on horizontal plane [kWh/m ²]	1960	1960
Irradiation on module plane [kWh/m ²]	1970.4	2182.4
Energy Yield [MWh]	339,997	231,905
Specific Yield [kWh/kWp]	1700	1932
Performance Ratio [%]	80.14	80.65
Capacity Factor [%]	19.41	22.10

4.5 Long Term Energy Yield Estimation

The long-term energy yield estimation is prepared based on the first-year energy production and applying guaranteed value of annual degradation. The long-term energy yield is also prepared at different Probability of Exceedance levels (P50, P75 and P90). The results are discussed and presented in the following sections.

4.5.1 Degradation

The long-term energy yield is estimated for the project life of 25 years, and considering an annual average degradation (from year 2 and onwards) of 0.45% of reduction in module name plate power. This degradation value is in line with the guarantees provided for the selected module by the manufacturer. For clarification, the first-year energy already includes the degradation of 2.0% which is also in line with the manufacturer's power guarantee provided for the module considered in this assessment.

For clarity purpose, the module performance (specifically LID and degradation) values included in this energy yield estimation represents the Consultant's conservative assumptions, mainly due the project being in early stage of development.

4.5.2 Uncertainty Estimation

The following table shows the uncertainty evaluation of presented energy yield result in this report. These parameters and values are based on the Consultant's project experiences. The total uncertainty as a result is calculated at 5.27 % for the energy yield estimation presented in this report.

Table 4-8: Uncertainties – Energy Yield Estimation

Uncertainties	1-Years	10-Years
Irradiance	4.3%	4.0%
Conversion to inclined surface (PVsyst)	2.0%	2.0%
Soiling	0.5%	0.5%
Spectral uncertainty (AM)	0.5%	0.5%
Albedo	0.5%	0.5%
Reflection	0.5%	0.5%
Deviation from module specs	0.5%	0.5%
Inverter and transformer losses	1.0%	1.0%
Mismatch	1.0%	1.0%
Ohmic losses	1.0%	1.0%
Shading losses	1.5%	1.5%
Availability	1.0%	1.0%
Total uncertainty	5.51%	5.27%

The total uncertainty on long term (eg.10 yrs.) energy yield estimation is 5.27%. Similarly, the uncertainty for energy estimation for 1-year period is estimated as 5.51%. This includes the variability effect of solar data which is generated based on standard deviation of 1.7% of long-term average GHI (for 23 year's time series data), as presented in section 4.3.1 of this report. Therefore, the uncertainty of 5.51% is used to estimate POE - 1 year and the uncertainty value of 5.27% is used to estimate POE-10 year's energy production.

4.5.3 Probability of Exceedance (PoE-10 Years) (Fixed Tilt)

The probability of Exceedance (PoE) describes how confident a calculated result is; in this case, the energy production. Beside the 50% (P50) confidence level, common PoE levels for financial calculations and institutions in the renewable energy sector are 75% (P75) and 90% (P90) in Pakistan. The following tables summarize the long-term energy yield estimation at different PoE levels of 200MWp installed capacity with Fixed tilt system at 7.5m Pitch and 22-degree orientation.

Table 4-9: Annual Breakdown of Long-Term Energy Yield (25 Years– 200MWp Fixed Tilt – POE 10 year)

Year of Operation	Annual Yield P50 [MWh]	Annual Yield P75 [MWh]	Annual Yield P90 [MWh]
Year-1 (without Degradation)	346,936	334,602	323,501
Year-1	339,997	327,910	317,031
Year-2	338,442	326,410	315,581
Year-3	336,887	324,910	314,131
Year-4	335,332	323,410	312,681
Year-5	333,776	321,910	311,231
Year-6	332,221	320,411	309,781
Year-7	330,666	318,911	308,330
Year-8	329,111	317,411	306,880
Year-9	327,556	315,911	305,430
Year-10	326,000	314,411	303,980
Year-11	324,445	312,911	302,530
Year-12	322,890	311,411	301,080
Year-13	321,335	309,911	299,630
Year-14	319,780	308,411	298,179
Year-15	318,224	306,911	296,729
Year-16	316,669	305,411	295,279
Year-17	315,114	303,911	293,829
Year-18	313,559	302,412	292,379
Year-19	312,003	300,912	290,929
Year-20	310,448	299,412	289,478
Year-21	308,893	297,912	288,028
Year-22	307,338	296,412	286,578
Year-23	305,783	294,912	285,128
Year-24	304,227	293,412	283,678
Year-25	302,672	291,912	282,228

4.5.4 Probability of Exceedance (PoE – 1 Year) (Fixed Tilt)

The POE-1-year estimation of 200MWp installed capacity with Fixed tilt system at 7.5m Pitch and 22-degree orientation is presented below:

Table 4-10: Annual Breakdown of Long-Term Energy Yield (25 Years – 200MWp Fixed Tilt – POE 1 year)

Year of Operation	Annual Yield P50 [MWh]	Annual Yield P75 [MWh]	Annual Yield P90 [MWh]
Year-1 (without Degradation)	346,936	334,054	322,460
Year-1	339,997	327,373	316,011
Year-2	338,442	325,876	314,565
Year-3	336,887	324,378	313,120
Year-4	335,332	322,881	311,674
Year-5	333,776	321,383	310,229
Year-6	332,221	319,886	308,783
Year-7	330,666	318,388	307,338
Year-8	329,111	316,891	305,892
Year-9	327,556	315,393	304,447
Year-10	326,000	313,896	303,001
Year-11	324,445	312,398	301,556
Year-12	322,890	310,901	300,110
Year-13	321,335	309,403	298,665
Year-14	319,780	307,906	297,219
Year-15	318,224	306,409	295,774
Year-16	316,669	304,911	294,328
Year-17	315,114	303,414	292,883
Year-18	313,559	301,916	291,437
Year-19	312,003	300,419	289,992
Year-20	310,448	298,921	288,546
Year-21	308,893	297,424	287,101
Year-22	307,338	295,926	285,655
Year-23	305,783	294,429	284,210
Year-24	304,227	292,931	282,764
Year-25	302,672	291,434	281,319

4.5.5 Probability of Exceedance (PoE-10 Years) (Single Axis Tracking)

The following tables summarizes the long-term energy yield estimation at different PoE levels of 120MWp installed capacity with Single Axis tracking system (N-S Orientation).

Table 4-11: Annual Breakdown of Long-Term Energy Yield (25 Years – 120MWp Single Axis – POE 10 year)

Year of Operation	Annual Yield P50 [MWh]	Annual Yield P75 [MWh]	Annual Yield P90 [MWh]
Year-1 (without Degradation)	236,637	228,225	220,653
Year-1	231,905	223,660	216,240
Year-2	230,844	222,637	215,251
Year-3	229,783	221,614	214,262
Year-4	228,722	220,591	213,273
Year-5	227,662	219,568	212,284
Year-6	226,601	218,545	211,295
Year-7	225,540	217,522	210,306
Year-8	224,479	216,499	209,316
Year-9	223,419	215,476	208,327
Year-10	222,358	214,453	207,338
Year-11	221,297	213,430	206,349
Year-12	220,236	212,407	205,360
Year-13	219,175	211,384	204,371
Year-14	218,115	210,361	203,382
Year-15	217,054	209,337	202,393
Year-16	215,993	208,314	201,403
Year-17	214,932	207,291	200,414
Year-18	213,872	206,268	199,425
Year-19	212,811	205,245	198,436
Year-20	211,750	204,222	197,447
Year-21	210,689	203,199	196,458
Year-22	209,628	202,176	195,469
Year-23	208,568	201,153	194,480
Year-24	207,507	200,130	193,490
Year-25	206,446	199,107	192,501

4.5.6 Probability of Exceedance (POE – 1 Year) (Single Axis Tracking)

The POE-1-year estimation of 120MWp installed capacity with Single Axis tracking system (N-S Orientation) is presented below:

Table 4-12: Annual Breakdown of Long-Term Energy Yield (25 Years - 120MWp Single Axis – POE 1 year)

Year of Operation	Annual Yield P50 [MWh]	Annual Yield P75 [MWh]	Annual Yield P90 [MWh]
Year-1 (without Degradation)	236,637	227,851	219,943
Year-1	231,905	223,294	215,544
Year-2	230,844	222,273	214,558
Year-3	229,783	221,251	213,572
Year-4	228,722	220,230	212,586
Year-5	227,662	219,208	211,600
Year-6	226,601	218,187	210,614
Year-7	225,540	217,166	209,628
Year-8	224,479	216,144	208,643
Year-9	223,419	215,123	207,657
Year-10	222,358	214,102	206,671
Year-11	221,297	213,080	205,685
Year-12	220,236	212,059	204,699
Year-13	219,175	211,037	203,713
Year-14	218,115	210,016	202,727
Year-15	217,054	208,995	201,741
Year-16	215,993	207,973	200,755
Year-17	214,932	206,952	199,769
Year-18	213,872	205,930	198,783
Year-19	212,811	204,909	197,797
Year-20	211,750	203,888	196,811
Year-21	210,689	202,866	195,825
Year-22	209,628	201,845	194,839
Year-23	208,568	200,823	193,853
Year-24	207,507	199,802	192,867
Year-25	206,446	198,781	191,882

4.5.7 Recommendations

Following are the few recommendations to be considered in order not to deviate the uncertainty range estimated for energy yield in this report.

➤ Land Utilization

- The Allotment Letter for the land does not specify the exact boundary co-ordinates. It locks the area in acres (612 acres) and the location on town planning maps. The exact boundary co-ordinates will be marked at the stage of land lease by the concerned department of GOS while staying in the same location and area identified in the Allotment Letter.
- For the purpose of this study, the coordinates have been marked jointly by the representatives of Client and Consultant based on site surveys and judgements. As a result, the Project feasibility study is based on the land co-ordinates given in Table 3-1: Site Coordinates, which must be considered at the time of land lease
- The procedure followed above is as per the practices for allocation and utilization of land at GOS.
- The Project is intended to build in the approximate area of 612 acres. The project site is irregularly shaped and has four (04) sections very close to each other as shown in Figure 3 8. Section 1 is of area 230 acres, Section 2 is of 140 acres, Section 3 is of 195 acres and Section 04 is of 45 acres. The maximum distance between any two sections is 250 m.
- Technical arrangements and their implementation in respect of right of way and cable crossings between these 04 sections should be planned and pursued by the successful bidder. The Client may consider extending support with the necessary approvals and permissions (such as for land use) for this interconnectivity within the project. This should be addressed in the RFP with more relevant details and clarity during auction tender process.
- The project land is clear which contain only small bushes and shrubs. The Project site in general has no shading due to terrain or natural objects that can cast shading on PV arrays.

➤ Design Phase

- Appropriate spacing between rows to be considered in order to minimize near shading loss.
- Technical characteristics of components in similar range as considered in the preliminary concept design.

➤ **Construction Phase**

- All the construction activities should be according to the design.
- Checking PV modules flash test data to ensure the module power are within the tolerance range.
- Sorting of PV modules during actual installation to minimize the mismatch losses.

➤ **Operation & Maintenance Phase**

- Timely operation and maintenance (O&M) are mandatory.
- Cleaning PV modules frequently to keep soiling loss not more than 3.0%.
- Maintaining inverter operating temperature within the manufacturer's recommendation range.
- Considering plant performance and/or plant availability as guarantee from O&M contractor during operation period.

5 RESULTS SUMMARY

Following are the main points of conclusions for Solar resource and Energy yield estimation.

- Site is generally flat having no buildings, trees or any obstruction in surrounding that could hinder the production. In this respect, site seems to be suitable for PV installation.
- The Typical Meteorological Year data for the Project site corresponds to the annual average GHI of 1960 kWh/m², annual average DHI of 927kWh/m², and annual average temperature of 26.5°C. TMY data sets are used for energy yield assessment for the Project.
- The energy yield estimation is performed using the standard practice and the result shows that the 200MWp Solar PV project for Fixed tilt system at 22 Degree Orientation and 7.5m Pitch:
 - ❖ With Fixed tilt system, the project is expected to produce maximum 339,997 MWh/year in comparison to different scenarios and technologies during its first year of operation. The corresponding annual average performance ratio and capacity factor are estimated as 80.14% and 19.41% respectively.
- The energy yield estimation is performed using the standard practice and the result shows that the 120MWp Solar PV project for Single Axis tracking system at N-S Orientation and 7.5m Pitch:
 - ❖ With Single Axis system, the project is expected to produce maximum 231,905 MWh/year in comparison to different scenarios and technologies during its first year of operation. The corresponding annual average performance ratio and capacity factor are estimated as 80.65% and 22.1% respectively.
- The uncertainty on long term annual energy estimation is +/- 5.27%.

ANNEXURE 1

- i. Solar Panel Datasheet (Trina Solar_Vertex_DEG21C.20_EN_2022)
- ii. Central Inverter Datasheet (Sungrow_SG2500HV_SG3000HV_EN)



BIFACIAL DUAL GLASS MONOCRYSTALLINE MODULE

PRODUCT: TSM-DEG21C.20

POWER RANGE: 645-665W

665W

MAXIMUM POWER OUTPUT

0~+5W

POSITIVE POWER TOLERANCE

21.4%

MAXIMUM EFFICIENCY



High customer value

- Lower LCOE (Levelized Cost Of Energy), reduced BOS (Balance of System) cost, shorter payback time
- Lowest guaranteed first year and annual degradation;
- Designed for compatibility with existing mainstream system components



High power up to 665W

- Up to 21.4% module efficiency with high density interconnect technology
- Multi-busbar technology for better light trapping effect, lower series resistance and improved current collection



High reliability

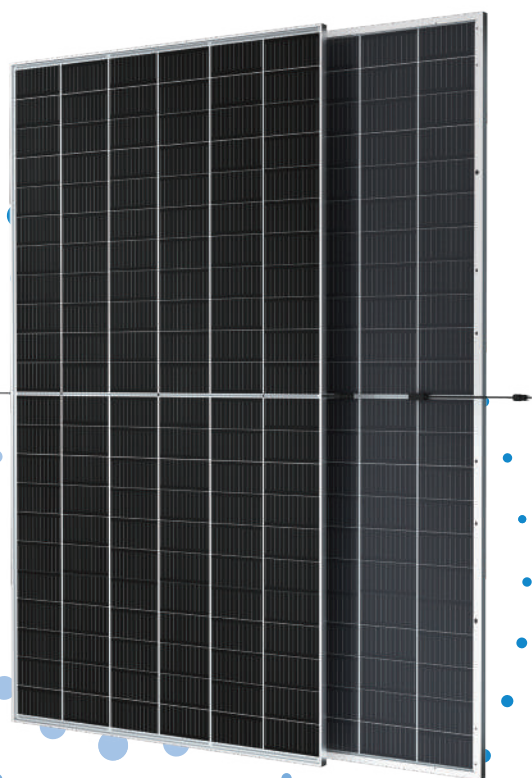
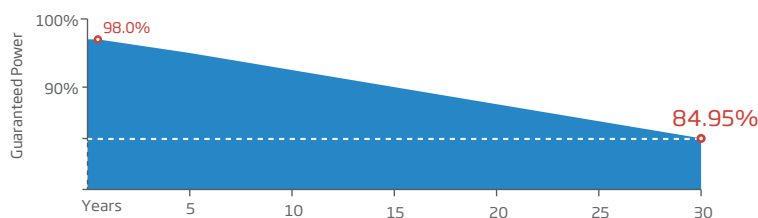
- Minimized micro-cracks with innovative non-destructive cutting technology
- Ensured PID resistance through cell process and module material control
- Resistant to harsh environments such as salt, ammonia, sand, high temperature and high humidity areas
- Mechanical performance up to 5400 Pa positive load and 2400 Pa negative load



High energy yield

- Excellent IAM (Incident Angle Modifier) and low irradiation performance, validated by 3rd party certifications
- The unique design provides optimized energy production under inter-row shading conditions
- Lower temperature coefficient (-0.34%) and operating temperature
- Up to 25% additional power gain from back side depending on albedo

Trina Solar's Vertex Bifacial Dual Glass Performance Warranty

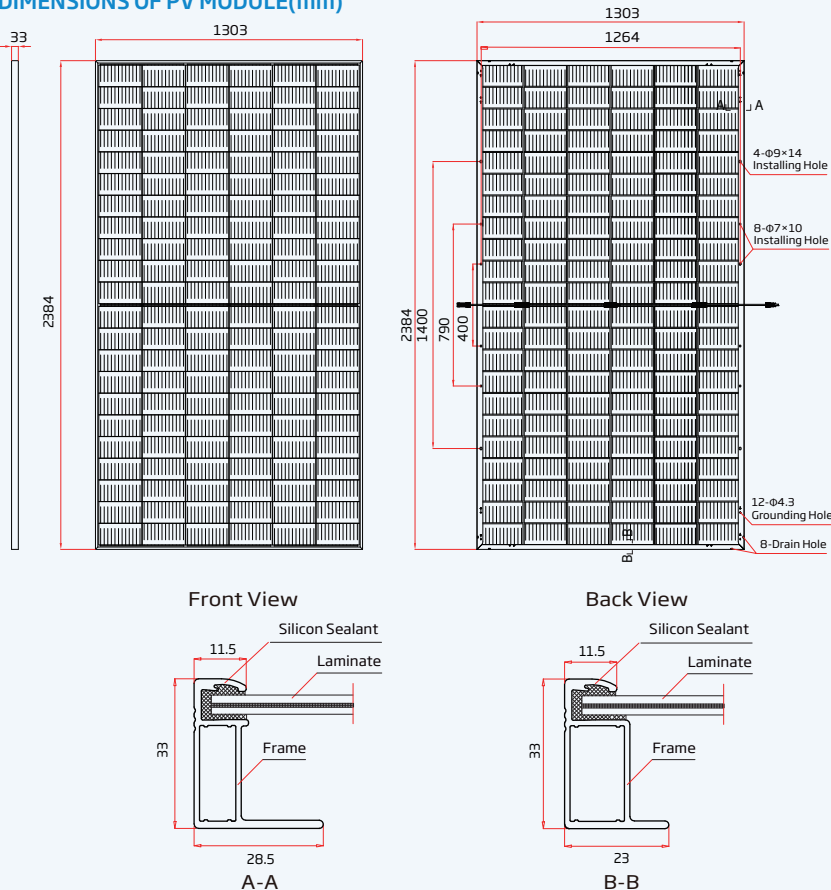


Comprehensive Products and System Certificates

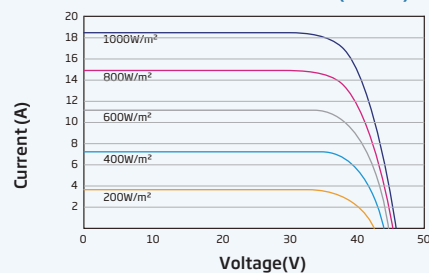


IEC61215/IEC61730/IEC61701/IEC62716/UL61730
 ISO 9001: Quality Management System
 ISO 14001: Environmental Management System
 ISO14064: Greenhouse Gases Emissions Verification
 ISO45001: Occupational Health and Safety Management System

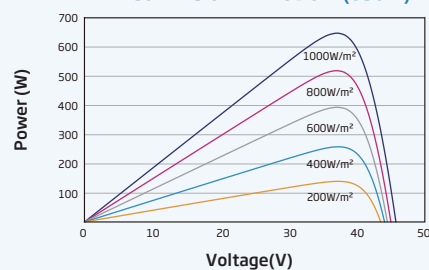
DIMENSIONS OF PV MODULE(mm)



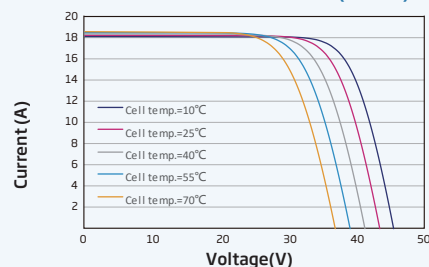
I-V CURVES OF PV MODULE(650 W)



P-V CURVES OF PV MODULE(650W)



I-V CURVES OF PV MODULE(650 W)



ELECTRICAL DATA (STC)

Peak Power Watts-P _{MAX} (Wp)*	645	650	655	660	665
Power Tolerance-P _{MAX} (W)	0 ~ +5				
Maximum Power Voltage-V _{MPP} (V)	37.5	37.7	37.9	38.1	38.3
Maximum Power Current-I _{MPP} (A)	17.23	17.27	17.31	17.35	17.39
Open Circuit Voltage-V _{OC} (V)	45.3	45.5	45.7	45.9	46.1
Short Circuit Current-I _{SC} (A)	18.31	18.35	18.40	18.45	18.50
Module Efficiency η _m (%)	20.8	20.9	21.1	21.2	21.4

STC: Irradiance 1000W/m², Cell Temperature 25°C, Air Mass AM1.5. *Measuring tolerance: ±3%.

Electrical characteristics with different power bin (reference to 10% Irradiance ratio)

Total Equivalent power -P _{MAX} (Wp)	690	696	701	706	712
Maximum Power Voltage-V _{MPP} (V)	37.5	37.7	37.9	38.1	38.3
Maximum Power Current-I _{MPP} (A)	18.44	18.48	18.52	18.56	18.60
Open Circuit Voltage-V _{OC} (V)	45.3	45.5	45.7	45.9	46.1
Short Circuit Current-I _{SC} (A)	19.59	19.63	19.69	19.74	19.79
Irradiance ratio (rear/front)	10%				

Power Bifaciality: 70±5%.

ELECTRICAL DATA (NOCT)

Maximum Power-P _{MAX} (Wp)	488	492	495	499	504
Maximum Power Voltage-V _{MPP} (V)	34.9	35.1	35.2	35.4	35.6
Maximum Power Current-I _{MPP} (A)	13.98	14.01	14.05	14.10	14.16
Open Circuit Voltage-V _{OC} (V)	42.7	42.9	43.0	43.2	43.4
Short Circuit Current-I _{SC} (A)	14.75	14.79	14.83	14.87	14.91

NOCT: Irradiance at 800W/m², Ambient Temperature 20°C, Wind Speed 1m/s.

MECHANICAL DATA

Solar Cells	Monocrystalline
No. of cells	132 cells
Module Dimensions	2384×1303×33 mm (93.86×51.30×1.30 inches)
Weight	38.3 kg (84.4 lb)
Front Glass	2.0 mm (0.08 inches), High Transmission, AR Coated Heat Strengthened Glass
Encapsulant material	POE/EVA
Back Glass	2.0 mm (0.08 inches), Heat Strengthened Glass (White Grid Glass)
Frame	33mm(1.30 inches) Anodized Aluminium Alloy
J-Box	IP 68 rated
Cables	Photovoltaic Technology Cable 4.0mm ² (0.006 inches ²), Portrait: 350/280 mm(13.78/11.02 inches) Length can be customized
Connector	MC4 EV02 / TS4*

*Please refer to regional datasheet for specified connector.

TEMPERATURE RATINGS

NOCT (Nominal Operating Cell Temperature)	43°C (±2°C)
Temperature Coefficient of P _{MAX}	-0.34%/°C
Temperature Coefficient of V _{OC}	-0.25%/°C
Temperature Coefficient of I _{SC}	0.04%/°C

MAXIMUM RATINGS

Operational Temperature	-40~+85°C
Maximum System Voltage	1500V DC (IEC) 1500V DC (UL)
Max Series Fuse Rating	35A

WARRANTY

12 year Product Workmanship Warranty
30 year Power Warranty
2% first year degradation
0.45% Annual Power Attenuation

(Please refer to product warranty for details)

PACKAGING CONFIGURATION

Modules per box: 33 pieces
Modules per 40' container: 594 pieces

SG2500HV/SG3000HV

Turnkey Station for 1500 Vdc System



High Yield

- Efficient three-level topology, max. system efficiency up to 99 %
- 1 or 2 MPPT, wide MPP voltage range
- Full power operation without derating at 50 °C
- One inverter unit fails, the other unit continues operation



Easy O&M

- Integrated zone current monitoring function for fast trouble shooting
- Module design and front service, easy for maintenance
- DC circuit breaker design for convenient maintenance



Saved Investment

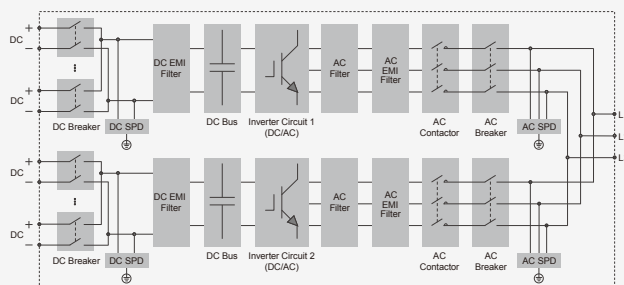
- DC 1500 V system, low system initial investment
- 10-foot container design, no need to build extra inverter house
- Integrated LV auxiliary power supply



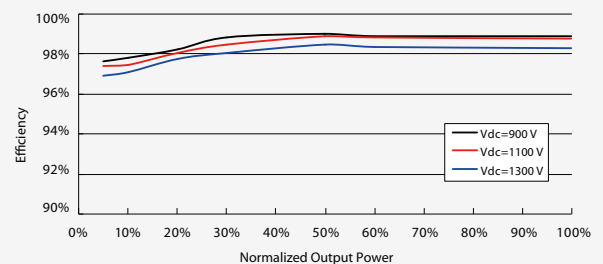
Grid Support

- Compliance with standards: IEC 62109, IEC 61727, IEC 62116, CE, G59/3
- Low/High voltage ride through (L/HVRT)
- Active & reactive power control and power ramp rate control

Circuit Diagram



Efficiency Curve



Input (DC)	SG2500HV	SG3000HV
Max. PV input voltage	1500V	
Min. PV input voltage / Startup input voltage	800 V / 840 V	900 V / 940 V
MPP voltage range for nominal power	800 – 1300 V	900 – 1300 V
No. of independent MPP inputs	1 or 2	
No. of DC inputs	16 – 24	
Max. PV input current	3508 A	
Max. DC short-circuit current	4210 A	
Output (AC)		
Nominal AC power	2500 kW (at 50 °C)	3000 kW (at 50 °C)
Max. AC output power at PF=1	2750 kW (at 45 °C)	3000 kW (at 50 °C)
Max. AC apparent power	2750 kVA (at 45 °C)	3000 kVA (at 50 °C)
Max. AC output current	2886 A	
Nominal AC voltage	550 V	600 V
AC voltage range	440 – 632 V	480 – 690 V
Nominal grid frequency / Grid frequency range	50 Hz / 45 – 55 Hz, 60 Hz / 55 – 65 Hz	
THD	< 3 % (at nominal power)	
DC current injection	< 0.5 % I _n	
Power factor at nominal power / Adjustable power factor	> 0.99 / 0.8 leading – 0.8 lagging	
Feed-in phases / Connection phases	3 / 3	
Efficiency		
Max. efficiency / Euro. efficiency	99.0 % / 98.7 %	
Protection		
DC reverse connection protection	Yes	
DC input protection	Circuit breaker	
AC output protection	Circuit breaker	
Overvoltage protection	DC Type II / AC Type II	
Grid monitoring / Ground fault monitoring	Yes / Yes	
Insulation monitoring	Yes	
Overheat protection	Yes	
Anti-PID function	Optional	
General Data		
Dimensions (W*H*D)	2991*2591*2438 mm	
Weight	5.9 T	
Isolation method	Transformerless	
Degree of protection	IP54	
Auxiliary power supply	220 Vac, 2 kVA / Optional: 380 Vac, up to 15 kVA	
Operating ambient temperature range	-35 to 60 °C (> 50 °C derating)	
Allowable relative humidity range (non-condensing)	0 – 95 %	
Cooling method	Temperature controlled forced air cooling	
Max. operating altitude	4500 m (> 3500 m derating)	4000 m (> 2000 m derating)
Display	Touch screen	
Communication	Standard: RS485, Ethernet; Optional: optical fiber	
Compliance	CEA, IEC 62109, IEC 61727, IEC 62116, IEC 60068, IEC 61683, CE, G59/3	
Grid support	LVRT, HVRT, active & reactive power control and power ramp rate control	
Type designation	SG2500HV-10	SG3000HV-10

