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

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Revision	Date	Author	Checked by	Approved by	Description
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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
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 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
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 Renewable Resources Pvt Ltd (RE2) (The Consultant) for Complete Feasibility of the Project.

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.

1.2 Solar Resource Assessment

This report has been prepared by Renewable Resources (Pvt.) Ltd, 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 marked for the project is 612 acres. However, due to presence of two HV transmission lines within the marked land, these have to be excluded from the project layout. The details are presented in Section 3.3. 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 120MWp based on Single Axis tracking system.

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. Following are the results estimated by using PV modules of reputable OEMs based on different PV technologies, while having similar assumptions and losses for all the scenarios.

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 1960.6 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 following tables show the first-year energy production expected from 120MWp PV plant on Single Axis, which will be available for feeding into the grid. These performances are shown in POE-1 year and POE-10 years at P50, P75 and P90.

Table 1-1: Summary of First Year Production with degradation (JA Bifacial – 120MWp Single Axis)

			PoE	AEP [MWh/a]
1-year period				
Production [MWh/a]		237,681	50%	237,681
Uncertainty	5.5%		75%	228,858
Standard Deviation [MWh]		13,081.10	90%	220,917
10-year period				
Production [MWh/a]		237,681	50%	237,681
Uncertainty	5.3%		75%	229,221
Standard Deviation [MWh]		12,543.53	90%	221,606

It is expected to produce 237,681 MWh during its first year of operation. This corresponds to annual average performance ratio and capacity factor of 85.31% and 22.61% respectively.

The detail loss estimation and energy yield at different Probability of Exceedance (POE) levels are presented in Section 4.4 and Section 4.5 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"), 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.

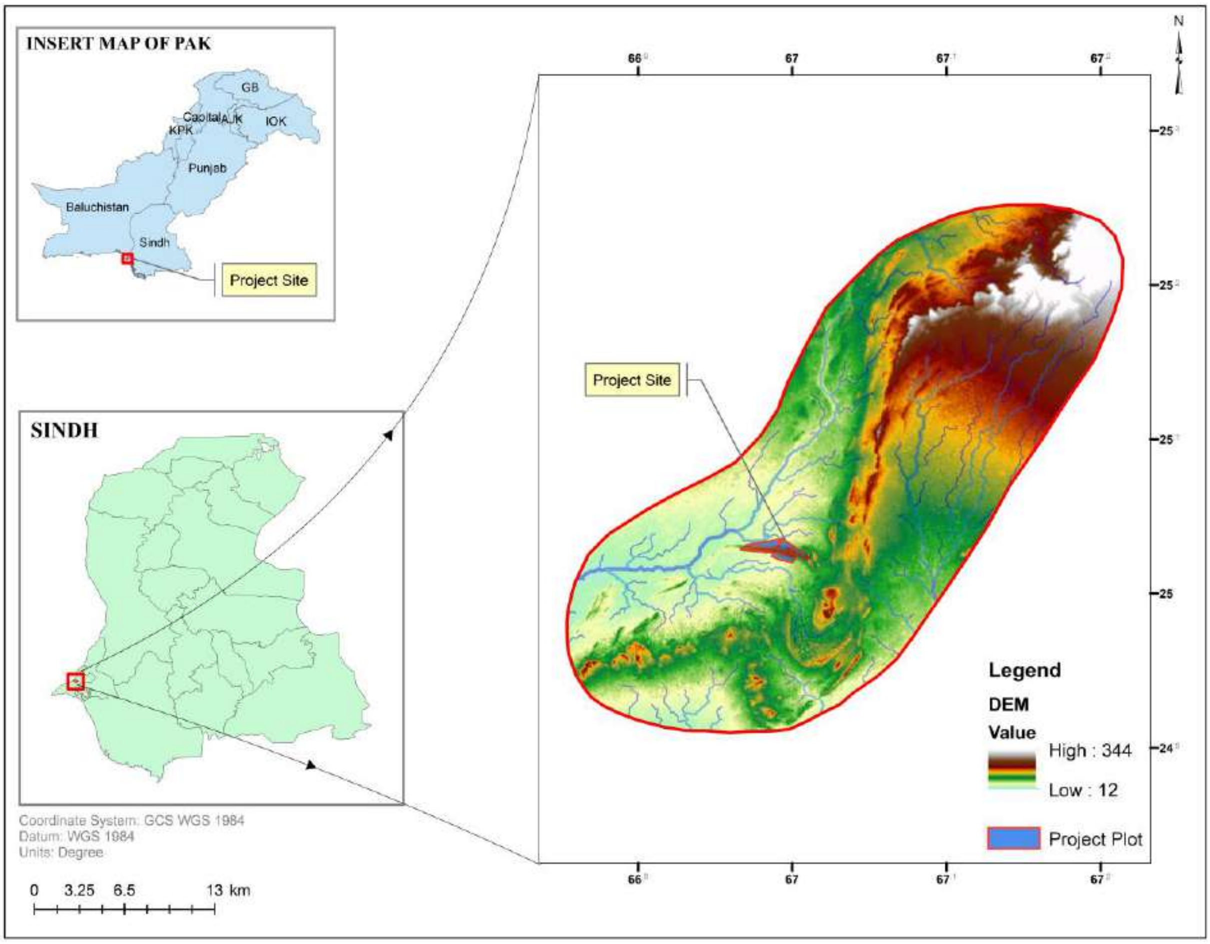

Figure 3-1: Project Site and Nearby Cities

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 Hazratabad 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.

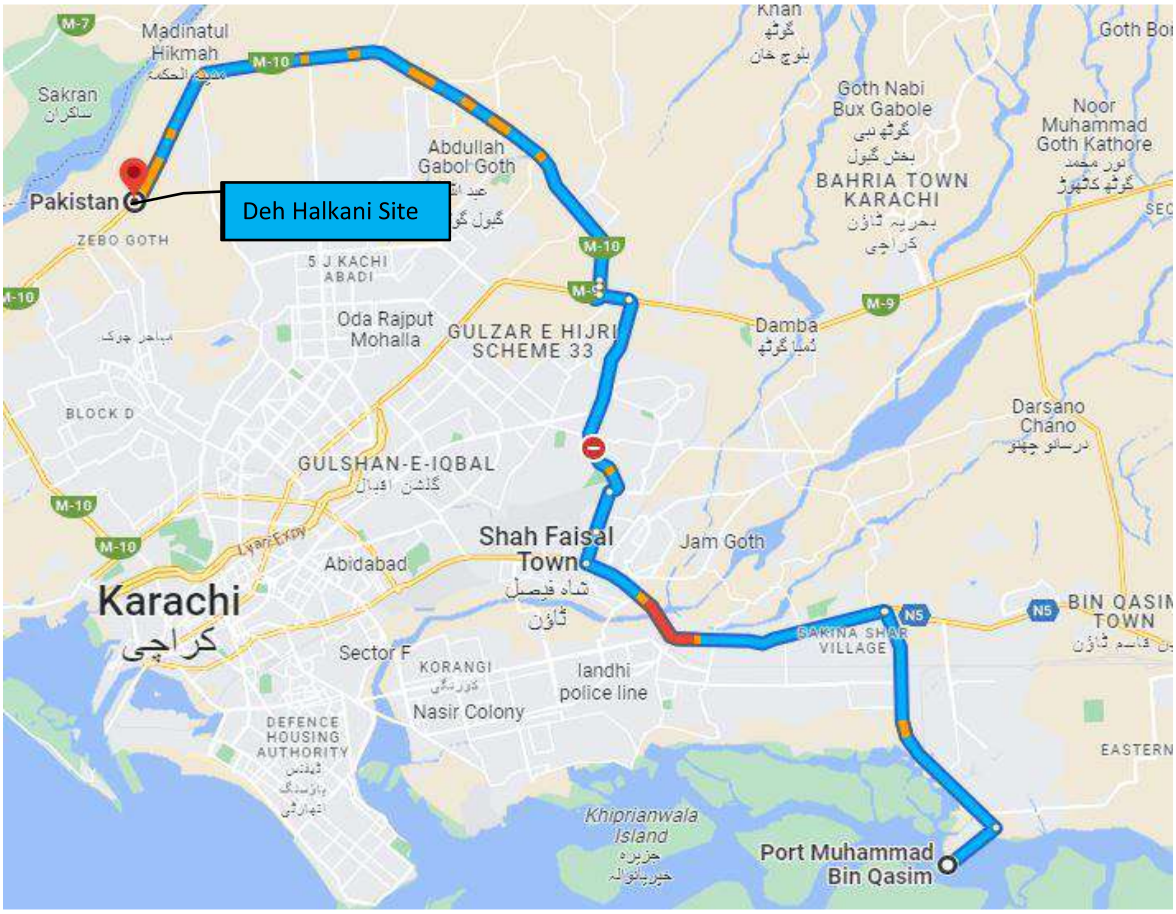

Figure 3-2: Project Location (via Google Map)

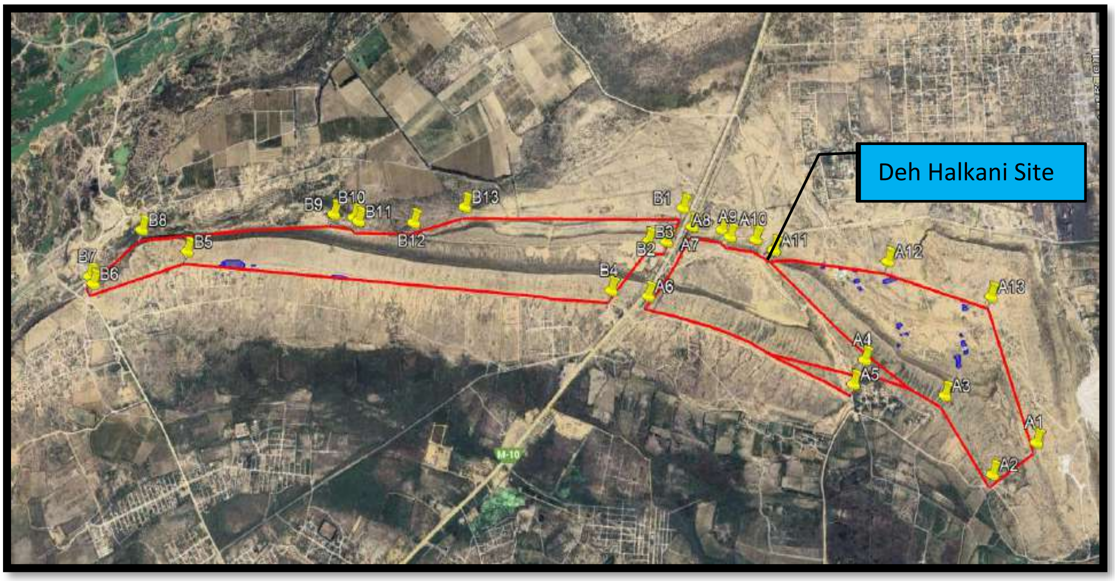

Figure 3-3: Geographical Location of the Project Site and Site Boundary

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

Table 3-1: Site Coordinates

Boundary	Latitude	Longitude
A1	25° 1'7.62"N	67° 0'45.53"E
A2	25° 1'2.03"N	67° 0'35.52"E
A3	25° 1'16.57"N	67° 0'25.60"E
A4	25° 1'23.49"N	67° 0'7.91"E
A5	25° 1'19.11"N	67° 0'5.17"E
A6	25° 1'36.36"N	66°59'19.33"E
A7	25° 1'48.93"N	66°59'29.76"E
A8	25° 1'48.22"N	66°59'36.54"E
A9	25° 1'46.88"N	66°59'38.31"E
A10	25° 1'46.25"N	66°59'44.13"E
A11	25° 1'44.16"N	66°59'48.22"E
A12	25° 1'41.50"N	67° 0'14.13"E
A13	25° 1'34.45"N	67° 0'37.11"E
B1	25° 1'52.54"N	66°59'27.82"E
B2	25° 1'46.32"N	66°59'23.82"E
B3	25° 1'46.39"N	66°59'19.67"E
B4	25° 1'37.58"N	66°59'10.98"E
B5	25° 1'47.03"N	66°57'34.52"E
B6	25° 1'41.58"N	66°57'12.98"E

B7	25° 1'42.92"N	66°57'12.12"E
B8	25° 1'51.30"N	66°57'24.06"E
B9	25° 1'53.25"N	66°58'7.94"E
B10	25° 1'52.47"N	66°58'12.57"E
B11	25° 1'51.76"N	66°58'13.58"E
B12	25° 1'51.25"N	66°58'26.20"E
B13	25° 1'53.93"N	66°58'37.96"E

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.

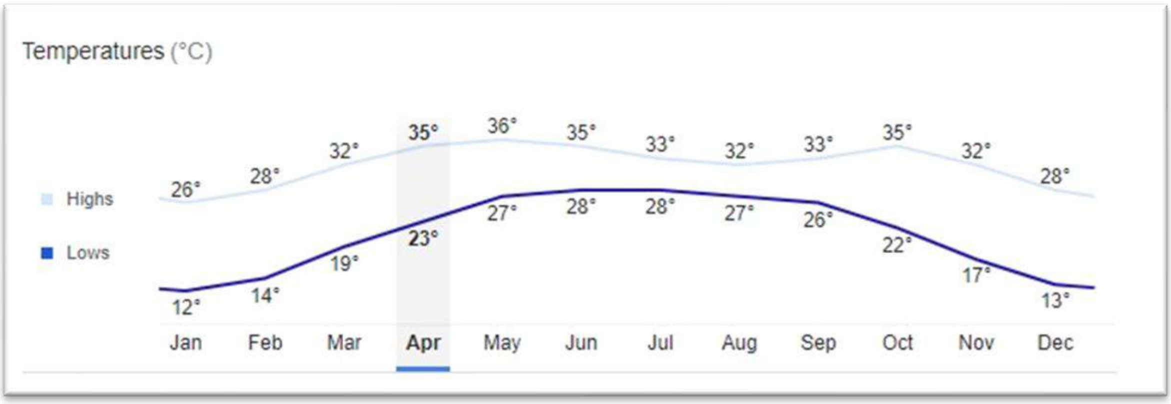

Figure 3-4: Average Annual Temperatures of Project Location (in °C)

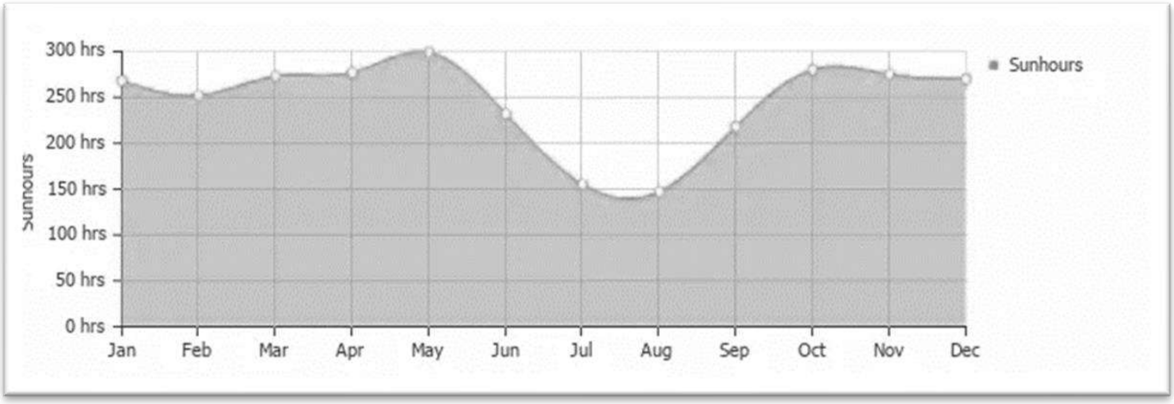

Figure 3-5: Average Monthly Sun hours of Project Location

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

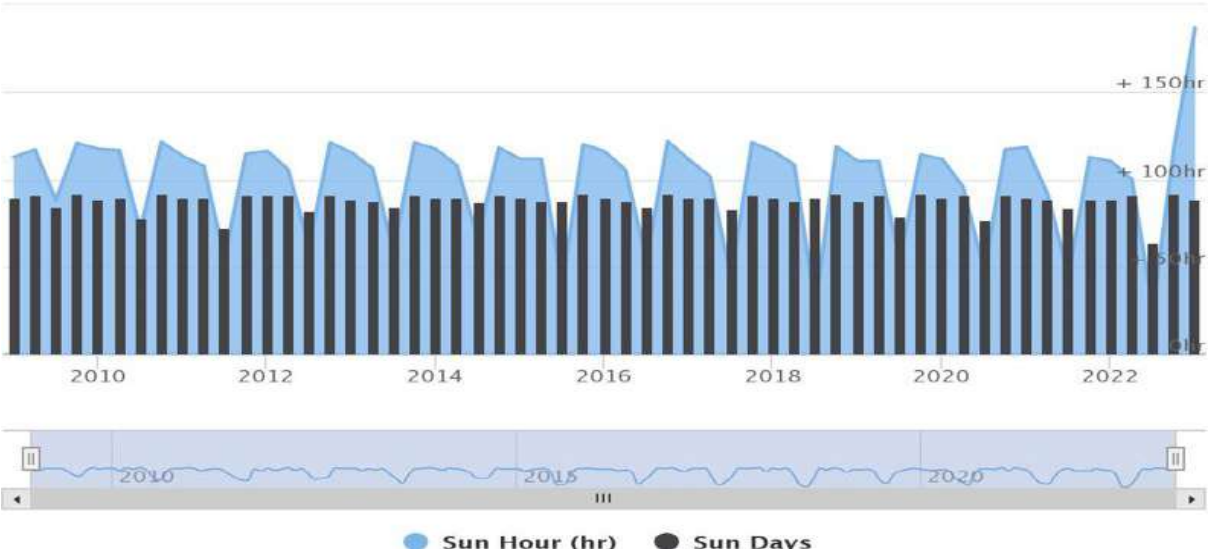

Figure 3-7: Average Yearly Sun Hours of Project Location

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 two (02) sections very close to each other as shown in Figure 3-8. Two transmission lines are crossing the B partial of the project site.

Technical arrangements and their implementation in respect of right of way and cable crossings between these 02 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.

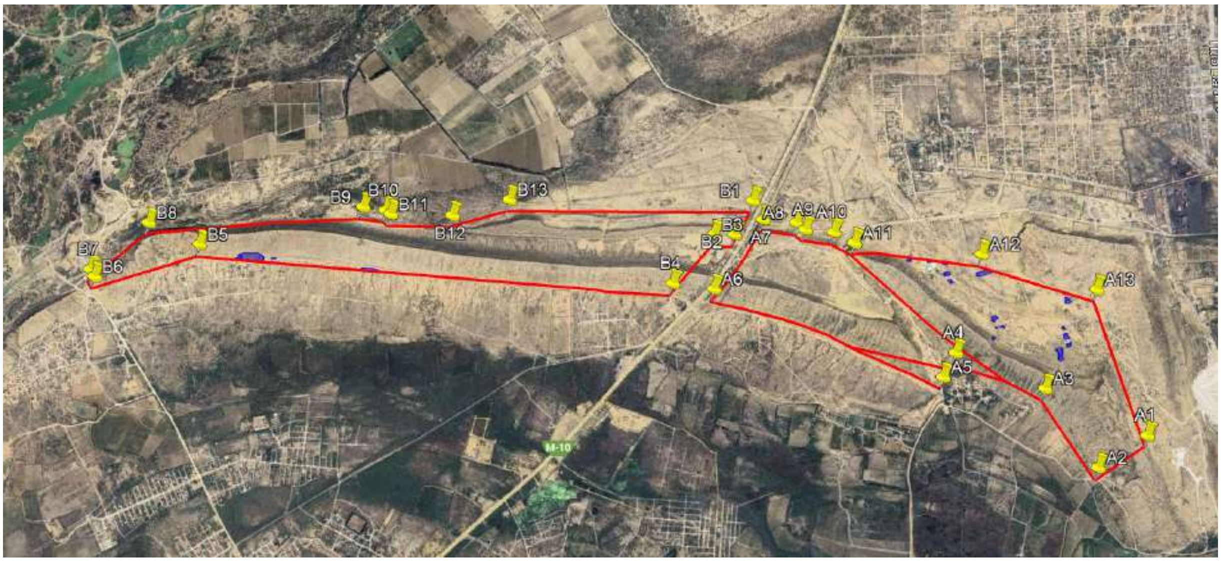

Figure 3-8: Deh Halkani Site Google Earth Imagery

No major horizon shading is expected for the project site. The average slope of the partial A in West to East direction is 3.9%, while that in North to South direction is 11.9% as seen in the Figure 3-9 and Figure 3-10 respectively.

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

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

The average slope of the partial B in West to East direction is 4.9%, while that in North to South direction is 18.3% as seen in the Figure 3-11 and Figure 3-12 respectively.

Figure 3-11: Partial B Elevation profile of Project Site W-E

Figure 3-12: Partial B Elevation profile of Project Site N-S

Figure 3-13: Panoramic View of West to East Slope Area

There are small hills in the site area that can compromise the installation of PV modules in some pockets and hence reducing total installed capacity. These are visible in the topographic maps of the site and also seen physically at site. The impacted area is approx. 330 acres.

Refer to below image for high level identification of impacted are identified in blue.

Figure 3-14: Impacted area

The Client has informed that the hills / inclined area will be removed / smoothened, such that the complete site area has maximum 10-degree slope. Same has been assumed for setting up the PV field layout in the Solar Resource Assessment and Energy Yield Estimation Report. The Client has further informed that a revised contour map will be prepared and circulated to the respective bidders for using as basis.

However, the Client is internally assessing whether such flattening will be arranged by the Client or if the bidders will be required to assume this activity in their scope. Such clarifications are recommended to go in the Tariff RFP package.

There are also two HV transmission lines passing through the west side land parcel of the site which are marked in green in the figure below. The exact coordinates for the transmission line are presented in the updated Topographical survey map.

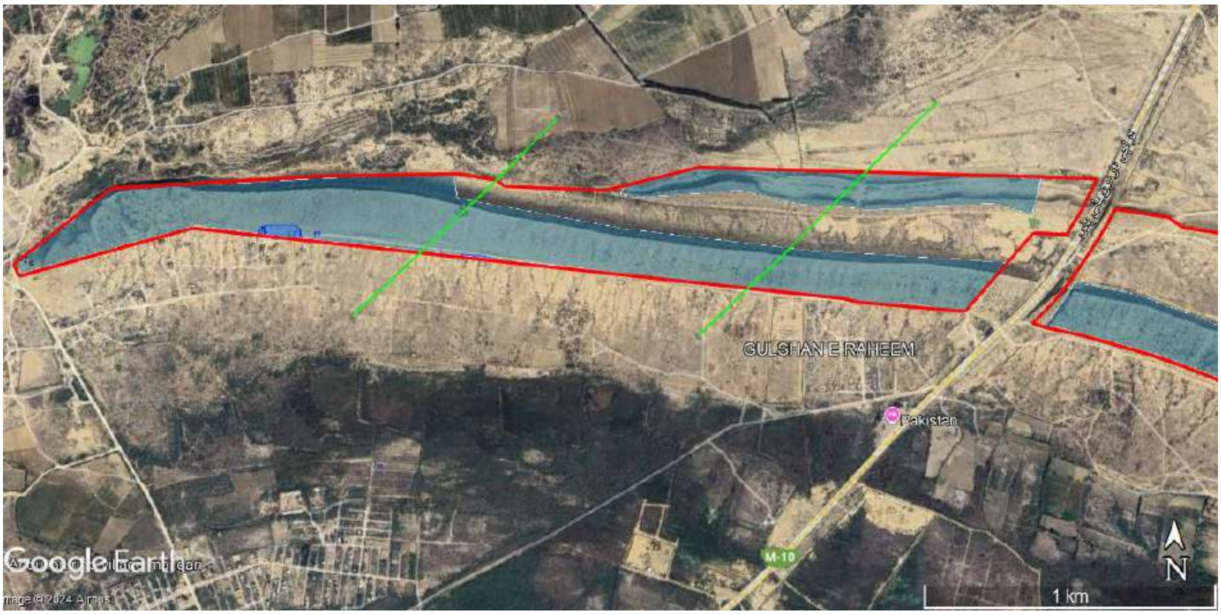

Figure 3-15: Location of HV Transmission lines in the map

The Consultant has considered all the land marks presented above while developing the layout for the 120MWp solar project and has left sufficient space around these obstacles considering the safety margins and access. The layout is shown in Section 4.2.2.

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 is 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.

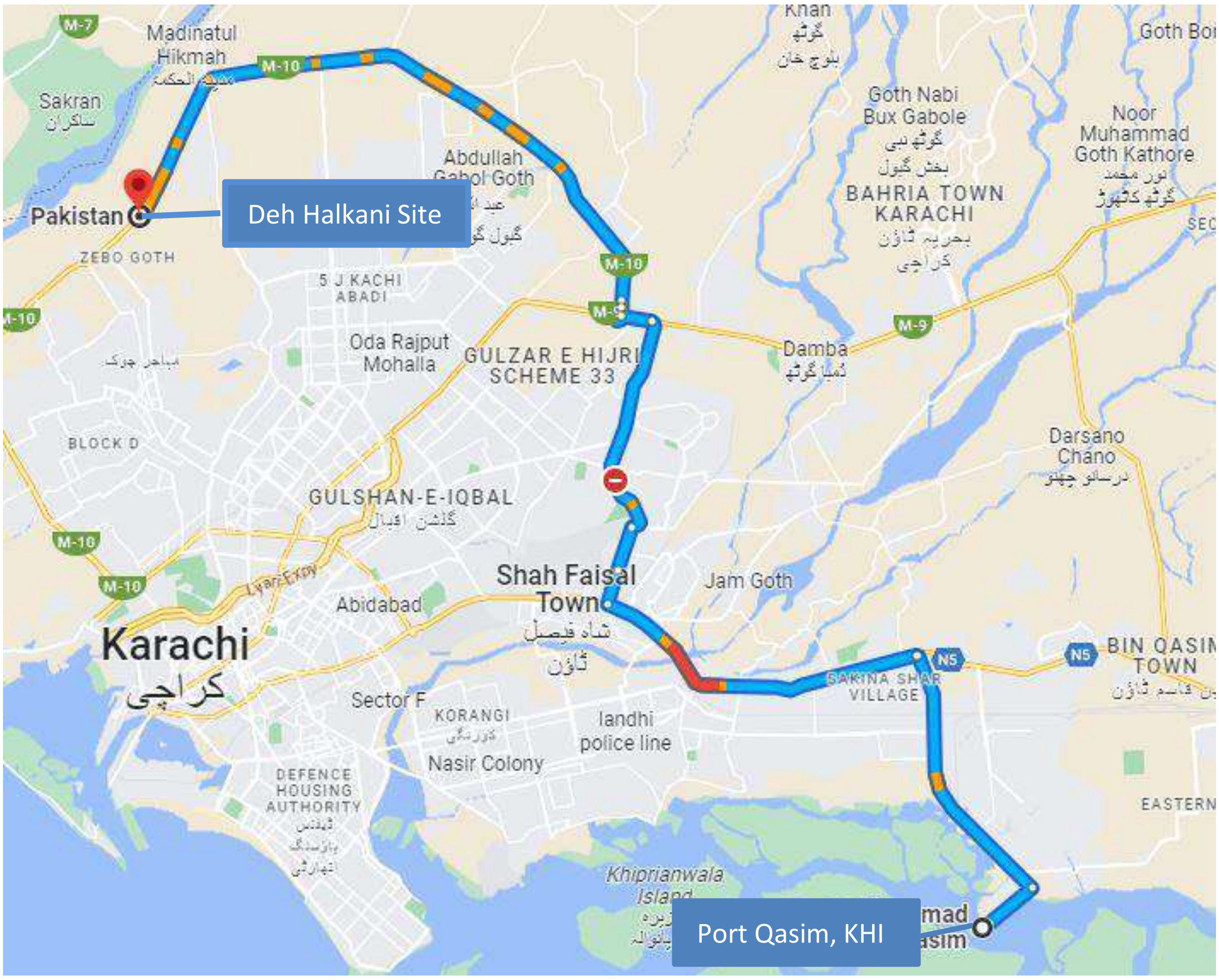

Figure 3-16: Route from Karachi (Port Muhammad Bin Qasim) to Project Site

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. Different technologies were analysed, including Trina solar (Si-mono), Trina Solar (Si-Mono Bifacial), Trina Solar (Si-poly), First Solar (thin-film/Cdte), Canadian Solar (Si-Mono) JA Solar (Si-Mono Bifacial) and Canadian Solar (Si-poly).

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

Technol-ogy Used	Shed De-sign	Tilt Angle	Pitch (m)	Perfor-mance Ratio PR	Produced Energy MWh/year	Specific prod. kWh/kWp/year	Near Shadings %	Capacity Factor %
Trina (mono)	S/A	+/-60	7.5	76.98	221365	1844	5.68	21.06
Trina (Bi-facial)	S/A	+/-60	7.5	80.57	231675	1930	5.68	22.04
Canadian Solar (Mono)	S/A	+/-90	7.5	76.2	219092	1826	5.68	20.84
JA Solar (Bifacial)	S/A	+/-60	6.3	85.31	237681	1981	2.1	22.6

First Solar (Thin film)	S/A	+/-60	7.5	78.85	226701	1889	5.68	21.56

4.2.2 Plant layout and configuration

An exemplary general layout for 120 MWp Single Axis tracking PV system installation is shown in Figure 4-1.

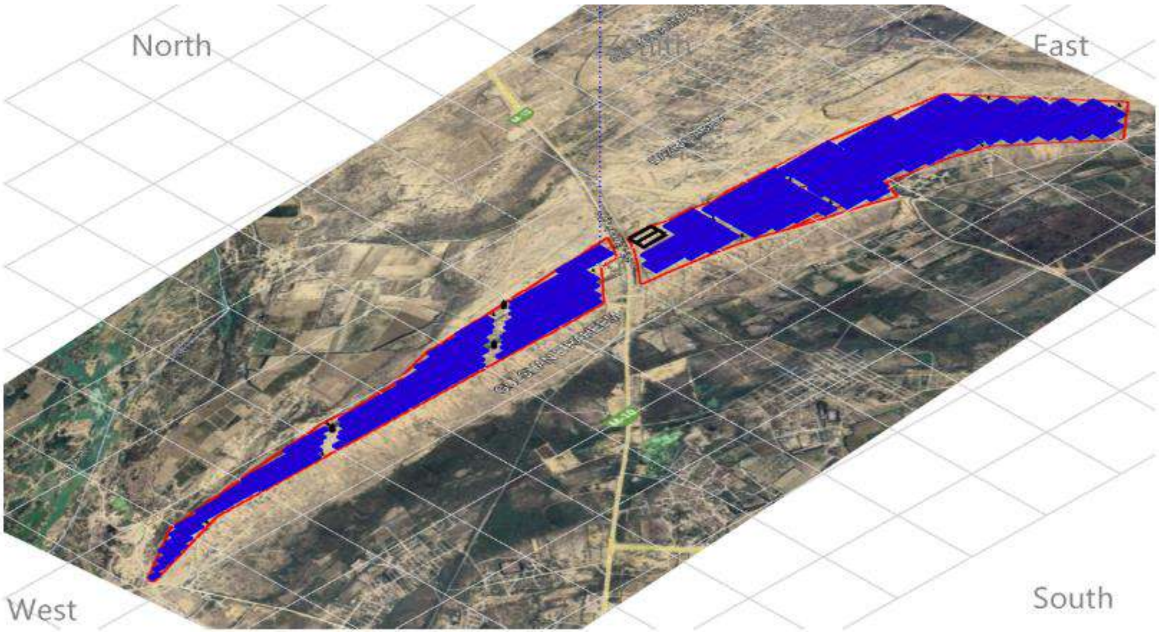

Figure 4-1: Exemplary Plant Layout 120MWp (Single Axis Tracking System)

The above layouts are made without considering the topography of the site because the site is generally flat with very few uneven areas and the Contractor will be required to further plain the uneven areas.

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 to Table 4-3. The PV module and inverter type considered in this report are selected by the Consultant as no preference was provided by Project Company. It shall be noted that the final selection of component likely to change at later stage of the project during bidding or as found feasible by the bidder.

Table 4-2: Major Technical characteristics of JA Solar – Mono Bifacial PV Module

Parameters	Description
Module Model	JAM66D45-620/LB
Manufacturer	JA Solar
Nominal Power [W]	620
Efficiency [%]	23
Power Tolerance [%]	± 5
Cell Type	Si-mono
Open Circuit Voltage [V]	48.5
Short Circuit Current [A]	17.42
MPP Voltage [V]	1500
MPP Current [A]	35
Power Coefficient of Temperature [-%/C]	-0.3
Nominal Operating Cell Temperature (NOCT)	45± 2
Height X Width X Thickness [mm]	2382X 1134 X 30

Table 4-3: Selected Inverter Main Characteristics

Parameters	Description
Inverter Model	Sungrow-8800kW
Manufacturer	Sungrow
Nominal AC Capacity	8800 kW
Maximum DC input Power	10560 kWp
MPP voltage range	938V – 1500 V
Maximum DC current	11840 A
Nominal AC Current	9240 A
Maximum Efficiency	99
European Efficiency	98.7
Operating temperature range	-35°C to +60°C

The Consultant assumed the configuration between PV modules and inverter below mentioned tables with different PV Modules and Shed structures as designed during the analysis:

Table 4-4: Plant Configuration

Parameter	Value
System Type	Single Axis (with backtracking)
Module Type	Si-Mono (Bifacial)
Inverter Type	SG8800
Pitch	6.3m
Tilt	Variable
Installed capacity (DC)	120MWp
Total Number of Modules	193,564
Modules per inverter	16,130
Number of Modules in series	28
DC/AC Ratio	1.14
Number of inverters	12
Nominal AC Power of One Inverter [kW]	8800
Total AC Power [kW]	105,600

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 1960.6 kWh/m². The blue spot in the Figure 4-2 below shows the site location.

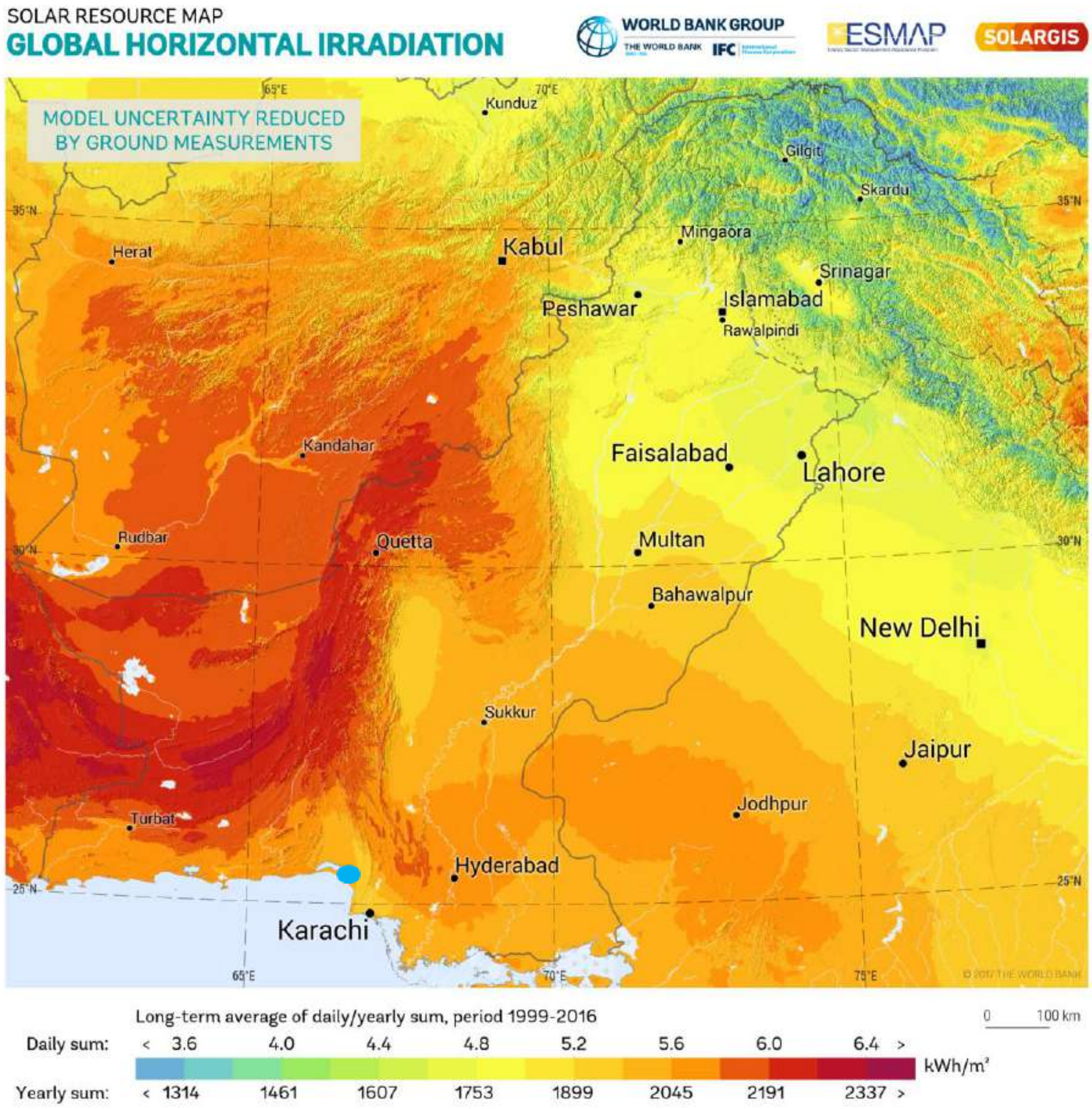

Figure 4-2: GHI Solar Resource Map of Pakistan (source: SolarGIS)

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 ±4% and ±8% (±5% and ±10% for 90% of observations), respectively. In complex geographies and extreme cases, uncertainty of GHI and DNI yearly summaries can be as high as ±8% and ±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 1960.6 kWh/m^2 and annual average temperature around 26.22°C. Direct Normal Irradiation (DNI) at project location on annual average basis is 1564 kWh/m^2. The respective annual average Diffuse Horizontal solar Irradiance (DHI) corresponds to 930.8 kWh/m^2.

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

Month	GHI [kWh/m²]	DHI [kWh/m²]	Ambient temperature [°C]
January	132	52	18.76
February	149.9	58.7	19.64
March	195.7	76.3	25.96
April	210.9	85.3	28.76
May	219	102.6	30.40
June	182.9	101.4	30.93
July	141.8	103.6	29.99
August	130.9	90.1	29.10
September	160.3	85.8	27.91
October	172	68.5	27.82
November	138.9	56.9	25.26
December	126.3	49.5	19.69
Annual	**1960.6**	**930.8**	**26.22**

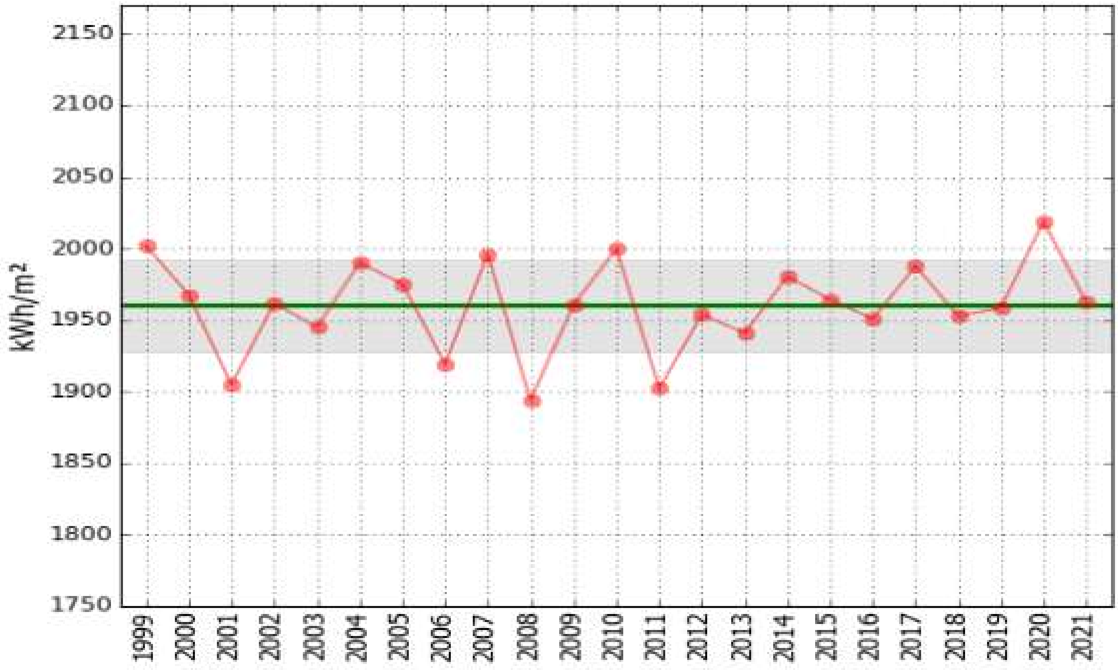

Figure 4-3: GHI Inter-annual Variation with Average line & STDEV band

Figure 4-3 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 ± 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 1960.6 kWh/m^2, annual average DHI of 930.8 kWh/m^2, and annual average temperature of 26.2°C are used for energy yield assessment for the Project. The uncertainty on annual average GHI, according to SolarGIS is +/- 5%.

4.4 Energy Yield Estimation

4.4.1 Approach and Methodology

The Consultant used PVsyst 7.4.8 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 technical characteristics of components and meteorological data considered by the Consultant as input for the energy yield estimation is presented in to **Error! Reference source not found.**, Table 4-4, **Error! Reference source not found.**, **Error! Reference source not found.**, **Error! Reference source not found.** 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.

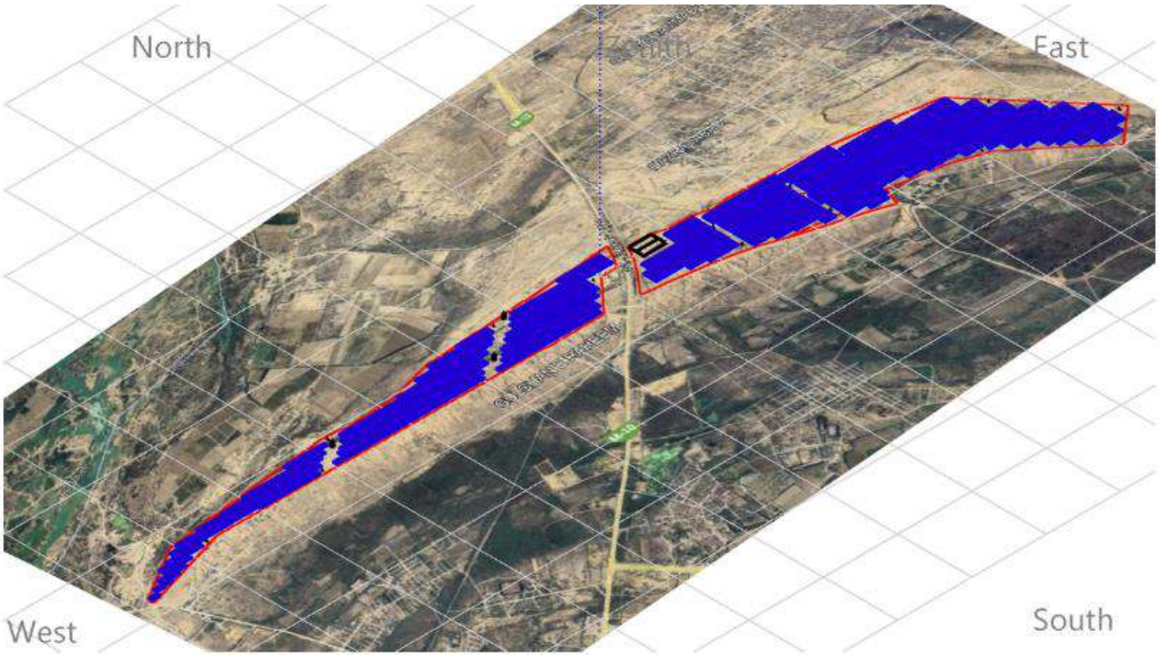

Figure 4-4: PVsyst 3D Modelling of the Project Site

Upon plant modelling with Single-Axis Tracking System, the near shading loss is calculated as 2.10% (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 0.19% for the 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 5.99% for the 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 +0.42% for the system.

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

Ground Reflection loss on back Side

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%.

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/m²], which is now normalised to the m² of collector area. Therefore, it is expressed as Irradiance (and not Power) this view factor is calculated in this case by PVsyst simulation as 71.66% for the 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 +25.88% for the 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 5%.

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 2.15% as mismatch loss for the 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 1.20% 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 0.30% for the 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, 0.75% 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 0.75% for the system.

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 1.48% for the system, as calculated by the PVsyst Simulation.

Medium Voltage Transformer loss

This loss refers to the energy losses that occur when electricity is converted from low voltage (LV) to medium voltage (MV) in a transformer. These losses include both no-load losses (core losses) and load losses (copper or winding losses). No-load losses occur continuously as long as the transformer is energized, while load losses depend on the current passing through the transformer. For the analysis the medium voltage of 33kV and Transformer of 8.8kVA is assumed and the losses are calculated to be in the range of -1.54% to -1.55%. The Consultant has assumed the medium voltage loss of 1.04% for the system.

MV line Ohmic loss

This loss refers to the energy losses due to the electrical resistance in medium voltage transmission lines. These losses occur as the current flows through the conductors, generating heat. PVsyst calculates these ohmic losses based on the properties of the cables (length, cross-sectional area, material) and the current passing through them. The Consultant has assumed the MV line ohmic loss of 0.20% for the system.

High Voltage Transformer Loss

In photovoltaic (PV) systems, high-voltage (HV) transformers are essential for converting the voltage from solar panels to levels suitable for transmission. However, they incur losses, primarily core losses and copper losses. Core losses arise from the magnetic field in the transformer’s core and are influenced by its design and material. Copper losses result from resistance in the transformer's windings and increase with current flow. Minimizing these losses is crucial for maintaining the efficiency of the PV system, achieved through careful design, quality materials, and regular maintenance. The Consultant has assumed the medium voltage loss of 1.20% for the system.

Plant Availability

In general, the annual plant availability of 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 of 120 MWp

Losses Type	Value%	Calculated [C] or Defined [D]
Front Side		
Global Incident in Coll. Plane	18.40%	C
Near Shading	-2.10%	C
IAM factor on global	-0.30%	C
Soiling losses	-3.00%	D
Ground reflection on front site	0.42%	C
Back side		
Ground reflection loss	-80%	C
View factor for rear side	-71.66%	C
Sky diffuse on rear side	25.88%	C
Shading loss on rear side	5.00%	D
Both sides		
Module Degradation Loss	-0.45%	D
PV loss due to irradiance level	-0.19%	C
Losses due to temperature	-5.99%	C
Auxiliaries	-0.78%	D
Module quality loss	0.75%	D
Light Induced Degradation	-2.00%	D
Module Array Mismatch loss	-2.15%	D
Mismatch for back irradiance	-0.66%	D
Ohmic wiring loss	-1.22%	C
Inverter loss	-1.48%	C
Unavailability loss	-1.93%	D
Medium Voltage Transformer Loss	-1.04%	C
MV Line Ohmic Loss	-0.20%	C
High Voltage Transformer Loss	-1.20%	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 of 120 MWp

Parameter	Single Axis
Installed DC Power [kWp]	120,000
Irradiation on horizontal plane [kWh/m²]	1,960.6
Irradiation on module plane [kWh/m²]	2,321.6
Energy Yield [MWh]	237,681
Specific Yield [kWh/kWp]	1,981
Performance Ratio [%]	85.31
Capacity Factor [%]	22.61

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 0.5% 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	5.3%	5.0%
PV Module modelling/parameters	1.0%	1.0%
Inverter efficiency uncertainty	0.5%	0.5%
Soiling and mismatch uncertainty	1.0%	1.0%
Degradation uncertainty	1.0%	1.0%
Total uncertainty	5.50%	5.28%

The total uncertainty on long term (eg.10 yrs.) energy yield estimation is 5.28%. Similarly, the uncertainty for energy estimation for 1-year period is estimated as 5.50%. This includes the variability effect of solar data which is generated based on standard deviation of 1.0% of long-term average GHI (for 23 year's time series data), as presented in section 4.3.1 of this report.

4.5.3 Probability of Exceedance (PoE-10 Years)

The following tables summarizes the long-term energy yield estimation at different PoE levels of 120MWp installed capacity with single axis tracking system.

Table 4-9: Long Term Energy Yield (25 Years – POE 10 years)

Year of Operation	Annual Yield P50 [MWh]	Annual Yield P75 [MWh]	Annual Yield P90 [MWh]
Year-1 (without Degradation)	242,532	233,899	226,129
Year-1	237,681	229,221	221,606
Year-2	236,711	228,285	220,701
Year-3	235,741	227,349	219,797
Year-4	234,771	226,414	218,892
Year-5	233,801	225,478	217,988
Year-6	232,830	224,543	217,083
Year-7	231,860	223,607	216,179
Year-8	230,890	222,671	215,274
Year-9	229,920	221,736	214,370
Year-10	228,950	220,800	213,465
Year-11	227,980	219,865	212,561
Year-12	227,010	218,929	211,656

Year of Operation	Annual Yield P50 [MWh]	Annual Yield P75 [MWh]	Annual Yield P90 [MWh]
Year-13	226,040	217,994	210,752
Year-14	225,069	217,058	209,847
Year-15	224,099	216,122	208,943
Year-16	223,129	215,187	208,038
Year-17	222,159	214,251	207,134
Year-18	221,189	213,316	206,229
Year-19	220,219	212,380	205,325
Year-20	219,249	211,444	204,420
Year-21	218,279	210,509	203,516
Year-22	217,308	209,573	202,611
Year-23	216,338	208,638	201,707
Year-24	215,368	207,702	200,802
Year-25	214,398	206,766	199,898

4.5.4 Probability of Exceedance (PoE - 1Year) The POE-1-year estimation is presented below:

Table 4-10: Long Term Energy Yield (25 Years – POE 1 year)

Year of Operation	Annual Yield P50 [MWh]	Annual Yield P75 [MWh]	Annual Yield P90 [MWh]
Year-1 (without Degradation)	242,532	233,529	225,426
Year-1	237,681	228,858	220,917
Year-2	236,711	227,924	220,015
Year-3	235,741	226,990	219,114
Year-4	234,771	226,056	218,212
Year-5	233,801	225,122	217,310
Year-6	232,830	224,187	216,409
Year-7	231,860	223,253	215,507
Year-8	230,890	222,319	214,605
Year-9	229,920	221,385	213,703
Year-10	228,950	220,451	212,802
Year-11	227,980	219,517	211,900
Year-12	227,010	218,583	210,998
Year-13	226,040	217,649	210,097
Year-14	225,069	216,715	209,195
Year-15	224,099	215,780	208,293
Year-16	223,129	214,846	207,391

Year of Operation	Annual Yield P50 [MWh]	Annual Yield P75 [MWh]	Annual Yield P90 [MWh]
Year-17	222,159	213,912	206,490
Year-18	221,189	212,978	205,588
Year-19	220,219	212,044	204,686
Year-20	219,249	211,110	203,785
Year-21	218,279	210,176	202,883
Year-22	217,308	209,242	201,981
Year-23	216,338	208,308	201,080
Year-24	215,368	207,373	200,178
Year-25	214,398	206,439	199,276

4.5.5 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 site land has some hills / inclined areas within the site boundary. The hills / inclined area will be removed / smoothened, such that the complete site area has maximum 10-degree slope. Same has been assumed for the purposes of this Solar Resource Assessment and Energy Yield Estimation Report.
- The Project is intended to build in the approximate area of 612 acres. The project site is irregularly shaped and has two (02) land parcels very close to each other as shown in Figure 3 8. There are two transmission lines crossing through the west land parcel of the project site.
- Technical arrangements and their implementation in respect of right of way and cable crossings between these 02 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.

- **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/m^2, annual average DHI of 930kWh/m^2, and annual average temperature of 26.22°C. TMY data sets are used for energy yield assessment for the Project.

- The uncertainty on long term annual energy estimation is +/- 5.28%.

- 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 6.3m Pitch:

  - With *JA Solar Bifacial panels – Single axis tracking system*, the project is expected to produce maximum 237,681 MWh 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 86.40% and 22.6% respectively.