Feasibility Analysis of Grid Tied Solar Park in Coastal Region

By

Hasan-Almamun

A Thesis
Submitted to the
Department of Industrial and Production Engineering,
In Partial Fulfillment of the
Requirements for the Degree
of
MASTER OF ENGINEERING IN
ADVANCED ENGINEERING MANAGEMENT

DEPARTMENT OF INDUSTRIAL AND PRODUCTION ENGINEERING

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

DHAKA-1000, BANGLADESH

March, 2021

The thesis titled "**Feasibility analysis of grid tied solar park in coastal region**" submitted by **Hasan-Almamun** Student no: 0415082101, Session April, 2015 has been accepted as a satisfactory in partial fulfillment of the requirements for the degree of Master of Engineering in Advanced Engineering Management on March, 2021.

Board of Examiners

Sparveen

Dr. Sultana Parveen
Professor
Department of Industrial and Production Engineering
BUET, Dhaka-1000.

Chairman
(Supervisor)

Dr. Ferdous Sarwar
Associate Professor
Department of Industrial and Production Engineering
BUET, Dhaka-1000.

Member

Shuva Ghosh

Dr. Shuva Ghosh
Associate Professor
Department of Industrial and Production Engineering
BUET, Dhaka-1000.

Member

DECLARATION

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Hasan-Almamun

This work is dedicated

To my beloved

Father

&

Mother

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AC	: Alternating Current
DC	: Direct Current
kWh	: Kilowatt Hour
kW	: Kilowatt
kWp	: Kilowatt Peak
PV	: Photovoltaic
FIT	: Feed in Tariff
GoB	: Government of the People's Republic of Bangladesh
SCADA	: Supervisory Control and Data Acquisition
GHI	: Global Horizontal Irradiation
DNI	: Direct Normal Irradiation
DHI	: Diffuse Horizontal Irradiation
GII	: Global In-Plane Irradiation
TMY	: Typical Meteorological Year
PVGIS	: Photovoltaic Geographical Information System
NASA-SSE	: NASA's Surface meteorology and Solar Energy
NREL	: National Renewable Energy Laboratory
NSRDB	: National Solar Radiation Database
STC	: Standard Test Condition
NOCT	: Nominal Operating Cell Temperature
NMOT	: Nominal Module Operating Temperature
MPPT	: Maximum Power Point Tracking
PR	: Performance Ratio
CUF	: Capacity Utilization Factor
LCOE	: Levelized Cost of Energy
CAPEX	: Capital Expenditure
OPEX	: Operational Expenditure
NPV	: Net Present Value
IRR	: Internal Rate of Return
PI	: Profitability Index
B/C	: Benefit to Cost Ratio
PPA	: Power Purchase Agreement
IA	: Implementation Agreement
PSMP	: Power System Master Plan
MPEMR	: Ministry of Power Energy and Mineral Resource
BPDB	: Bangladesh Power Development Board
BREB	: Bangladesh Rural Electrification Board
PGCB	: Power Grid Company of Bangladesh
GDB	: Gross Domestic Product

Acknowledgement

At first the authors want to convey their deepest gratefulness to the almighty ALLAH, the beneficial, the merciful for granting them to bring this research work into light. The authors would like to express their sincere respect and gratitude to Dr. Sultana Parveen, Professor, Department of Industrial & Production Engineering (IPE), Bangladesh University of Engineering and Technology (BUET), Dhaka, for his thoughtful suggestions, constant guidance and encouragement throughout this research work.

The authors also want to express their heartiest thanks to all of the colleagues of the Department of Industrial and Production Engineering (IPE), BUET, Dhaka for their cooperation and motivation.

The authors are also grateful to all writers and publishers of the books and journals that have taken as references while conducting this research.

With a very special recognition the authors would like to thank their parents as well as the family members, who provided their continuous inspiration, sacrifice and support which encouraged them to complete the research work successfully.

Abstract

This project work focuses on energy yield assessment and feasibility analysis of a grid tied solar photovoltaic power plant in coastal region of Bangladesh. Bangladesh is experiencing a gradual depletion of its primary energy resource such as natural gas and time has come to explore and harness the full potential of alternative energy sources to ensure our long-term energy security as well as sustainable economic development.

Realizing the importance, Bangladesh Government attaches due importance on renewable energy. One of the most common sources of renewable energy now a day is solar and its production over other energy sources rising globally. With the advancement in carbon emission reduction and the development of low carbon power system, solar power technology has become a new hot issue of renewable energy and it is of crucial importance to solve the interlinked global challenges of climate change and energy security.

The selected site located at sabrang, Teknaf, Cox's Bazar near to BREB substation Teknaf-4 (Proposed), latitude is 20.83º N and longitude is 92.31º E. Global Horizontal Irradiation (GHI) at sabrang is 1863 kWh/m^2 /Year. To assess solar irradiation and estimate annual energy yield for this location, a simulation has been conducted with photovoltaic simulation software PVsyst version 7.1.2. This project work also taken into account all measurable loss factor such as optical losses, PV array losses, DC to AC conversion losses and others system losses.

Finally, a financial analysis has been done by calculating the key financial profitability indicators such as levelized cost of electricity (LCOE), net present value (NPV), internal rate of return (IRR), Payback period (PBP) benefit-to-cost ratio (B/C) or profitability index (PI). Project work also assessed the measurable risk for this selected project.

CHAPTER 1
INTRODUCTION

1.1 General Introduction

Energy plays a pivotal role in our daily activities. The degree of development and civilization of a country is measured by the amount of utilization of energy by human beings. Energy demand is increasing day by day due to increase in population, urbanization and industrialization. On the other hand, the world's fossil fuel supply such as coal, petroleum and natural gas will thus be depleted in a few hundred years. The rate of energy consumption increasing, supply is depleting resulting in inflation and energy shortage this is called energy crisis.

Renewable energy is the alternative sources of energy, that have to be developed to meet future energy requirement. The most popular renewable energy sources currently are solar wind, hydro, tidal, geothermal and biomass energy. Solar is one of the fastest growing energy sources in the world. The energy is free and the supply is unlimited. The largest photovoltaic power plant in the world is Tengger Desert Solar Park, produces 1,547 MWp and it is located at Zhongwei, Ningxia, China. Since Bangladesh has abundant sources of renewable energy especially sunlight, it can fulfill to major part of the energy needs of the country. Grid interconnection of photovoltaic (PV) power generation system has the advantage of more effective utilization of generated power.

In 2019, the global energy related CO_2 emissions recorded around 33 Gt. The photovoltaic power plants not only give us power, it also avoids the CO_2 emissions to produce electricity and power generation from PV is continuously increasing. Based on the total electricity generated by the cumulative PV capacity installed globally at the end of 2019, around 720 Mt of yearly CO_2 emissions were avoided. This amount is calculated based on the emissions that would have been generated from the same amount of electricity produced by the different grid mixes in all countries and taking into consideration life cycle emissions of PV systems. This represents around 5.5% of the total power sector emissions according to (IEA-PVPS report, snapshot of the global PV markets-2020).

1.2 Solar PV Development Worldwide

Based on the report a snapshot of the global PV markets-2020 (Arnulf Jäger-Waldau, I. Kaizuka, Alice Detollenaere, Johan Lindahl, 2020) by end of the 2019 estimated 12% that around to 115 GW solar photovoltaic market were increased. Strong demand observed in Europe, United States and emerging markets around the world at the end of the decade, on the other hand substantial decline occurred in China, which is the largest market in the world. In 2019 solar PV global market grew about 44% except China. Including on and off grid the total global capacity is 627 GW by end of the 2019, compares to a total of less than 23 GW only 10 years earlier presented in Figure 1.1.

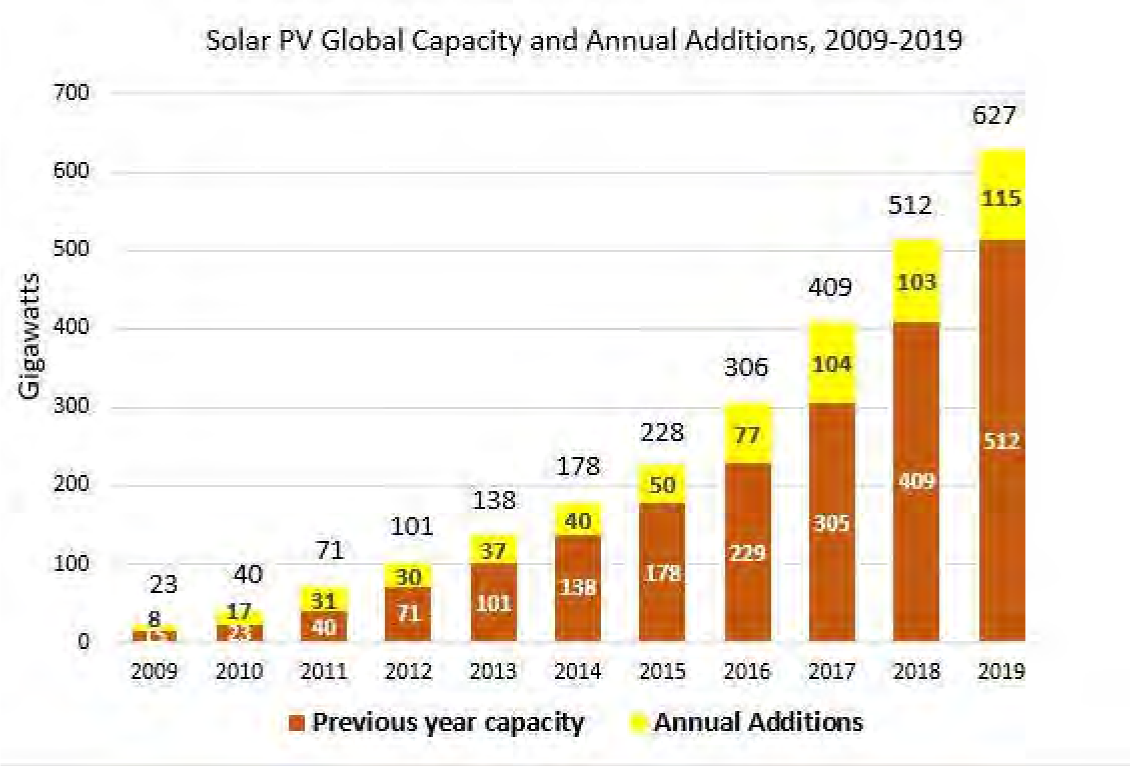


Figure 1.1 Evolution of cumulative installed capacity for photovoltaic

By end of the 2019 the total cumulative installed capacity amounted globally 627 GW. China continues to lead with a cumulative capacity of 204.7 GW, followed by the European Union 131.3 GW, the USA 75.9 GW, Japan 63.0 GW and India 42.8 GW. In the Asia-Pacific region, Australia reached 14.6 GW and Korea 11.2 GW. In the European Union, Germany leads with 49.2 GW, followed by Italy 20.8 GW and the UK 13.3 GW. Rest of all other countries that added below the 10GW capacity in 2019.

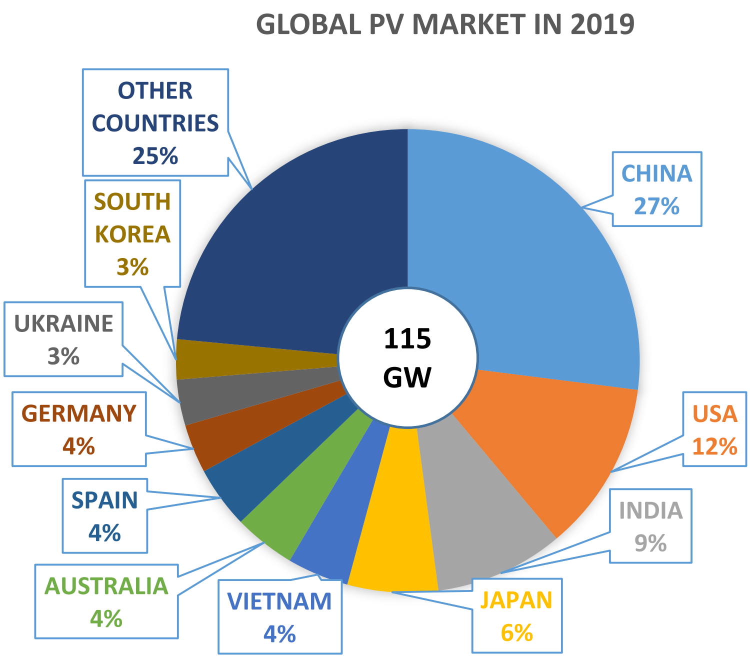


Figure 1.2 Global photovoltaic market in 2019

Demand of solar photovoltaic power is expanding day by day for the residential and commercial applications. Due to fossil fuels costs and CO_2 emission solar photovoltaic power system will be the most competitive and alternative option to produce electricity in future. Cumulative capacity of top ten countries in 2019 presented in figure 1.3.

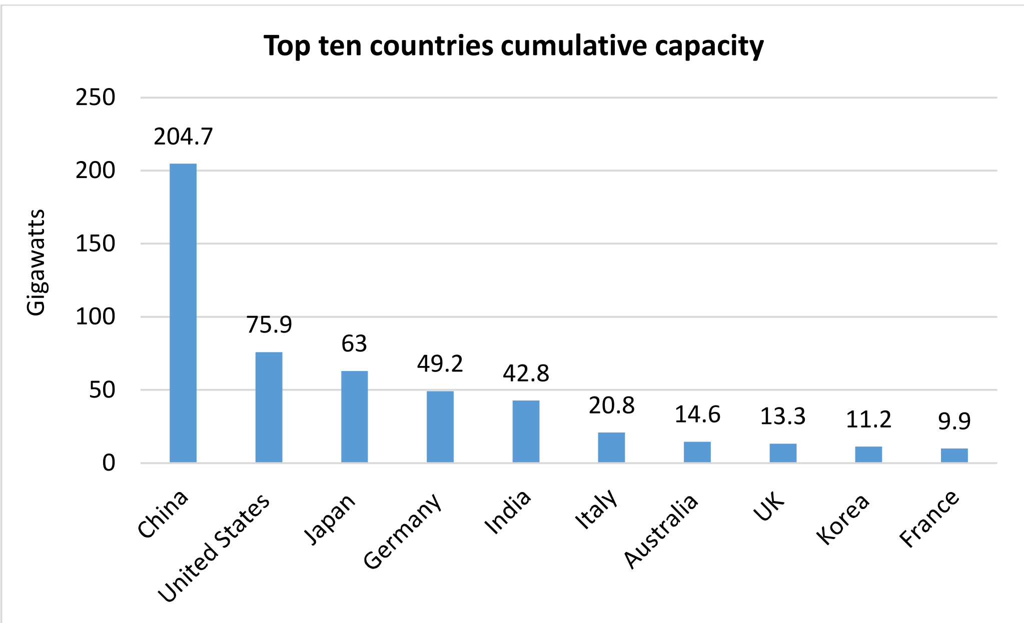


Figure 1.3 Solar PV cumulative capacity of top 10 countries in 2019

Figure 1.4 illustrated about solar power plant total installed cost, that contains cost of PV Module & Balance of system. Balance of system contains the cost of Hardware, Equipment Installation & and soft cost.

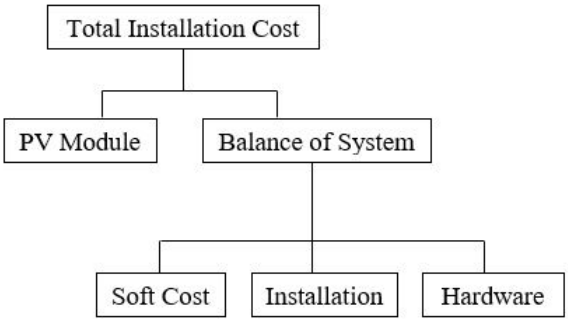


figure 1.4 Total installed cost

Total installed costs of solar power plant declined accordingly with decline of PV module and balance of system cost, as per (Michael Taylor, 2020) the installed costs declined 13% from 2018 and 79% from 2010 but capacity factor stable around 18% up to 2019 showed in figure 1.5.

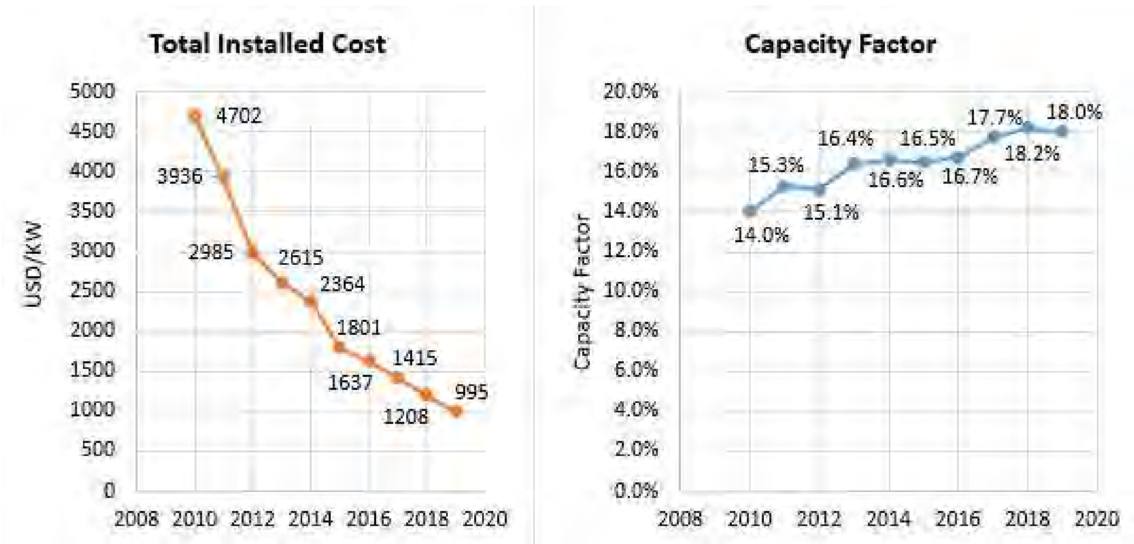


Figure 1.5 Solar PV cost trends & Capacity factor

Bangladesh is a semi-tropical region lying in northeastern part of South Asia gets abundant sunlight year around. This means that a largescale PV project in Bangladesh would be sensible and compliant with industry trends. The increase in Solar PV developments is not by chance but rather it is due to a combination of proven technology (thus lowering PV prices) and government's FIT's ensuring fixed sustainable incomes for longer periods.

1.3 Problem Statement

Bangladesh is experiencing a gradual depletion of its primary energy resource such as natural gas and time has come to explore and harness the full potential of alternative energy sources to ensure our long-term energy security as well as sustainable economic development. Realizing the importance, Bangladesh Government attaches due importance on renewable energy. One of the most common sources of renewable energy now a day is Solar and its production over other energy sources rising globally. With the advancement in carbon emission reduction and the development of low carbon power system, solar power technology has become a new hot issue of renewable energy and it is of crucial importance to solve the interlinked global challenges of climate change and energy security.

In Bangladesh, 93.0% of total populations have access to electricity but reliable and quality power is still a faraway. The government had earlier prepared a Power System Master Plan-2016 (PSMP) to improve and expand electricity supply to support GDP growth in the 7 to 8 percent range. According to Power System Master Plan-2016, total generation capacity requirement will be about 94,000 MW to meet the demand 82,292 MW in 2041 for high case studies. To meet the renewable energy policy target 10%, as per plan the renewable based capacity will be 9,400 MW by 2041 and 2,800 MW by 2021. Total generation capacity requirement will be about 79,500 MW to meet the demand 72,000 MW in 2041 for low case studies. To meet the renewable energy policy target 10%, as per plan the renewable based capacity will be 7,950 MW by 2041 and 2,600 MW by 2021.

The government is currently preparing the competitive bidding by IPPs, drafting FIT and providing other incentives (mainly financial ones) for renewable energy businesses. In seventh five-year plan (FY2016-FY2020), the Government adopted a strong and well -rounded reform Programme to increase the supply of electricity involving substantial investment, sector reforms and regional trade.

1.4 Research Gap and Motivations

The main purpose of this report is to present a realistic approach for producing a feasibility analysis of 10MW grid tied solar park at coastal region in Bangladesh. But feasibility study of grid tied solar park at coastal region in Bangladesh, doesn't receive much attention in the literature. This lack of research is the inspiration for this study. This study will serve as a meticulous guide for solar PV developers in Bangladesh via highlighting the local policies and risk assessment and financial analysis for the unilateral fulfilment of financial return.

In the context of Bangladesh, the required land acquisition for the project is very much tuff and considered one of the crucial important and difficult tasks, that's why we choose non agriculture field as per GoB guideline in coastal region, most of the field is using as salt bed. We successfully overcome land acquisition complexities by selecting suitable location. The solar irradiance level at sabrang, which are comparatively higher than other's location of the country, that is the main advantages for this proposed project. The government is currently preparing the competitive bidding by IPPs, drafting FIT and providing other incentives (mainly financial ones) for renewable energy businesses. FIT for renewable power is comparatively higher than conventional Power plant, that will be very much helpful for revenue return and financial feasibility.

1.5 Objectives of the study

The main purpose of this report is analyzing feasibility of 10MW grid tied solar park at coastal region in Bangladesh. To achieve this main objective, the following goals will be attempted:

- To estimate of solar irradiation for the project located at sabrang, Teknaf, the site location Latitude is 20.83° N, and Longitude is 92.31° E
- To estimates annual electrical energy production and revenue.
- To calculate initial investment & yearly operational expenses
- To find out financial feasibility of 10MW grid tied solar park by calculating Net Present Value (NPV), Payback Period, Internal Rate of Return (IRR) and Profitability Index (PI) or Benefit to cost ratio (B/C).

1.6 Methodology

1.6.1. Site identification

According to solar resource map of Bangladesh (Appendix 1), higher solar potentials observed at Chattogram division. Cox's Bazar district as well as Teknaf region showing maximum solar potentials (deep red marked) comparatively than other locations of Bangladesh. That’s why author select Teknaf region for analysis feasibility of 10MWac grid tied solar park at Sabrang, Teknaf near to proposed 10MVA PBS substation (Teknaf-4). The selected site Latitude is 20.83° N and Longitude is 92.31° E.

1.6.2. Data collection

Solar resources and meteorological data are the most important input to calculate yearly energy yield of a solar power plant. Relevant data (global horizontal irradiation, direct normal irradiation and diffuse horizontal irradiation) can be sourced from different data source such as METEONORM7.3, NASA's Surface Meteorology and Solar Energy (NASA-SSE), National Renewable Energy Laboratory (NREL) and Photovoltaic Geographical Information System (PVGIS TMY). METEONORM7.3 data set is comparatively reliable than other data set. Information about national grid and grid substation capacity will be needed to make a plan for power plant hook-up with national grid to inject the generated power.

1.6.3. Data analysis and feasibility study

After selecting site location, meteorological dataset, such as solar irradiation, ambient temperature, wind speed and relative humidity are found by conducting simulation with PVsyst software. comprehensive analysis has been done on collected meteorological data, grid information and project design. Based on the project design, estimates annual electrical energy production & revenue of planned 10MW grid tied solar park. Initial investment and yearly operation expenses figure out by the discussion with technical expert and related materials supplier.

The literature review covers site potential assessment using PVsyst Software, grid connected photovoltaic systems, module mounting system, solar inverter topology, string sizing, tilting angle and pitch optimization, annual energy yield estimation, Calculate CAPEX and OPEX, risk assessment and find out feasibility.

Finally, financial feasibility analysis of 10MW grid tied solar park has been done by calculating Net Present Value (NPV), Payback Period, Internal Rate of Return (IRR) and Profitability Index (PI) or Benefit to cost ratio (B/C).

1.7 Organization of the Project

This thesis consists of six chapters, along with a list of references and appendices, references and appendices are presented at the end of the thesis as follows:

Chapter 1 is entitled "INTRODUCTION" this chapter describes the general introduction, solar PV development worldwide, background of this research for feasibility analysis of grid tied solar park in coastal region, Bangladesh. Research objectives and outline of the methodology (Appendix 2) are also described here.

Chapter 2 tilted "LITERAURE REVIEW" discussed the theoretical background of grid connected photovoltaic systems. Previous studies focusing on site potential assessment using PVsyst Software, module mounting system design, solar inverter topology, string sizing, calculation of tilting angle and pitch optimization, annual energy yield estimation, calculation of initial investment and yearly operational expenses, risk assessment and financial analysis.

Chapter 3 named "SIMULATION AND RESULTS" this chapter presents simulation procedure step by step with photovoltaic simulation software PVsyst 7.1.2 and finally generate a report that contained simulation results.

Chapter 4 titled "SOLAR RESOURCES AND ENERGY YIELD ASSESMENT" The topics discussed in this chapter are solar resource assessment, comparison of solar resource data such as GHI, DHI, DNI, GII, climates, losses during operation and energy yield calculation for an annum or life time 20 years.

Chapter 5 entitled "FINANCIAL ANALYSIS" This chapter discussed about solar power economics, project cost, sales revenue and financial analysis and financial indicators such as net present value (NPV), internal rate of return (IRR) and benefit to cost ratio (B/C) or profitability index (PI).

Chapter 6 termed as "CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH" This chapter briefly summarizes the work of this thesis, the findings, and provides recommendations for future research.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

A literary review on feasibility analysis of grid tied solar park and the theoretical background of grid connected photovoltaic systems, system design, solar resource assessment and financial analysis techniques are described in this chapter.

2.2 Major components of Grid Tied Solar Park

A schematic diagram (Ramanan P., Kalidasa Murugavel K. Karthick A., 2019) of the grid-tied solar park shown in figure 2.1. The major components of photovoltaic system are PV module, module mounting structure, string combiner box, solar inverter, switchgear, transformer, weather station and SCADA. Description of major components as follows.

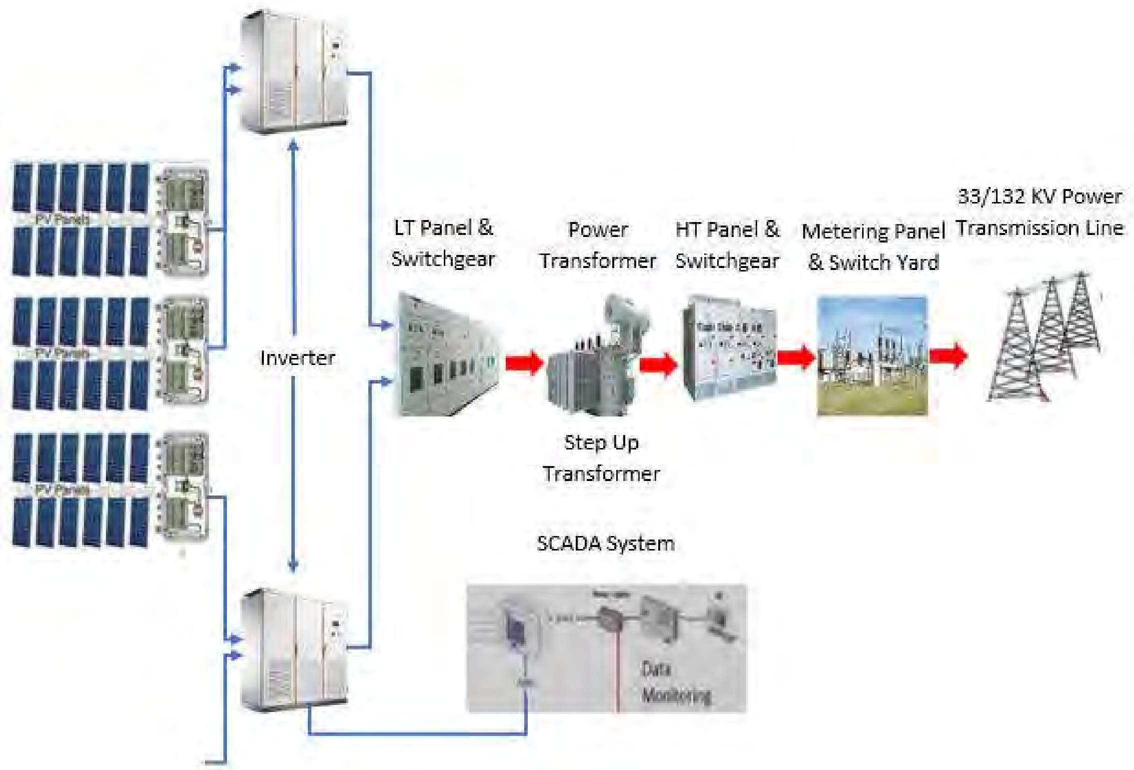


Figure 2.1 Schematic diagram of grid tied solar park

2.2.1 Solar PV modules

These modules convert solar radiation directly into electricity through the photovoltaic effect in a silent and clean process that requires no moving parts. The PV effect is a semiconductor effect whereby solar radiation falling onto the semiconductor PV cells generates electron movement. The output from a solar PV cell is DC electricity. A PV power plant contains many cells connected together in modules and many modules connected together in strings to produce the required DC power output. For this project selected PV module specifications presented in table 2.1.

Table 2.1 PV Module specification at standard test condition

Parameters	Value
Manufacturer	Trina Solar
Model	TSM-DE18M(II)
Cell Type	Monocrystalline
Maximum Power, P_{MAX} (Wp)	505
Maximum power voltage, V_{MPP} (V)	43
Maximum power current, I_{MPP} (A)	11.75
Open circuit voltage, V_{OC} (V)	51.9
Short circuit current, I_{SC} (A)	12.35
Module Efficiency η_m (%)	21.1
Temperature co-efficient of Voc (%/°C)	-0.26
Module Length (mm)	2176
Module Width (mm)	1098
Module Thickness (mm)	35
Module Weight (kg)	27

2.2.2 Module mounting structure (MMS)

The mounting structures are used to support the solar PV modules. Solar panels are mounted on iron fixtures so that they can withstand wind and weight of panels. The panels are mounted to face south in northern hemisphere and north in the southern hemisphere. According to (NI Hongjun, LU Wenfan, Wang Xingxing, Lu Haoyang, Zhang Yongpei, Zhang Minqi, 2015) mounting systems may be either fixed or tracking type.

Fixed mounting system: A fixed-tilt system positions the modules at a fixed tilt angle and orientation that depends on the location. Fixed tilt systems are typically used for large projects and are comprised of either single-post or dual-post designs. Especially for large facilities, a fixed tilt system results in high-cost savings in terms of assembly time due to a smaller number of posts needing to be placed. We have considered 19° PV array tilting angle for this project.

Figure 2.2 Fixed tilt mounting system

Tracking System: while solar tracker systems automatically adjust the positions of the PV array so that the PV modules consistently "track" the sun throughout the day. Compared to a fixed-tilt PV array (Rustu Eke, Ali Senturk, 2012) 30.79% more PV electricity is obtained in the double axis sun-tracking system for the same size array.

There are solar PV module mounting structures that can be tracked either manually or automatically based on the movement of the sun. The tracking system is further classified as single axis tracking and dual axis tracking.

Figure 2.3 Horizontal single axis tracker

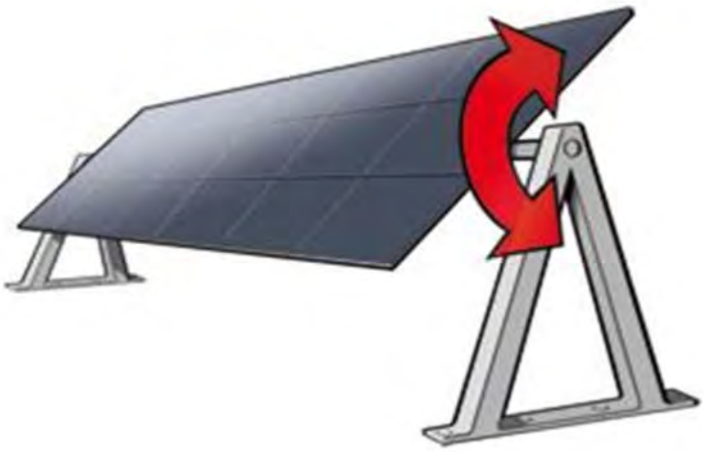


Figure 2.4 Horizontal single axis tracker rotation

single-axis solar trackers track the sun east to west, rotating on a single point, moving either in unison, by panel row or by section, presented in figure 2.3 and 2.4. Single-axis trackers are the most common tracking systems installed today. Also, single-axis trackers are more cost-effective and reliable.

Figure 2.5 Dual axis tracker

Dual-axis trackers rotate on both the X and Y axes, making panels track the sun directly, presented in figure 2.5. Although dual-axis trackers can increase total energy production by 5-10% above a single-axis tracker. The additional energy produced by a dual-axis tracker rarely, if ever, outweighs the additional land, installation and operations and maintenance (O&M) costs required. Most importantly, the rapid decline in PV module pricing has led investors to prefer increasing a system's power capacity (number of modules) to achieve energy targets rather than using more complex tracking systems that improve efficiency.

2.2.3 Solar Inverter

The solar inverter can be defined as an electrical converter that changes the DC (direct current) output of a solar panel into an AC (alternating current). DC power is converted into AC power by the inversion process taking place in the inverter. This process of DC to AC Conversion is achieved by using a set of solid-state devices like Insulated Gate Bipolar Transistors (IGBT's.). These devices when connected in a typical H-Bridge arrangement oscillate the DC power thereby creating AC power. For this project selected solar inverter specifications presented in table 2.2.

Table 2.2 Solar inverter specification

Input Data (DC)	
Maximum DC Input Voltage	1500 V
Minimum DC Voltage to Startup	800 V
Max. DC Current	1754 A
MPP Voltage Range	800-1300 V
No of Independent MPP Trackers	1
No. of DC Inputs	08-12
Output Data (AC)	
Maximum AC output Power	1375 kW
Nominal AC output Power	1250 kW
Output AC Voltage Range	440-632 V
Nominal AC Voltage	550 V
Maximum AC Current	1443 A
Frequency Range	45-65 Hz
Frequency	50, 60 Hz
Power Factor (Cosθ)	0.99
THD at nominal power	< 3 %
No of feed-in phases	3
Maximum Efficiency	99%
Euro Efficiency	98.70%
General Data	
Dimensions (H/W/D)	1915x1805x835 mm
Weight	1650 kg

Power Consumption at Night	< 20 W
Operating Temperature	-30 ~ +65 ℃
Transformer	Transformer less
Protection Class	IP21
Humidity	0-95 %
Cooling	Fan
Maximum operating altitude	4500 m
Communication Interface	RS485/Modbus, Ethernet
Display	Touch Screen
Compliance	IEC 62109, IEC 61727, IEC 62116

Based on the application (Zoltan Corba, Boris Dumnic, Vladimir A. Katic, Dragan Milicevic, 2012) the classification of solar inverters are string inverter and central inverter.

String Inverter: A string inverter is connected to a series or "string" of solar panels and used to convert the Direct Current (DC) electricity generated by solar panels into a usable form of Alternating Current (AC) that can be utilized to integrate with the grid. Solar panels are wired together in series (a string of panels) which increases the voltage and keeps the current low so that wiring is simpler and wire size can be smaller.

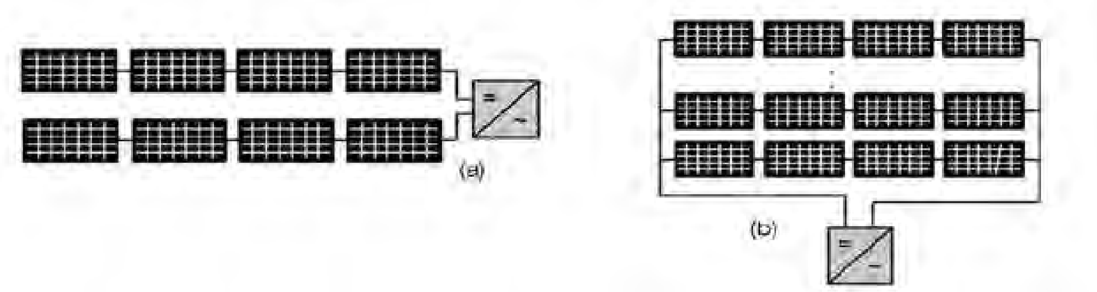


Figure 2.6 (a) String Inverter (b) Central Inverter

String inverters are designed to be wired to a single series string of 24 solar modules for this project. String inverter are currently the most widely used inverter type, presented in figure 2.6 (a). String inverters are typically warranted for 5 years.

Advantages of a String Inverter:

1. Smaller in size when compared to central inverters
2. Better MPPT capability per string
3. Scalability for future expansion by adding parallel strings
4. Short DC wires
5. Monitoring at string level

Disadvantages of a String Inverter:

1. The installation requires special racking for the inverter for each string
2. Poor flexibility at partial shading
3. Higher per Watt cost than central inverter

Central inverter: A central inverter is a high-capacity inverter designed for use with large commercial or utility (power station) sized solar systems. It is like large string inverter designed to handle more power and offer efficiencies / economies of scale. Central inverters are not used for residential solar systems, presented in figure 2.6 (b).

Advantages of a Central Inverter:

1. The most traditional inverter topology
2. Easy system design and implementation
3. Low cost per watt
4. Easy accessibility for maintenance and troubleshooting

Disadvantages of a Central Inverter

1. High DC wiring costs and power loss due to Voltage Drop.
2. Single MPPT for the entire PV system
3. System output can be drastically reduced in case of partial shading and string mismatch
4. Difficult to add strings or arrays for future expansion
5. Single failure point for the entire system
6. Monitoring at array level

2.3 String Sizing

To design a solar PV system, it’s very much important to know the minimum and maximum number of PV modules that can be connected in series, referred to as a string. PV modules produce more voltage in low temperatures and less voltage in high temperatures. If too many modules are on the same string then the maximum input voltage of the inverter may be exceeded and the electrical equipment connected to that string could be damaged, or worse, start a fire. If too few modules are on the same string, then the inverter might shutoff when the outside temperature is high and the system will underperform during the summer months. To getting better performance, we have to choose appropriate string size between the minimum & maximum string size. Considered 24 PV modules in series according to specifications of the selected plant equipment's TRINA solar 505Wp PV module and sungrow 1250 KW string inverter. Maximum & minimum string size depends on the PV module and inverter parameter as well as string voltage that is dependent of temperature and irradiation.

Table 2.3 Meteonorm 7.3 long term temperature profile.

Month	GHI (kWh/m2/day)	Total Available Days	Total GHI (kWh/m2/Month)	Total GII (kWh/m2/Month)	Ambient Temperature (°C)
January	4.81	31.00	149.00	188.30	21.30
February	5.56	28.00	155.70	183.40	23.70
March	6.04	31.00	187.30	202.20	26.60
April	6.43	30.00	192.80	193.40	28.20
May	5.66	31.00	175.50	167.00	29.00
June	4.89	30.00	146.80	137.10	28.10
July	3.94	31.00	122.00	115.20	28.10
August	4.30	31.00	133.20	129.70	28.30
September	4.66	30.00	139.70	143.20	28.00
October	5.06	31.00	156.90	176.90	28.30
November	5.11	30.00	153.30	190.10	25.60
December	4.86	31.00	150.60	196.40	22.90
Yearly Total	61.31	365.00	1862.80	2022.90	318.10
Yearly Avg.	5.11	30.42	155.23	168.58	26.51

Calculation of minimum & maximum string size already calculated by simulation. However manual calculation done to cross check. String sizing calculation described below step by step according to (Todd Karin and Anubhav Jain, 2020); (Matheus Gemignani, Guido Rostegui, Mauricio B. C. Salles, 2017).

1. Inputs

a) Temperature considered for string sizing

Minimum Temperature (T_{min}) = 5^o C

Maximum Temperature (T_{max}) = 45^o C

b) PV Module Parameter at STC Conditions (505 Wp (Trina Solar – TSM-DE18M(II))

Irradiance 1000 W/m2

Cell temperature (T_{STC}) = 25 ^{o} C

Open Circuit Voltage (V_{OC}) = 51.9 V

Maximum Power Voltage (V_{MPP}) = 43.0 V

Temperature Coefficient (βV_{OC}) = -0.26%/ ^{o} C

c) Inverter Parameter

Inverter 1250 kW (SUNGROW – SG1250HV)

Maximum DC input Voltage VDC_{max} = 1500 V

Minimum DC input Voltage VDC_{min} = 800 V

2. String size calculation

Step-1: Calculation maximum voltage of PV module using the low temperature

$V_{max} = V_{OC} \times [1 + \{(T_{min} - T_{STC}) \times \beta V_{OC}/100\}]$

$= 51.9 \times [1 + \{(5-25) \times (-0.26)/100\}]$

$= 54.5988 \approx 54.60$

Step-2: Calculation of the maximum number of PV module per string

$Smax = VDC_{max}/V_{max} = 1500/54.60 = 27.47 \approx 28$ (Rounded)

Step-3: Calculation minimum voltage of PV module using the high temperature

$V_{min} = V_{MPP} \times [1 + \{(T_{max} - T_{STC}) \times \beta V_{OC}/100\}]$

$= 43.0\times [1+ \{(45-25) \times (-0.26)/100\}]$

$= 40.7640 \approx 41.00$

Step-4: Calculation of the minimum number of PV module per string

$Smax = VDC_{min}/V_{min} = 800/41.00 = 19.5121 \approx 20$ (Rounded)

2.4 Tilting Angle and Pitch Optimization

The optimum energy generation on a PV module depends not only on the solar irradiation, but also on the angle between the PV array and the sun. PV array tilting is crucial important to getting maximum energy from collector plane. the maximum energy will be generated for fixed tilt PV system, when the collector plane and the sunlight are perpendicular to each other.

The amount of solar radiation incident on a tilted module surface is the component of the incident solar radiation which is perpendicular to the module surface. The following figure shows how to calculate the radiation incident on a tilted surface (S_{module}) given either the solar radiation measured on horizontal surface ($S_{horizontal}$) or the solar radiation measured perpendicular to the sun ($S_{incident}$).

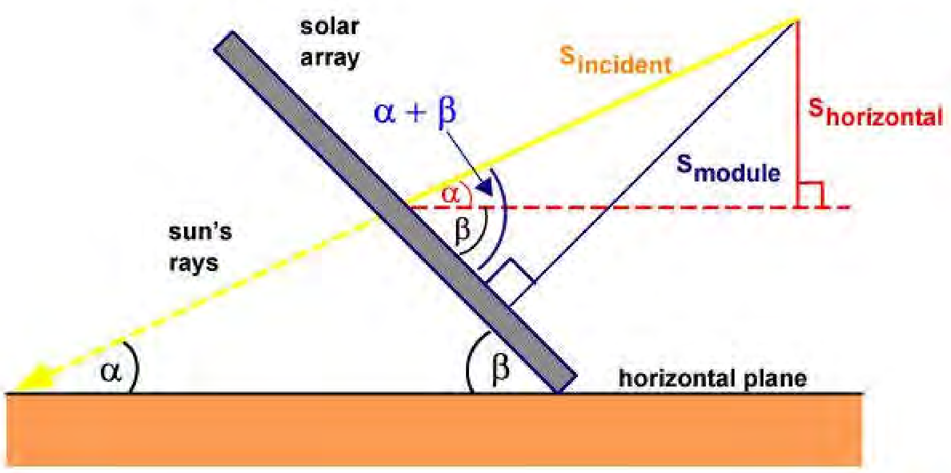


Figure 2.7 Solar radiation geometry.

From above figure we can the equations relating S_{module}, $S_{horizontal}$ and $S_{incident}$ are:

$$S_{horizontal} = S_{incident} \times \text{Sin } \alpha$$
$$S_{module} = S_{incident} \times \text{Sin } (\alpha + \beta)$$

From the above equations, S_{module} can be determined

$$S_{module} = \{S_{horizontal} \times \text{Sin } (\alpha + \beta)\} / \text{Sin } \alpha$$

The elevation angle is the angular height of the sun in the sky measured from the horizontal. The elevation is 0° at sunrise and 90° when the sun is directly overhead (which occurs for example at the equator on the spring and fall equinoxes). The elevation angle varies throughout the day. It also depends on the latitude of a particular location and the day of the year.

An important parameter in the design of photovoltaic systems is the maximum elevation angle, that is, the maximum height of the sun in the sky at a particular time of year. This maximum elevation angle occurs at solar noon and depends on the latitude and declination angle. The elevation angle at solar noon can be determined according to the formula

The elevation angle $\alpha = 90 - \phi - \delta$

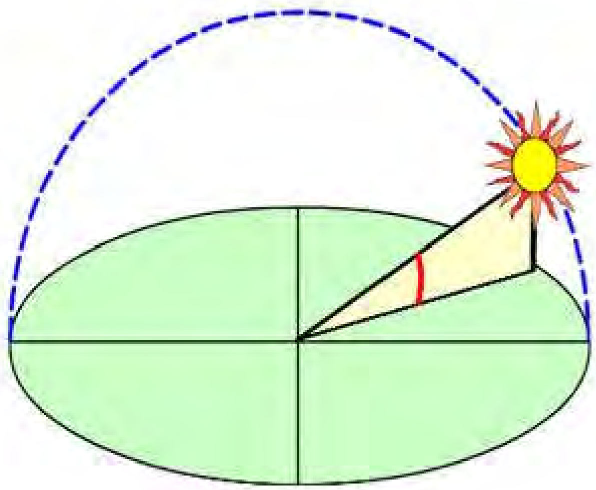


Figure 2.8 Elevation angle (α)

The declination angle, denoted by δ, varies seasonally due to the tilt of the Earth on its axis of rotation and the rotation of the Earth around the sun. If the Earth were not tilted on its axis of rotation, the declination would always be 0°. However, the Earth is tilted by 23.45° and the declination angle varies plus or minus this amount. Only at the spring and fall equinoxes is the declination angle equal to 0°.

$$\text{Sun declination angle } \delta = 23.45 \times \sin [360/365\ (d-81)]$$

Where:

α is the elevation angle

β is the tilt angle of the PV array measured from the horizontal.

ϕ is the latitude

δ is the sun declination angle

d is the day of the year

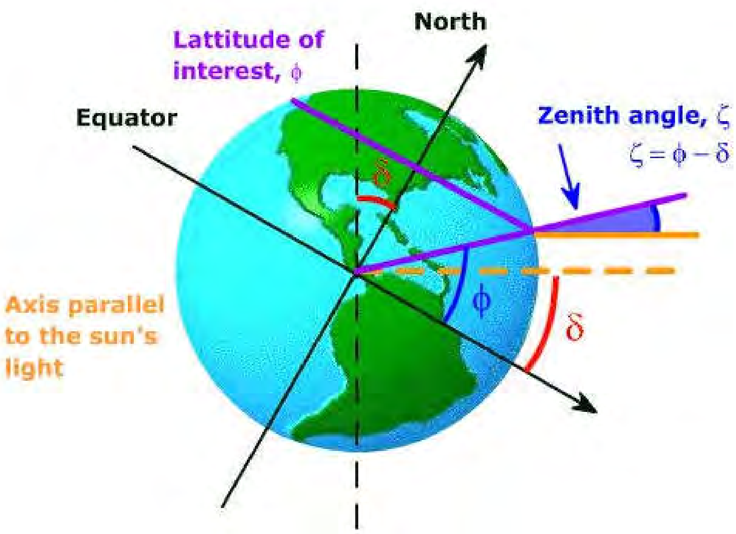
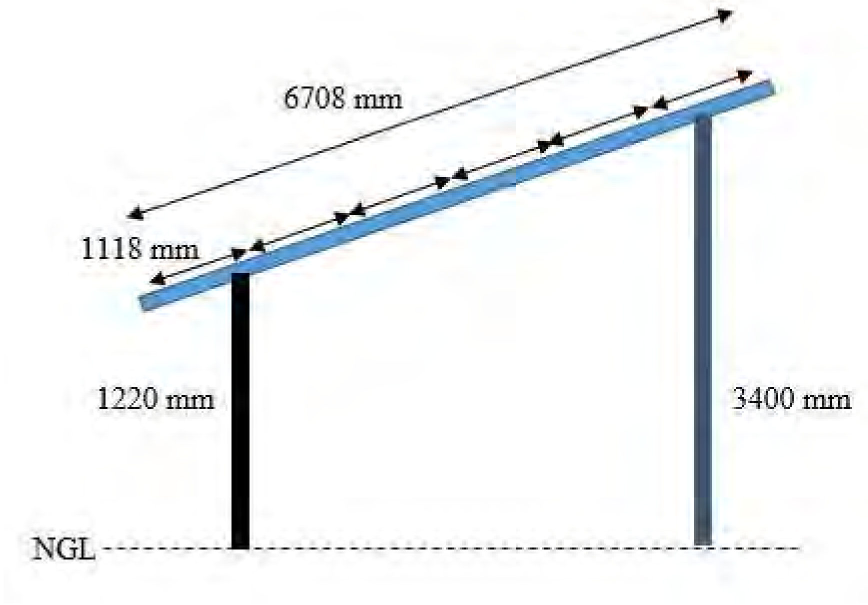
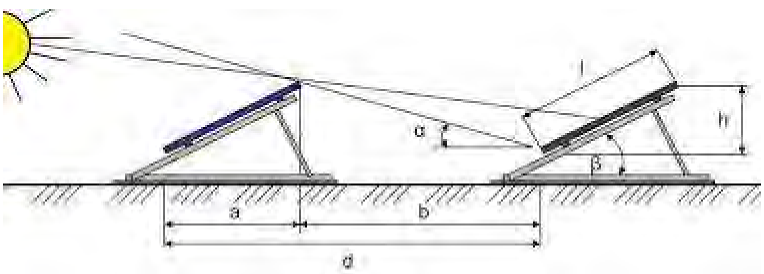


Figure 2.9 Declination angle (δ) and zenith angle (ζ)

(Syed Muhammad Sami ur Rehman, Muhammad Ammar Nazeer, Zafar Iqbal, Muhammad Abdul Basit, Aqeel Ahmed, 2018) conducted mathematical analysis for calculation of an optimum tilt angle of solar panels. Sun elevation angle α, declination angle δ will be calculated according to their prescribe formula.



(a) PV Table 6x48 (Row x Column), module in landscape orientation



(b) PV Array

Figure 2.10 (a) PV table orientation (b) PV Array

(Mark Z. Jacobson, Vijaysinh Jadhav, 2018) found optimum tilting angle 25 degree for chattogram region of Bangladesh, they conducted research based on the station latitude 22.27º N and station longitude 91.82º E. By using photovoltaic simulation software PVsyst V7.1.2, we have also found optimum tilting angle 25.7 degree, present in table 2.4. However, project feasibility has been done by using tilting angle 19 degree on the basis of wind speed (sabrang is the cyclone area), module mounting structure height. To calculate pitch, the elevation angle (α) considered 25º (worst case).

If we consider tilting angle 25 degree, inter row distance or pitch and module mounting structure height will be increased accordingly. Higher pitch required the extra land and increase shading loss, module mounting structure height increase causes extra expenses. On occasion, costal region faces high wind speed, that can occur and increases uplifting possibility of PV table. (maximum speed observed 77 m/s at selected location),

Table 2.4 Relation among tilting angle, pitch and structure height.

SL	Tilting Angle (Degree)	Tilting Angle (Rad)	Energy Yield (kWh/m2)	MMS Height (mm)	Inter Row Spacing (mm)	Pitch (mm)
1	15	0.2618	2009	1,736.16	4,770.06	10,202.94
2	16	0.2793	2015	1,848.98	5,080.02	10,412.49
3	17	0.2967	2021	1,961.23	5,388.43	10,621.26
4	18	0.3142	2026	2,072.89	5,695.21	10,824.52
5	19	0.3316	2030	2,183.91	6,000.25	11,026.60
6	20	0.3491	2034	2,294.27	6,303.46	11,223.28
7	21	0.3665	2038	2,403.93	6,604.75	11,418.49
8	22	0.384	2041	2,512.86	6,904.03	11,608.35
9	23	0.4014	2043	2,621.02	7,201.21	11,796.45
10	24	0.4189	2045	2,728.39	7,496.19	11,979.26
11	25	0.4363	2047	2,834.92	7,788.89	12,160.04
12	26	0.4538	2048	2,940.59	8,079.22	12,335.53
13	27	0.4712	2048	3,045.37	8,367.08	12,508.82
14	28	0.4887	2048	3,149.22	8,652.40	12,676.80
15	29	0.5061	2048	3,252.10	8,935.08	12,842.31
16	30	0.5236	2047	3,354.00	9,215.04	13,002.57
17	31	0.5411	2045	3,454.88	9,492.19	13,158.90
18	32	0.5585	2044	3,554.70	9,766.45	13,312.50
19	33	0.576	2041	3,653.44	10,037.74	13,460.78
20	34	0.5934	2038	3,751.07	10,305.97	13,606.21
21	35	0.6109	2035	3,847.55	10,571.06	13,746.26

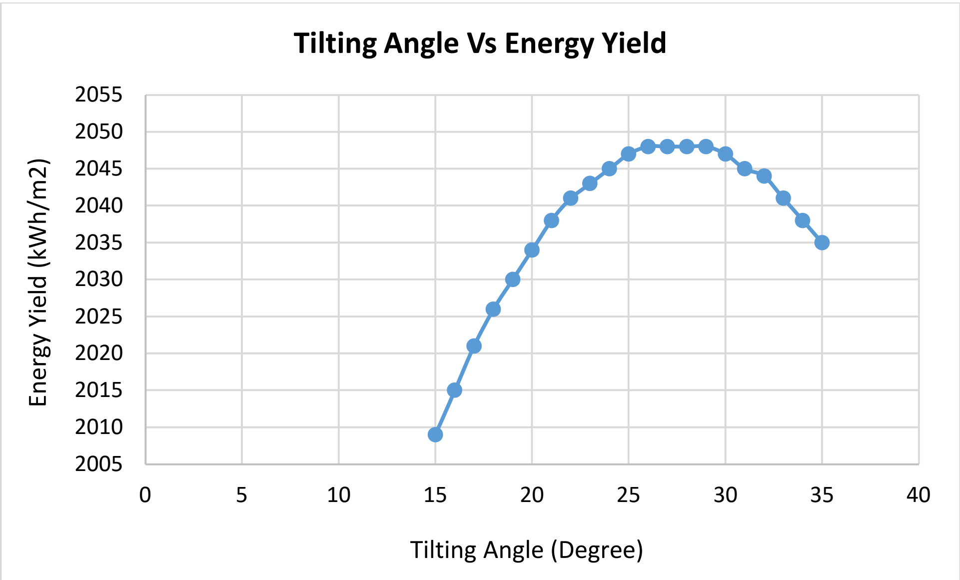


Figure 2.11 Relation between tilting angle and energy yield

2.5 Site Potential Assessment Using PVsyst Software version 7.1.2

Investors need to understand the specific site requirements and conditions that help to optimize a solar power plant's output. A solar site analysis involves evaluation of site suitability, solar access, shadowing considerations and other variables. Investments in large scale solar power plants require accurate estimation of the site's suitability in order to ensure the viability of the project. Site potentials estimation is the crucial important to protects investment by assessing geological conditions as well as providing an estimation of energy yield.

According to (C.P. Kandasamy, P. Prabu, K. Niruba, 2013) the site potentials has been assessed by simulation with PVsyst Software version 7.1.2. The project simulation process with PVsyst 7.1.2 includes the basic steps such as data organization, orientation, system, detailed losses, near shading and simulation, described as follows.

Data organization- define the specific location, where the 10MW solar park will be installed and based on this location meteorological data such as global horizontal irradiation, diffused horizontal irradiation, ambient temperature, wind velocity will be generated.

Orientation – define module azimuth and tilting angle, considered azimuth 0^0 and array tilting angle 19° according to site location.

System – in this section we have to choose the system equipment such as PV modules, solar inverters, transformer and put some information based on system design. 505Wp PV module, 1250 kW string inverter and 2500 kVA step-up transformer considered for the planned $10MW_{AC}$ project.

Detailed Losses – considered related all losses up to power injection into grid, such as thermal parameter, ohmic losses, module quality loss, LID-Light Induced Degradation, mismatch loss of modules & strings, soiling loss, IAM losses, auxiliaries and system unavailability. Table 2.3 presented losses with percentage.

Table 2.5 Loss profile.

Losses	Percent (%)
Far Shadings/Horizon	1.19
Near Shadings: Irradiance Loss	0.86
IAM factor on global/Incident angle	1.81
Soiling Loss Factor	1.50
Module Degradation loss for First year	2.50
PV loss due to irradiance Level	0.54
PV loss due to Temperature	7.33
Module quality loss	0.10
LID-Light Induced Degradation	1.50
Mismatch Loss Modules & Strings	0.60
DC Ohmic Loss	0.43
Inverter Loss during Operation (Efficiency)	1.21
Inverter Loss over nominal inverter power	0.02
Auxiliary Consumption	1.25
AC ohmic loss	0.03
Medium voltage transformer loss	0.82
System unavailability	1.60

During the simulation, the shading calculations have to be computed at each hour, and applied differently on the beam, diffuse and albedo components. For the beam component of near shadings, we have to consider two kinds of losses, Irradiance losses which correspond to the deficit of irradiance on the cells (formerly called "Linear shading losses"), Electrical losses, resulting from the mismatch of electrical response of the modules in series and strings in parallel.

In a string of modules (or cells), the total current is always determined by the current in the weakest cell. PVsyst provides two different ways for treating these electrical losses Shading factor "according to strings", which is a rough evaluation giving an upper limit to the shading loss, detailed electrical calculation according to the exact positioning of each module in the field.

Simulation – view a summary of the system's energy output

2.6 Financial Analysis

A financial analysis has conducted to determine the economic viability of the proposed 10MW$_{AC}$ solar park. This analysis identifies the initial investment, yearly operational and maintenance cost, makes projections of profits and cash flows and determines the return of the investment.

Estimates capital expenditure or initial investment for capital machinery purchase based on recent market price trends and discussion with major equipment supplier and technical expert. Estimate yearly operational expenditure based on the discussion with officials of different power plant in Bangladesh especially renewable power plant and as well as conventional power plant.

Tariff rate considered according to previous power purchase agreement (PPA), that type of contract already signed between Bangladesh power development board (BPDB) and private company limited.

According to (Leandro Alves Aguilar, 2015) finally conducted financial analysis by calculating profitability indicators such as levelized cost of electricity (LCOE), net present value (NPV), internal rate of return (IRR) and benefit to cost ratio (B/C) or profitability index (PI).

CHAPTER 3
SIMULATION AND RESULTS

3.1 Introduction

Site potentials such as solar resources and meteorological data are the most important input to calculate yearly energy yield of a solar power plant. Revenue return depends on the energy generation capacity at specific location. This chapter presents the simulation process with simulation software PVsyst version 7.1.2. Author select sabrang, Teknaf for this analysis, site location Latitude is 20.83° N and Longitude is 92.31° E. Several steps were involved in simulation process with PVsyst software. All the necessary steps such as data organization, orientation, system, detailed losses, near shading and run simulation has been explained below.

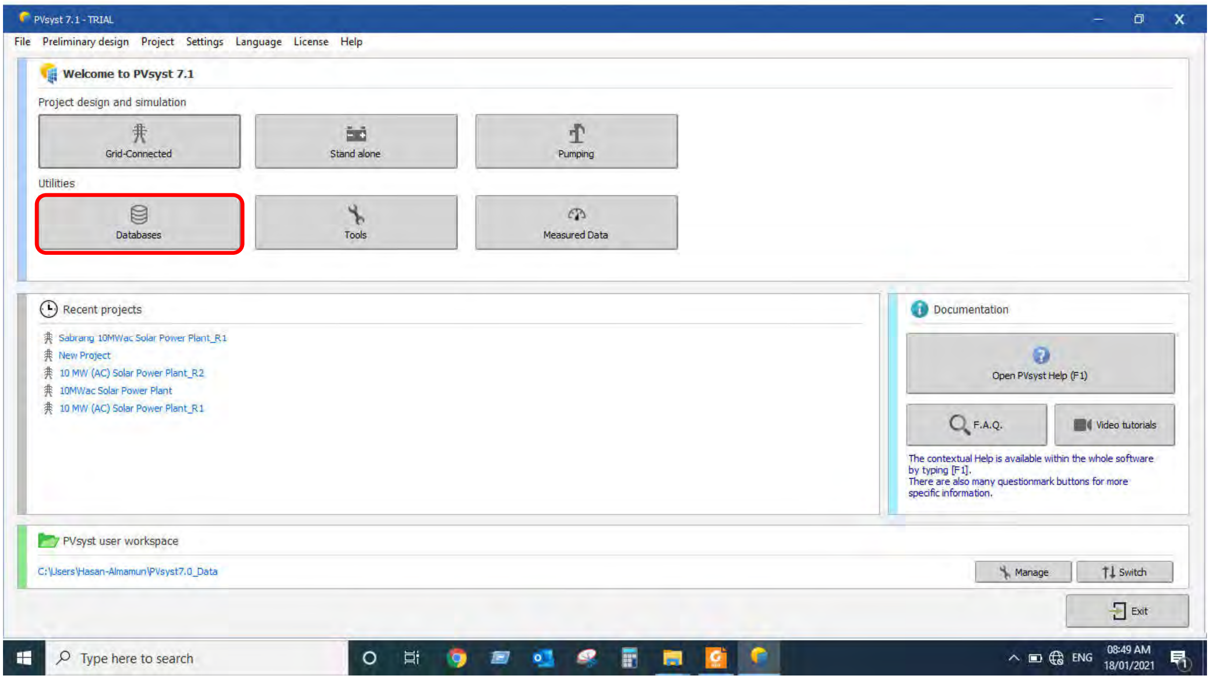
3.2 Data Organization

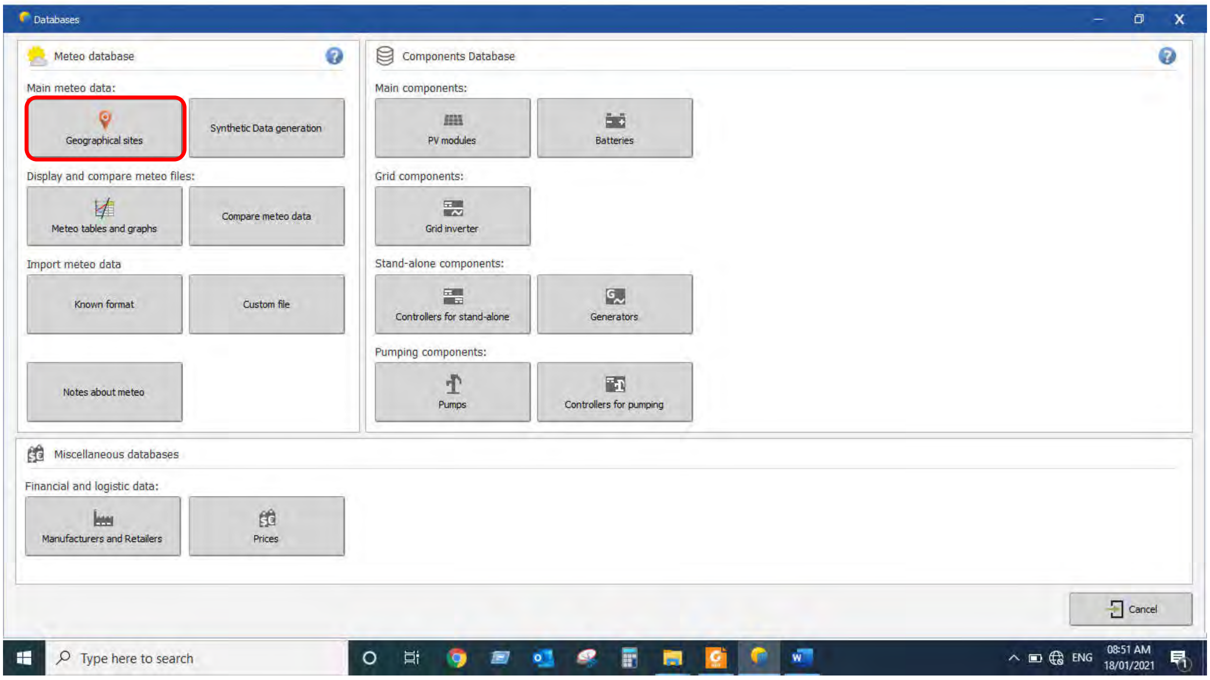
The first input that PVsyst needs is the geographical location of the project to be simulated. This will determine the sun path over the year, and allow to interpolate meteorological data for places where no direct measurements were taken. The meteorological data that is used as input for the simulation consists of the following quantities:

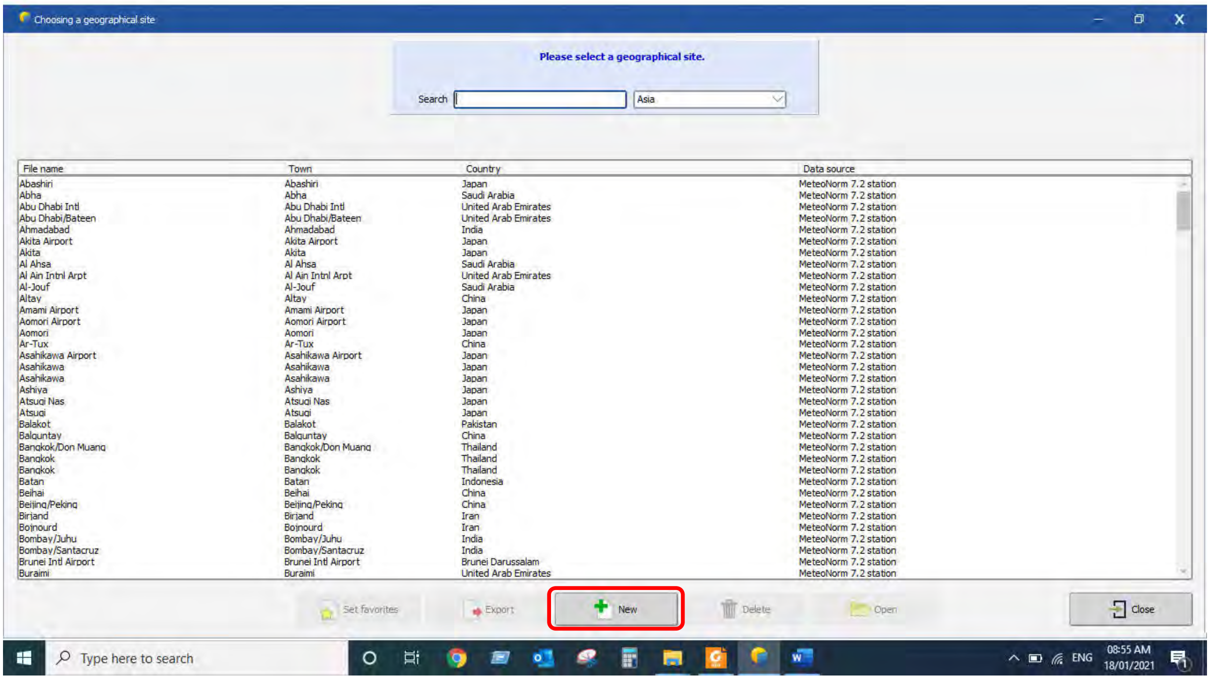
- Horizontal global irradiation
- Average External Temperature
- Horizontal diffuse irradiation
- Wind velocity

The first two, horizontal global irradiation and average external temperature, have to be supplied as external input to the simulation. There is no good way to estimate them just from the geographical location. The other two quantities can either also be supplied as external measured data or, in case there are no good measurements available, they are estimated by PVsyst with the help of established models.

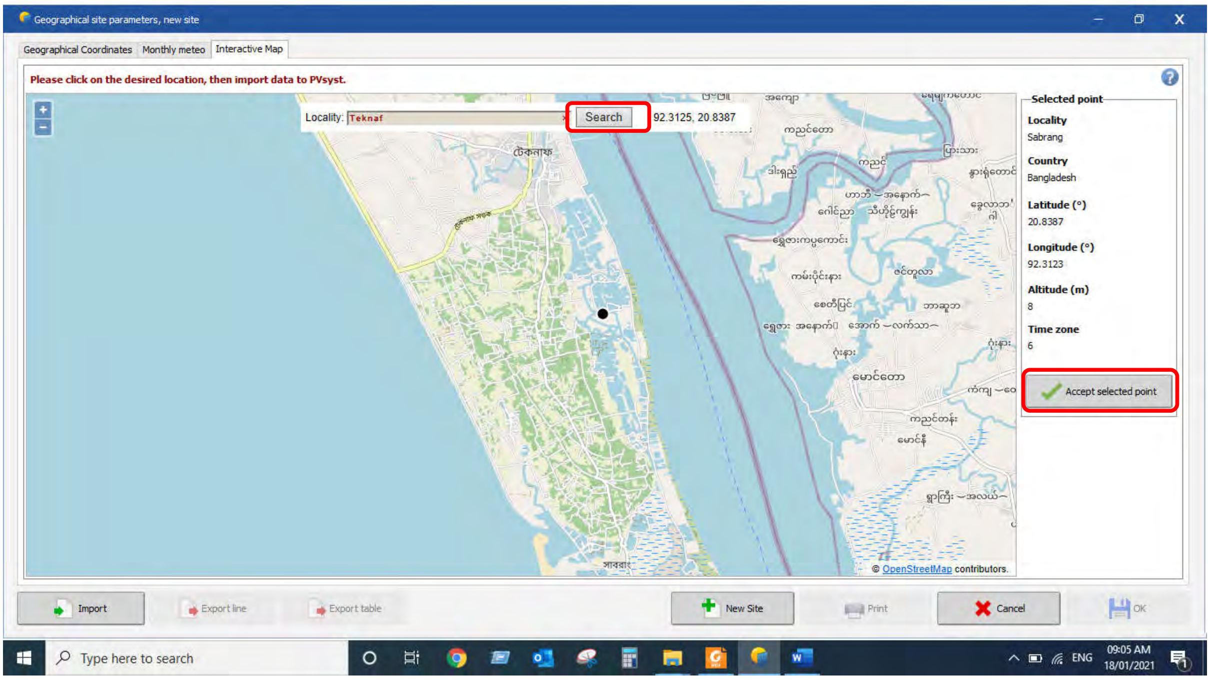
Choose the Databases and then select Geographical Sites in the main PVsyst screen.



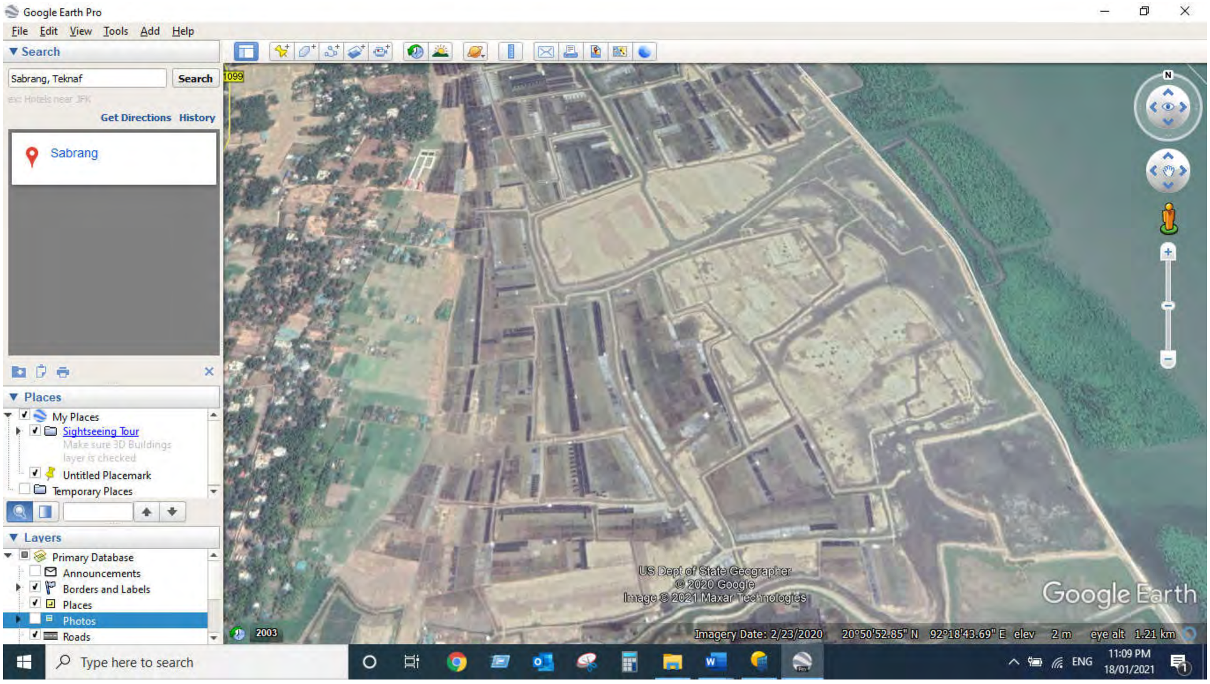


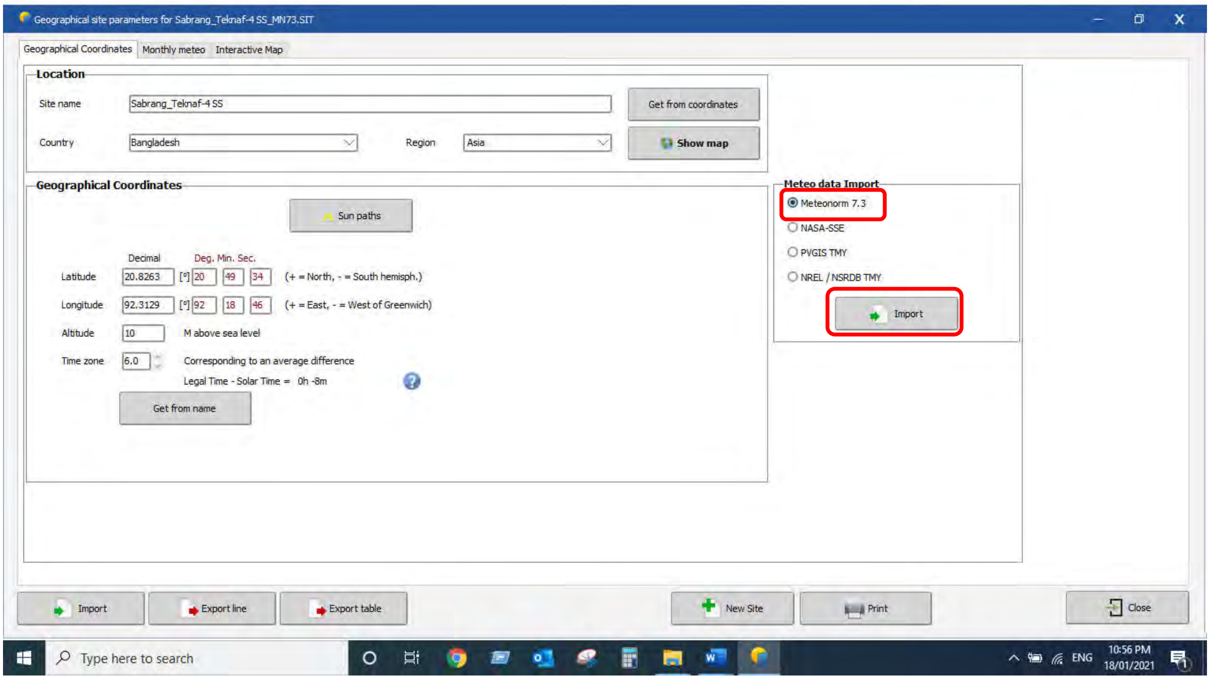


Click the “New” project option, after clicking “New” interactive map will open then write Teknaf in search box and click “Search”. New window will show Teknaf district map, where we have to select specific point by double clicking then click “Accept Selected Point”



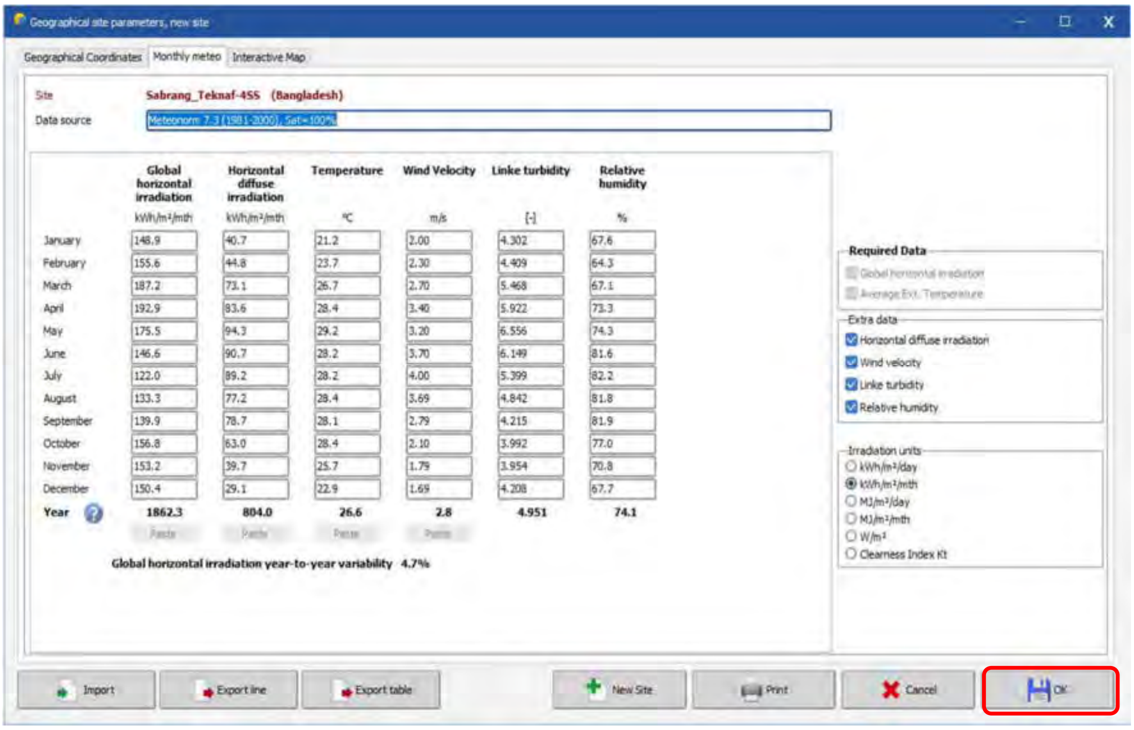
According Latitude 20.83° N and Longitude 92.31° E, another picture sourced from google earth for getting better concept about the selected site location Sabrang.

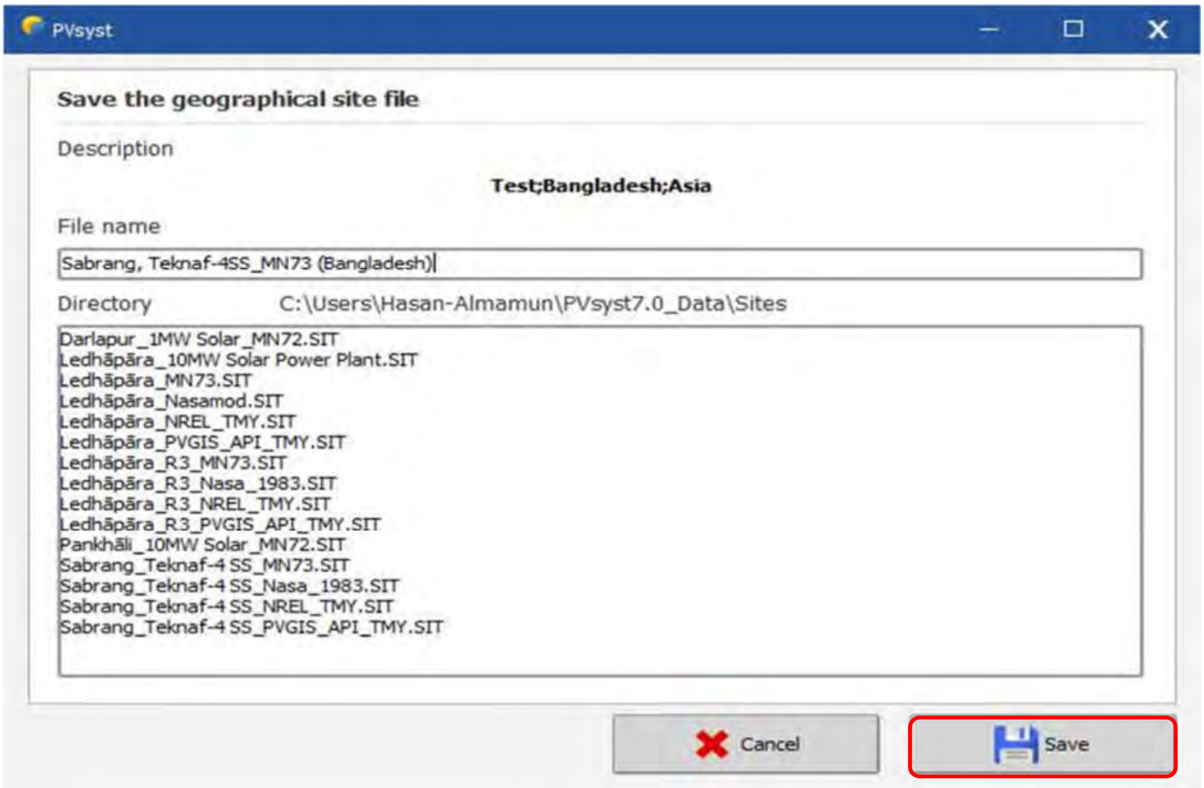




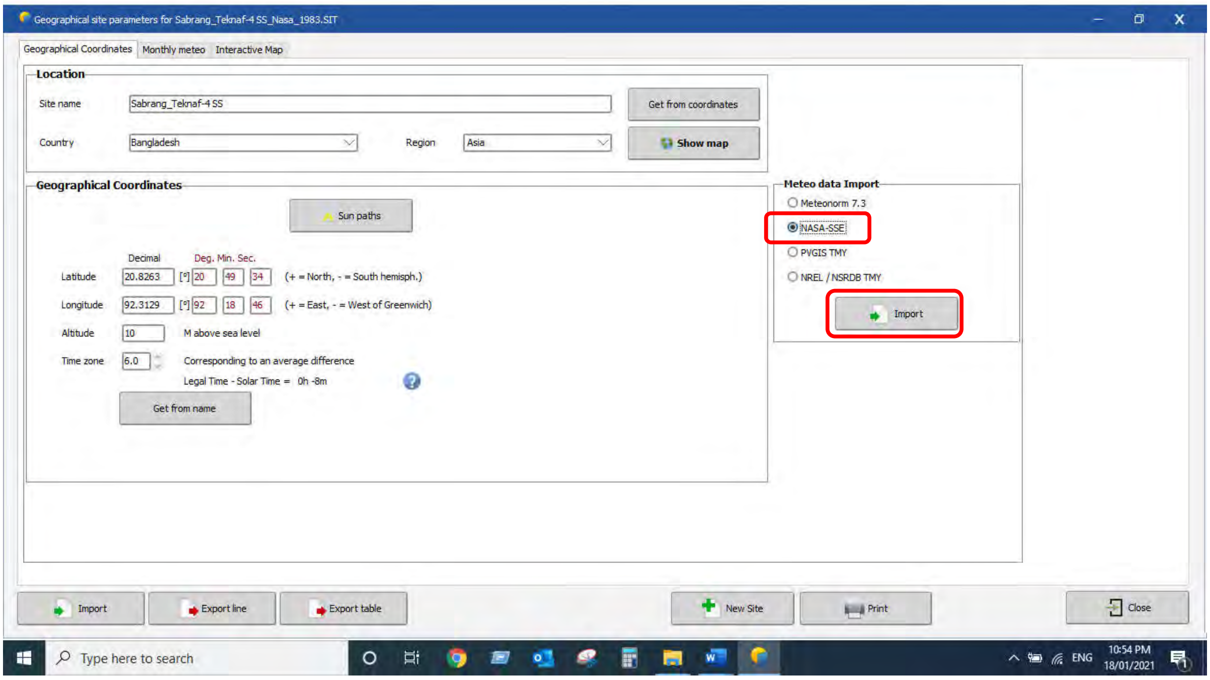
After selecting specific site location above PVsyst screen will open. We have to write the site name first “Sabrang_Teknaf-4 SS” then import dataset one by one. Four satellite-based data sources available here 1. Meteonorm7.3 2. NASA-SSE 3. PVGIS TMY and 4. NREL/NSRDB TMY.

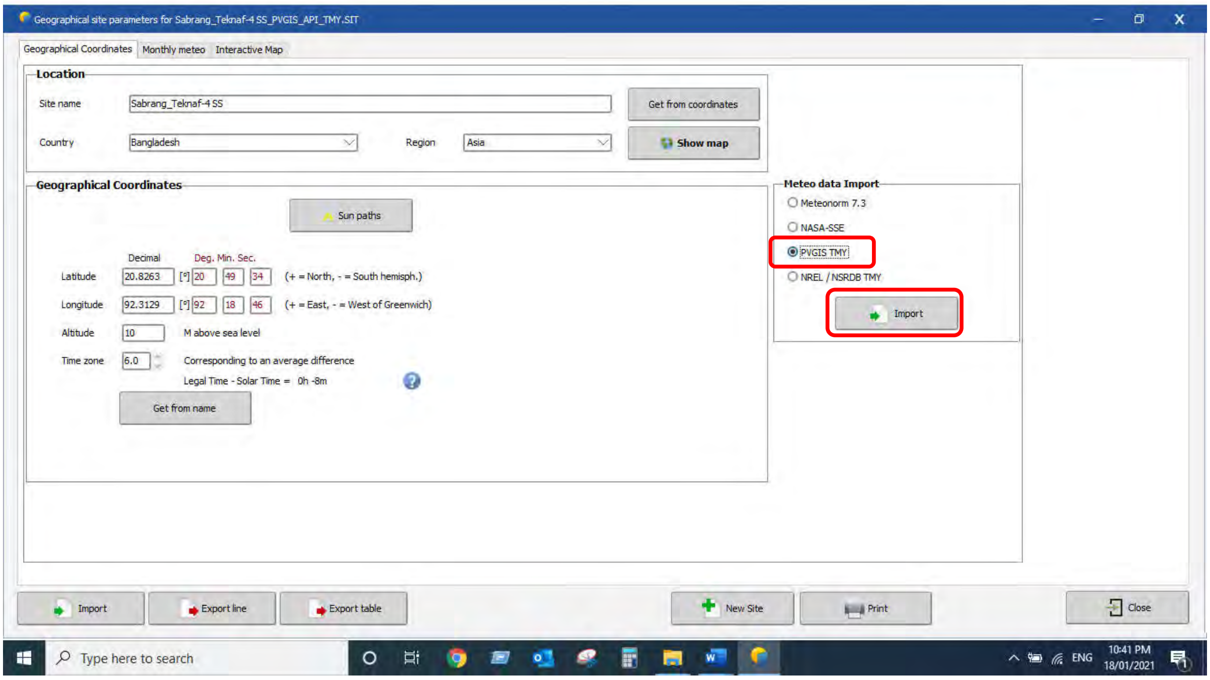
To import Meteonorm7.3 dataset, choose Meteonorm7.3 and click “Import” option after clicking “Import” Meteonorm7.3 dataset will be showed then click “OK” and “save” next.

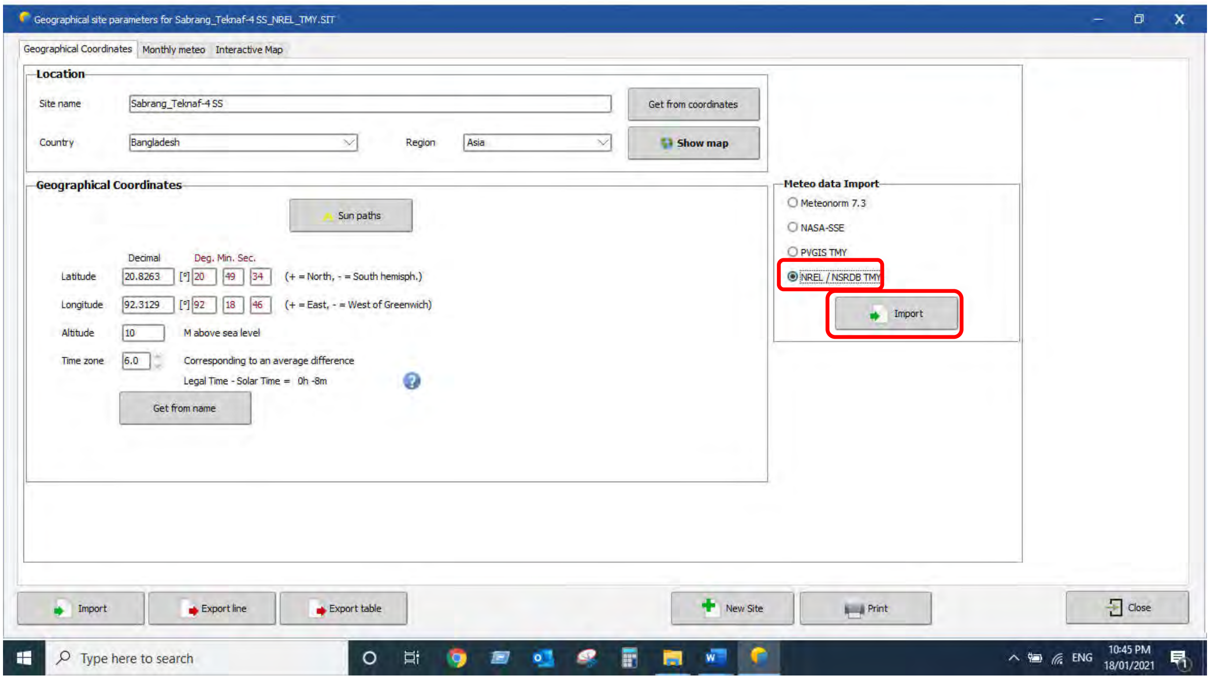




Similarly rest of three datasets (NASA-SSE, PVGIS TMY and NREL/NSRDB TMY) will be imported one by one following the above procedure



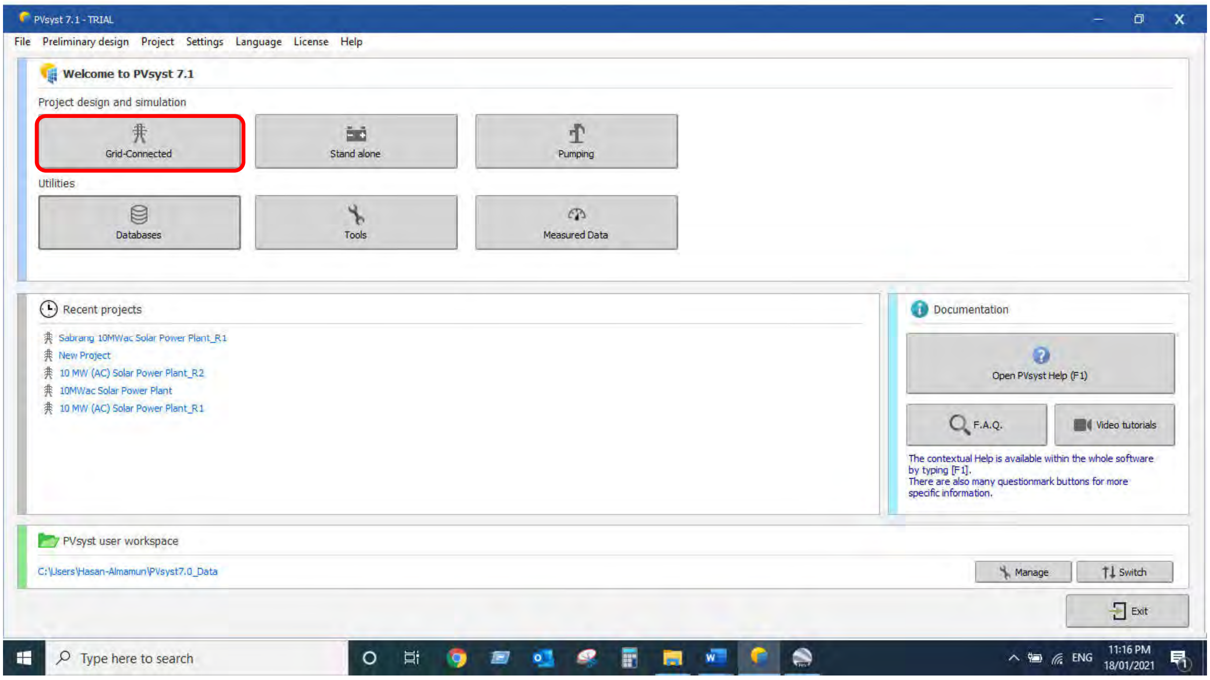


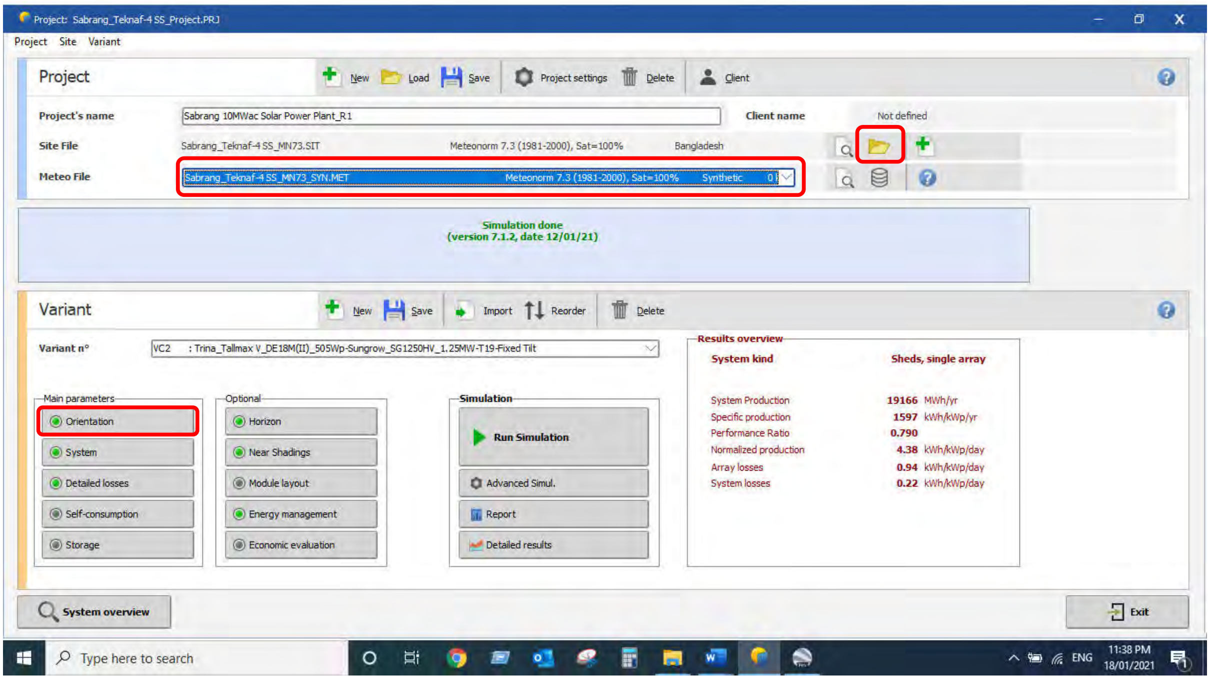


3.3 Orientation

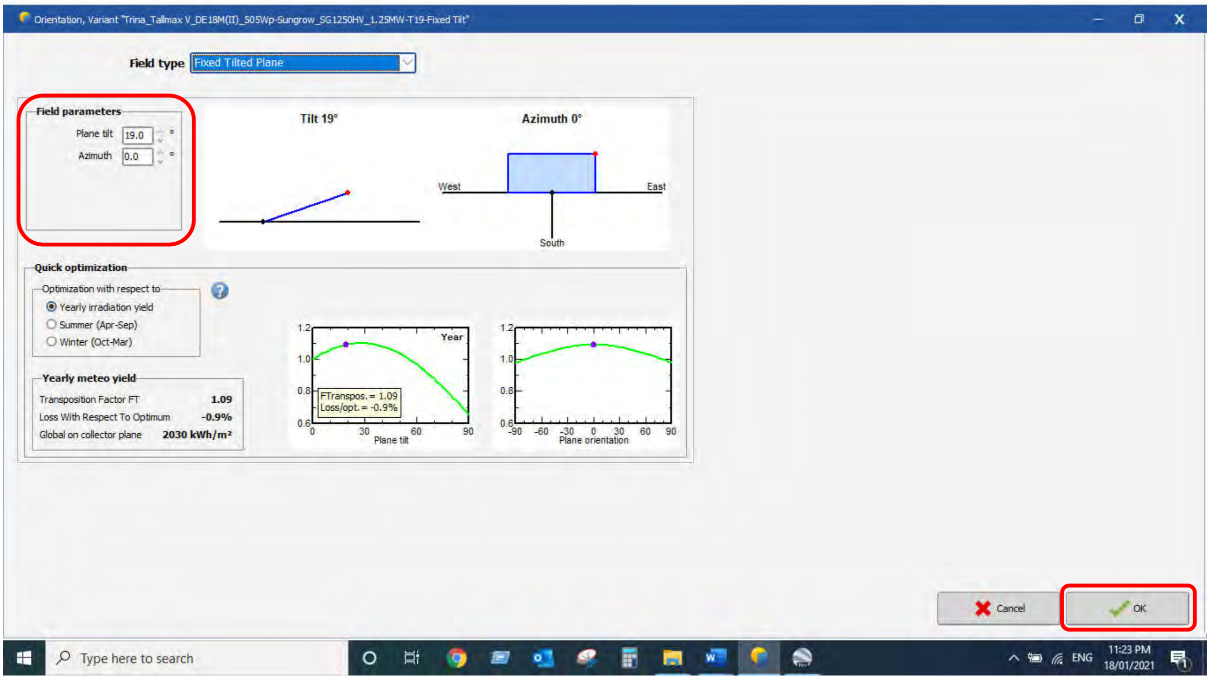
After defined the site and the meteorological input of the project, then create the first Variant. PVsyst screen will notice, that in the beginning there are two buttons marked in red: “Orientation” and “System”. The red color means that this variant of the project is not yet ready for the simulation, additional input is required. The basic parameters that have to be defined for any of the variants, and that we have not specified yet, are the orientation of the solar panels, the type and number of PV modules and the type and number of inverters that will be used.

First, click on “Grid Connected” option, the grid connected dialog will open. where we have to uploaded site meteorological file that already imported and saved. After completed uploading meteorological file, file name will show in the below text box.



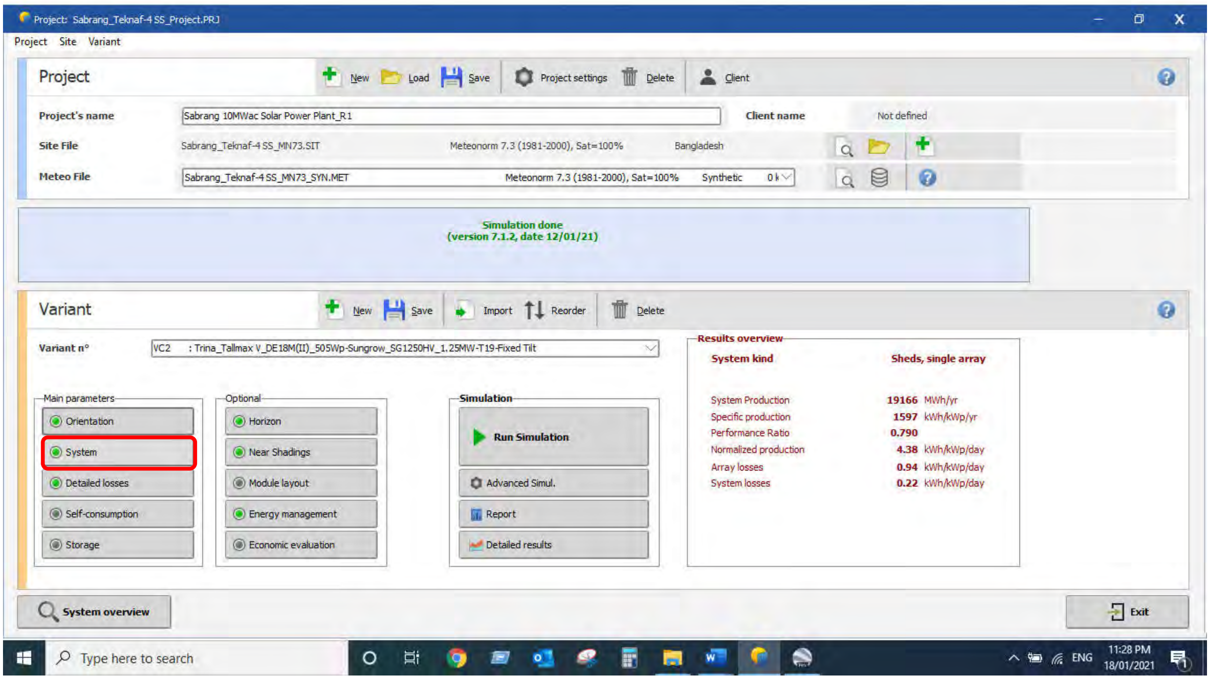


PVsyst screen will notice, that in the beginning the "Orientation" button marked in red. So, click "Orientation" first, the orientation screen will open, here we have to select the type of field and put tilt and azimuth angles. To analysis feasibility of 10 MW_{AC} grid tied solar park at sabrang, Teknaf, we have considered field type "Fixed Tilted Plane", plant tilt angle 19º and azimuth 0º. After putting required and necessary information then click OK

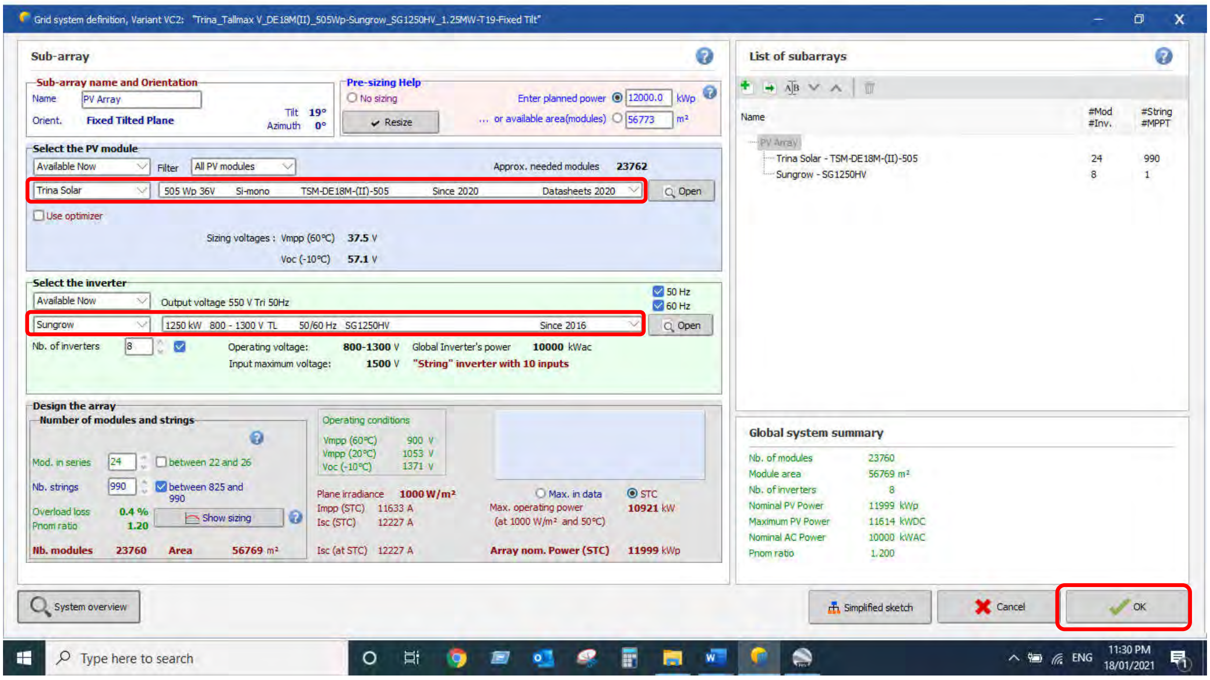


3.4 System

In this step of simulation, we have to select major plant equipment such as PV module, Inverter and transformer. Also required additional information will be putted here according to equipment's specification and site requirement.



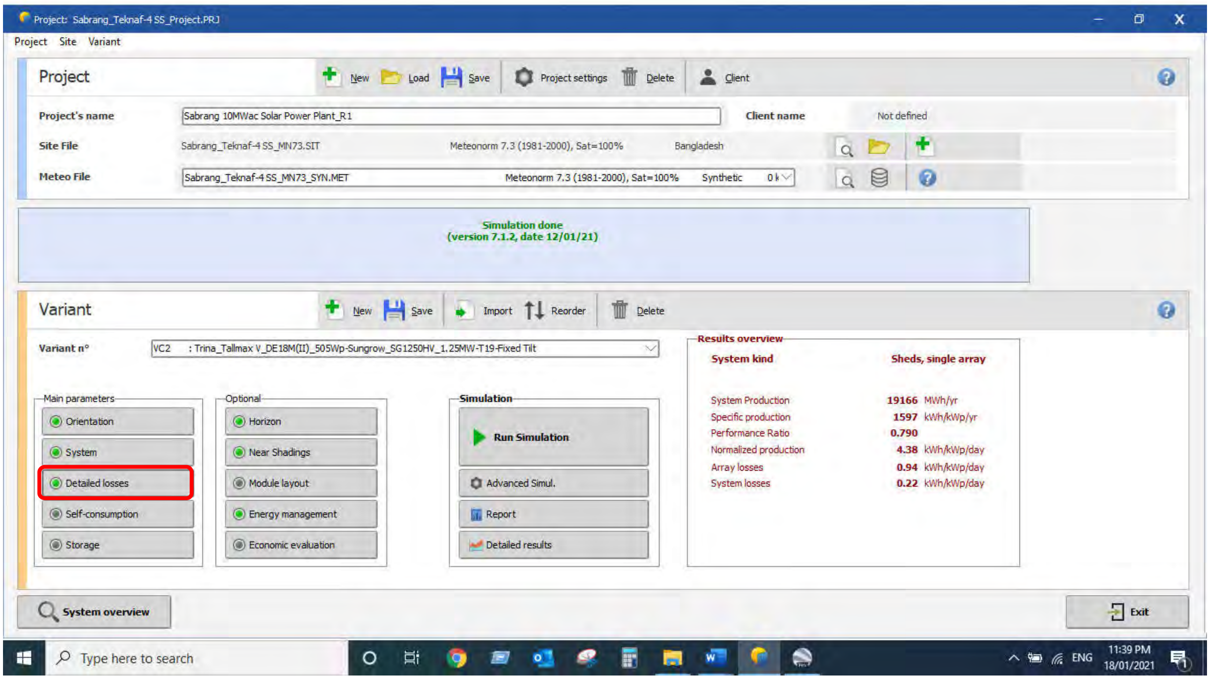
Click on "System" the system dialog will open then select PV module, solar inverter and put necessary information such as planned power, frequency and cable length then click OK. We have selected 505Wp PV module Trina solar brand and 1.25MW inverter Sungrow brand as reference for this simulation.

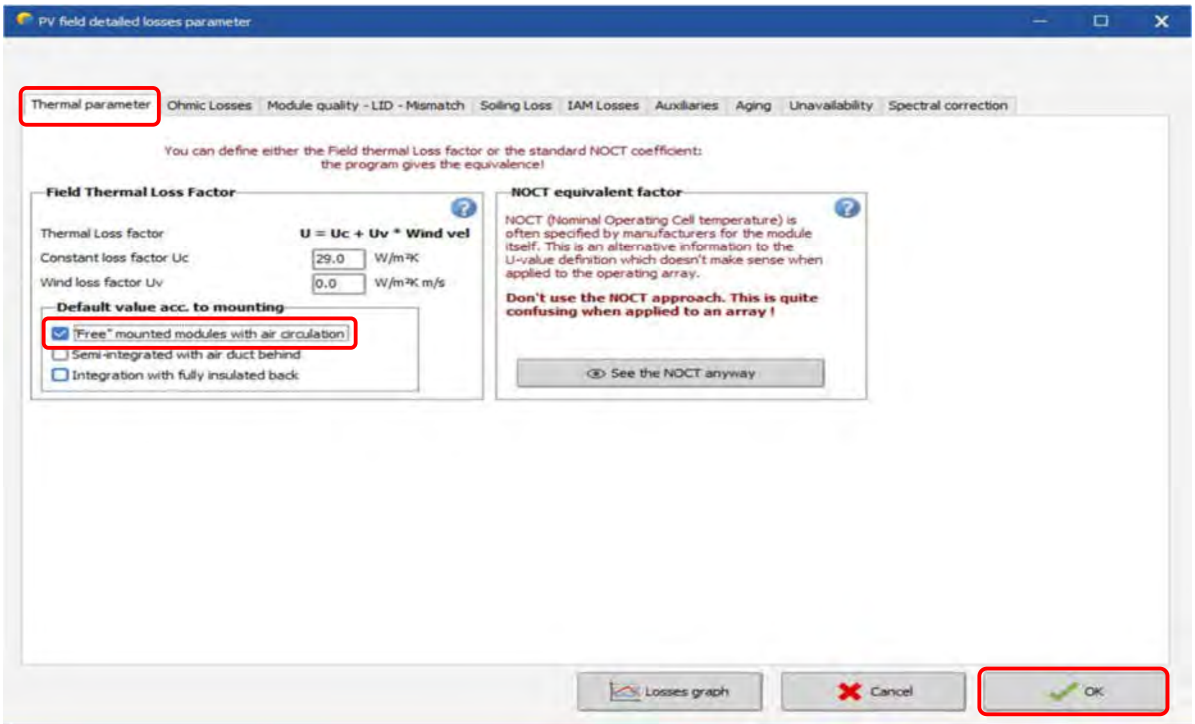


3.5 Detailed Losses

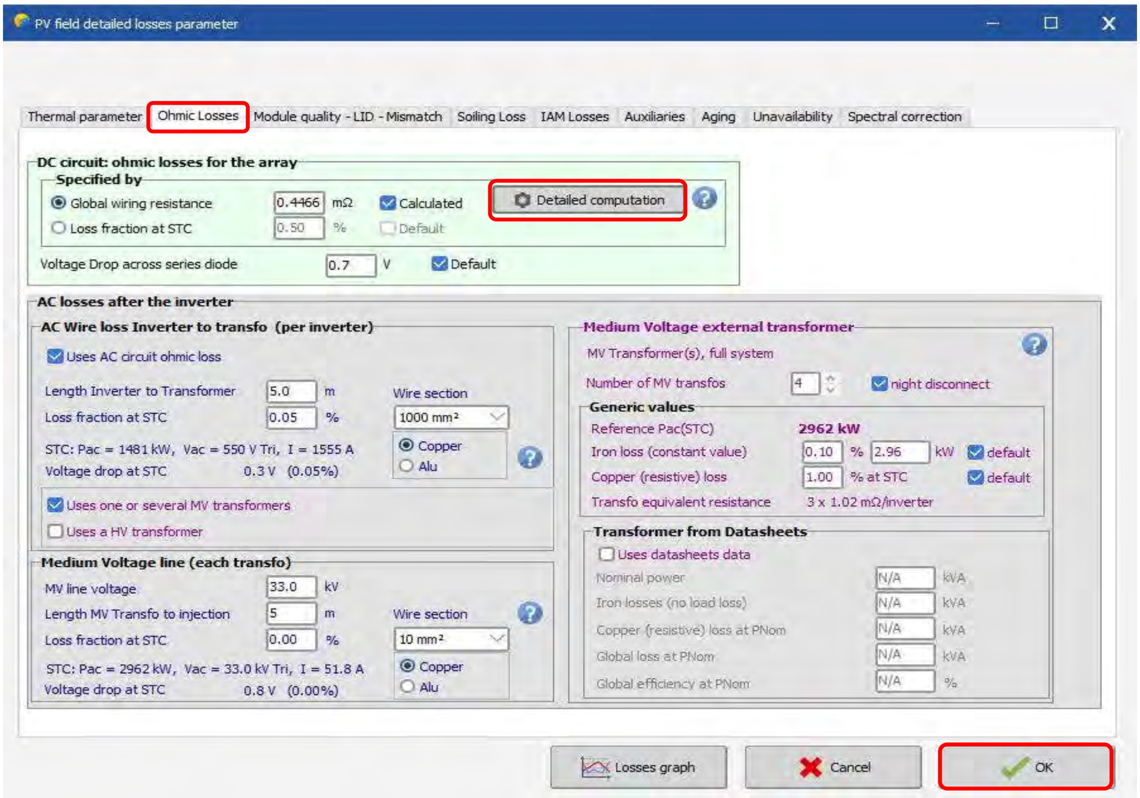
Detail losses includes, thermal parameter, ohmic losses, module quality loss, LID-light induced degradation, mismatch loss of modules & strings, soiling loss, IAM losses, auxiliaries and system unavailability.

Click on "Detailed Losses" option, the detailed losses dialog will open where we have to put required information based on the planned 10MWAC grid tied solar power plant.





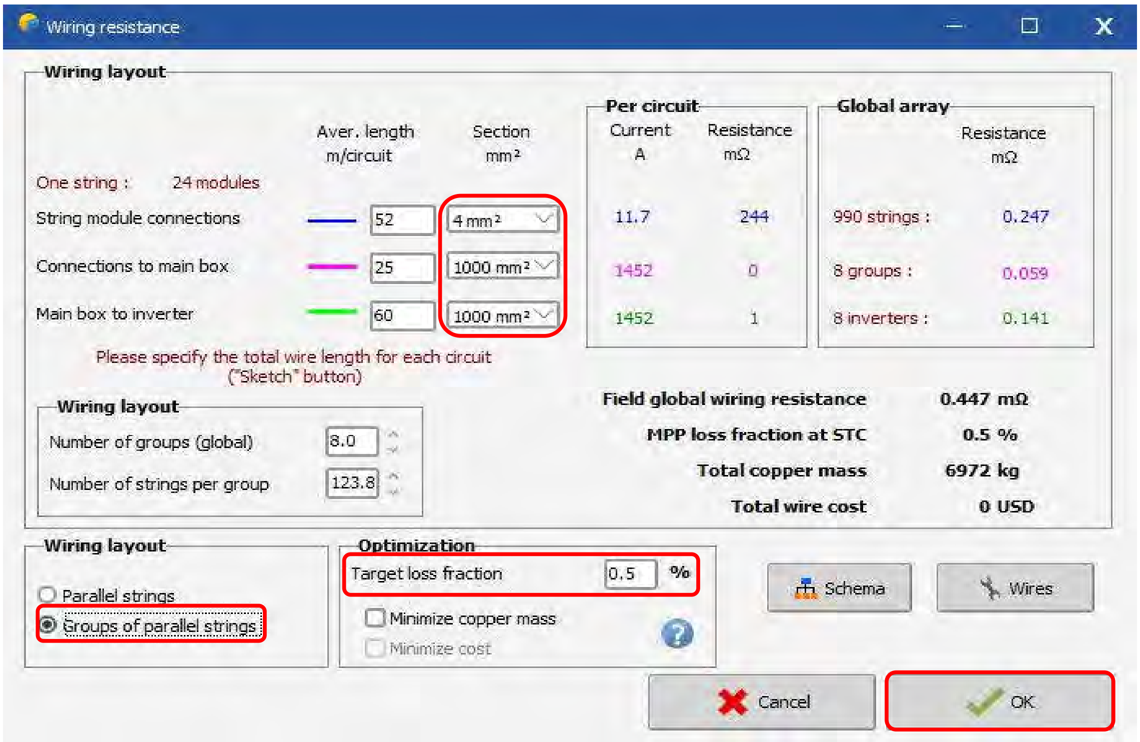
Thermal Parameter: The thermal behavior of the array is computed at each simulation step, by a thermal balance. This establishes the instantaneous operating temperature, to be used by the PV modules modelling. The thermal balance involves the "Heat loss factor" $U = U_c + U_v \times$ wind speed [$W/m^2 \cdot K$]. Our project will install in open space, so select the “Free” mounted modules with air circulation option, thermal loss factor will be generated by default then click OK.



Ohmic Losses: The wiring ohmic resistance induces losses ($I^2 \times R$) between the power available from the modules and that at the terminals of the array. These losses can be characterized by just one parameter R defined for the global array.

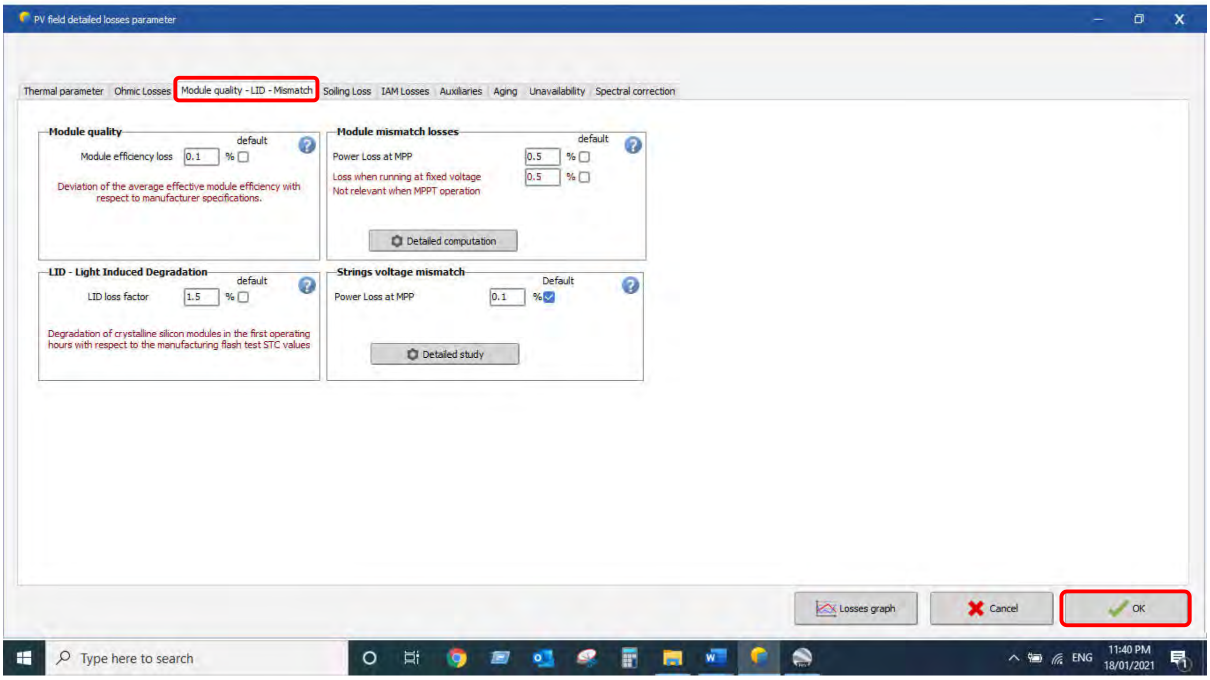
Click “Ohmic Losses” the ohmic losses window will open, here we have to specified DC and AC circuit losses. So, choose global wiring resistance first then select option “Calculated” and click “Detail computation”. After clicking “Detail computation” option new PVsyst window will open.

In PVsyst new window select “Groups of parallel string” then select cable cross section as per system and finally set targeted loss fraction then click OK.

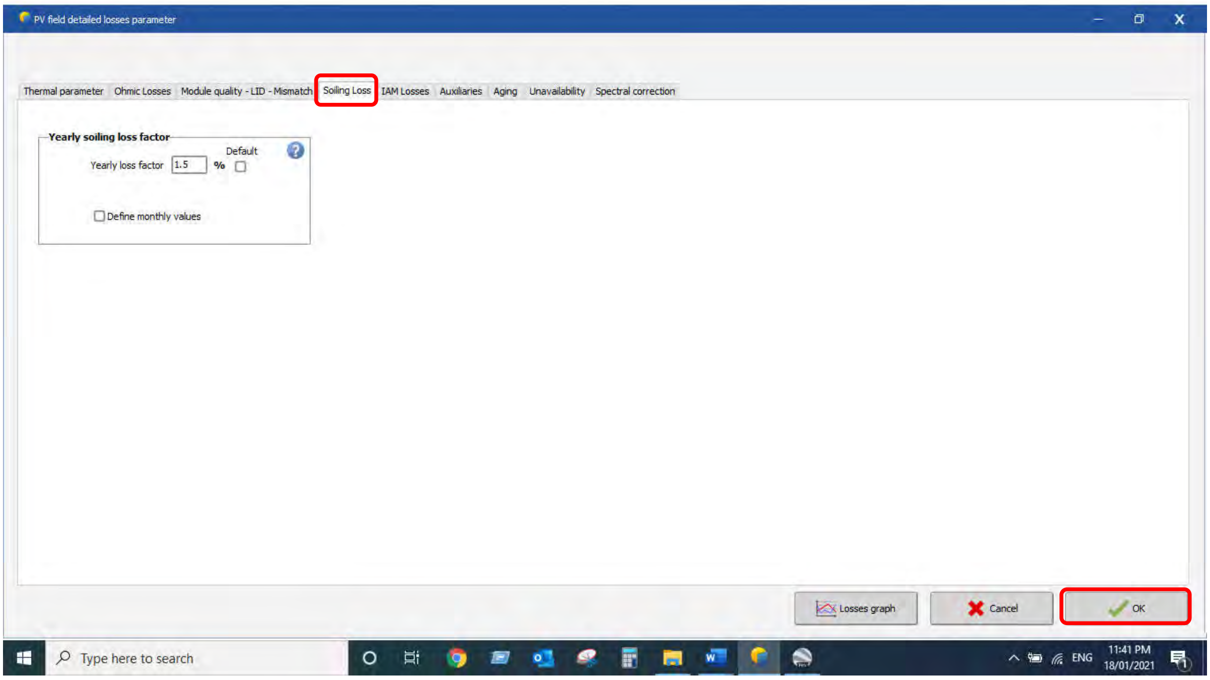


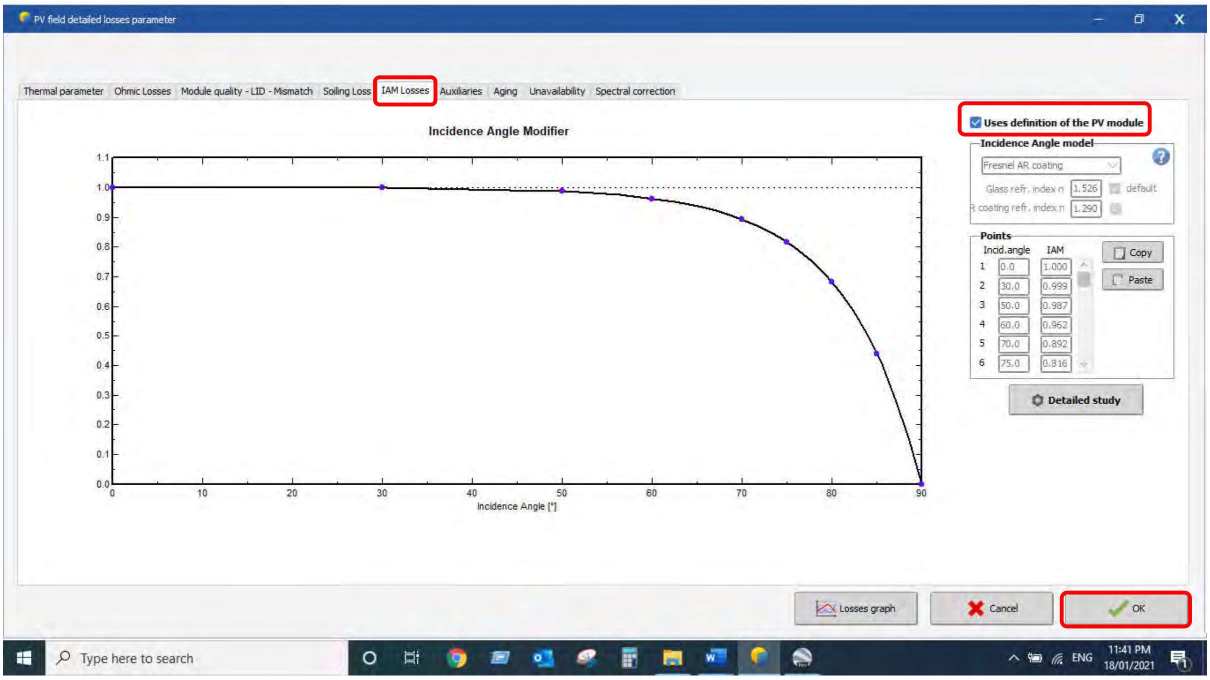
For this selected project considered inverter to transformer length is 5.0 meter and MV transformer to injection is 5.0 meter then click OK.

Click on "Module quality-LID-Mismatch" the Module quality-LID-Mismatch dialog will open where we have to put the required data then click OK.



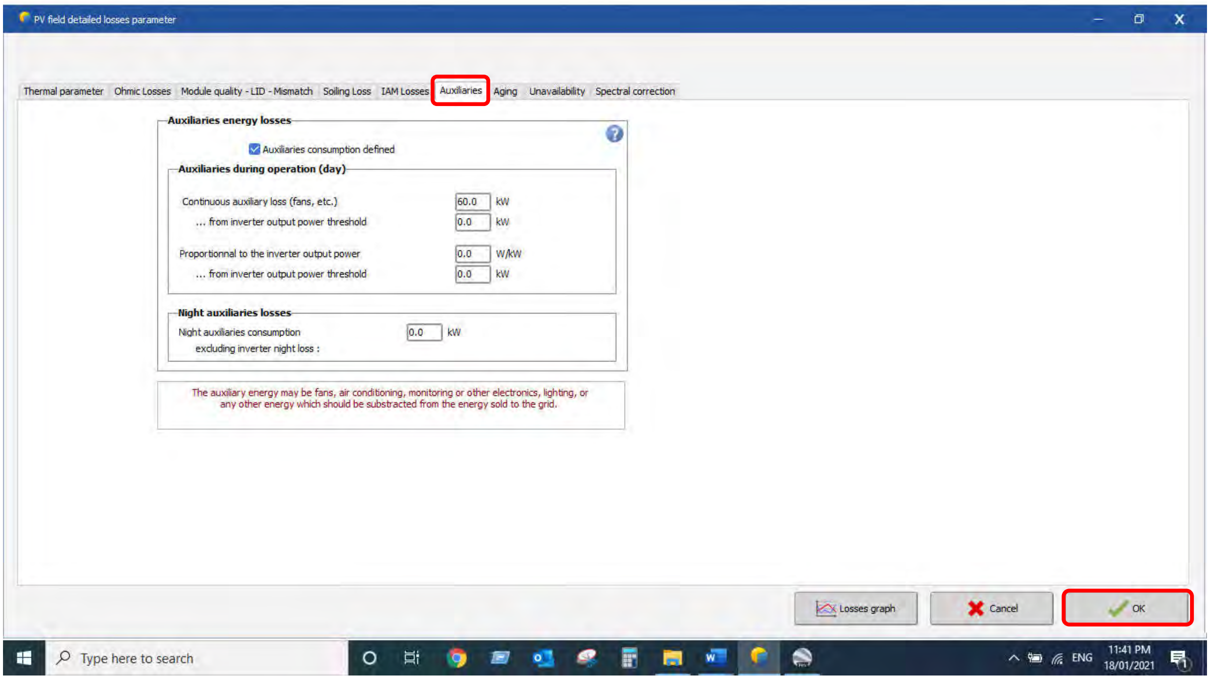
Click on “Soiling Loss” the Soiling Loss dialog will open and put the yearly loss factor 1.5% (estimated) then click OK.

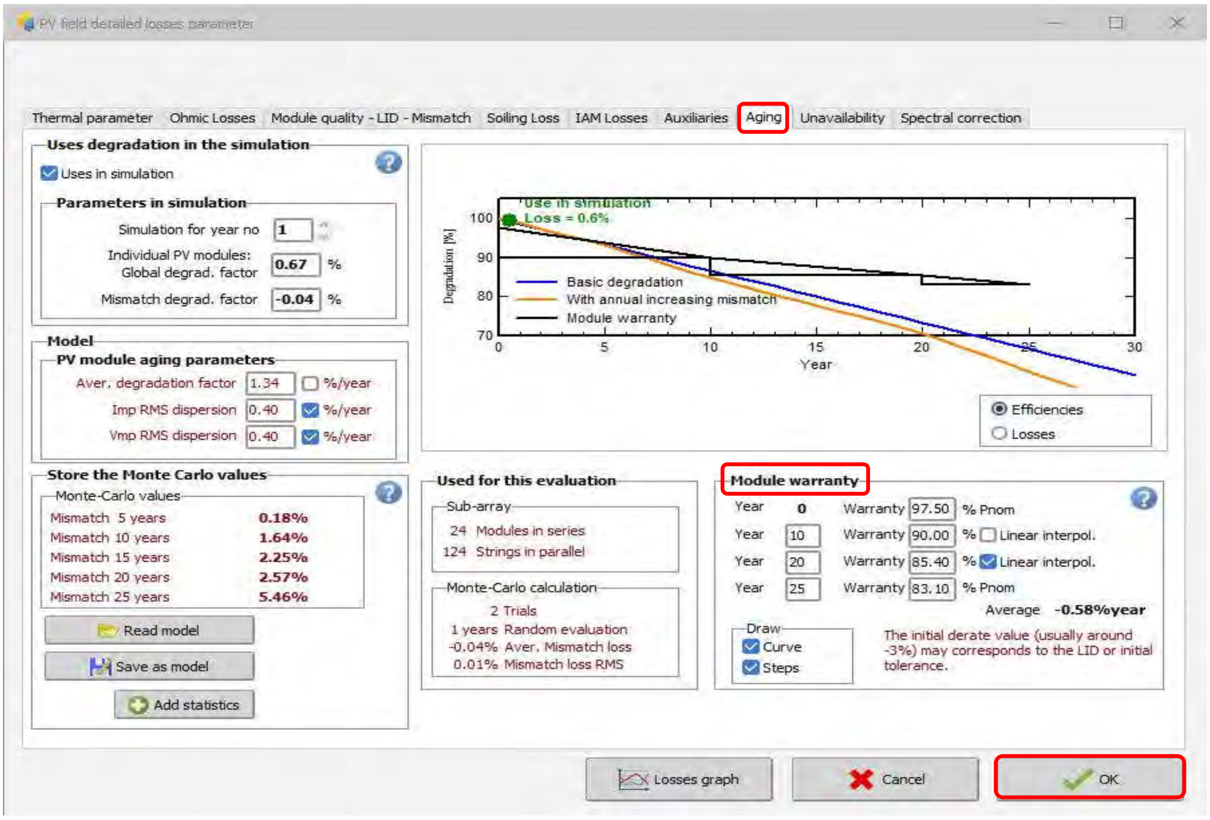




Click IAM losses option and select “Uses definition of the PV module” then click OK.

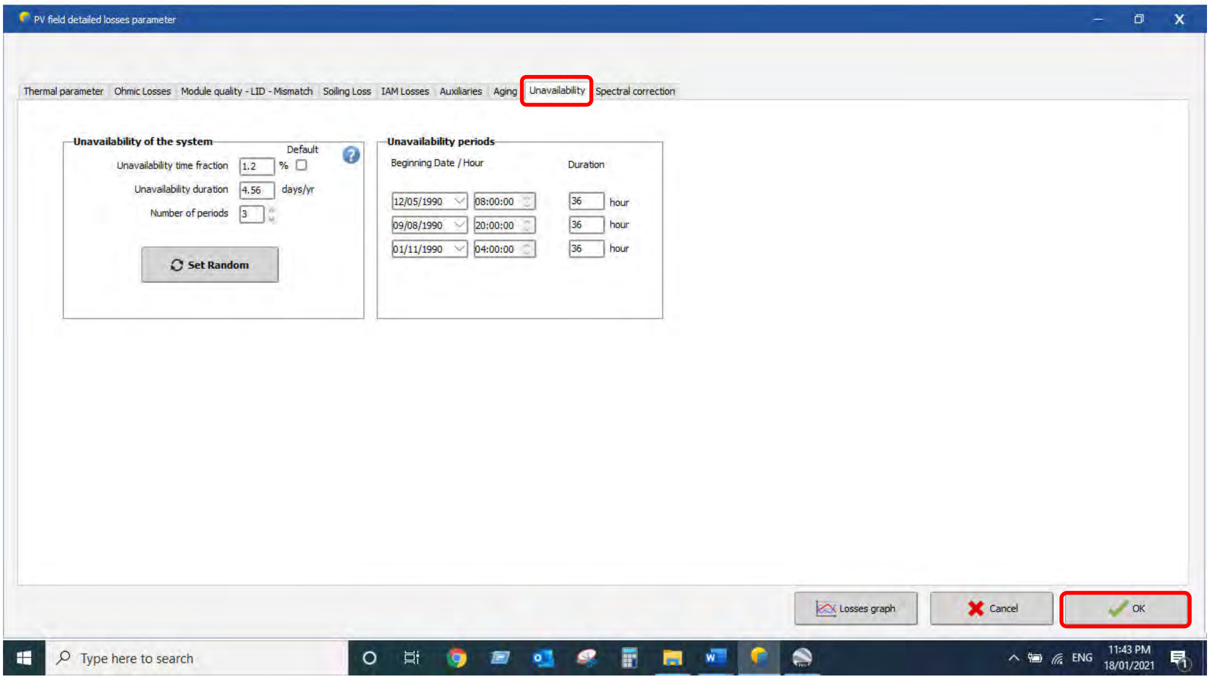
Click on “Auxiliaries” the Auxiliaries dialog will open, based on discussed with expert put continuous auxiliary loss 60 kW/day, then click OK.





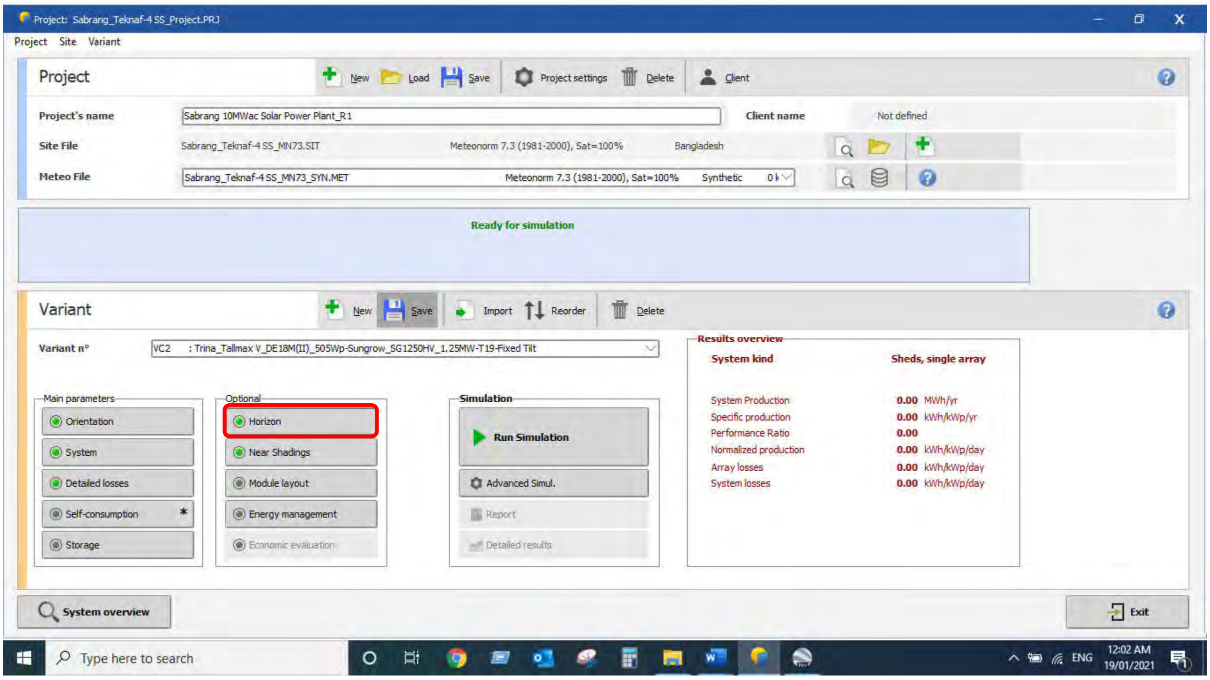
Click on “Aging” the aging dialog will open and put here module warranty information as per PV module specification and click OK.

Click on “Unavailability” the Unavailability dialog will open and put 1.2% (estimated) unavailable time fraction for this project on the basis of real experienced then click OK.

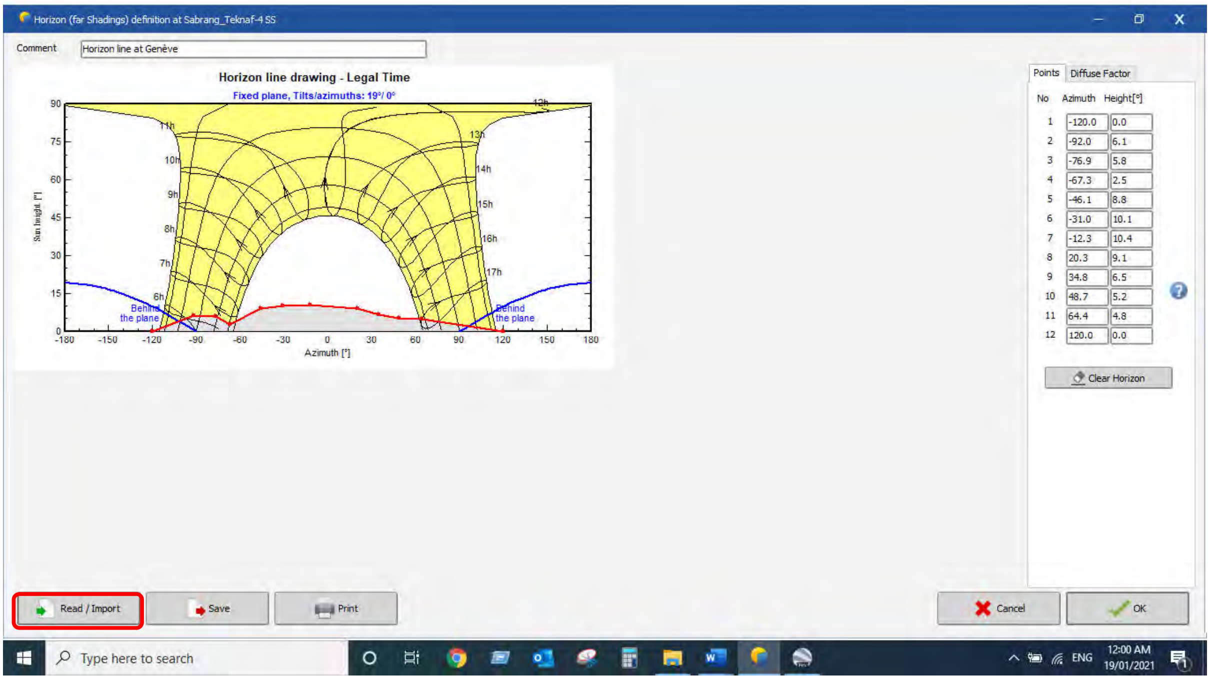


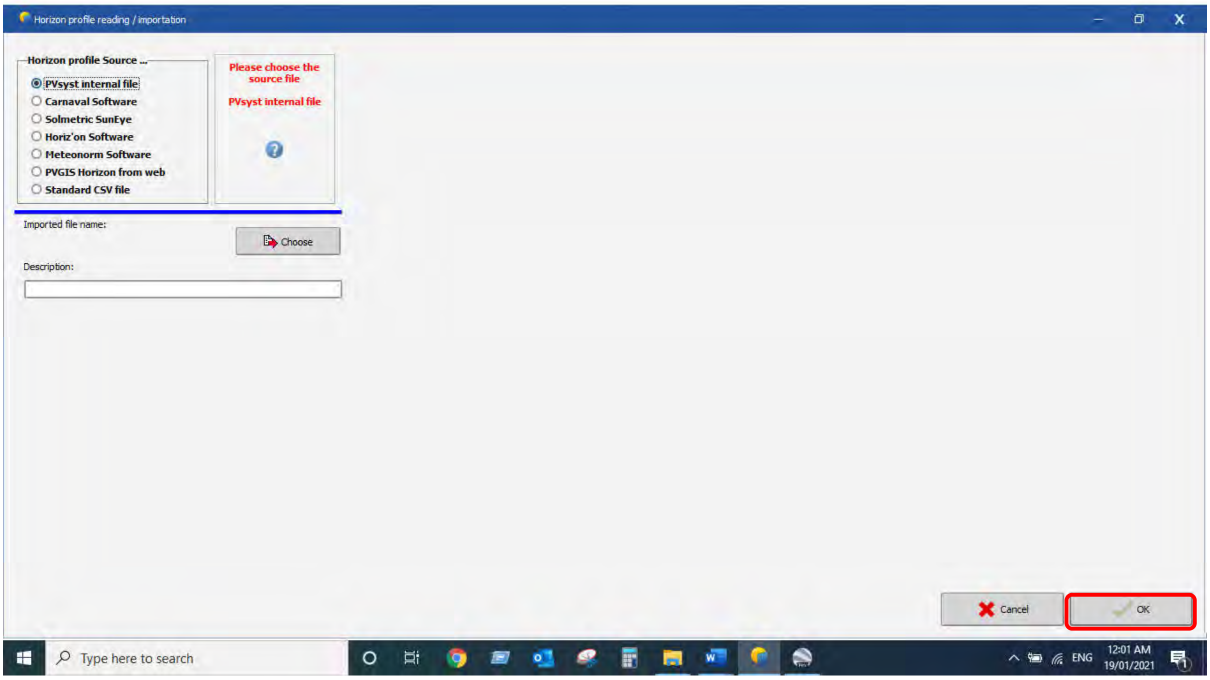
3.6 Horizon

The horizon profile is only suited for shading objects that are located sufficiently far from your PV system, so that the shadings may be considered global on your array. This is the case when the distance to the shading object is more than about 10 times the PV system size. The Horizon Profile is a curve that is defined by a set of (Height, Azimuth) points.



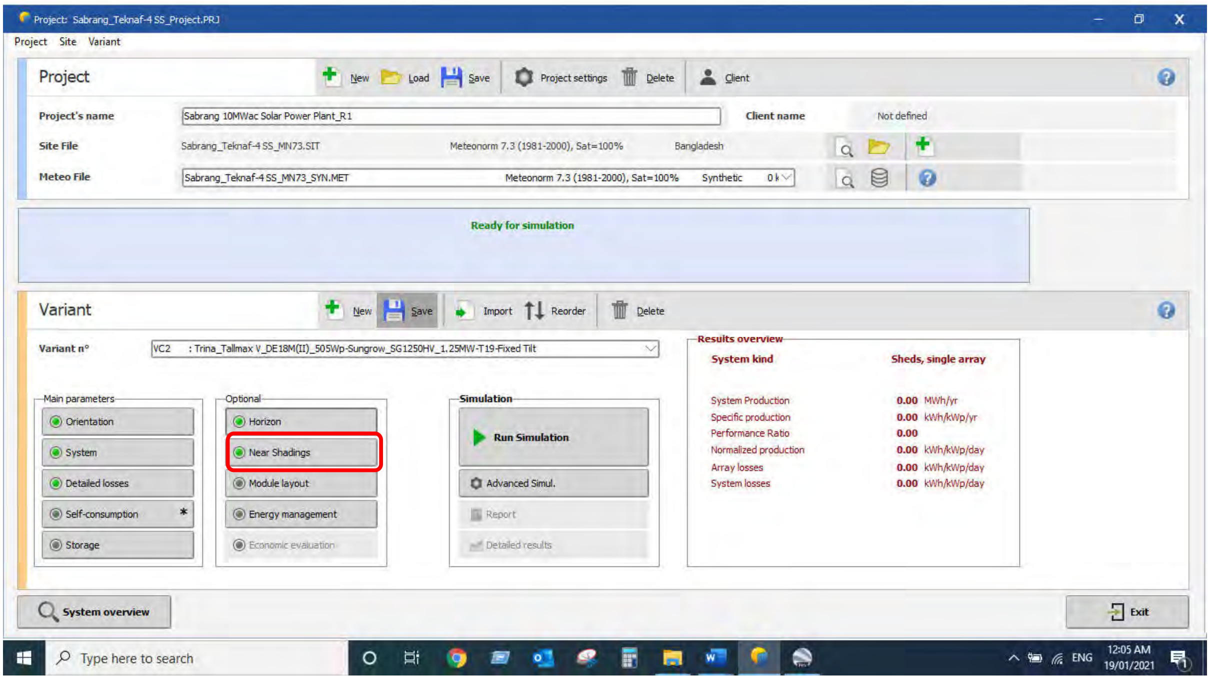
Click on “Horizon” the Horizon dialog will open then click Read/Import button and chose PVsyst internal file then click OK.

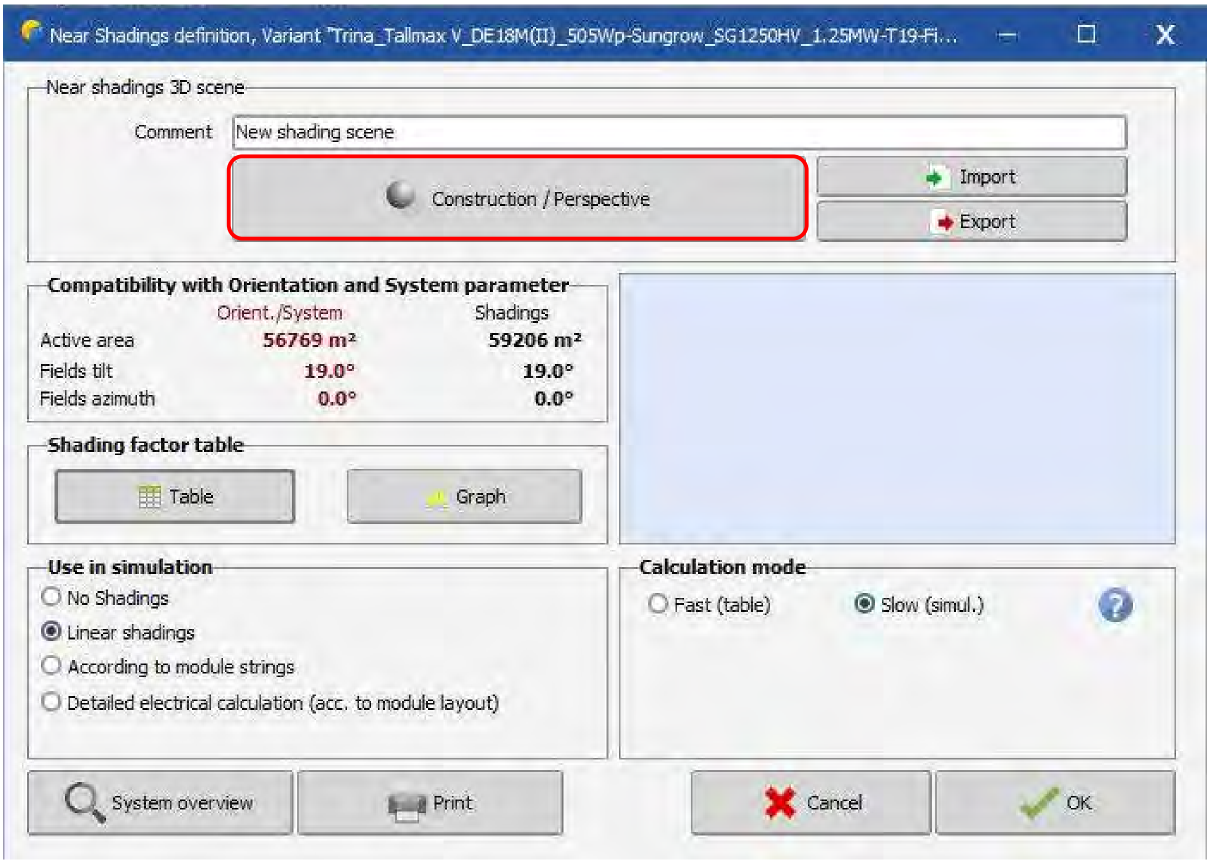




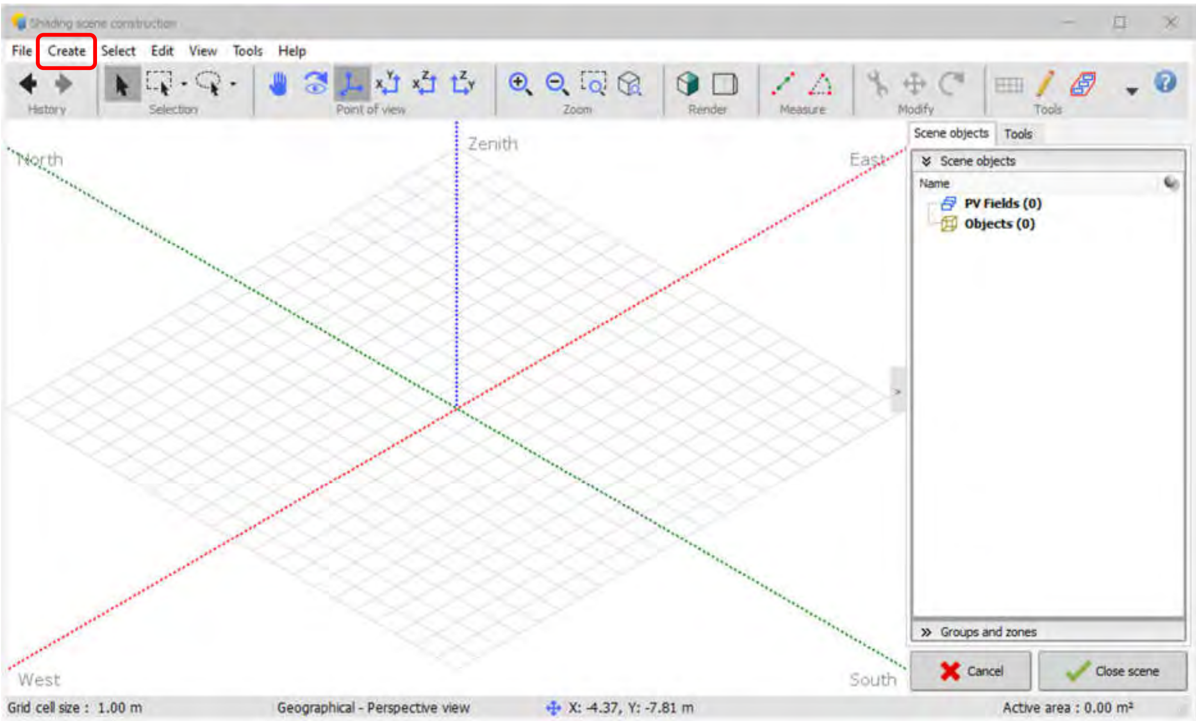
3.7 Near Shading

Near shadings are shadings produced by near objects, which draw visible shades on the PV field.

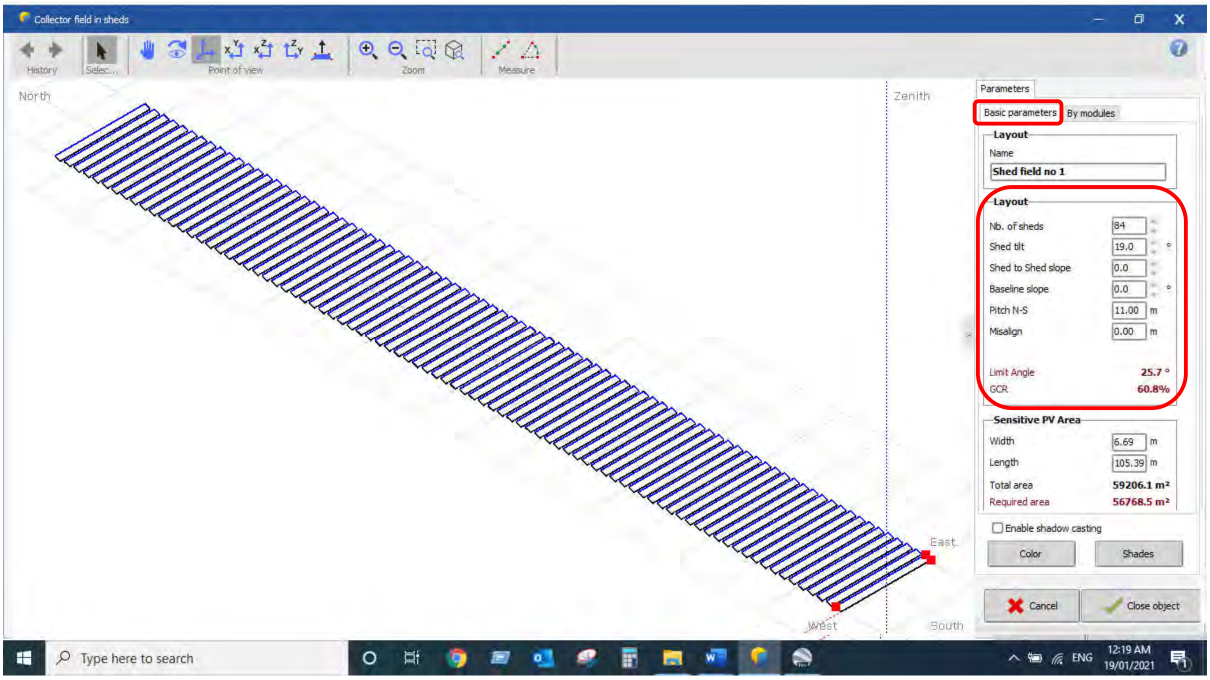




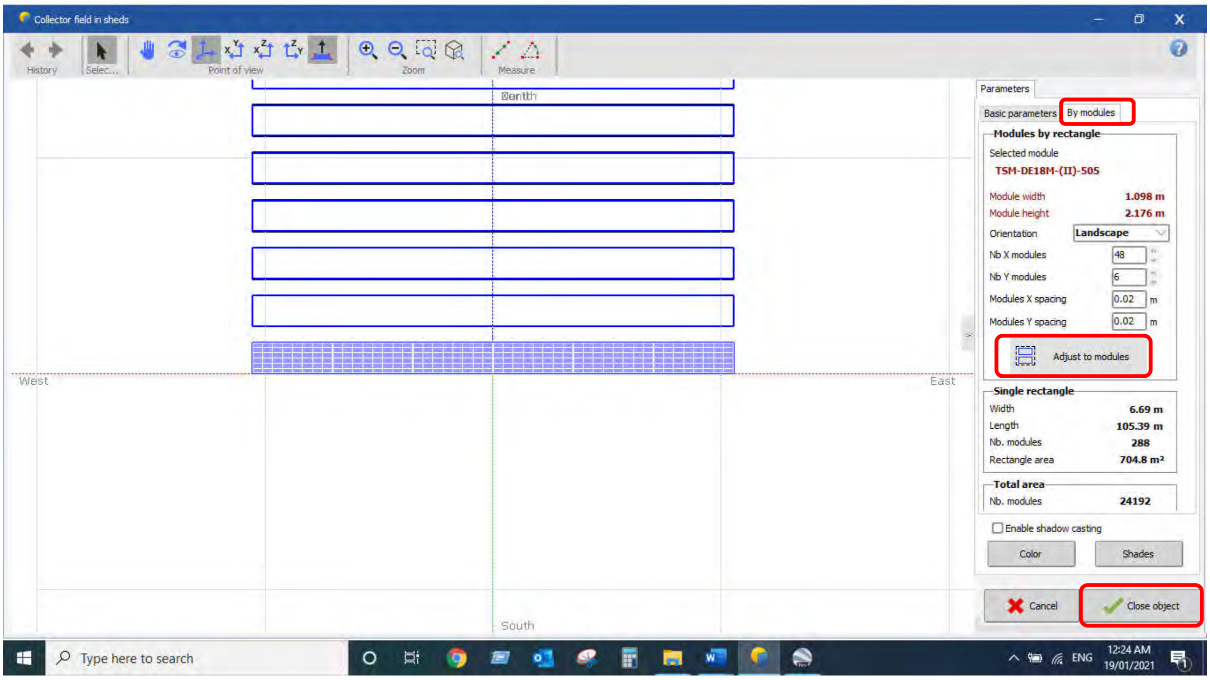
Click on “Near Shading” the Near Shading dialog will open then click construction /prospective option. After clicking “construction /prospective” new window will open.



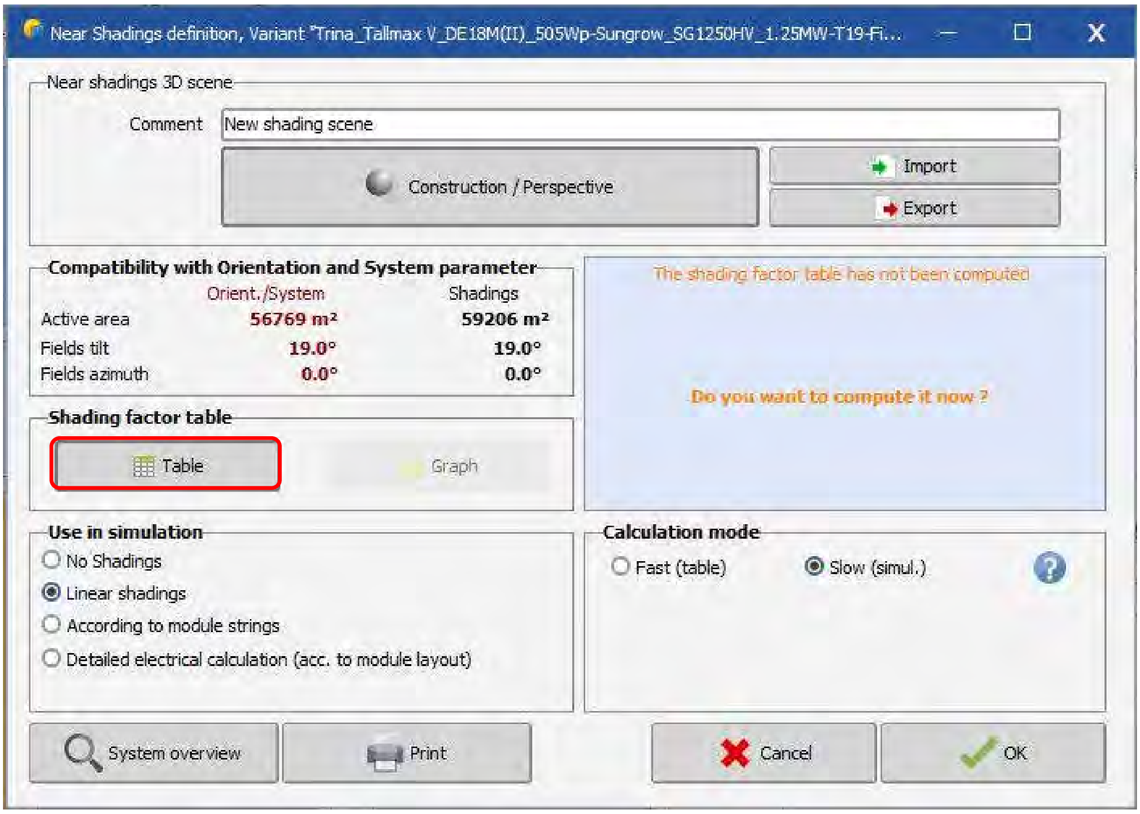
Click create to make a new shed field 1, after create shed field 1 put information based on planned 10MW$_{AC}$ solar park, by selecting basic parameters and by module one by one.



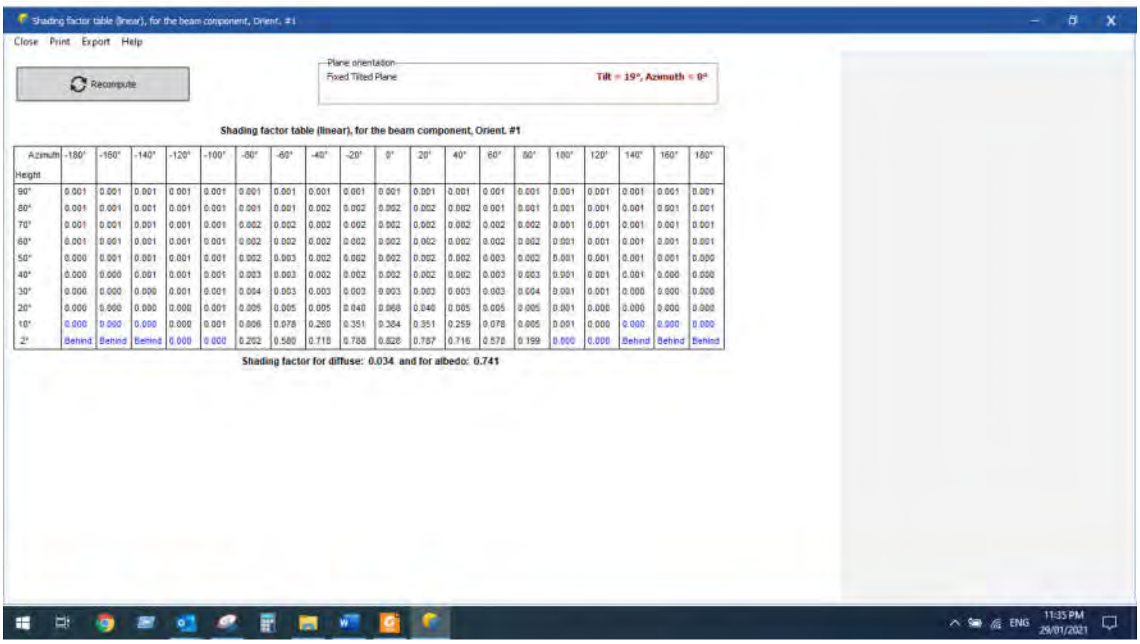
Select By modules and put number of X module, number of Y module, module X spacing, module Y spacing then click “Adjust to module” button and close object



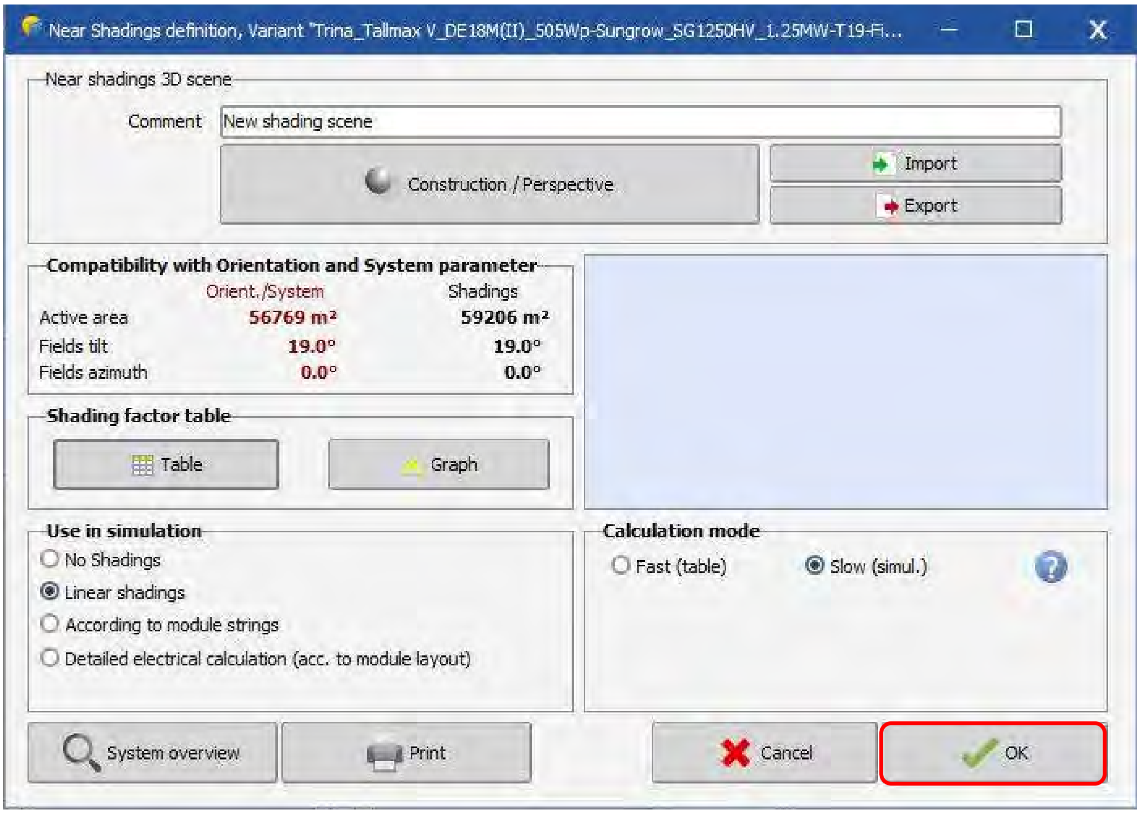
According to below screen message, click the table for computation.



Click on table for computation, PVsyst screen will display below page and close it

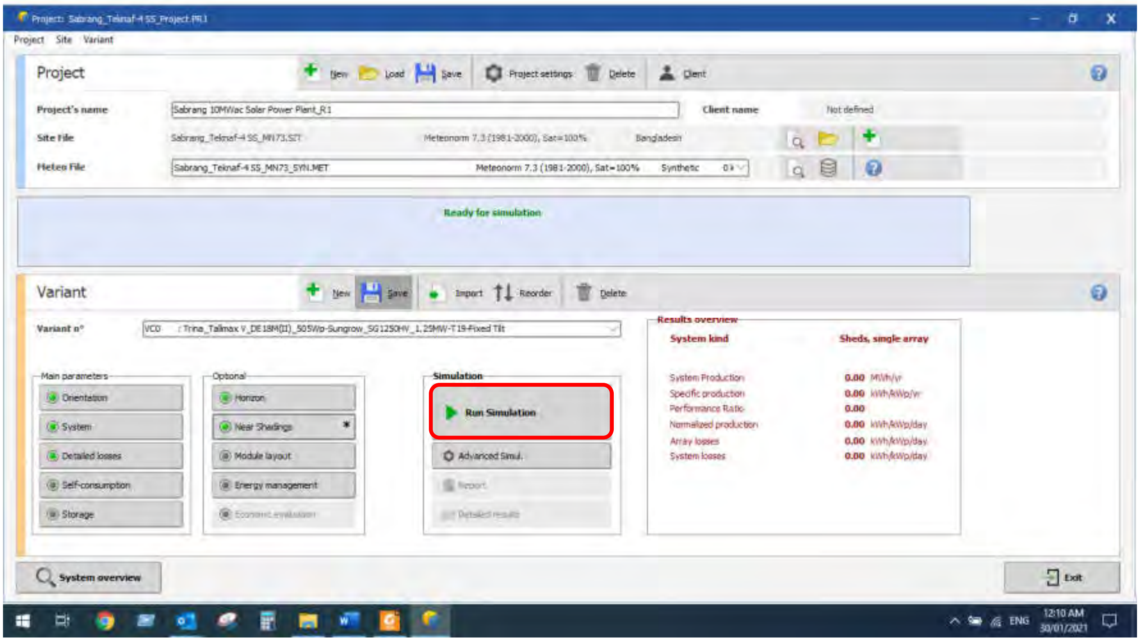


After closing above screen another PVsyst screen will open then click OK.

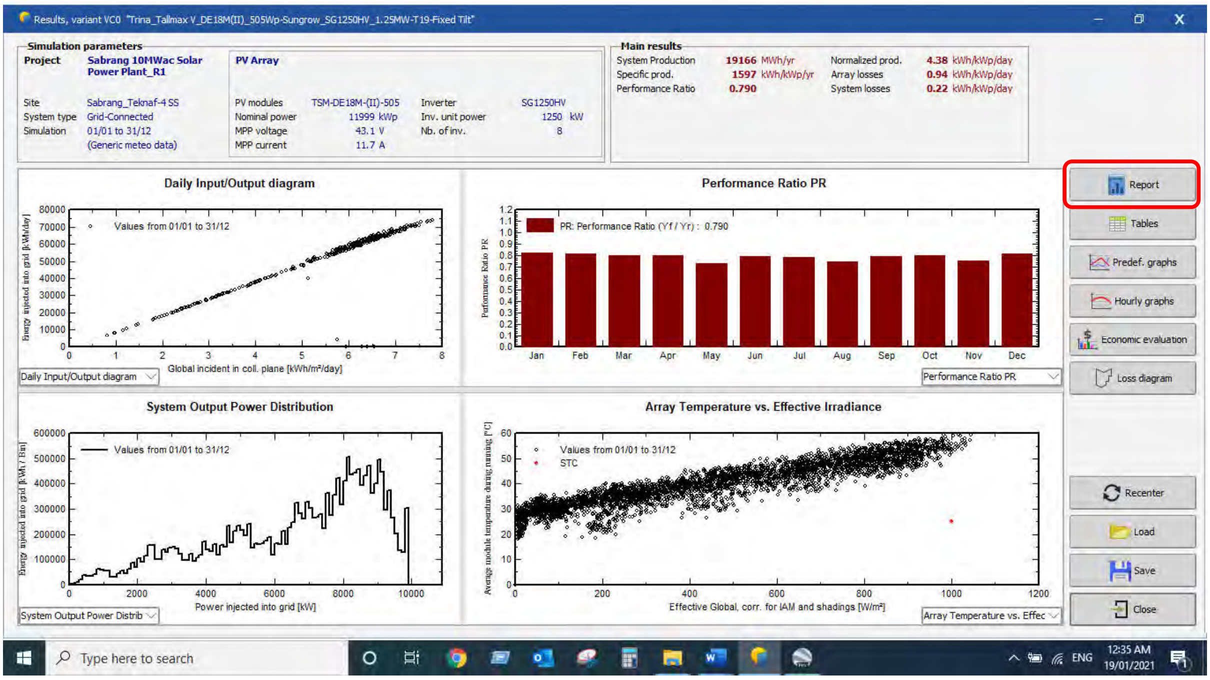


3.8 Run Simulation

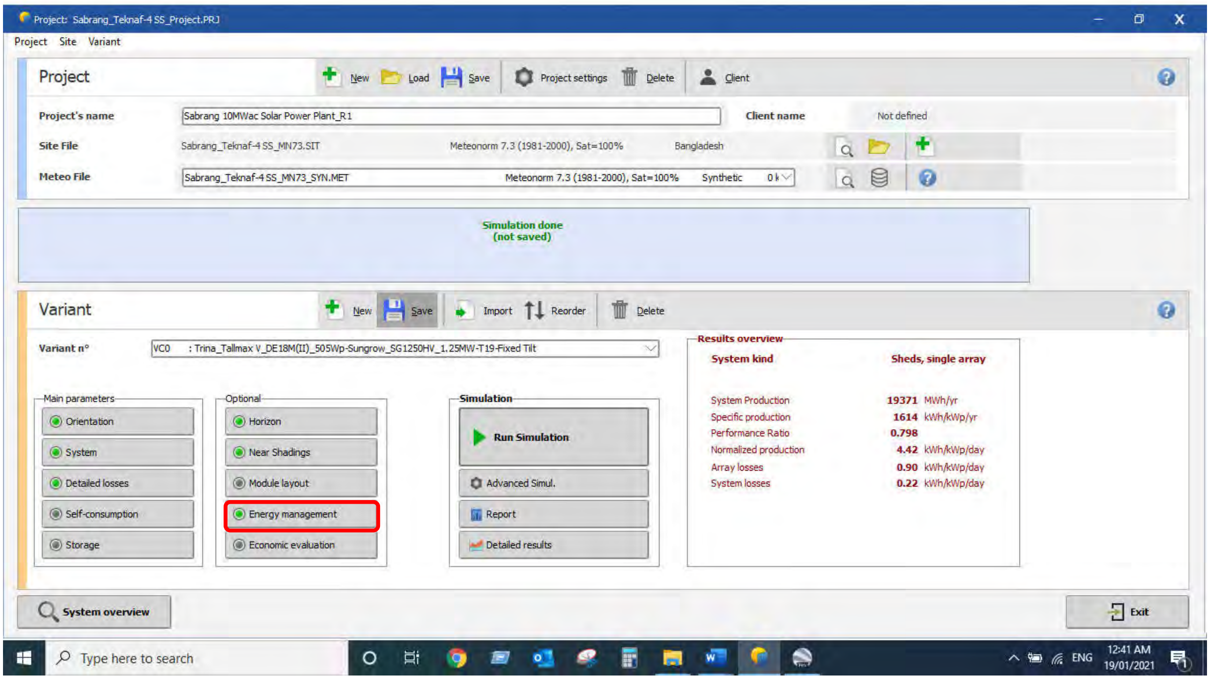
In the below PVsyst screen main parameters orientation, system, detailed losses and optional parameter horizon, near shading are showing green light, that means project is ready for simulation, then click on "Run Simulation" option. Upon completion of the simulation, a report will be available/generated.

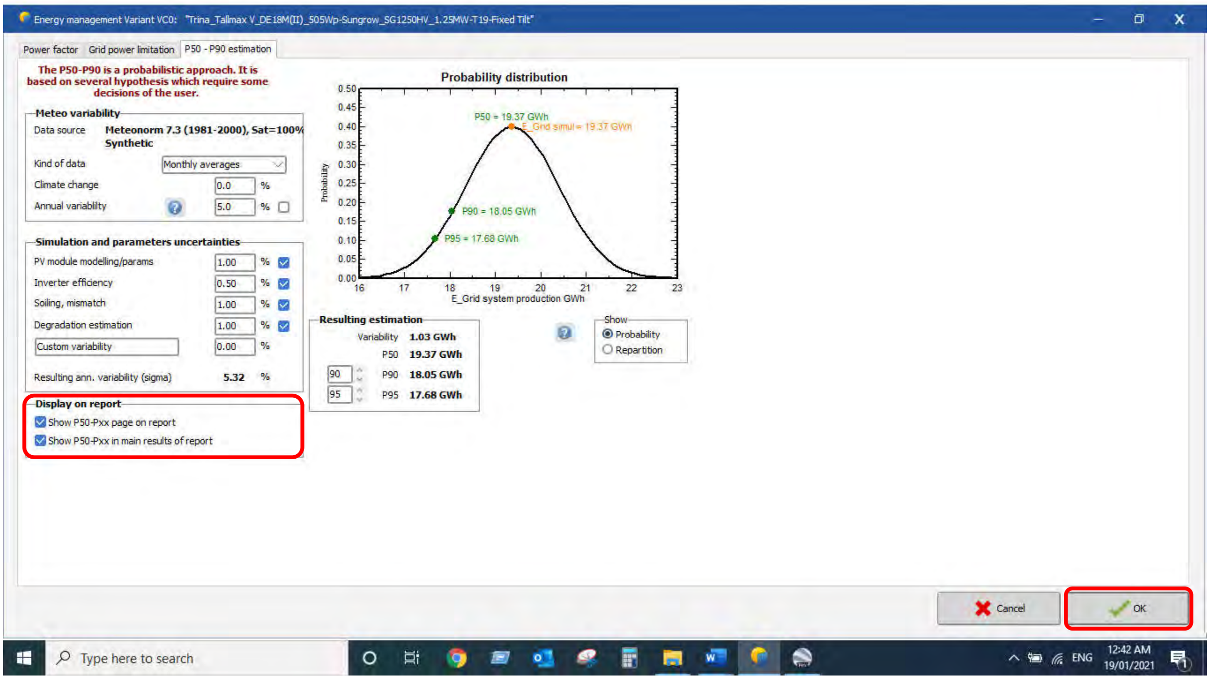


After completed simulation click on “Report” to getting detailed report

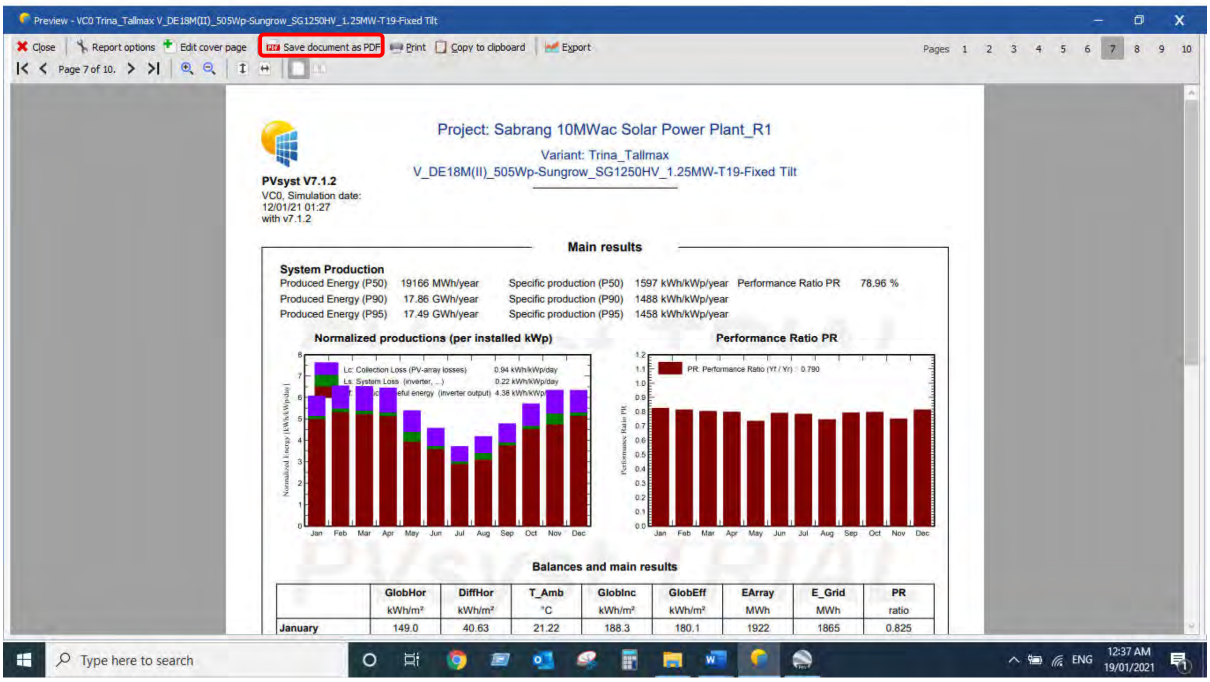


To add P50 & P90 with simulation report click "Energy management" then select P50 and P90 to display on report then click OK.





Finally generated a simulation report, to save the document as pdf, click on "Save document as pdf"



3.9 Simulation Results

The simulation report contains meteorological data and predicted first year generation. Based on the simulation result, necessary calculation has been done to assess the technical feasibility for this selected project, simulation result presented in below table.

Table 3.1 Simulated and calculated data

Particulars	Value
Yearly GHI (kWh/m^2)	1863.00
First Year generation (MWh)	19166.00
Performance Ratio (PR)	78.96%
Capacity Utilization Factor (CUF)	18.23%
Levelized Cost of Energy - LCOE (USD/kWh)	0.049
Produced Energy (P50) Mwh/Year	19166.00
Produced Energy (P90) Gwh/Year	17.86
Produced Energy (P95) Gwh/Year	19166.00
Average Ambient Temperature (^0C)	26.62
Average nominal wind speed (m/s)	2.80
Yearly Precipitation (mm)	2306.62

CHAPTER 4
SOLAR RESOURCES AND ENERGY YIELD ASSESMENT

4.1 Introduction

Solar resources and meteorological data are the most important inputs to calculate yearly energy yield of a solar power plant accurately. This chapter presents the energy yield assessment for the selected site location, Latitude is 20.83° N and Longitude is 92.31° E.

4.2 Solar Resource

The plant generation or energy yield of a solar power plant is directly dependent on the solar resources that are available at the projected area. Solar radiation, often called the solar resource or just sunlight, is a general term for the electromagnetic radiation emitted by the sun. Solar radiation can be captured and turned into useful forms of energy, such as heat and electricity, using a variety of technologies. However, the technical feasibility and economic analysis at a specific location depends on the available solar resource. These parameters are described below.

Global Horizontal Irradiation (GHI) - The global horizontal irradiation (GHI) measures the total amount of light received by a square meter on the ground of horizontal surface. It is the sum of Direct Normal Irradiance (DNI), Diffuse Horizontal Irradiance, and ground-reflected radiation. The units of GHI are given in kWh/m^2. Values are often provided for a period of a day, a month or a year. GHI = Direct Normal Irradiation (DNI) X cos(θ) + Diffuse Horizontal Irradiation (DHI), showed in figure 4.1.

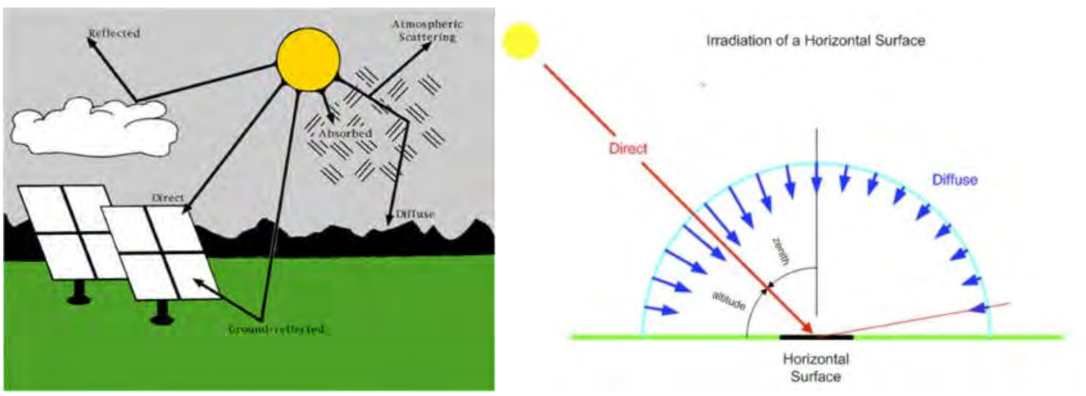


Figure 4.1 Direct and Diffuse Irradiation on the ground

Diffuse Horizontal Irradiation (DHI) - The diffuse horizontal irradiation is the amount of radiation received per unit area by a surface (not subject to any shade or shadow) that does not arrive on a direct path from the sun, but has been scattered by molecules and particles in the atmosphere and comes equally from all directions. It is measured in kWh/m^2 and values are strongly dependent on weather conditions and the clearness of the air.

Direct Normal Irradiation (DNI) - The direct normal irradiation is the amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky. The units of DNI are kWh/m^2.

Global Tilted Irradiation (GTI) -The global tilted irradiation is the total solar energy received on a unit area of a tilted surface. It includes direct and diffuse irradiation along with ground reflected irradiation. The units of GTI are kWh/m2.

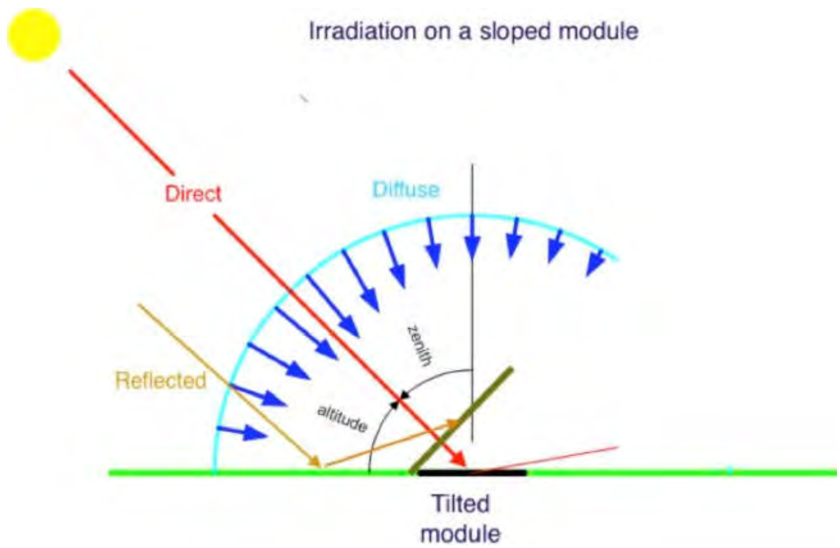


Figure 4.2 Direct and diffuse irradiation on a tilted module

In the northern hemisphere, tilting the modules at an angle towards the south, increases the total annual global irradiation that is received on the module plane compared to the horizontal plane. This is quantified by the global tilted irradiation. The optimal tilt angle varies primarily with latitude and also depends on local weather patterns, ground conditions and plant layout configurations. Tilted modules also benefit from irradiation reflected from the ground which is dependent on the ground reflectance, or albedo.

Albedo - The ground albedo or reflectance affects the irradiation on a plane when it is tilted from horizontal and increases the GTI. The albedo is highly site and weather dependent, with typical grass coverings giving an albedo of approximately 0.2 and fresh snow giving an albedo of approximately 0.8, meaning that 20% and 80% respectively of the irradiation is reflected back into the atmosphere.

4.3 Comparison of resource data

Solar resources and meteorological data are the most important input to calculate yearly energy yield of a solar power plant accurately. Relevant data, global horizontal irradiation, direct normal irradiation and diffuse horizontal irradiation can be sourced from different data source such as METEONORM (version 7.3), NASA's Surface Meteorology and Solar Energy (SSE) satellite data, National Renewable Energy Laboratory (NREL) and PVGIS TMY.

The **METEONORM (version 7.3):** Meteonorm is a unique combination of reliable data sources and sophisticated calculation tools. It provides access to typical years and historical time series. Meteonorm generates accurate and representative typical years for any place on earth. User can choose from more than 30 different weather parameters. The database consists of more than 8000 weather stations, five geostationary satellites and a globally calibrated aerosol climatology. On this basis, sophisticated interpolation models, based on more than 30 years of experience, provide results with high accuracy worldwide.

NASA's Surface Meteorology and Solar Energy (SSE) satellite data; The Surface meteorology and Solar Energy (SSE) data set contains over 200 parameters formulated for assessing and designing renewable energy systems. The SSE data set is formulated from NASA satellite and reanalysis derived insolation and meteorological data for the 22 years period 1983 through 2005. Results are provided for 1 degree latitude by 1 degree longitude grid cells over the globe. The data are suitable for pre-feasibility studies of solar energy projects.

National Renewable Energy Laboratory (NREL) data was developed from NREL's Climatological Solar Radiation (CSR) Model using primary data from geostationary satellites. The satellites provide information on the reflection of the earth-atmosphere system and the surface and atmospheric temperature which is useful in determining cloud cover. Model outputs are verified with ground -based data to ensure quality of the measurements.

PVGIS TMY: PVGIS is a web application that allows the user to get data on solar radiation and photovoltaic (PV) system energy production, at any place in most parts of the world. It is completely free to use, with no restrictions on what the results can be used for, and with no registration necessary. A typical meteorological year (TMY) is a set of meteorological data with data values for every hour in a year for a given geographical location.

The data are selected from hourly data in a longer time period (normally 10 years or more). The TMY is generated in PVGIS following the procedure described in ISO 15927-4. The TMY tool can be used to interactively visualize all the data or to download it as a text file. The solar radiation database used is the default database for the given location, either PVGIS-SARAH, PVGIS-NSRDB or PVGIS-ERA5. The other meteorological variables are obtained from the ERA-Interim reanalysis.

Table 4.1 showed the yearly Global Horizontal Irradiation (GHI) and Figure 4.3 showed monthly Global Horizontal Irradiation (GHI) for the selected site location sabrang, that are sourced from METEONORM (version 7.3), NREL/NSRDB, NASA's Surface Meteorology and Solar Energy (SSE), PVGIS TMY data source.

Table 4.1 Yearly GHI sourced from different data sources

Data Source	GHI (kWh/m2/Year)
METEONORM 7.3	1862.80
NREL	1871.10
NASA-SSE	1749.20
PVGIS TMY	1850.30

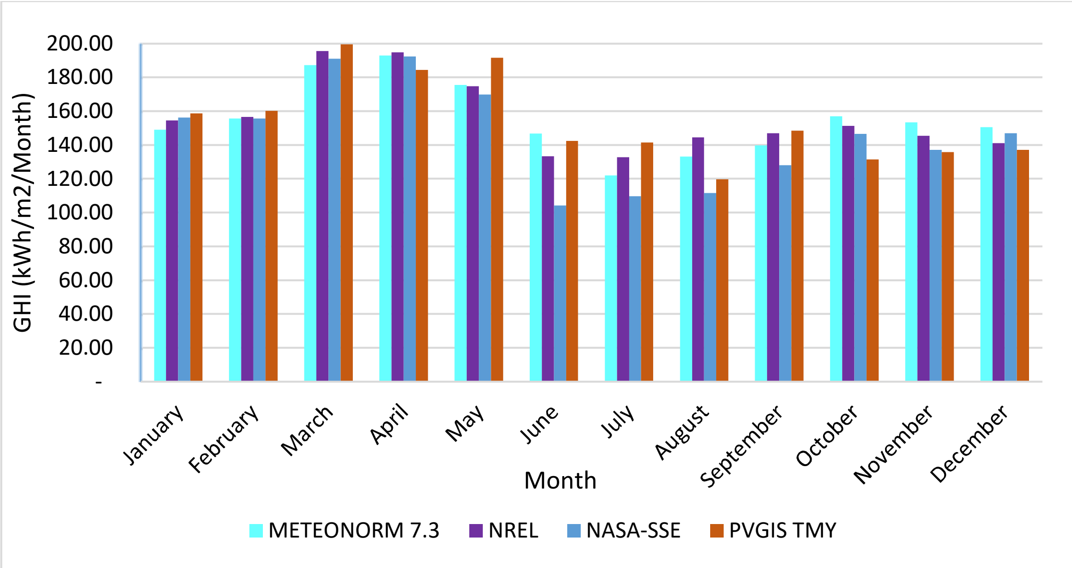


Figure 4.3 Monthly Global Horizontal Irradiation

Based on reliability and accuracy Meteonorm 7.3 dataset has selected for feasibility analysis of $10MW_{AC}$ grid tied solar park at sbrang, Teknaf.

4.4 Global Horizontal Irradiation (GHI) & Diffuse Horizontal Irradiation (DHI)

Monthly Global Horizontal Irradiation (GHI) & Diffuse Horizontal Irradiation (DHI) are presented in Table 4.2 and as per calculation diffuse irradiation observed 43.26% of the total Global Horizontal Irradiation (GHI).

Table 4.2 Global & diffuse irradiation on horizontal plane

Month	Monthly GHI (kWh/m2)	Monthly Diffuse (kWh/m2)	Proportion of DHI to GHI
January	149.00	40.60	27.25%
February	155.70	44.80	28.77%
March	187.30	72.60	38.76%
April	192.80	84.10	43.62%
May	175.50	94.60	53.90%
June	146.80	89.10	60.69%
July	122.00	88.70	72.70%
August	133.20	80.50	60.44%
September	139.70	79.40	56.84%
October	156.90	63.10	40.22%
November	153.30	39.50	25.77%
December	150.60	28.90	19.19%
Total	1862.80	805.90	43.26%

4.5 Global In-plane Irradiation (GII)

PVsyst is a PC software package for the study, sizing and data analysis of complete PV systems. Simulation has been done by the PV modelling software PVsyst (Version 7.1.2) based on the meteorological databases of the selected site. For this analysis tilting angle considered 19° south facing and albedo 0.2. Table 4.3 and figure 4.4 presented the monthly GII profile.

Table 4.3 Monthly Global In-plane Irradiation (GII) data

Month	Monthly GII (kWh/m2)
January	188.30
February	183.40
March	202.20
April	193.40
May	167.00
June	137.10
July	115.20
August	129.70
September	143.20
October	176.90
November	190.10
December	196.40
Yearly Total	2022.90

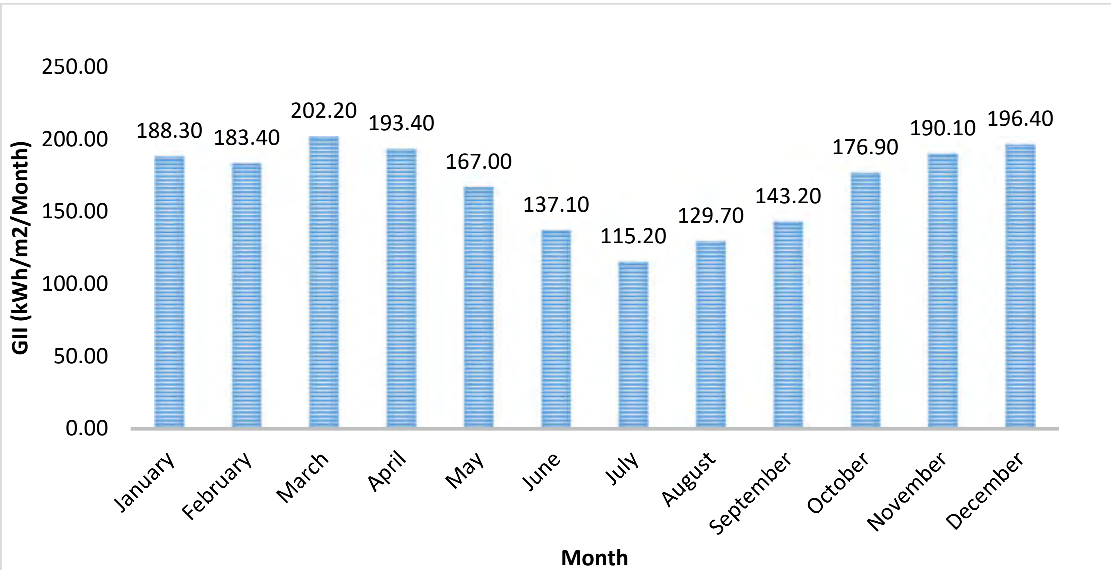


Figure 4.4 Monthly Global In-plane Irradiation (GII)

4.6 Climate

Climate is the average weather in a given area over a longer period of time. A description of a climate includes information on, such as the average temperature in different seasons, rainfall, wind speed, pressure and sunshine. Most of the variables of climate is closely related to solar power generation.

Wind: The records of last 50 years showed that the Teknaf Upazila faced peak wind speed up to 278 km/h (173 mph) or 77 m/s, that was produced by a cyclone occurred on April 29, 1991. However nominal wind speed of the selected site has found by the simulation with PVsyst V7.1.2, presented in Table 4.4.

Table 4.4 Wind speed at ground level

Month	Average Wind Speed at Ground Level (m/s) Meteonorm 7.3 data
January	2.00
February	2.30
March	2.70
April	3.40
May	3.20
June	3.70
July	4.00
August	3.70
September	2.80
October	2.10
November	1.80
December	1.70
Yearly Average	**2.80**

Temperature: Monthly average temperature data has sourced from the PVsyst V7.1.2 database that are presented in Table 4.5. As per data sheet of selected PV module and inverter, the operating temperature range for PV modules and inverter is -40∘C to +85∘ C and -30∘C to +65∘C.

Table 4.5 PVsyst V7.1.2 Temperature Data

Months	**Monthly Average Ambient Temperature (°C)**
January	21.30
February	23.70
March	26.60
April	28.20
May	29.00
June	28.10
July	28.10
August	28.30
September	28.00
October	28.30
November	25.60
December	22.90
Yearly Average	**26.51**

According to temperature data for the selected site, the PV modules and inverter both are suitable to operate normally.

Precipitation: Precipitation data has sourced from different website for Teknaf region, illustrated in figure 4.5.

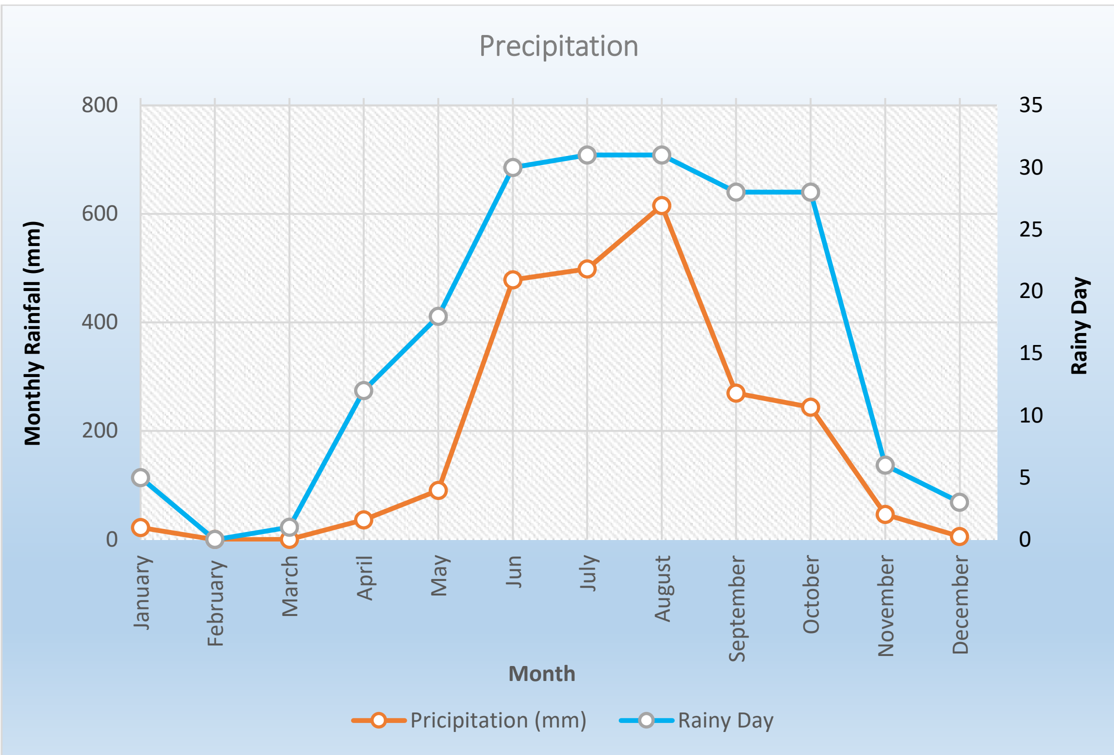


Figure 4.5 Monthly precipitation

According to precipitation data, selected site is the moderate rainfall region, that will be added advantages for reduce soiling effect. From the graph PV module has to clean only six month (November to April) and rest of time PV module will be cleaned naturally by rainfall.

Soiling has a negative impact on the economic revenues of PV installations, not only it reduces the amount of energy converted by the PV modules, but also it introduces additional operating and maintenance costs at the same time. Soiling consists of mineral dust, soot particles, aerosols, pollen, fungi and/or other contaminants that deposit on the surface of PV modules. Soiling absorbs, scatters, and reflects a fraction of the incoming sunlight, reducing the intensity that reaches the active part of the solar cell, due to soiling 1.5% loss factor considered for this project.

4.7 Losses

Losses includes far shadings/horizon, near Shadings, IAM factor on global/incident angle, soiling loss, module degradation loss, PV loss due to irradiance Level, PV loss due to Temperature, module quality loss, LID-Light Induced Degradation, mismatch loss of modules & strings, DC Ohmic Loss, inverter loss during operation (Efficiency), inverter loss over nominal inverter Power, auxiliary consumption, AC ohmic loss, medium voltage transformer loss, system unavailability, showed in figure 4.2.

Far shadings: shading to sun rays from surrounding obstacles such as trees, building, structures, hills or mountains is often referred to as ‘far shading’. The shaded area can be calculated from astronomical solar data. The diagram below shows for a sample the shading length from trees on a particular site.

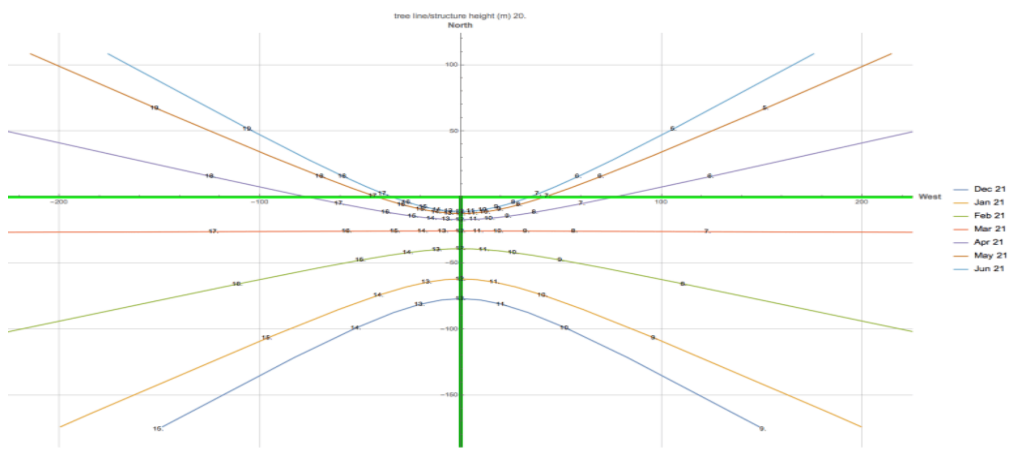


Figure 4.6 Far shading

Far shading may significantly reduce the PV system efficiency and must be avoided as much as possible. Shading from adjacent modules is often referred to as 'inter-shading' Shading on PV modules can significantly reduce the energy harvest and need to be minimized.

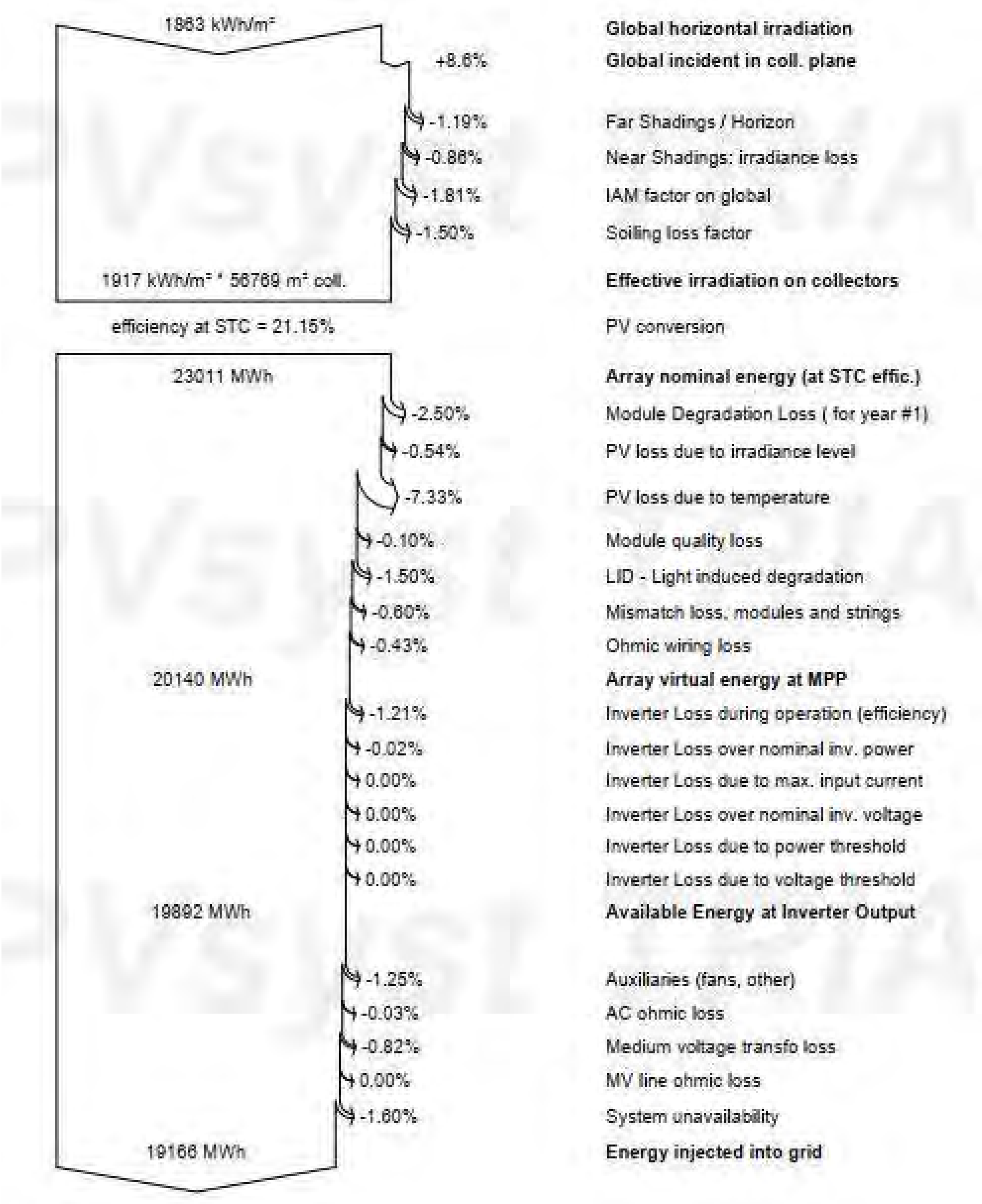


Figure 4.7 Loss diagram

Near shading: Near shadings are shadings produced by near objects, which draw visible shades on the PV field. We call Shading Factor the ratio of the shaded area, with respect to the total sensitive area of the field. The treatment of near shadings is much more complex than far shadings, it cannot be done without a detailed 3D description of the full PV system and its environment.

The incidence effect (IAM, for “Incidence Angle Modifier”) corresponds to the decrease of the irradiance really reaching the PV cells surface, with respect to irradiance under normal incidence, due to reflections increasing with the incidence angle. Soiling loss is accumulation of dirt and its effect on the system performance is an uncertainty, which strongly depends on the environment of the system, rain conditions.

PV loss due to irradiance level: PV cells have a lower efficiency at low irradiance level. The irradiance loss with respect to 1000 W/m² may vary for different PV modules brands and manufacturers.

PV loss due to temperature: The electrical resistance of a conductor increases with its temperature. Photovoltaic cells as semi-conductors follow that rule. For the selected PV module, the power temperature coefficient is -0.36%/°C. The efficiency decreases when the ambient temperature increases. Hourly ambient temperature taking into account for simulation, overall efficiency loss in the projected area due to temperature is 7.33%.

The real behavior of modules, with respect to the specifications, is one of the greater uncertainties in the PV system performance evaluation. For this reason, module quality loss considered 0.10%.

Mismatch loss: The mismatch performance derating is mainly due to the fact that in a string of modules (or cells), the lowest current drives the current of the whole string.

Ohmic loss: The ohmic wiring resistance induces losses both in DC (between the modules and the inverter) and AC (between the inverter and the step-up transformer).

Inverter loss (efficiency): Inverters transform the DC current produced by the modules into AC current used by the grid. The efficiency of the selected inverter 98.79% (i.e.1.21% loss).

Medium voltage transformer loss: The main losses associated with the transformer are iron losses (mostly due to hysteresis and eddy currents in the core) and copper losses in either the primary and in the secondary windings (coils that draw energy in one side and deliver it in its transformed state back out the other side)

4.8 Annual Energy Yield

Annual energy yields estimation has been done based on 505Wp Monocrystalline PV module, 1.25MW sungrow string inverter, considering plant tilting angle 19º fixed tilt system. Planned DC installed capacity is 12MWp and energy will be injected into grid is $10MW_{AC}$, so DC to AC ratio is 1.2 for the projected. Some data such as site potentials, losses profile and 1st year performance ratio that are taken from PVsyst simulation report. site potentials are presented in Table 4.7.

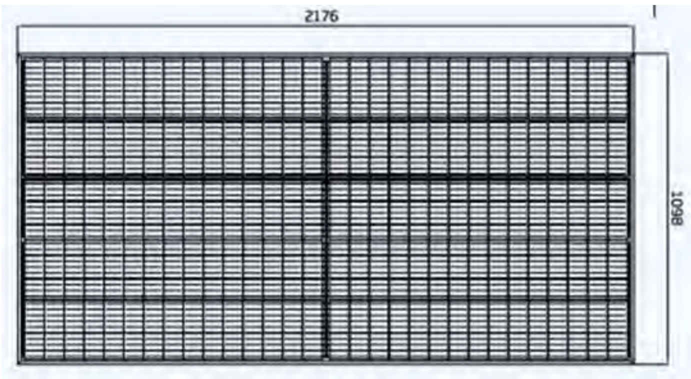
Table 4.6 Site Potentials

Month	GHI (kWh/m2/day)	Total Available Days	Total GHI (kWh/m2/Month)	Total GII (kWh/m2/Month)	Ambient Temperature (°C)
January	4.81	31.00	149.00	188.30	21.30
February	5.56	28.00	155.70	183.40	23.70
March	6.04	31.00	187.30	202.20	26.60
April	6.43	30.00	192.80	193.40	28.20
May	5.66	31.00	175.50	167.00	29.00
June	4.89	30.00	146.80	137.10	28.10
July	3.94	31.00	122.00	115.20	28.10
August	4.30	31.00	133.20	129.70	28.30
September	4.66	30.00	139.70	143.20	28.00
October	5.06	31.00	156.90	176.90	28.30
November	5.11	30.00	153.30	190.10	25.60
December	4.86	31.00	150.60	196.40	22.90
Yearly Total	61.31	365.00	1862.80	2022.90	318.10
AVG	5.11	30.42	155.23	168.58	26.51

Dimension of PV Module (L×W)

$= 2.176 \times 1.098 \text{ m}^2$

$= 2.389248 \approx 2.39 \text{ m}^2$



Total Collector Plane Area = Number of PV Module × Module Dimension (m^2)

$= 23{,}800 \times 2.389248 \text{ m}^2$

$= 56{,}864.10 \text{ m}^2$ Showed in table 4.7

Table 4.7 PV Module dimension & Total Collector plane area

PV Panel	
As per data sheet Area/Per PV Module (m2)	2.389248
Number of PV Module to be used	23,800.00
Total Collector Plane Area (m2)	56,864.10

Global In-plane Irradiation-GII (kWh/m2/Year) = 2,022.90 (According to simulation report)

Total Collector Plane Area = 56,864.10 m^2

Solar Resource can Produce Energy = GII × Total Collector Plane Area

= 2,022.90 × 56,864.10 kWh/Year

= 115,030,392.74 kWh/Year

PV Module efficiency = 21.10% (According to data sheet)

Solar Energy conversion into Electrical Energy = 115,030,392.74 × 21.10%

= 24,271,412.87 kWh/Year

First Year Performance Ratio (PR) = 78.96% (According to simulation report)

Total Energy Injected into Grid = 24,271,412.87 × Performance Ratio

= 24,271,412.87 × 78.96% kWh/Year

= 19,164,707.60 kWh/Year

Energy Yield Calculation	
Global In-plane Irradiation-GII (kWh/m2/Year)	2,022.90
PV Conversion	21.10%
Total Energy Yield (kWh/m2/Year)	24,271,412.87
Total Loss Factor	21.04%
1st Year Performance Ratio (PR)	78.96%
Total Energy Injected into Grid (kWh/Year)	19,164,707.60

Degradation is the gradual deterioration of the characteristics of photovoltaic module which may affects ability to operate within the limits of acceptability criteria and which is caused by the operating conditions. As per photovoltaic module data sheet, first year degradation of selected module is 2.5% and 0.6% average annual power decline considered for remaining 24 years. Showed in figure 4.8

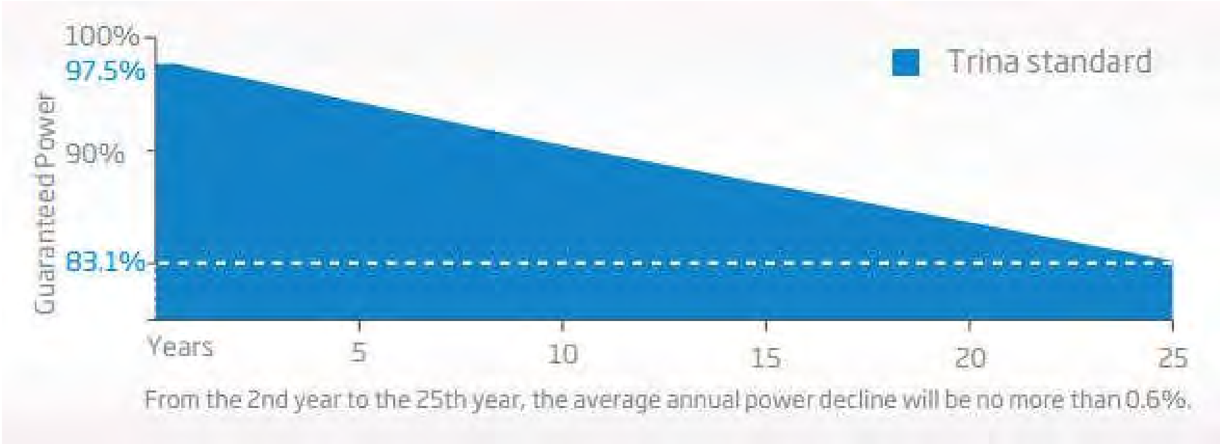


Figure 4.8 Annual power decline up to 25 years

Total life cycle generation of the $10MW_{AC}$ solar power plant has been calculated considering photovoltaic module degradation 2.5% for first year and 0.6% average annual power decline from 2 year to 25 year, presented in table 4.8.

Table 4.8 Total life cycle operation of the 10MW solar power plant

Total Life Cycle Operation of the 10MW solar power Plant				
YEAR	kWh	YEAR	kWh	
Year1	19,164,707.60	Year11	18,045,380.40	**Total Life Cycle Generation**
Year2	19,049,719.36	Year12	17,937,108.12	
Year3	18,935,421.04	Year13	17,829,485.47	
Year4	18,821,808.51	Year14	17,722,508.56	
Year5	18,708,877.66	Year15	17,616,173.51	**kWh = 362,213,228.09**
Year6	18,596,624.40	Year16	17,510,476.46	**MWh = 362,213.23**
Year7	18,485,044.65	Year17	17,405,413.61	**GWh = 362.21**
Year8	18,374,134.38	Year18	17,300,981.12	
Year9	18,263,889.58	Year19	17,197,175.24	
Year10	18,154,306.24	Year20	17,093,992.19	

CHAPTER 5
FINANCIAL ANALYSIS

5.1 Introduction

This chapter presents the financial analysis and risk assessment of 10MW photovoltaic power plant. The major cost component, key performance indicator such as levelized cost of electricity (LCOE), performance ratio (PR), capacity utilization factor (CUF) and profitability indicators will be discussed and figure out. these analyses will be provided adequate information to investor about the project viability.

5.2 Solar Power Economics

Total life cycle includes pre-planning, design & engineering, construction, operation & maintenance and dismantling & recycling, shown in figure 5.1. From the presented life cycle of solar power plant, only cost and benefits will be highlighted in this chapter.

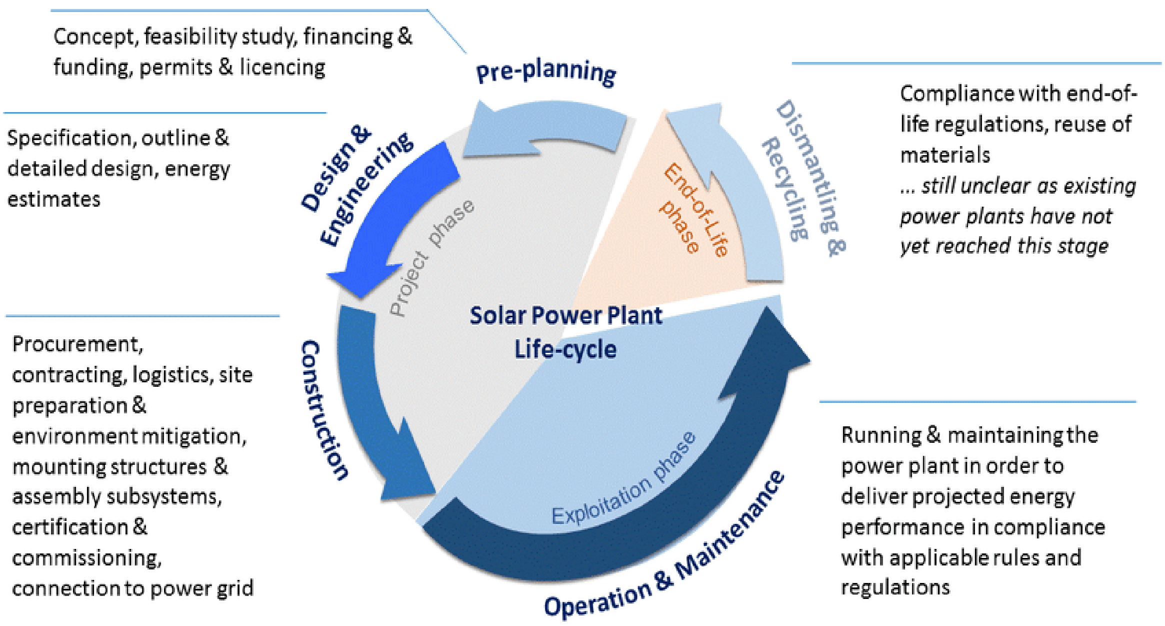


Figure 5.1 solar power plant life cycle

The levelized cost of electricity (LCOE) is a measurement used to assess and compare alternative methods of energy production, also LCOE is a very important metric in determining whether or not to move forward with a project. The LCOE will determine if a project will break even or be profitable. Using the LCOE to assess a project is one of the first fundamental steps taken in analyzing projects of this nature. Levelized cost of electricity (LCOE) represents the ratio between the project's total cost and total electrical energy produced over lifetime.

$$\text{LCOE} = \frac{\text{Total Costs over Lifetime}}{\text{Total Electrical Energy Produced over Lifetime}}$$

$$\text{LCOE} = \frac{17{,}774{,}871.76}{362{,}213{,}228.09}$$

Levelized cost of energy (LCOE) = 0.049

The second indicator is performance ratio (PR). The performance ratio (PR) is a measure of the quality of a PV plant that is independent of location and it therefore often described as a quality factor. The performance ratio (PR) is stated as percent and describes the relationship between the actual and theoretical energy outputs of the PV plant as follows.

$$\text{PR} = \frac{\text{Energy Injected to grid (kWh)}}{\text{Plant Capacity (kWp)x GII (kWh/m2)}} \times 100\%$$

$$\text{PR} = \frac{19{,}164{,}707.60}{12{,}000 \text{ x } 2022.90} \times 100\%$$

Performance Ratio (PR) ≈ 78.96

The third indicator is capacity utilization factor (CUF). The performance of a PV power plant is often denominated by a metric called the capacity utilization factor (CUF). It is the ratio of the actual output from a solar plant over the year to the maximum possible output from it for a year under ideal conditions. Capacity utilization factor also known as plant load factor (PLF) and it is usually expressed in percentage.

$$\text{CUF} = \frac{\text{Actual Energy Generated per annum (kWh)}}{\text{Plant Capacity (kWp)} \times 24 \times 365} \times 100\%$$

$$\text{CUF} = \frac{19{,}164{,}707.60}{12{,}000 \times 24 \times 365} \times 100\%$$

Capacity Utilization Factor (CUF) = 18.23%

Table 5.1 Key Performance Indicators for 10 MW_{AC} solar power plant.

Particulars	Value
Ideal generation (GWh/Year)	458.73
Actual generation (GWh/Year)	362.21
Performance Ratio (PR)	78.96%
Capacity Utilization Factor (CUF)	18.23%
Levelized Cost of Energy - LCOE (USD/kWh)	0.049

5.3 Risk Assessment and Mitigation

The project works assed the major risk for selected site and prescribe suitable mitigation procedure as follows.

5.3.1 Solar policy and government commitment

Limited effective policy in addressing the challenges of utility-scale renewable energy development. Government is committed, but currently does not have a strategy on how to achieve its commitments and targets. Renewable energy targets in government policy have either expired or look too far ahead (closest target after 2021 is 2041). Policy guidelines and incentives for the private sector do not always apply to renewable energy projects as they do for conventional fossil fuel projects. The link between carbon reduction commitments and country targets for new renewable energy capacity is absent.

The Government of Bangladesh should consider revising the power system master plan (PSMP) or investigate long-term least-cost technology options to meet Nationally Determined Contribution of Bangladesh (NDC) targets, sustainable development goals and projected electricity demand. Improved coordination between government agencies will go a long way in providing clarity on policy and easing the many onerous processes and approvals for renewable energy projects. Bangladesh needs a more holistic approach to policy that will be able to address the major bottlenecks along the entire project development process.

Consider setting up an IPP procurement agency that is responsible for all procurement activities and communication. It can be the point of coordination between all government agencies and institutions and provide developers and investors with all the required information such as bidding documents, guidance on applicable laws and permitting requirements, and timely communication of all bidding activities.

Review the roles, responsibilities and activities of government institutions to ensure they are effective in supporting the aims of the government's renewable energy plan with respect to utility-scale renewable energy generation capacity.

5.3.2 Grid stability

Renewable energy targets and plans are not synchronized with future electricity transmission infrastructure plans, as they are for conventional power plants. Different policies and support for new transmission infrastructure for conventional power plants and renewable energy plants. Limited assessment of potential sites for renewable energy based on transmission capacity and difficult to access substation or load distribution information. Limited coordination between BPDB and PGCB when negotiating for available grid capacity with developers. No standard guidelines for grid integration, or not publicly available. Limited feasibility studies done on grid stability and no integrated study on grid expansion.

Bangladesh's grid network currently has a limited amount of spare grid capacity, although no current studies have determined the exact amount of grid capacity available. In addition, future grid transmission plans outlined in the PSMP 2016 are not synchronized with any future renewable energy generation capacity increases, as they are for future fossil fuel generation increases. As a matter of urgency, the government needs to undertake a study to identify those areas of the grid where spare capacity is available for renewable energy plants to tie into. The study should extend its scope to cover what network upgrades can be done to easily unlock further free capacity. In the short term, this represents the quickest path to maximizing the use of the existing grid system. It will also provide valuable insight into the optimum capacity of the renewable energy plants the government should be pursuing and can be overlaid onto any future land studies.

5.3.3 Solar resource

Energy Generation of any photovoltaic power plant directly depends on natural solar resources. Solar power energy has an intermittent characteristic, for this reason it is difficult to predict energy generation exactly. However reliable data source Meteonorm 7.3 TMY data set is used for predicting the energy yield for the selected site. This energy generation risk as well as solar resource risk can be mitigated by collecting reliable and accurate long term typical meteorological year (TMY) data set.

5.3.4 Natural hazards

Natural hazards are extreme natural events that can cause loss of life, extreme damage to property and disrupt human activities. This means that investment can damage by the unexpected natural hazard. Cyclones, storms and lightning surge are major natural hazards for this selected site. Also, insurance policy will not cover damage due to natural hazards.

To mitigate unexpected natural hazards, project work considered 60 m/s wind speed for structure design and sufficient lightning arrester & surge arrester will be installed all over the projected area.

5.4 Project Cost

The project costs are mainly capital expenditure (CAPEX) and operational expenditure (OPEX). CAPEX which includes cost of all capital machineries and expenses during construction period. OPEX which are includes operation and maintenance cost, insurance charges and equipment's replacement.

5.4.1 Capital expenditure (CAPEX)

Monocrystalline photovoltaic modules:

Based on recent market price index, the price of monocrystalline module considered 0.37 USD/Wp with system voltage 1500 Volt, power output 505Wp and maximum efficiency 21.1%.

Balance of system (BOS):

The Balancing of System (BOS), which includes Inverter, module mounting structure (MMS), cabling, switch gear, transformers, energy meters, SCADA monitoring system and related or optional equipment depending on nature and scope of system. The prices of balance of system USD 0.64/Wp considered based the recent market price & by the discussion with technical expert and materials supplier.

Civil construction and others:

Civil construction that includes subsoil investigation, land development and construction of module mounting structure base, inverter station, main control room, internal road, boundary fencing and related construction as per scope of civil work. The costs of civil construction considered USD 0.089/Wp according to real experience. The remaining costs is considered 1.35% of the total capital costs as consultancy fees and expenses for approval of local government.

5.4.2 Operational expenditure (OPEX)

Operational expenditure (OPEX) is an ongoing cost for running the power plant. Operating expenses include O&M costs, insurance charges, land rent and research & development expenses. Due to lower labor costs, operational expenses are cheapest in Bangladesh comparatively other countries. Operational expenditure (OPEX) is considered USD 0.021/Wp/Year.

5.5 Sales Revenue

The accounting for cash inflow calculates sales revenue by the multiplying monthly total net generation that has been supplied into national grid by the tariff rate. Sales revenue will be calculated from the below equation, where SR_Y is yearly sales revenue, TR is tariff rate, NEO_Y is net energy output measured in kWh during the year "Y".

$$SR_Y = TR \times NEO_Y$$

5.6 Cash Flow Statement

A cash flow excel sheet (Appendix 6) will be used for 20 years project duration from the year zero. In year zero the net cash flow is negative and equal to the total capital investment, which means the plant is in under construction and non- operational.

The following formula is used to calculate net cash flow where Rt is the net cash flow, R is the total revenue, C_{op} is the annual operating cost.

$$Rt = R - Cop$$

Eventually, the net cash flow of the entire project will be equal to the sum of all yearly cash flows.

5.7 Net Present Value (NPV)

Net present value (NPV) is the difference between the present value of all cash inflows and the present value of all cash outflows over a period of time. NPV is used in capital budgeting and investment planning to analyze the profitability of a projected investment or project. For the 20 years project the discount rate (r) will increase exponentially from year 1 to 20. This also requires the input of an acceptable discount rate. Outflow (initial investment) doesn't need to be discounted, because the equipment is paid for up front, and there is no elapsed time that needs to be accounted for. The following formula is used to calculate NPV

$$NPV = \sum_{t=0}^{n} \frac{Rt}{(1+r)^t}$$

where:

Rt = Net cash flow during a single period *t*

r =Discount rate or return that could be earned in alternative investments

t=The number of time periods

5.8 Internal Rate of Return (IRR)

The internal rate of return is a metric used in financial analysis to estimate the profitability of potential investments. The internal rate of return is a discount rate that makes the net present value (NPV) of all cash flows equal to zero in a discounted cash flow analysis. IRR calculations rely on the same formula as NPV does. The calculation of the IRR is done iteratively via excel, where the IRR is the rate that brings the project's NPV to zero. The formula and calculation used to determine this figure is as follows, where C_O is total initial investment cost

$$0 = NPV = \sum_{t=0}^{n} \frac{Rt}{(1 + IRR)^t} - C_0$$

5.9 Payback Period and Benefit to Cost Ratio (B/C)

The payback period refers to the amount of time how long it takes the project to recover the initial investment. Simply the payback period is the length of time, that an investment reaches a break-even point.

Finally, profitability index (PI) or benefit to cost ratio (B/C) is calculated by dividing the present value of all cash inflows by the initial investment. This parameter is a measure of a project's or investment's attractiveness, also give an idea to investor about the profit margin of an investment in present terms.

Table 5.2 presented the results of all profitability indicators considering 100% equity finance, all indicator results are acceptable for financial viability of this selected project.

Table 5.2 Profitability indicators data of 10 MW_{AC} solar park

Particulars	Value
Discount rate of interest or Opportunity cost of capital value	8.00%
Cash Inflow	13,063,913.81
Cash Outflow	9,492,000.00
Net Present Value (NPV)	3,571,913.81
Internal Rate of Return (IRR)	14.47%
Benefit to Cost Ratio (B/C) or Profitability Index (PI)	1.38
Payback Period (PBP)	6 Year & 1 Month
Yearly Average Production Cost	414,143.59
Levelized Cost of Energy (USD/kWh)	0.049

The project work also calculated of all profitability indicator result considering 60% Equity and 40% Debt Finance at 9% interest rate. Indicators result comparison between two types of financing system presented in table 5.3 as follows

1. 100% Equity Finance
2. 60% Equity and 40% Debt Finance at 9% interest rate

Table 5.3 Indicators result comparison between two financing system

Particulars	100% Equity Finance	60% Equity & 40% Debt Finance
Discount rate of interest	8.00%	8.00%
Cash Inflow	13,063,913.81	11,822,599.07
Cash Outflow	9,492,000.00	9,492,000.00
Net Present Value (NPV)	3,571,913.81	2,330,599.07
Internal Rate of Return (IRR)	14.47%	12.45%
Benefit to Cost Ratio (B/C)	1.38	1.25
Payback Period (PBP)	6 Year & 1 Month	7 Year & 1 Month
Yearly Average Production Cost	414,143.59	414,143.59
Levelized Cost of Energy (USD/kWh)	0.049	0.049

CHAPTER 6
CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Bangladesh is experiencing a gradual depletion of its primary energy resource such as natural gas and time has come to explore and harness the full potential of alternative energy sources to ensure our long-term energy security as well as sustainable economic development. Realizing the importance, Bangladesh Government attaches due importance on renewable energy. To meet the Power System Master Plan-2016 (PSMP), the government has set a target for generating 10% of the country's total electricity through using renewable energy by 2021. The government is helping renewable energy project developers and investors with financial supports and policy initiative, that is positive sign, which will be accelerated the development work of renewable energy sector.

Because of sufficient non-agriculture land availability at sabrang, Teknaf, author have conducted a simulation with PVsyst for this site location (latitude is 20.83º N and longitude is 91.32º E). According to simulation report monthly average global horizontal irradiation at sabrang is 5.11 kWh/m2 /day, which is the highest solar energy potentials comparatively others zone of Bangladesh. This indicates that the selected area has huge scope to exploit solar energy due to its favorable geographical position.

Finally, a financial analysis has been done by calculating net present value (NPV), internal rate of return (IRR), benefit to ratio (B/C), payback period and risk assessment. In the risk assessment the project work identified measurable risk and prescribed suitable procedure to mitigation the major risk,

In the financial analysis, NPV is positive (USD 3,571,913.81), internal rate of return (IRR) achieved 14.47 %, profitability index (PI) or benefit to cost ratio (B/C) is 1.38 estimated payback period 6 years & 1 months and levelized cost of electricity is 0.049 USD/kWh. Based on above information, all profitability indicators result is acceptable and we can conclude that the selected project is feasible.

6.2 Recommendation for Future Research

Land acquisition is a difficult task as well as major challenge to install solar photovoltaic power plant in Bangladesh due to non-agriculture land limitation. Another challenge is grid stability, solar energy resources are intermittent energy sources whose output can vary widely within short time frames, depending on the sun shining. But Bangladesh's national grid is not robust or reliable enough to manage intermittent electricity beyond a certain capacity. Grid integration strategies have been successfully implemented in other countries and studies will need to be undertaken in Bangladesh to achieve the same.

Solar Park has become one of the largest sources now a day and has a great potential to be the largest source of renewable energy in near future. Bangladesh receives an average daily solar radiation in the range of 4.5 $kWh/m^2/day$. To effective utilization of unlimited solar potentials, more research is required to analyze feasibility of utility scale floating solar power plant and rooftop solar on residential building roof, industry roof, railway station.

Further research is also required to ascertain with more certainty whether the grid can accommodate solar based renewable energy. That will be very much helpful for project developers to understand the requirements of connecting solar power plant at specific locations on the network.

REFERENCES

[1]. Arnulf Jäger-Waldau, I. Kaizuka, Alice Detollenaere, Johan Lindahl (2020). *snapshot of the global PV markets 2020*. DOI: 10.13140/RG.2.2.13687.44968

[2]. Michael Taylor, (2020). *Renewable Power Generation Costs in 2019: Latest Trends and Drivers.* https://irena.org/renewables/KnowledgeGateway/webinars /2020/Jan/IRENA-insights

[3]. Ramanan P., Kalidasa Murugavel K. Karthick A. (2019) "Performance analysis and energy metrics of grid-connected photovoltaic systems" *Energy for sustainable development, October 2019*. DOI: 10.1016/j.esd.2019.08.001

[4]. Samir Kouro, Jose I. Leon, Dmitri Vinnikov, Leopoldo Garcia Franquelo (2015) "Grid-Connected Photovoltaic Systems: An Overview of Recent Research and Emerging PV Converter Technology" *IEEE Industrial Electronics Magazine March 2015*. DOI: 10.1109/MIE.2014.2376976

[5]. NI Hongjun, LU Wenfan, Wang Xingxing, Lu Haoyang, Zhang Yongpei, Zhang Minqi (2015) "Research Progress of PV Mounting System for Solar Power Station" *International Conference on Chemical, Material and Food Engineering, July 2015*, https://doi.org/10.2991/cmfe-15.2015.70.

[6]. Rustu Eke, Ali Senturk (2012), "Performance comparison of a double-axis sun tracking versus fixed PV system", *Solar Energy 86 (2012) 2665–2672*, DOI: 10.1016/j.solener.2012.06.006

[7]. Zoltan Corba, Boris Dumnic, Vladimir A. Katic, Dragan Milicevic (2012) "In-grid solar-to-electrical energy conversion system modeling and testing" *Thermal Science, Vol. 16 (Suppl. 1), pp. S159-S171, January 2012,* DOI: 10.2298/TSCI120224069C

[8]. Savita Nema, Rajesh Nema (2011) "Inverter topologies and control structure in photovoltaic applications A review" *Journal of Renewable and Sustainable Energy, January 2011*. DOI: 10.1063/1.3505096

[9]. Todd Karin and Anubhav Jain (2020) "Photovoltaic String Sizing Using Site-Specific Modeling" *IEEE Journal of Photovoltaics, Volume: 10, Issue: 3, May 2020*. DOI: 10.1109/JPHOTOV.2020.2969788

[10]. Matheus Gemignani, Guido Rostegui, Mauricio B. C. Salles, Nelson Kagan (2017) "Methodology for the Sizing of a Solar PV Plant: A Comparative Case" *6th International Conference on Clean Electrical Power (ICCEP), 2017*. DOI: 10.1109/ICCEP39853.2017

[11]. Syed Muhammad Sami ur Rehman, Muhammad Ammar Nazeer, Zafar Iqbal, Muhammad Abdul Basit, Aqeel Ahmed (2018) "Mathematical Analysis for Calculation of an optimum Tilt Angle of Solar Panels for Islamabad" *International Conference on Power Generation Systems and Renewable Energy Technologies (PGSRET), September 2018*. DOI: 10.1109/PGSRET.2018.8685993

[12]. Mark Z. Jacobson, Vijaysinh Jadhav (2018) "World estimates of PV optimal tilt angles and ratios of sunlight incident upon tilted and tracked PV panels relative to horizontal panels" *Solar Energy Volume 169, 15 July 2018, Pages 55-66*. https://doi.org/10.1016/j.solener.2018.04.030

[13]. C.P. Kandasamy, P. Prabu, K. Niruba (2013) "Solar Potential Assessment Using PVSYST Software" *International Conference on Green Computing, Communication and Conservation of Energy (ICGCE), December 2013*. DOI: 10.1109/ICGCE.2013.6823519

[14]. Irfan Jamil, Jinquan Zhao, Li Zhang, Rehan Jamil, Syed Furqan Rafique (2017) "Evaluation of Energy Production and Energy Yield Assessment Based on Feasibility, Design, and Execution of 3×50MW Grid-Connected Solar PV Pilot Project in Nooriabad" *International Journal of Photoenergy Volume 2017, Article ID 6429581*, https://doi.org/10.1155/2017/6429581

[15]. Eero Vartiainen, Gaëtan Masson, Christian Breyer, David Moser, Eduardo Román Medina (2019) "Impact of weighted average cost of capital, capital expenditure, and other parameters on future utility-scale PV levelized cost of electricity" *wiley online library, 29 August 2019.* https://doi.org/10.1002/pip.3189

[16]. Leandro Alves Aguilar (2015), “Feasibility Study of Developing Large Scale Solar PV Project in Ghana: An Economical Analysis” *SE 412 96 Gothenburg, Sweden,2015.* https://publications.lib.chalmers.se/records/fulltext/218869/218869

[17]. M. Pauzi, M. Kassim, Karam M. Al-Obaidi, M. Arkam C. Munaaim, Abd. Mokhti Salleh “Feasibility Study on Solar Power Plant Utility Grid under Malaysia Feed-in Tariff” *American Journal of Engineering and Applied Sciences 2015, 8 (2): 210.222,* DOI: 10.3844/ajeassp.2015.210.222

[18]. Samuel Tesema (2016) “Wind and Solar Resource Assessment and Feasibility Study of Large Scale Off-Grid Hybrid System for Remote Districts of Werder Zone – Ethiopia” *researchget.net publications.* DOI: 10.13140/RG.2.1.5173.3521.

[19]. Pankaj Chauhan, Sandesh Ghandat, (2015) “Feasibility Study for Setting Up of a Solar PV Power Plant in Dehradun, India” *researchget.net publications. Solar - Science topic.* DOI: 10.13140/RG.2.1.4027.1841.

[20]. Ratan Mandala, Srinjoy Panja (2015) “Design and feasibility studies of a small scale Grid Connected Solar PV Power Plant” *Energy Procedia 90 (2016) 191 – 199, 5th International Conference on Advances in Energy Research, ICAER 2015, India.* DOI: 10.1016/j.egypro.2016.11.185

[21]. Mevin Chandel, G.D. Agrawal, Sanjay Mathur, Anuj Mathur (2014) “Techno-economic analysis of solar photovoltaic power plant for garment zone of Jaipur city” *Case Studies in Thermal Engineering Volume 2, pp. 1-7, 2014.* https://doi.org/10.1016/j.csite.2013.10.002

[22]. Power Division, Ministry of Power, Energy & Mineral Resources, “Power System Master Plan 2016 Summary”. Government of the People’s Republic of Bangladesh.

[23]. B. Shiva Kumar, K. Sudhakar (2015) “Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India” *Energy Reports, Volume 1, pp 184-192, 2015,* DOI: 10.1016/j.egyr.2015.10.001

[24]. D.P. Kothari, K.C. Singal, Rakesh Ranjan (2011) “Renewable Energy Sources and Emerging Technologies” *ISBN-978-81-203-4470-9, Second Edition-November, 2011.*

[25]. Miklos Bankuti, Debabrata Chattopadhyay, Chong-Suk Song (2018) “Integrating Variable Renewable Energy in the Bangladesh Power System: A Planning Analysis” *world bank group library, policy research working paper, 8 Aug, 2018*. https://doi.org/10.1596/1813-9450-8517

[26]. Pankaj kalita, Samar das, Dudul das, Pallab, borgohain, Anupam dewan, Rabindra kangsha banik (2019) “Feasibility study of installation of MW level grid connected solar photovoltaic power plant for northeastern region of India” *Indian Academy of Sciences, 2019.* DOI: 10.1007/s12046-019-1192-z

[27]. Adel Soualmia, Rachid Chenni (2016) “Modeling and Simulation of 15MW Grid -Connected Photovoltaic System using PVsyst Software” *International Renewable and Sustainable Energy Conference (IRSEC), 2016*. DOI: 10.1109/IRSEC.2016.7984069

[28]. Ajay Kumar, Vikas Gupta, Dr Nitin Gupta (2017) “A Comprehensive Review on Grid-Tied Solar Photovoltaic System” *Journal of Green Engineering January 2017,* DOI: 10.13052/jge1904-4720.71210

[29]. Diptiman Dey, Bidyadhar Subudhi (2020) “Design, simulation and economic evaluation of 90 kW grid connected Photovoltaic system” *Energy Reports 6:1778-1787, November 2020.* DOI: 10.1016/j.egyr.2020.04.027

[30]. Sakhr M. Sultan, M.N. Ervina Efzan “Review on recent PhotovoltaicThermal (PVT) technology advances and applications” *Solar Energy Volume 173, October 2018, Pages 939-954.* doi:10.1016/j.solener.2018.08.032

[31]. Hong Fang, Xu Wang, Wenyan Song (2020) "Technology selection for photovoltaic cell from sustainability perspective: An integrated approach" *Renewable Energy 153(5), February 2020.* https://doi.org/10.1016/j.renene.2020.02.064

[32]. Vasanthkumar, Dr. S. Kumarappa, Dr. H. Naganagouda (2017) "Design and Development of 5MW Solar PV Grid Connected Power Plant Using PVsyst" *International Research Journal of Engineering and Technology (IRJET), Volume: 04 Issue: 08, August -2017. e-ISSN: 2395-0056, p-ISSN: 2395-0072*.

[33]. Nasir Sheikh, D.F. Kocaoglu (2011) "A comprehensive assessment of solar photovoltaic technologies: Literature review" *Conference: Technology Management in the Energy Smart World (PICMET), 2011 Proceedings of PICMET '11*. https://www.researchgate.net/publication/224258201

[34]. Tamer Khatib, Azah Mohamed, K. Sopian (2012) "A Software Tool for Optimal Sizing of PV Systems in Malaysia" *Hindawi Publishing Corporation Modelling and Simulation in Engineering Volume 2012, Article ID 969248, 11 pages,* doi:10.1155/2012/969248.

[35]. Emanuele Calabrò (2013) "An Algorithm to Determine the Optimum Tilt Angle of a Solar Panel from Global Horizontal Solar Radiation" *Hindawi Publishing Corporation Journal of Renewable Energy, Volume 2013, Article ID 307547,* http://dx.doi.org/10.1155/2013/307547

[36]. Akif Karafil, Harun Özbay, Metin Kesler, Hüseyin Parmaksiz (2015) "Calculation of Optimum Fixed Tilt Angle of PV Panels Depending on Solar Angles and Comparison of the Results with Experimental Study Conducted in Summer in Bilecik, Turkey" *9th International Conference on Electrical and Electronics Engineering (ELECO) at Bursa November 2015.* DOI: 10.1109/ELECO.2015.7394517

[37]. S. Sánchez-Carbajal and P. M. Rodrigo (2019) "Optimum Array Spacing in Grid-Connected Photovoltaic Systems considering Technical and Economic Factors" *Hindawi International Journal of Photoenergy Volume 2019, Article ID 1486749, 14 pages,* https://doi.org/10.1155/2019/1486749.

[38]. Moustafa M. Elsayed, Abdullah M. Al-Turki (1991) "Calculation of shading factor for a collector field" *Solar Energy Volume 47, Issue 6, pp. 413-424, 1991.* https://doi.org/10.1016/0038-092X(91)90109-A

[39]. B. Kailash Krishna Prasad, K. Prahlada Reddy, K. Rajesh, P. Viswanath Reddy (2020) "Design and Simulation Analysis of 12.4 kWp Grid Connected Photovoltaic system by using PVSYST Software" *International Journal of Recent Technology and Engineering (IJRTE), ISSN: 2277-3878, Volume-8 Issue-5, January 2020.* DOI: 10.35940/ijrte.E6243.018520

[40]. A. Aronescu, J. Appelbaum (2017) "Design optimization of photovoltaic solar fields-insight and methodology" *Renewable and Sustainable Energy Reviews, Volume 76, September 2017*. https://doi.org/10.1016/j.rser.2017.03.079

[41]. Dimitris Diamantidis, Miroslav Sýkora (2014) "Optimal Design of ground mounted solar systems" *Conference: European Safety and Reliability ConferenceAt: Wroclaw, Poland, September 2014*. DOI: 10.1201/b17399-298

[42]. Miguel Silva, Rui Castro, Mário Batalha (2020) "Technical and Economic Optimal Solutions for Utility-Scale Solar Photovoltaic Parks" *Electronics 2020, 9, 400.* doi:10.3390/electronics9030400

[43]. Anton Fedorov (2015) "Photovoltaic System Design for a Contaminated Area in Falun – Comparison of South and East West Layout" *European Solar Engineering School No.194, June 2015.* https://www.diva-portal.org/smash/get/diva2:853199/FULLTEXT01.pdf

[44]. B. Decker, U. Jahn (1997) "Performance of 170 grid connected PV plants in Northern Germany—Analysis of yields and optimization potentials" *Solar Energy Volume 59, Issues 4–6, April–June 1997.* https://doi.org/10.1016/S0038-092X(96)00132-6

[45]. Ehsanul Kabir, Pawan Kumar, Sandeep Kumar, Adedeji A. Adelodun, Ki-Hyun Kim (2018) "Solar energy: Potential and future prospects" Renewable and Sustainable Energy Reviews, Volume 82, Part 1, February 2018, Pages 894-900. https://doi.org/10.1016/j.rser.2017.09.094

[46]. Brahim Belmahdi, Abdelmajid El Bouardi (2019) "Solar Potential Assessment using PVsyst Software in the Northern Zone of Morocco" *13th International Conference Interdisciplinarity in Engineering (INTER-ENG 2019), Procedia Manufacturing Volume 46, 2020, Pages 738-745,* https://doi.org/10.1016/j.promfg.2020.03.104

[47]. Abdul Qayoom Jakhrani, Al-Khalid Othman, Andrew R.H. Rigit, Saleem Raza Samo, Shakeel Ahmed Kamboh (2012) "Estimation of Incident Solar Radiation on Tilted Surface by Different Empirical Models" *International Journal of Scientific and Research Publications, Volume 2, Issue 12, December 2012.* http://www.ijsrp.org/research-paper-1212/ijsrp-p1255.pdf

[48]. Edjadessamam Akoro, Seidou Maiga Amadou, Tevi Gabriel Jean-Philippe (2017) "Different topologies of three-phase grid connected inverter for photovoltaic systems, a review" *Cames 2017 - Published Online January 2017 - Vol. 2(2), pp. 33-41, ISSN 2312-8712.* http://publication.lecames.org/

[49]. L. Hassaine, E. OLias, J. Quintero, V. Salas (2014) "Overview of power inverter topologies and control structures for grid connected photovoltaic systems" *Renewable and Sustainable Energy Reviews Volume 30, February 2014, Pages 796-807.* https://doi.org/10.1016/j.rser.2013.11.005

[50]. Mehmet Ali Kallioğlu, Aydın Durmuş, Hakan Karakaya & Adem Yılmaz (2019) "Empirical calculation of the optimal tilt angle for solar collectors in northern hemisphere" *Energy Sources, Part A: Recovery, Utilization and Environmental Effects, September 2019*. DOI: 10.1080/15567036.2019.1663315

[51]. Fajer Alelaj, Abdullah Alkhalaf (2019) "Optimization of the Tilt Angle of Photo-voltaic Module in Kuwait" *IEEE 10th GCC Conference & Exhibition (GCC), April 2019.* DOI: 10.1109/GCC45510.2019.1570525127

[52]. Ida Bagus Ketut Sugirianta, I G A M Sunaya, IGNA Dwijaya Saputra (2020) "Optimization of tilt angle on-grid 300Wp PV plant model at Bukit Jimbaran Bali" *Journal of Physics Conference Series (J Phys Conf), February 2020.* DOI: 10.1088/1742-6596/1450/1/012135

[53]. T. Khatib, A. Mohamed, M. Mahmoud & K. Sopian (2015) "Optimization of the Tilt Angle of Solar Panels for Malaysia" *Energy Sources, Part A: Recovery, Utilization and Environmental Effects, March 2015.* DOI: 10.1080/15567036.2011.588680

[54]. Mian Guo, Haixiang Zang, Shengyu Gao, Tingji Chen, Jing Xiao, Lexiang Cheng, Zhinong Wei and Guoqiang Sun (2017) "Optimal Tilt Angle and Orientation of Photovoltaic Modules Using HS Algorithm in Different Climates of China" *Appl. Sci. September 2017, 7(10), 1028;* https://doi.org/10.3390/app7101028

[55]. Manoj Kumar Sharma, Deepak Kumar, Sandeep Dhundhara, Dipesh Gaur, and Yajvender Pal Verma (2020) "Optimal Tilt Angle Determination for PV Panels Using Real Time Data Acquisition" *published online 18 February 2020.* https://doi.org/10.1002/gch2.201900109

[56]. Naihong Shu, Nobuhiro Kameda, Yasumitsu Kishida & Hirotora Sonoda (2018) "Experimental and Theoretical Study on the Optimal Tilt Angle of Photovoltaic Panels" *Journal of Asian Architecture and Building Engineering, 5:2, 399-405, October 2018*. DOI: 10.3130/jaabe.5.399

[57]. Ross Ure Anderson (2020) "Derivation of Solar Position Formulae" *published online September 2020*. DOI: arXiv:2009.07094v1 [physics.pop-ph] 14 Sep 2020

[58]. Ibrahem Altarawneh, Saleh Rawadieh, Muafag Tarawneh, Sultan Mohammad Alrowwad (2016) "Optimal tilt angle trajectory for maximizing solar energy potential in Ma'an area in Jordan" *Journal of Renewable and Sustainable Energy, May 2016*. DOI: 10.1063/1.4948389

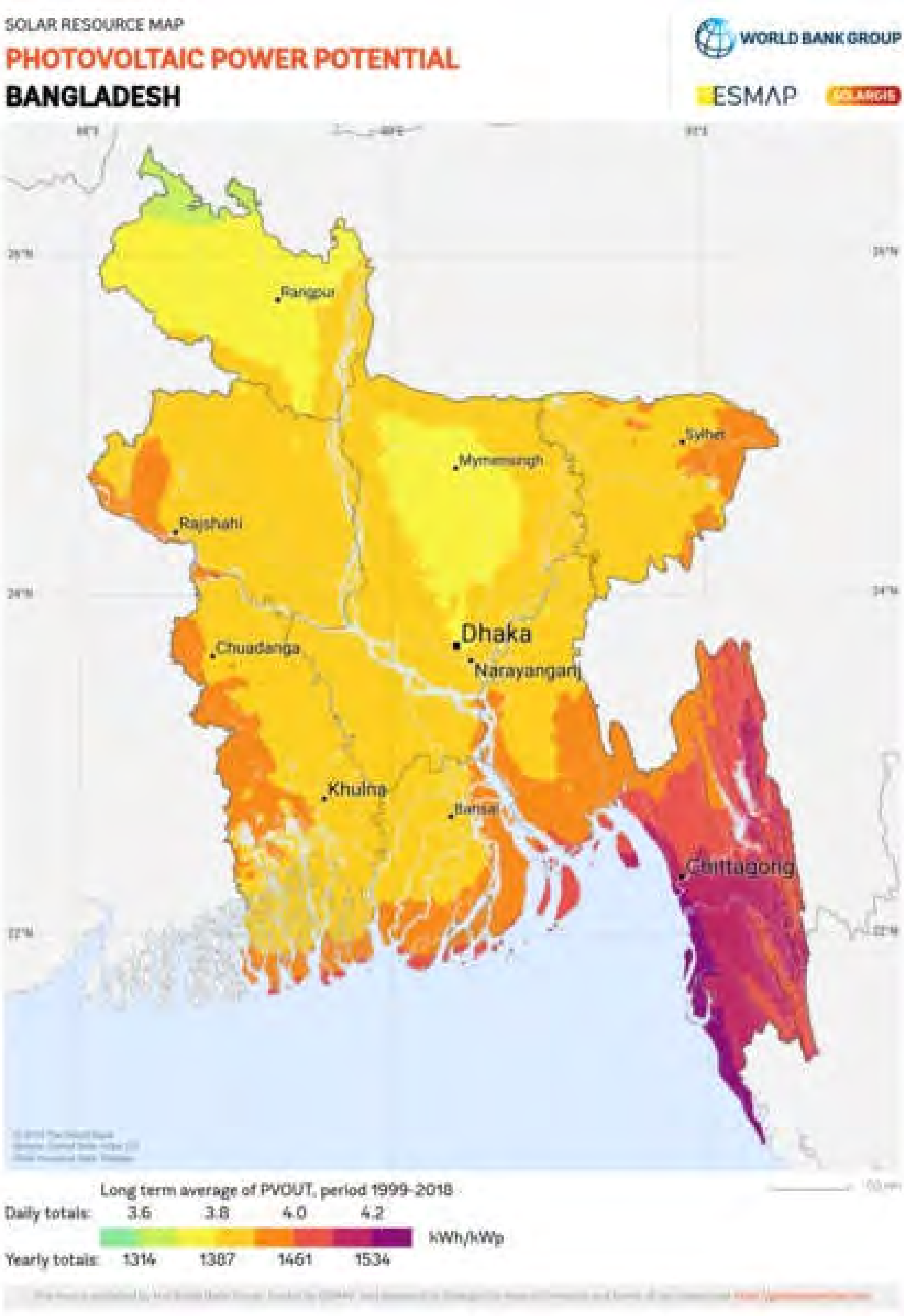
[59]. Hamed Pourgharibshahi, Roohollah Fadaeinedjad (2013) "Optimal tilt angle determination of photovoltaic panels and comparing of their mathematical model predictions to experimental data in Kerman" *Canadian Conference on Electrical and Computer Engineering, May 2013.* DOI: 10.1109/CCECE.2013.6567674

[60]. Syed Faizan Ali Shah, Irfan A. Khan, Hassan Abbas Khan (2019) "Performance Evaluation of Two Similar 100MW Solar PV Plants Located in Environmentally Homogeneous Conditions" *IEEE Access (Volume 7), November 2019.* DOI: 10.1109/ACCESS.2019.2951688

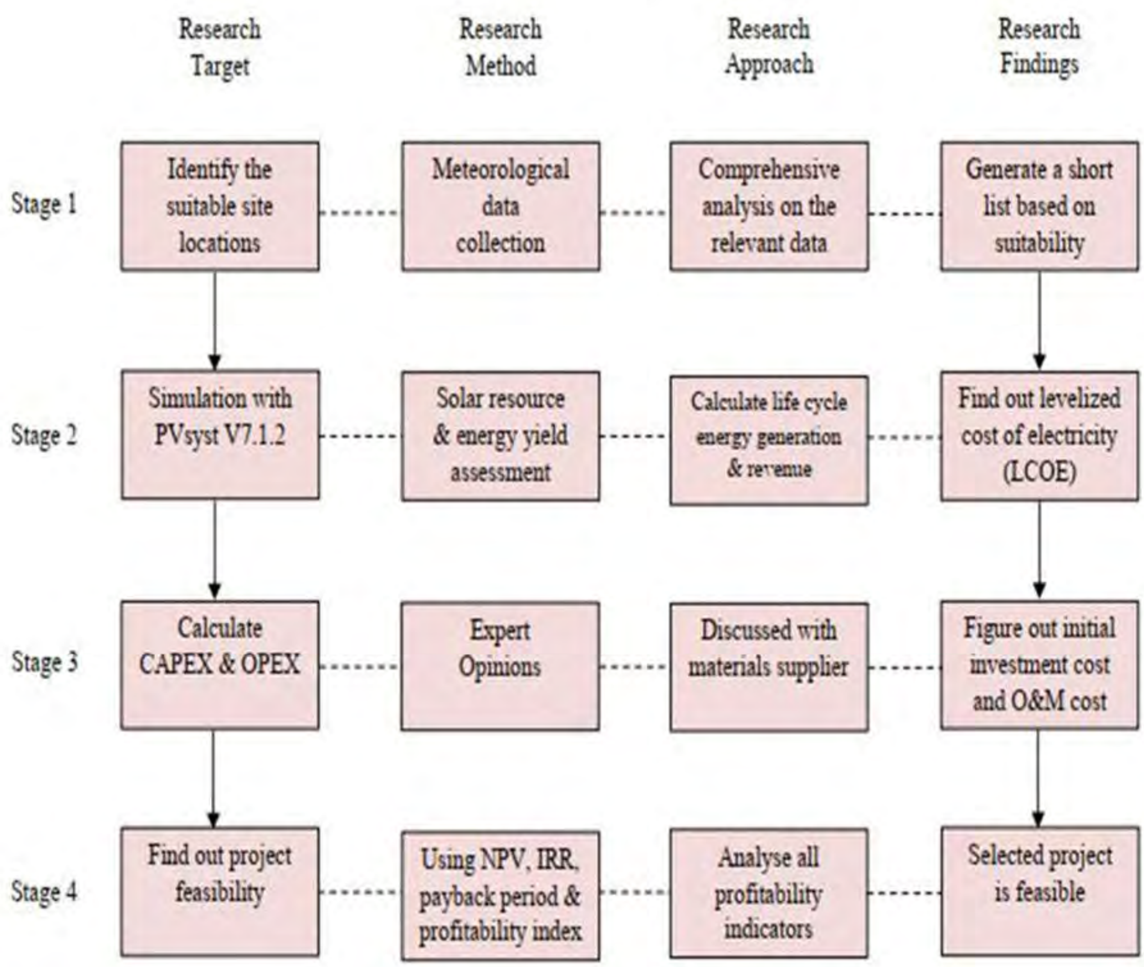
[61]. Zhi Li, Kai Bai, Zhengpai Cui, Peng Song, Na Li, Hanmin Liu (2019) "Research on Grid-connected PV Power Station Condition Evaluation Technology Based on SCADA and Hierarchical Progression" *Journal of Physics Conference Series (J Phys Conf), March 2019.* DOI: 10.1088/1742-6596/1176/6/062028

APPENDICES

Appendix 1: Solar resource map of Bangladesh.



Appendix 2: Research Methodology



Appendix 3: Capital or initial investment

Capital/Initial Investment		
DC Install Capacity (kWp) =	**12000**	
DC to AC Ratio =	**1.2**	
Total Plant AC Capacity (kW) =	**10000**	
Description	**USD/kWp**	**Total (USD)**
Photovoltaic Module	370.00	4,440,000.00
Balance of System (BOS)		
Solar Inverter	50.00	600,000.00
Power, Control & Monitoring Cable	25.00	300,000.00
Rest of Electrical Equipment's [1]	70.00	840,000.00
Module Mounting Structure (MMS)	72.00	864,000.00
Evacuation Line Construction	4.00	48,000.00
Plant Erection, Testing & Commissioning	8.00	96,000.00
Cable Tray, Lightning Protection System, Fire Protection System, Module Cleaning System, Health & Safety Equipment, Erection Tools and Materials, Air Conditioner, Gas Generator	11.00	132,000.00
Logistics		
Land Freight	2.50	30,000.00
C&F and Customs Expenses	30.00	360,000.00
Total Erection & Procurement	**642.50**	**7,710,000.00**
Civil Construction		
Subsoil investigation	1.00	12,000.00
Land Development & MMS Base Construction	65.00	780,000.00
Inverter Station, Main Control Room & Others Construction	15.00	180,000.00
Internal Road	3.00	36,000.00
Boundary & Internal Fencing with illumination	4.50	54,000.00
Total Construction	**88.50**	**1,062,000.00**
Consultancy & Government Approval		
Consultancy Fees, Government Approval & Documentation	10.00	**120,000.00**
Total Project Costs		**8,892,000.00**
	USD/KW	USD/Watt
	889.20	**0.89**

1) Inverter Transformer, LT & HT Switchgear, SCADA, Energy Meters, Weather Station, Plant Earthing etc.

Appendix 4: Operation and Maintenance Cost for 20 year

YEAR	Salaries	Dormitory Rent	Utilities	Stationary	Transport	Miscellaneous (Including Mobile Bill)	Land Lease	Insurance charge (0.15% of Total Project Cost)	Scheduled Maintenance	Total Operation & Maintenance Cost in BDT	Total Operation & Maintenance Cost in USD
1	7,164,000.00	600,000.00	240,000.00	180,000.00	360,000.00	600,000.00	3,250,000.00	1,133,730.00	7,500,000.00	21,027,730.00	
2	7,701,300.00	645,000.00	258,000.00	193,500.00	387,000.00	645,000.00	3,493,750.00	1,133,730.00	8,062,500.00	22,519,780.00	
3	8,238,600.00	690,000.00	276,000.00	207,000.00	414,000.00	690,000.00	3,737,500.00	1,133,730.00	8,625,000.00	24,011,830.00	
4	8,775,900.00	735,000.00	294,000.00	220,500.00	441,000.00	735,000.00	3,981,250.00	1,133,730.00	9,187,500.00	25,503,880.00	
5	9,313,200.00	780,000.00	312,000.00	234,000.00	468,000.00	780,000.00	4,225,000.00	1,133,730.00	9,750,000.00	26,995,930.00	
6	9,850,500.00	825,000.00	330,000.00	247,500.00	495,000.00	825,000.00	4,468,750.00	1,133,730.00	10,312,500.00	28,487,980.00	
7	10,387,800.00	870,000.00	348,000.00	261,000.00	522,000.00	870,000.00	4,712,500.00	1,133,730.00	10,875,000.00	29,980,030.00	
8	10,925,100.00	915,000.00	366,000.00	274,500.00	549,000.00	915,000.00	4,956,250.00	1,133,730.00	11,437,500.00	31,472,080.00	
9	11,462,400.00	960,000.00	384,000.00	288,000.00	576,000.00	960,000.00	5,200,000.00	1,133,730.00	12,000,000.00	32,964,130.00	
10	11,999,700.00	1,005,000.00	402,000.00	301,500.00	603,000.00	1,005,000.00	5,443,750.00	1,133,730.00	12,562,500.00	34,456,180.00	8,282,871.76
11	12,537,000.00	1,050,000.00	420,000.00	315,000.00	630,000.00	1,050,000.00	5,687,500.00	1,133,730.00	13,125,000.00	35,948,230.00	
12	13,074,300.00	1,095,000.00	438,000.00	328,500.00	657,000.00	1,095,000.00	5,931,250.00	1,133,730.00	13,687,500.00	37,440,280.00	
13	13,611,600.00	1,140,000.00	456,000.00	342,000.00	684,000.00	1,140,000.00	6,175,000.00	1,133,730.00	14,250,000.00	38,932,330.00	
14	14,148,900.00	1,185,000.00	474,000.00	355,500.00	711,000.00	1,185,000.00	6,418,750.00	1,133,730.00	14,812,500.00	40,424,380.00	
15	14,686,200.00	1,230,000.00	492,000.00	369,000.00	738,000.00	1,230,000.00	6,662,500.00	1,133,730.00	15,375,000.00	41,916,430.00	
16	15,223,500.00	1,275,000.00	510,000.00	382,500.00	765,000.00	1,275,000.00	6,906,250.00	1,133,730.00	15,937,500.00	43,408,480.00	
17	15,760,800.00	1,320,000.00	528,000.00	396,000.00	792,000.00	1,320,000.00	7,150,000.00	1,133,730.00	16,500,000.00	44,900,530.00	
18	16,298,100.00	1,365,000.00	546,000.00	409,500.00	819,000.00	1,365,000.00	7,393,750.00	1,133,730.00	17,062,500.00	46,392,580.00	
19	16,835,400.00	1,410,000.00	564,000.00	423,000.00	846,000.00	1,410,000.00	7,637,500.00	1,133,730.00	17,625,000.00	47,884,630.00	
20	17,372,700.00	1,455,000.00	582,000.00	436,500.00	873,000.00	1,455,000.00	7,881,250.00	1,133,730.00	18,187,500.00	49,376,680.00	

Appendix 5: Total 20 Year Life Cycle Generation

Total Life Cycle Operation of the 10MW solar power Plant				
YEAR	kWh	YEAR	kWh	
Year1	19,164,707.60	Year11	18,045,380.40	**Total Life Cycle Generation**
Year2	19,049,719.36	Year12	17,937,108.12	
Year3	18,935,421.04	Year13	17,829,485.47	
Year4	18,821,808.51	Year14	17,722,508.56	
Year5	18,708,877.66	Year15	17,616,173.51	**kWh = 362,213,228.09**
Year6	18,596,624.40	Year16	17,510,476.46	**MWh = 362,213.23**
Year7	18,485,044.65	Year17	17,405,413.61	**GWh = 362.21**
Year8	18,374,134.38	Year18	17,300,981.12	
Year9	18,263,889.58	Year19	17,197,175.24	
Year10	18,154,306.24	Year20	17,093,992.19	

Appendix 6: Cashflow Statement for 20 Year (100% equity finance)

YEAR	Capital Investment (USD)	Energy Generation (kWh)	Unit Price of Electricity (USD/kWh)	Total Revenue (USD/Year)	Operation & Maintenance Cost (USD/Year)	Net Cash Flow (USD/Year)	Present Value (USD)	Cumulative Cash Flow (USD)
0	8,892,000.00					- 8,892,000.00		
1	-	19,164,707.60	0.094	1,801,482.51	247,385.06	1,554,097.46	1,438,979.13	1,554,097.46
2	-	19,049,719.36	0.094	1,790,673.62	264,938.59	1,525,735.03	1,308,071.87	3,079,832.49
3	-	18,935,421.04	0.094	1,779,929.58	282,492.12	1,497,437.46	1,188,714.13	4,577,269.95
4	-	18,821,808.51	0.094	1,769,250.00	300,045.65	1,469,204.35	1,079,909.06	6,046,474.30
5	-	18,708,877.66	0.094	1,758,634.50	317,599.18	1,441,035.32	980,744.43	7,487,509.62
6	-	18,596,624.40	0.094	1,748,082.69	335,152.71	1,412,929.99	890,385.56	8,900,439.61
7	-	18,485,044.65	0.094	1,737,594.20	352,706.24	1,384,887.96	808,068.82	10,285,327.57
8	-	18,374,134.38	0.094	1,727,168.63	370,259.76	1,356,908.87	733,095.64	11,642,236.44
9	-	18,263,889.58	0.094	1,716,805.62	387,813.29	1,328,992.33	664,827.04	12,971,228.77
10	-	18,154,306.24	0.094	1,706,504.79	405,366.82	1,301,137.96	602,678.63	14,272,366.73
11	600,000.00	18,045,380.40	0.094	1,696,265.76	422,920.35	673,345.40	288,786.30	14,945,712.13
12	-	17,937,108.12	0.094	1,686,088.16	440,473.88	1,245,614.28	494,650.57	16,191,326.41
13	-	17,829,485.47	0.094	1,675,971.63	458,027.41	1,217,944.22	447,835.56	17,409,270.64
14	-	17,722,508.56	0.094	1,665,915.80	475,580.94	1,190,334.86	405,262.65	18,599,605.50
15	-	17,616,173.51	0.094	1,655,920.31	493,134.47	1,162,785.84	366,558.59	19,762,391.34
16	-	17,510,476.46	0.094	1,645,984.79	510,688.00	1,135,296.79	331,382.31	20,897,688.13
17	-	17,405,413.61	0.094	1,636,108.88	528,241.53	1,107,867.35	299,422.15	22,005,555.48
18	-	17,300,981.12	0.094	1,626,292.23	545,795.06	1,080,497.17	270,393.37	23,086,052.64
19	-	17,197,175.24	0.094	1,616,534.47	563,348.59	1,053,185.88	244,035.87	24,139,238.53
20	-	17,093,992.19	0.094	1,606,835.27	580,902.12	1,025,933.15	220,112.12	25,165,171.68

Appendix 7: Cashflow Statement for 20 Year (60% equity & 40% debt finance)

Cash Streams Scenario for PPA-20								
Capital Investment (USD)	Energy Generation (kWh)	Unit Price of Electricity (USD/kWh)	Total Revenue (USD/Year)	Operation & Maintenance Cost (USD/Year)	Loan Interest Payment (USD/Year)	Net Cash Flow (USD/Year)	Present Value (USD)	Cumulative Cash Flow (USD)
8,892,000.00						- 8,892,000.00		
-	19,164,707.60	0.094	1,801,482.51	247,385.06	184,992.50	1,369,104.96	1,267,689.77	1,369,104.96
-	19,049,719.36	0.094	1,790,673.62	264,938.59	184,992.50	1,340,742.53	1,149,470.62	2,709,847.49
-	18,935,421.04	0.094	1,779,929.58	282,492.12	184,992.50	1,312,444.96	1,041,861.12	4,022,292.45
-	18,821,808.51	0.094	1,769,250.00	300,045.65	184,992.50	1,284,211.85	943,934.05	5,306,504.30
-	18,708,877.66	0.094	1,758,634.50	317,599.18	184,992.50	1,256,042.82	854,841.64	6,562,547.12
-	18,596,624.40	0.094	1,748,082.69	335,152.71	184,992.50	1,227,937.49	773,808.91	7,790,484.61
-	18,485,044.65	0.094	1,737,594.20	352,706.24	184,992.50	1,199,895.46	700,127.48	8,990,380.07
-	18,374,134.38	0.094	1,727,168.63	370,259.76	184,992.50	1,171,916.37	633,149.95	10,162,296.44
-	18,263,889.58	0.094	1,716,805.62	387,813.29	184,992.50	1,143,999.83	572,284.73	11,306,296.27
-	18,154,306.24	0.094	1,706,504.79	405,366.82	184,992.50	1,116,145.46	516,991.31	12,422,441.73
600,000.00	18,045,380.40	0.094	1,696,265.76	422,920.35		673,345.40	288,786.30	13,095,787.13
-	17,937,108.12	0.094	1,686,088.16	440,473.88		1,245,614.28	494,650.57	14,341,401.41
-	17,829,485.47	0.094	1,675,971.63	458,027.41		1,217,944.22	447,835.56	15,559,345.64
-	17,722,508.56	0.094	1,665,915.80	475,580.94		1,190,334.86	405,262.65	16,749,680.50
-	17,616,173.51	0.094	1,655,920.31	493,134.47		1,162,785.84	366,558.59	17,912,466.34
-	17,510,476.46	0.094	1,645,984.79	510,688.00		1,135,296.79	331,382.31	19,047,763.13
-	17,405,413.61	0.094	1,636,108.88	528,241.53		1,107,867.35	299,422.15	20,155,630.48
-	17,300,981.12	0.094	1,626,292.23	545,795.06		1,080,497.17	270,393.37	21,236,127.64
-	17,197,175.24	0.094	1,616,534.47	563,348.59		1,053,185.88	244,035.87	22,289,313.53
-	17,093,992.19	0.094	1,606,835.27	580,902.12		1,025,933.15	220,112.12	23,315,246.68

Appendix 8: Information summary of financial analysis (considered 100% equity)

Particulars	Value
Discount rate of interest or Opportunity cost of capital value	8.00%
Cash Inflow	13,063,913.81
Cash Outflow	9,492,000.00
Net Present Value (NPV)	3,571,913.81
Internal Rate of Return (IRR)	14.47%
Benefit to Cost Ratio (B/C) or Profitability Index (PI)	1.38
Payback Period (PBP)	6 Year & 1 Month
Yearly Average Production Cost	414,143.59
Levelized Cost of Energy (USD/kWh)	0.049

Appendix 9: Profitability indicators result comparison between two financing system (100% Equity Finance and 60% Equity & 40% Debt Finance at 9% interest rate)

Particulars	100% Equity Finance	60% Equity & 40% Debt Finance
Discount rate of interest	8.00%	8.00%
Cash Inflow	13,063,913.81	11,822,599.07
Cash Outflow	9,492,000.00	9,492,000.00
Net Present Value (NPV)	3,571,913.81	2,330,599.07
Internal Rate of Return (IRR)	14.47%	12.45%
Benefit to Cost Ratio (B/C)	1.38	1.25
Payback Period (PBP)	6 Year & 1 Month	7 Year & 1 Month
Yearly Average Production Cost	414,143.59	414,143.59
Levelized Cost of Energy (USD/kWh)	0.049	0.049