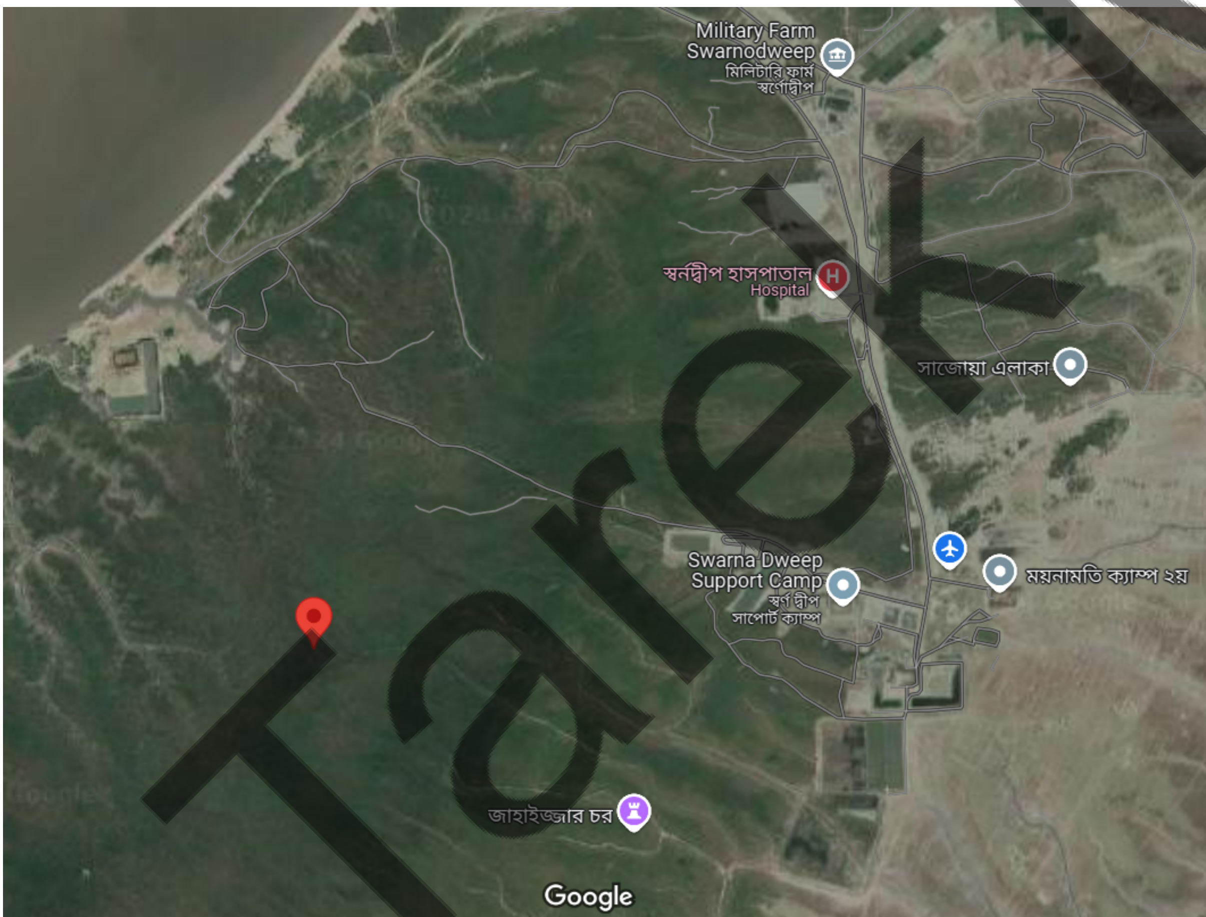
# Design of a Grid-Connected Solar Photovoltaic Power Plant for a School in Swarna Dweep



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# Chapter 1

# Introduction

## 1.1 Background of the Project

The design of a grid-connected solar photovoltaic power plant for a proposed school in Swarna Dweep, Bangladesh, addresses the critical issue of reliable electricity supply in remote island communities, which could significantly impact future educational quality and operational costs. Many remote areas in Bangladesh currently struggle with unreliable or non-existent grid connections, often relying on polluting diesel generators. Early literature, such as Hossain et al. (2023), highlights the potential of solar energy in Bangladesh's remote areas [1], while Ali et al.(2023) discuss the technical and economic feasibility of grid-connected solar PV systems [2]. State-of-the-art solar technology includes high-efficiency panels, smart inverters, and advanced energy management systems (Taft et al., 2023) [3]. Swarna Dweep's tropical climate offers abundant sunlight, motivating solar energy use, but also presents challenges like humidity and cyclones that affect system design and durability. The project's future may be influenced by evolving solar technologies, potential improvements in energy storage, and changes in Bangladesh's renewable energy policies, with the Sustainable and Renewable Energy Development Authority (SREDA) continuously updating regulations that could introduce new incentives or requirements for such projects.

## 1.2 Type of Project

The project is focused on providing renewable energy infrastructure specifically for the school, which serves as the primary consumer of the generated electricity. A thorough analysis of the school's energy consumption, detailed in Chapter 2, determined that a 60 kW solar power system is necessary to meet its electricity demands, covering essential functions such as lighting, heating, cooling, and educational equipment operation. This grid-connected system will allow excess energy to be fed back into the grid through net metering, reducing electricity costs and potentially generating revenue through energy credits. Ultimately, this project represents a strategic investment in sustainable energy, fulfilling the school's immediate energy needs while promoting environmental responsibility and serving as a model for renewable energy adoption in the educational sector.

## 1.3 Location

The proposed grid-connected solar photovoltaic power plant for the school in Swarna Dweep will be located at coordinates 22.544417° N, 91.303639° E, as shown in Figure 1.1. This location has been strategically selected based on data from the Global Solar Atlas, which indicated a high photovoltaic power output (PVOUT) for this specific site. The Global Solar Atlas provided crucial information on solar resource potential, allowing for an informed decision on the optimal placement of the solar power plant.

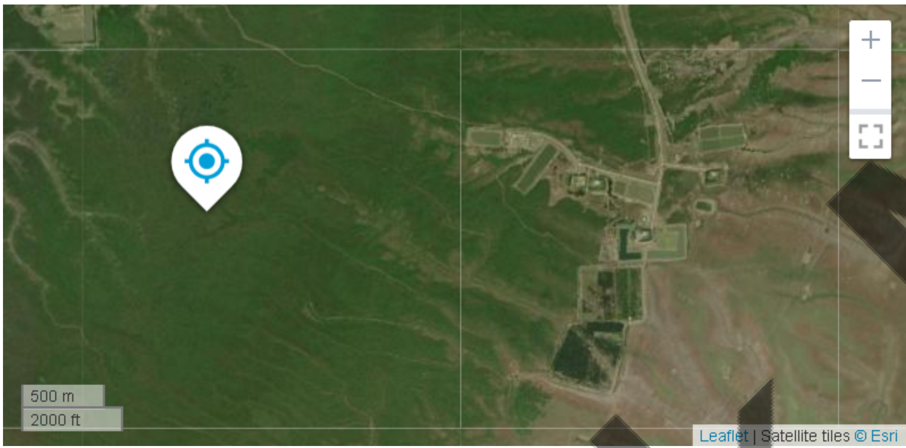



Figure 1.1: Location of the Solar Power Plant Site

The selected location that is seen on Figure 1.1 offers multiple favorable factors for a solar power installation. Primarily, it is in close proximity to the envisioned school site, which will ensure minimal transmission losses and reduce infrastructure costs. The high PVOUT at this location is critical for maximizing the system's efficiency and overall energy production.

Furthermore, other key solar energy parameters reinforce the suitability of this site. These include:

1. Substantial global irradiation levels, providing ample solar resources throughout the year.
2. Optimal dry bulb temperature range for photovoltaic panel operation, balancing energy production with system durability.
3. Favorable air mass, diffuse radiation, and wind speed conditions that contribute positively to the expected performance of the solar power plant.

By leveraging data from the Global Solar Atlas and considering these additional parameters, we have identified a location that provides an ideal balance between proximity to the school and optimal conditions for solar energy harvesting. This careful selection sets a strong foundation for the project's success and long-term viability, ensuring efficient and sustainable power generation for the school in Swarna Dweep.

# Chapter 2

# Demand Analysis

## 2.1 Load Demand

Load demand analysis is a crucial initial step in designing an efficient and reliable solar photovoltaic (PV) power system. This analysis is particularly important for projects like the proposed school in Swarna Dweep, as it provides essential insights into energy consumption patterns, peak load requirements, and overall electrical needs throughout the day. By conducting a thorough load demand analysis, designers can accurately size the solar PV system to ensure it meets the facility's energy demands without interruption. This process involves cataloging all electrical appliances, their power ratings, and their expected usage patterns, allowing for a comprehensive understanding of both instantaneous power requirements and total daily energy consumption.

**Formula:**

To calculate the hourly energy production required for each appliance, we use the following equation:

$$\text{Hourly energy production (W)} = \frac{\text{Total Energy (Wh)}}{\text{Operating Hours}} \tag{2.1}$$

For the school in Swarna Dweep, the load demand analysis encompasses a wide array of 388 appliances, each serving specific educational and operational purposes. These appliances are distributed across various areas of the school, including administration offices, classrooms, laboratories, common areas, and support facilities. The diversity of these appliances reflects the complex energy needs of a modern educational institution, ranging from basic lighting and fans to more power-intensive equipment such as air conditioners, computers, and laboratory apparatus. This comprehensive approach ensures that all potential energy demands are accounted for in the system design.

Table 2.1 provides a detailed breakdown of power consumption and energy usage for various areas within the school. It categorizes appliances by location, specifying the number of rooms for each area. The table includes columns for the type of appliance, its power rating in watts, the number of units, total power consumption, operating hours, and total energy usage in watt-hours. This structured approach allows for a clear understanding of how energy is distributed across different parts of the school. A key aspect of load demand analysis is determining the hourly energy production required to meet the school's needs. This can be calculated using the provided formula. While many areas exhibit a consistent hourly energy requirement, the machine room, specifically the water pump, demonstrates a difference due to its intermittent operation.

Table 2.1: Power Consumption and Energy Usage for Various Areas

| Place (No. of Rooms) | Appliances | Power (W) | No. of Units | Total Power (W) | Operating Hours | Total Energy (Wh) |
|---|---|---|---|---|---|---|
| Administration (4): Principal room, Teachers room, Conference, Auditorium | Light Bulb | 60 | 30 | 1800 | 6 | 10800 |
| | Fan | 80 | 4 | 320 | 6 | 1920 |
| | AC | 1885 | 7 | 13195 | 3 | 39585 |
| | Refrigerator | 85 | 2 | 170 | 6 | 1020 |
| | TV Station | 75 | 2 | 150 | 2 | 300 |
| | Smart Board | 300 | 1 | 300 | 2 | 600 |
| | Sound Box | 180 | 4 | 720 | 2 | 1440 |
| | Mesh Wi-Fi | 22.32 | 2 | 44.64 | 6 | 267.84 |
| | Printer | 710 | 2 | 1420 | 3 | 4260 |
| | Computer | 854 | 3 | 2562 | 6 | 15372 |
| Classrooms (15) | Light Bulb | 60 | 135 | 8100 | 6 | 48600 |
| | Fan | 80 | 90 | 7200 | 6 | 43200 |
| | Smart Board | 300 | 15 | 4500 | 6 | 27000 |
| Lab Room (3): Physics Lab, Chemistry Lab, Biology Lab | Light Bulb | 60 | 18 | 1080 | 4 | 4320 |
| | Fan | 80 | 15 | 1200 | 4 | 4800 |
| | Computer | 854 | 5 | 4270 | 4 | 17080 |
| Common Room (1) | Light Bulb | 60 | 2 | 120 | 4 | 480 |
| | Fan | 80 | 2 | 160 | 4 | 640 |
| Library (1) | Light Bulb | 60 | 6 | 360 | 4 | 1440 |
| | Fan | 80 | 8 | 640 | 4 | 2560 |
| Washroom (5) | Light Bulb | 18 | 10 | 180 | 6 | 1080 |
| | Exhaust Fan | 40 | 5 | 200 | 6 | 1200 |
| Security Room (1) | Light Bulb | 18 | 1 | 18 | 6 | 108 |
| | Fan | 80 | 2 | 160 | 6 | 960 |
| | Exhaust Fan | 40 | 1 | 40 | 6 | 240 |
| | Monitor | 40 | 1 | 40 | 6 | 240 |
| | CC Camera | 4.5 | 5 | 22.5 | 6 | 135 |
| Machine Room (1) | Pump | 1492 | 1 | 1492 | 0.22 | 328.24 |
| | Exhaust Fan | 40 | 1 | 40 | 0.5 | 20 |
| Canteen (1) | Oven | 1300 | 1 | 1300 | 1 | 1300 |
| | Water Filter | 40 | 2 | 80 | 6 | 480 |
| | Fan | 80 | 4 | 320 | 1 | 320 |
| | Coffee Maker | 820 | 1 | 820 | 6 | 4920 |
| | | | | 53024.14 | | 237016.08 |

It also reveals significant power requirements across various areas of the school. The administration area, comprising four rooms, exhibits substantial energy needs, with air conditioning units contributing 13,195 watts. Fifteen classrooms are equipped with essential items such as light bulbs, fans, and smart boards. Specialized areas like laboratories are outfitted with additional equipment, reflecting their technical nature. Support facilities, including the security room, machine room, and canteen, are allocated resources specific to their functions. A high-power water pump in the machine room and food preparation appliances in the canteen are noted as crucial components. The analysis indicates a maximum instantaneous power demand of approximately 53,024.14 watts and a cumulative daily energy consumption of 237,016.08 watt-hours. These figures serve as a foundation for designing a solar PV system capable of meeting the school's diverse energy needs and ensuring an uninterrupted power supply for all operations.

## 2.2 The Daily Load Curve

The daily load curve provides a comprehensive view of the energy consumption patterns throughout a typical school day, offering invaluable insights into peak demand periods and variations in power usage. This detailed analysis is essential for ensuring that the solar PV system can meet the school's energy needs efficiently and reliably, accounting for the dynamic nature of energy consumption in an educational setting.

Table 2.2 provides a detailed breakdown of power consumption and energy usage for various areas within the school. It categorizes appliances by location, specifying the number of rooms for each area. The table includes columns for the type of appliance and the hourly energy consumption from 8 AM to 2 PM. This structured approach allows for a clear understanding of how energy is distributed across different parts of the school during specific hours of the day.

Table 2.2: Appliance Energy Consumption Table

| Place (No. of rooms) | Appliances | 8-9 h | 9-10 h | 10-11 h | 11-12 h (Break) | 12-13 h | 13-14 h |
|---|---|---|---|---|---|---|---|
| Administration (4):<br>Principal room<br>Teachers room<br>Conference<br>Auditorium | Light Bulb | 1800 | 1800 | 1800 | 1800 | 1800 | 1800 |
| | Fan | 320 | 320 | 320 | 320 | 320 | 320 |
| | AC | | | 13195 | 13195 | 13195 | |
| | Refrigerator | 170 | 170 | 170 | 170 | 170 | 170 |
| | TV Station | | 150 | | 150 | | |
| | Smart Board | | | 300 | 300 | | |
| | Sound Box | | | 720 | 720 | | |
| | Mesh WI-FI | 44.64 | 44.64 | 44.64 | 44.64 | 44.64 | 44.64 |
| | Omni Printer | 1420 | | 1420 | | 1420 | |
| | Computer | 2562 | 2562 | 2562 | 2562 | 2562 | 2562 |
| Classroom (15) | Light Bulb | 8100 | 8100 | 8100 | 8100 | 8100 | 8100 |
| | Fan | 7200 | 7200 | 7200 | 7200 | 7200 | 7200 |
| | Smart Board | 4500 | 4500 | 4500 | 4500 | 4500 | 4500 |
| Lab Room (3):<br>Physics Lab<br>Chemistry Lab<br>Biology Lab | Light Bulb | 1080 | | 1080 | | 1080 | 1080 |
| | Fan | 1200 | | 1200 | | 1200 | 1200 |
| | Computer | | 4270 | 4270 | 4270 | 4270 | |
| Common Room (1) | Light Bulb | | 120 | 120 | 120 | 120 | |
| | Fan | | 160 | 160 | 160 | 160 | |
| Library (1) | Light Bulb | | 360 | 360 | 360 | 360 | |
| | Fan | | 640 | 640 | 640 | 640 | |
| Washroom (5) | Light Bulb | | 180 | 180 | 180 | 180 | |
| | Exhaust Fan | 200 | 200 | 200 | 200 | 200 | 200 |
| Security Room (1) | Light Bulb | 18 | 18 | 18 | 18 | 18 | 18 |
| | Fan | 160 | 160 | 160 | 160 | 160 | 160 |
| | Exhaust Fan | 40 | 40 | 40 | 40 | 40 | 40 |
| | Monitor | 40 | 40 | 40 | 40 | 40 | 40 |
| | CC Camera | 22.5 | 22.5 | 22.5 | 22.5 | 22.5 | 22.5 |
| Machine Room (1) | Pump | | 164.12 | | | 164.12 | |
| | Exhaust Fan | | 10 | | | 10 | |
| Canteen (1) | Fan | | | | 320 | | |
| | Water Filter | 80 | 80 | 80 | 80 | 80 | 80 |
| | Coffee Maker | 820 | 820 | 820 | 820 | 820 | 820 |
| | Oven | | | | 1300 | | |

To visualize the energy consumption of various appliances over time, we can plot a graph using the summation of wattage for each hour. The table provides the total wattage consumed by all appliances for each hour from 8 AM to 2 PM. After converting wattage to kilowatt, and plotting these values on a graph, with time on the x-axis and wattage on the y-axis, we can see the fluctuations in energy usage throughout the day.

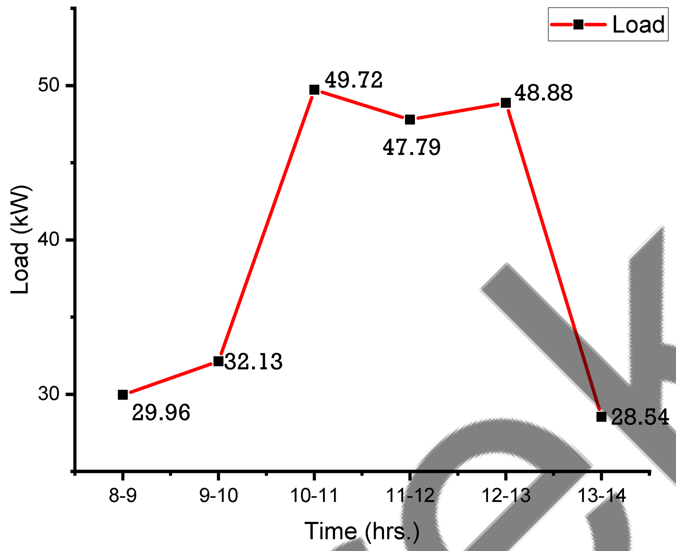



Figure 2.1: Load Curve

Here, figure 2.1 reveals significant hourly variations in energy consumption, with a notable peak demand period occurring from 10 AM to 1 PM. This three-hour window coincides with the core hours of school activities, likely due to the simultaneous operation of multiple classrooms, laboratories, and administrative facilities at full capacity. The concentration of peak demand during these hours underscores the importance of designing a system capable of meeting these intense energy requirements. Outside this peak window, the load profile shows a more moderate demand, possibly corresponding to preparatory activities in the early morning and wind-down periods in the early afternoon.

This detailed understanding of the load distribution allows for strategic system design, potentially incorporating energy storage solutions to manage peak loads effectively. By carefully analyzing these load demands and their temporal distribution, the solar PV system can be optimized to enhance energy efficiency measures and implement load management strategies to effectively handle the identified peak periods while ensuring reliable power supply throughout the school day.

Chapter 3

# Resource Assessment

## 3.1 Detailed Resources Assessment

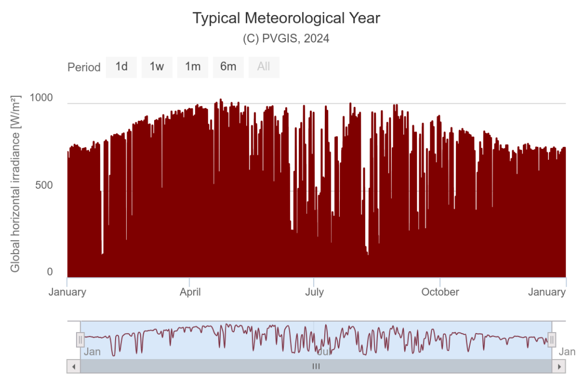
Resource assessment is crucial for designing and implementing a grid-connected solar photovoltaic power plant for the proposed school in Swarna Dweep. This assessment directly impacts the system's performance, efficiency, and viability. The project site's solar potential is influenced by its geographical location, including latitude, which affects the sun's angle and daily sunlight duration. Local climate conditions along with potential shading from nearby structures or vegetation, are also key factors in determining the available solar resources.

For this resource assessment, we employed the Photovoltaic Geographical Information System (PVGIS), developed by the European Commission's Joint Research Centre. PVGIS combines satellite data with advanced algorithms to provide accurate, site-specific solar radiation and PV system performance simulations. Inputting the coordinates 22.544° N, 91.304° E for Swarna Dweep, the PVGIS-SARAH database produced promising results are shown in table 3.1 below. Detailed calculations for the 60 kW solar plant capacity will be presented in Chapter 4.

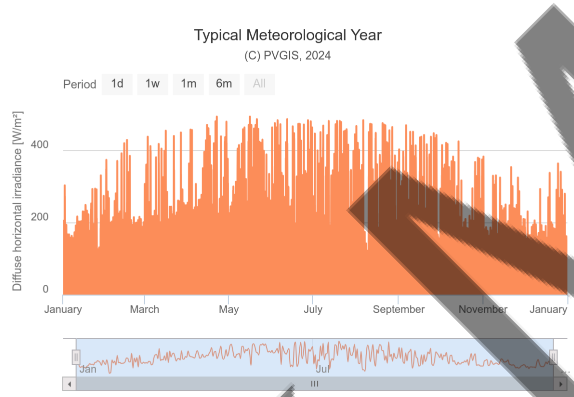
Table 3.1: Provided inputs and simulation outputs for the PV system (PVGIS)

| | |
|---|---|
| **Provided inputs:** | |
| **Location [Lat/Lon]:** | 22.544, 91.304 |
| **Horizon:** | Calculated |
| **Database used:** | PVGIS-SARAH |
| **PV technology:** | Crystalline silicon |
| **PV installed [kW]:** | 60 |
| **System loss [-]:** | 14 |
| **Simulation outputs:** | |
| **Slope angle [°]:** | 27 (opt) |
| **Azimuth angle [°]:** | 7 (opt) |
| **Yearly PV energy production [kWh]:** | 89333.73 |
| **Yearly in-plane irradiation [kWh/m²]:** | 1979.73 |
| **Year-to-year variability [kWh]:** | 2971.51 |
| **Changes in output due to:** | |
| **Angle of incidence [-]:** | -2.64 |
| **Spectral effects [-]:** | NaN |
| **Temperature and low irradiance [-]:** | -10.18 |
| **Total loss [-]:** | -24.79 |

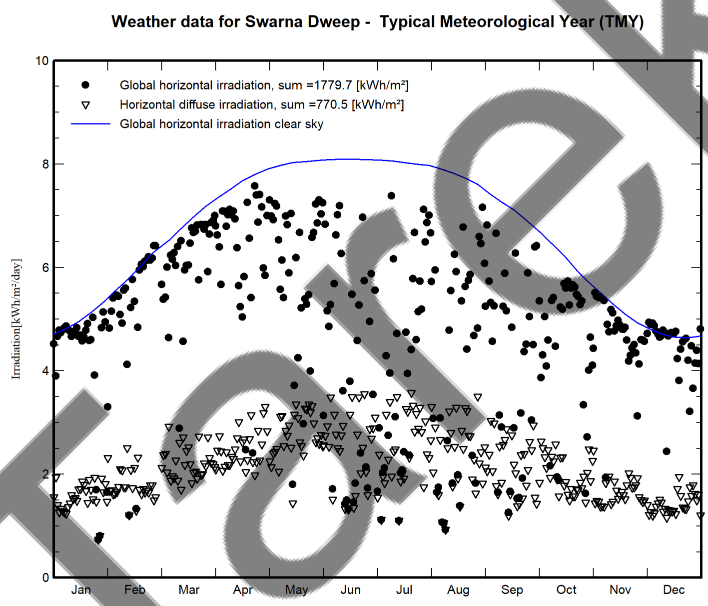
With an annual energy production of 89,333.73 kWh and a substantial yearly in-plane irradiation of 1,979.73 $kWh/m^2$, the chosen location demonstrates excellent solar resource potential. The optimized tilt (27°) and azimuth (7°) angles will maximize energy capture, enhancing system efficiency. While the total system loss of 24.79% is present, it remains within acceptable parameters for the given geographical context. These results validate the site selection and system sizing, providing a robust foundation for detailed design and financial analysis.




(a) Global Horizontal Irradiance (2005-2016)




(b) Horizontal Diffuse Irradiance (2005-2016)




(c) Global Horizontal and Horizontal Diffuse Irradiation (1990)

Figure 3.1: Comparison of (a) Global Horizontal Irradiance and (b) Horizontal Diffuse Irradiance with (c) Global Horizontal and Horizontal Diffuse Irradiation

The comparison of Global Horizontal Irradiance (GHI) and Horizontal Diffuse Irradiance (HDI) data from the PVGIS-SARAH database (2005-2016) with the Typical Meteorological Year (TMY) data from 1990 validates the accuracy of the more recent dataset. Figures 3.1(a) and 3.1(b) depict GHI and HDI, while figure 3.1(c) illustrates the TMY data. The observed similarity between these datasets underscores the reliability of PVGIS-SARAH data for current solar resource assessments, ensuring precise solar energy planning and system optimization.

Figure 3.2 presents monthly in-plane irradiation data for a fixed-angle solar installation at the Swarna Dweep project site, simulated by PVGIS. It reveals significant seasonal variations in solar resource availability throughout the year.

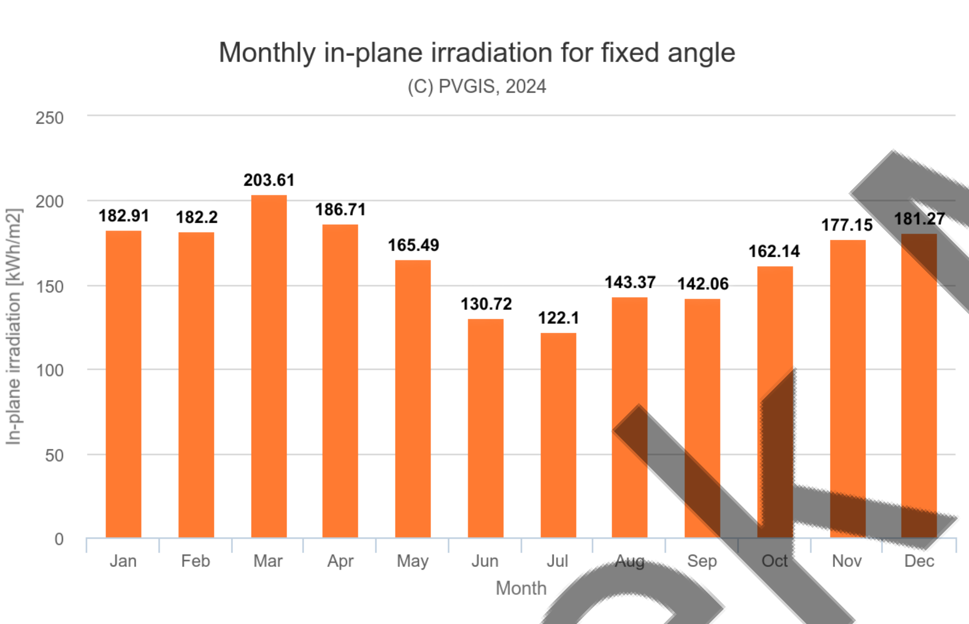



Figure 3.2: Monthly in-plane irradiance for fixed angle

March exhibits the peak irradiation at 203.61 kWh/m², while July records the lowest at 122.1 kWh/m². This information is vital for system design and performance predictions. Notably, July is identified as the critical "worst month" for solar resource availability, which will be a key consideration in sizing the PV array and associated components.

Table 3.2: Monthly Irradiation and Temperature Data (2005-2016)

| **Month** | **H(h)_m** | **T2m (°C)** |
|---|---|---|
| Jan | 139.37 | 20.39 |
| Feb | 150.47 | 23.23 |
| Mar | 187.22 | 26.93 |
| Apr | 189.60 | 28.68 |
| May | 179.04 | 28.83 |
| Jun | 144.16 | 28.47 |
| Jul | 132.98 | 27.87 |
| Aug | 149.27 | 27.90 |
| Sep | 137.52 | 28.13 |
| Oct | 141.91 | 27.58 |
| Nov | 138.24 | 25.04 |
| Dec | 133.35 | 21.53 |

Table 3.2 accurately assesses which month can generate the lowest solar power, data from 2005 to 2016 was analyzed using the PVGIS-SARAH radiation database. This analysis focused on two key parameters, *H(h)_m*: Irradiation on the horizontal plane (kWh/m²/mo) and *T2m*: 24-hour average temperature (°C). The data provides insights into the variability of solar irradiation and temperature across different months. For instance, July recorded the lowest

irradiation at 132.98 kWh/m²/mo, while December had the lowest temperature at 21.53°C. By evaluating these figures, a comprehensive understanding of the least favorable conditions for solar energy generation is achieved, ensuring that the design accommodates even the most challenging periods.

Table 3.3: Hourly Global Irradiance and Temperature Data for July

| Time (UTC+6) | G(i) (W/m²) | T2m (°C) |
|---|---|---|
| 06:00 | 24.37 | 27.18 |
| 07:00 | 69.03 | 27.19 |
| 08:00 | 163.74 | 27.50 |
| 09:00 | 285.31 | 28.25 |
| 10:00 | 405.76 | 28.16 |
| 11:00 | 484.26 | 28.38 |
| 12:00 | 534.99 | 28.45 |
| 13:00 | 546.21 | 28.47 |
| 14:00 | 496.33 | 28.58 |
| 15:00 | 403.76 | 28.71 |
| 16:00 | 300.63 | 28.28 |
| 17:00 | 166.48 | 28.33 |
| 18:00 | 55.11 | 28.36 |

In July, identified as the worst month for solar power generation, daily data provides an hourly breakdown of global irradiance on a fixed plane [G(i)] and the 2-meter air temperature (T2m). As shown in Table 3.3, irradiance gradually increases from early morning, peaks at 13:00 UTC+6 with 546.21 W/m², and then decreases toward evening. The temperature remains stable at around 28°C throughout the day. The school operates from 8 AM to 2 PM, so the focus is on the irradiance between 8:00 and 14:00 which are highlighted in blue. During these hours, irradiance rises from 163.74 W/m² at 8:00 to 496.33 W/m² at 14:00, indicating substantial solar energy potential during school hours, even in the worst-performing month. This analysis is crucial for optimizing the solar power system to meet the school's energy needs.

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 - 1 | | | | | | | | | | | | |
| 1 - 2 | | | | | | | | | | | | |
| 2 - 3 | | | | | | | | | | | | |
| 3 - 4 | | | | | | | | | | | | |
| 4 - 5 | | | | | | | | | | | | |
| 5 - 6 | | | | 0.050 | 0.265 | 0.299 | 0.218 | 0.048 | | | | |
| 6 - 7 | 0.027 | 0.168 | 0.913 | 2.815 | 3.541 | 2.942 | 2.594 | 2.206 | 2.216 | 1.871 | 1.394 | 0.140 |
| 7 - 8 | 5.127 | 6.446 | 8.718 | 10.656 | 9.980 | 7.432 | 6.774 | 6.889 | 7.770 | 10.667 | 11.421 | 6.931 |
| 8 - 9 | 15.656 | 17.841 | 19.090 | 20.371 | 17.865 | 13.079 | 12.473 | 13.466 | 15.238 | 19.932 | 22.834 | 18.012 |
| 9 - 10 | 25.829 | 28.535 | 28.916 | 28.820 | 24.791 | 19.005 | 18.884 | 20.570 | 22.513 | 27.646 | 31.891 | 27.750 |
| 10 - 11 | 33.652 | 36.921 | 36.531 | 34.801 | 29.478 | 23.211 | 23.935 | 25.872 | 28.192 | 32.913 | 37.681 | 35.112 |
| 11 - 12 | 38.375 | 41.254 | 40.668 | 37.710 | 32.127 | 25.826 | 26.800 | 29.039 | 31.247 | 34.966 | 40.096 | 38.906 |
| 12 - 13 | 39.502 | 42.312 | 41.254 | 37.665 | 31.668 | 26.375 | 27.804 | 30.007 | 31.925 | 34.447 | 39.065 | 38.813 |
| 13 - 14 | 36.660 | 39.729 | 38.778 | 35.051 | 29.088 | 24.835 | 26.970 | 28.871 | 30.643 | 31.857 | 35.032 | 35.023 |
| 14 - 15 | 30.225 | 33.512 | 33.034 | 29.594 | 24.509 | 21.112 | 23.265 | 24.815 | 26.150 | 25.852 | 27.460 | 27.820 |
| 15 - 16 | 20.496 | 24.105 | 23.674 | 21.142 | 17.465 | 15.570 | 17.141 | 18.204 | 17.723 | 16.429 | 17.482 | 17.722 |
| 16 - 17 | 8.200 | 11.942 | 12.651 | 11.367 | 9.800 | 9.132 | 10.105 | 10.120 | 8.609 | 6.161 | 3.660 | 4.465 |
| 17 - 18 | 0.220 | 1.002 | 2.370 | 2.542 | 3.063 | 3.361 | 3.820 | 2.959 | 1.114 | 0.094 | | |
| 18 - 19 | | | | | 0.058 | 0.181 | 0.234 | 0.046 | | | | |
| 19 - 20 | | | | | | | | | | | | |
| 20 - 21 | | | | | | | | | | | | |
| 21 - 22 | | | | | | | | | | | | |
| 22 - 23 | | | | | | | | | | | | |
| 23 - 24 | | | | | | | | | | | | |
| Sum | 254 | 284 | 287 | 273 | 234 | 192 | 201 | 213 | 223 | 243 | 268 | 251 |

Source: globalsolaratlas.info

Figure 3.3: Average hourly solar radiation data from Global Solar Atlas

Here, the Global Solar Atlas was used alongside PVGIS to enhance the resource assessment for the site. It provided average hourly solar radiation data, displayed in a heatmap chart that shows the temporal distribution across hours of the day and months of the year. The vertical axis represents hours, the horizontal axis represents months, and a green-to-red color gradient indicates the intensity of solar radiation, with green for lower levels and red for higher levels. In figure 3.3, it is observed that peak solar radiation occurs during midday hours across all months, with the highest intensities recorded from May to August. Conversely, the lowest irradiance levels are noted during early morning and late evening hours throughout the year. The monthly sums of daily average irradiance values, displayed at the bottom of the chart, ranged from 2.54 kWh/m$^2$/day in December to 7.34 kWh/m$^2$/day in May.

This detailed hourly data from the Global Solar Atlas is crucial for accurately predicting solar energy production and optimizing the design of photovoltaic systems for enhanced efficiency and reliability. By incorporating this data, a more comprehensive understanding of the site's solar potential is achieved, thereby facilitating better decision-making for solar power projects.

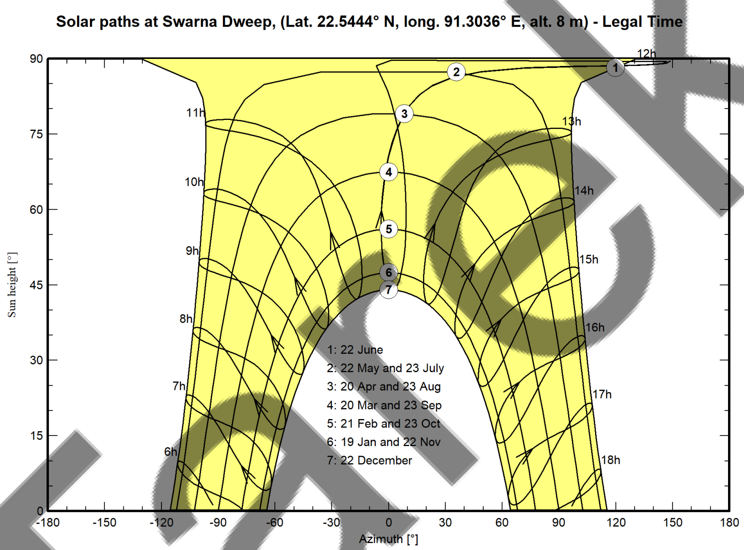



Figure 3.4: Solar path at Swarna Dweep

The solar path diagram from figure 3.4 enables precise determination of optimal panel orientation and tilt angles, facilitating maximum solar irradiance capture throughout the year. Furthermore, it allows for accurate shading analysis, critical in educational environments where buildings and vegetation may cast shadows at various times. By leveraging this information, we can strategically position arrays to minimize energy losses and maximize the system's overall efficiency.

## 3.2 Key Findings

1. **Optimal Slope and Azimuth Angles**:

   - **Slope Angle:** 27°
   - **Azimuth Angle:** 7°

   These angles were found to be optimal for maximizing solar energy capture at the project site. Proper orientation of the solar panels is crucial for enhancing energy production efficiency throughout the year.

2. **Yearly PV Energy Production:** 89,333.73 kWh
   This estimated annual energy production confirms that the designed system meets the energy needs of the school, providing a reliable source of power.

3. **Yearly In-Plane Irradiation:** 1,979.73 kWh/m²
   This value represents the total solar energy received by the panel surface over the year, supporting the selection of the optimal tilt and orientation angles.

4. **Horizontal Plane Irradiation:** 132.98 kWh/m²/month
   The monthly horizontal irradiation data provides insight into the baseline solar energy available in the region, validating the system's expected performance throughout the year.

5. **Monthly Electricity Generation:**

   - **April:** 13,695.56 kWh (highest)
   - **June:** 4,259.83 kWh (lowest)

   Monthly variations in electricity generation were observed, with April producing the highest output due to optimal sun hours and June the lowest, emphasizing the need for strategic planning in energy management.

6. **Total Estimated Yearly Electricity Generation:** 109,915.78 kWh
   This total ensures the system's capability to meet the school's annual electricity demands, confirming the viability of the solar PV system design.

7. **Solar Path Analysis:**

   - **Location:** Swarna Dweep (22.5444° N, 91.3036° E)

   **Impact on Design:** The solar path diagram highlights the sun's trajectory across the sky throughout the year, with key dates like the solstices and equinoxes marking the extremes. This analysis is crucial for determining the optimal panel orientation to maximize solar exposure during school hours, thereby enhancing system performance. Understanding the sun's height and azimuth angles throughout the year helps in designing a system that captures the maximum solar energy, especially during the school's operational hours from 8:00 AM to 2:00 PM.

# Chapter 4

# Selection of Conversion Technology

## 4.1 Overall System

### 4.1.1 Seasonal Sun Hours

Before determining the solar plant size, we need to identify the average sun hour throughout the year to generate enough electricity each month, even at the worst month giving the lowest sun hour. After that dividing by that average sun hour value we can establish how many kilowatt of power we need for our solar project.

Table 4.1: Seasonal Sun Hours in Swarna Dweep

| Season | Months | Sun Hours | Avg Sun Hours (Season) |
|---|---|---|---|
| Winter | Nov - Feb | 4.60, 4.30, 4.50, 5.37 | 4.69 |
| Summer | Mar - Jun | 6.04, 6.32, 5.78, 4.81 | 5.74 |
| Monsoon | Jul - Oct | 4.29, 4.82, 4.58, 4.58 | 4.57 |
| | | Avg of all seasons: | 5.00 |

The solar irradiance data for Swarna Dweep shows significant seasonal variations in table 4.1 above. Summer months (March-June) have the highest average sun hours at 5.74, indicating peak energy production potential. During the monsoon season (July-October), the average drops to 4.57 hours, with July at 4.29 hours. Despite an overall average of 5 sun hours (using equation 4.1), we'll conservatively use 4 sun hours for system design reliability in less favorable conditions. Winter (November-February) averages 4.69 sun hours, showing moderate exposure. This pattern suggests excess energy generation opportunities in summer and parts of winter, enhancing economic viability by feeding back to the grid. Design considerations should focus on consistent performance in low-irradiance periods while optimizing for higher irradiance seasons using efficient inverters and panel orientation to maximize annual energy yield and system resilience.

### 4.1.2 Solar System Sizing

The process of sizing a solar system is essential to ensure that the system can consistently meet the daily energy demands of the intended application. For this system, the daily electric load has been calculated to be approximately 240 kWh (237,016.08 Wh, rounded to 240 kWh). This value represents the total energy consumption of all connected appliances and devices over 24 hours.

**Formulas:**

$$[1]\ \text{Average Peak Sunshine Hours} = \frac{\text{Daily Sunshine Hours in Summer} + \text{Winter} + \text{Monsoon}}{3} \tag{4.1}$$

This formula calculates the average number of peak sunshine hours the location receives, taking into account the seasonal variations across summer, winter, and monsoon periods. Peak sunshine hours refer to the equivalent full hours of sunlight per day that are strong enough to generate the rated output of a solar panel. This average is crucial for accurate system sizing, as it ensures that the system can operate effectively throughout the year, even during periods with lower sunlight.

$$[2]\ \text{System Size (kW)} = \frac{\text{Daily Energy Demand (kWh)}}{\text{Average Peak Sunshine Hours}} \tag{4.2}$$

This formula determines the size of the solar system needed to meet the daily energy demand. By dividing the daily energy demand by the average peak sunshine hours, we calculate the required system capacity in kilowatts (kW). This ensures that the system is capable of generating enough electricity during the available sunlight hours to meet the energy needs of the system.

**Calculation**

Given that the average peak sunshine hours for the location are 4 hours, using equation 4.2 we get the following result,

$$\text{System Size} = \frac{240\ \text{kWh}}{4\ \text{hours}} = 60\ \text{kW}$$

Thus, the required solar system size is 60 kW (or 60,000 Watts). This sizing ensures that the solar system can generate enough electricity to meet the daily energy demand of 240 kWh. By basing the system size on average peak sunshine hours, we account for seasonal variations in sunlight, ensuring that the system provides consistent and reliable energy generation throughout the year. Designing the system to handle the average low sunshine periods ensures that energy production remains stable even during less favorable weather conditions.

### 4.1.3 Inverter Sizing

Inverter sizing is crucial for efficiently converting DC power from solar panels to AC power for appliance use. Our system's maximum rated power for all appliances is approximately 54 kW (53,024.14 W, rounded up for design margin).

**Formulas:**

$$[1]\ \text{Total Electrical Load (VA)} = \frac{\text{Maximum Rated Power (W)}}{\text{Power Factor (P.F)}} \tag{4.3}$$

This formula converts watts to volt-amperes, accounting for the power factor. We use a power factor of 0.95, as recommended by Global Sustainable Energy Solutions (GSES) in their published article. This value reflects the typical efficiency of modern electrical appliances under normal operating conditions.

$$[2]\ \text{Inverter Capacity (VA)} = \frac{\text{Total Electrical Load (VA)} \times \text{Correction Factor}}{\text{Inverter Efficiency}} \tag{4.4}$$

This formula determines the required inverter capacity, incorporating a correction factor for system reliability and accounting for inverter efficiency. We apply a correction factor of 1.25, which falls within the industry-standard range of 1.2 to 1.3. This factor provides a safety margin for temporary overloads and future system expansion, enhancing overall reliability and longevity.

#### Calculation:

Given: - Power factor = 0.95 (GSES recommendation) - Correction factor = 1.25 (within 1.2-1.3 industry standard range) - Inverter efficiency = 95

$$\text{Total Electrical Load (VA)} = \frac{54,000\ \text{W}}{0.95} = 56,842.11\ \text{VA} \approx 57,000\ \text{VA}$$

$$\text{Inverter Capacity (VA)} = \frac{57,000\ \text{VA} \times 1.25}{0.95} = 75,000\ \text{VA} = 75\ \text{kVA}$$

By using equations 4.3 and 4.4 respectively, the required inverter capacity is 75 kVA. This sizing ensures adequate handling of the maximum electrical load with a safety margin for potential overloads and future expansion. The 1.25 correction factor enhances system reliability and longevity. By incorporating the GSES-recommended power factor and industry-standard correction factor, we ensure the inverter can effectively support the entire solar power system under various operating conditions, providing a robust and future-proof design.

### 4.1.4 Transformer Selection

Transformer selection is critical for integrating the solar PV system with the grid, ensuring proper voltage matching and power quality. Our system requires a transformer that can handle the output of the selected inverter while accounting for power factor considerations.

#### Inverter Selection

Based on the calculated inverter capacity of 75 kVA, we have selected the MAX 80KTL3 LV inverter with an 80 kW capacity. This choice was made due to the unavailability of a 75 kVA inverter from the BSTI-approved list, opting for the nearest available capacity. Detailed specifications of this inverter are discussed in section 4.2.

#### Formula:

$$\text{[1] Transformer Capacity (kVA)} = \frac{\text{Inverter Rated Power (kW)}}{\text{Minimum Power Factor}} \tag{4.5}$$

This formula determines the required transformer capacity based on the inverter's rated power and its minimum power factor capability. The power factor range of the selected inverter is crucial in this calculation.

#### Calculation

Given:
- Inverter rated power = 80 kW
- Inverter adjustable power factor range = 0.8 leading to 0.8 lagging (Inverter Datasheet)

$$\text{Transformer Capacity (kVA)} = \frac{80\ \text{kW}}{0.8} = 100\ \text{kVA}$$

Therefore, using equation 4.5, the required transformer capacity is 100 kVA. This sizing ensures that the transformer can handle the full output of the inverter even at its minimum power factor setting. The calculation accounts for the inverter's ability to operate at power factors as low as 0.8, which is a common range for grid-tied inverters. This approach provides flexibility in system operation and ensures compatibility with grid requirements for power factor correction. The selected transformer capacity will adequately support the solar PV system's output while maintaining power quality and grid integration standards.

### 4.1.5 String Combiner Box (SCB)

The String Combiner Box (SCB) plays a critical role in solar photovoltaic (PV) systems, where it aggregates the output from multiple strings of solar panels into a unified DC output. The SCB is responsible for safeguarding, monitoring, and effectively managing the electrical flow from the solar array to the inverter.

#### SCB Configuration Based on Strings

The configuration of the SCB is determined by the number of strings utilized within the solar system. Each string, consisting of a series-connected group of solar panels, requires an appropriate SCB setup to ensure optimal performance and protection.

- **SCB 1/1:** Applicable for systems with a single string.
- **SCB 2/2:** Designed for systems with two strings, allowing for individual protection and monitoring of each string.
- **SCB 4/2:** Used in configurations involving four strings, where multiple strings are combined into pairs for efficient management.

Selecting the appropriate SCB configuration is essential for ensuring the safety, reliability, and operational efficiency of the solar array.

### 4.1.6 Net Meter (Bi-Directional Meter)

The net meter, or bi-directional meter, is an indispensable component of grid-connected solar PV systems. It accurately measures the electricity consumed from the grid and the surplus electricity generated by the solar system that is fed back into the grid. This metering system facilitates the bidirectional flow of energy, optimizing the financial return by tracking both energy usage and export.

### 4.1.7 Wiring Path

The wiring path in the solar photovoltaic (PV) system is meticulously designed to ensure efficient and safe transmission of electricity from the solar panels to the national grid. The sequence is as follows:

1. **Single String to SCB:** The electrical output from each string of solar panels is directed to the String Combiner Box (SCB).
2. **SCB to Inverter:** The SCB consolidates the DC output from multiple strings and directs it to the inverter for conversion from DC to AC.
3. **Inverter to Transformer:** The AC output from the inverter is then transmitted to the transformer, where it is adjusted to the appropriate voltage level.
4. **Transformer to Net Meter:** The adjusted AC voltage is conveyed to the net meter for precise energy monitoring and recording.
5. **Net Meter to National Grid:** Finally, the electricity is either consumed by the facility or exported to the national grid.

In designing this wiring path, careful consideration was given to the type and gauge (AWG) of wiring required to handle the electrical load efficiently over various distances. The following table outlines the selected wire gauges, their respective distances, and the associated costs:

Table 4.2: Wire Gauge Selection, Distance, and Cost

| **Gauge (AWG)** | **12 AWG** | **14 AWG** | **16 AWG** | **3/0 AWG** | **Total** |
|---|---|---|---|---|---|
| **Distance (m)** | 3289 | 25 | 80 | 150 | **3196** |
| **Price (BDT)** | 526,240 | 3,775 | 11,360 | 2,465 | **543,840** |

Table 4.2 highlights the careful selection of four different wire gauges based on the specific requirements of the installation. The total distance covered by the wiring is 3,196 meters, with a total cost of 543,840 BDT. Detailed calculations of wire size and wire gauge selection will be provided in chapter 5.

### 4.1.8 Lightning Arrester

We installed two lightning arresters for the solar plant project to protect the system from voltage surges caused by lightning strikes. We position one arrester on the primary, high-voltage side of the transformer to guard against direct strikes and surges on incoming power lines. The second arrester is placed on the secondary, low-voltage side to protect downstream solar equipment, including inverters and combiner boxes. This strategy ensures comprehensive protection for both high-voltage and low-voltage components, thereby enhancing the system's reliability and longevity.

### 4.1.9 Other Accessories

The installation of solar panels at a precise 27-degree tilt angle requires careful planning and the use of specialized materials. To ensure both stability and optimal performance, two main components are critical: column supports and fasteners. Below is a detailed breakdown of the materials and costs involved:

#### Column Supports

1. Base Columns: Two 20-meter columns per string cost 351.35 USD (41,259 BDT) each [4]
2. Angle Support Columns: Ten 2-meter columns distributed among 14 panels per string cost around 8.78 USD (1,031 BDT) each [4]

For 7 strings, the total column cost is calculated as:

$$(2 \times 7 \times 41,259) + (2 \times 10 \times 7 \times 1,031) = 721,966 \text{ BDT}$$

#### Fasteners

1. For 20-meter columns: 4 fasteners per string at 1 USD each
2. For 2-meter columns: 2 fasteners per pair cost about 6 USD

Total fastener cost for 7 strings:

$$(4 \times 7 \times 1 \times 117.43) + (2 \times 10 \times 7 \times 6 \times 117.43) = 101,929 \text{ BDT}$$

The combined cost for columns and fasteners totals 823,895 BDT, providing a robust support structure for the solar panel installation at the specified 27-degree tilt angle. This setup ensures the solar panels are securely mounted and optimally positioned, paving the way for efficient and sustainable energy production.

## 4.2 Selection of Components through Literature Review

We have identified optimal components for our solar power project based on extensive research of academic papers and official documents from the Bangladesh Sustainable and Renewable Energy Development Authority (SREDA). Our selection prioritizes efficiency, reliability, and compatibility with local conditions.

### 4.2.1 Solar Panels

The BSTI-approved JA Solar JAM72D42-620/LB N-type Bifacial solar panels were selected for their high power output of 620 Wp, which reduces the total number of panels required. This efficiency is crucial for optimizing space utilization and reducing installation costs. By capturing light from both sides, the N-type bifacial design offers lower degradation rates and higher energy yield. PV modules using thin film technology have not been considered for this project as their efficiency and durability are low. The fill factor is another important parameter that tells about the quality of the cell/module and its value should lie between 0.7–0.8 as per IEC standard. The efficiency '$\eta$' and fill factor of PV modules were calculated as:

$\eta = \frac{W_p}{G \times A}$

Fill factor $= \frac{V_{mp} \times I_{mp}}{V_{oc} \times I_{sc}}$

With a 22.2% efficiency and fill factor of 0.75, these panels are well-suited to Bangladesh's environmental conditions, ensuring long-term performance and reliability. It is manufactured as per IEC 61215 standards which define the impact of mechanical, electrical, and thermal stresses on power output, and qualifies for IEC 61730 standards for safety qualification.

### 4.2.2 Inverter

The Growatt MAX 80KTL3 LV inverter was chosen based on our calculated requirement of 75 kW for a 60 kW solar plant. As the nearest BSTI-approved option to our calculation, this 80 kW inverter provides the necessary capacity with a slight buffer for optimal performance. Its 99% maximum efficiency and multiple MPPT channels ensure minimal energy loss and maximum power output. The robust design and advanced cooling system make it ideal for Bangladesh's high-temperature environment, crucial for system stability and longevity.

### 4.2.3 Transformer

We selected the 3Ø 100 KVA 11/0.415KV transformer from the BSEC-approved list as it precisely matches our 100 kVA requirement. This transformer is essential for stepping down the voltage from 11 kV to 415 V, making it compatible with the grid and the output of our chosen Growatt inverter. The selection adheres strictly to SREDA's guidelines for grid integration, ensuring seamless power distribution and compliance with local regulations.

### 4.2.4 Other components

In addition to the primary components, we carefully selected supporting elements essential for the solar plant's efficiency and safety. The SCB models 4/2, 2/2, and 1/1 (discussed in chapter 5) were chosen for their durability and compatibility with high-voltage arrays. Two lightning arresters were installed, one on the primary and one on the secondary side, to safeguard against voltage surges. For wiring, we used 3,196 meters across various gauges (12 AWG, 14 AWG, 16 AWG, and 3/0 AWG) to ensure reliable energy transmission. Structurally, corrosion-resistant columns and high-grade stainless steel screws were selected to maintain the panels at the optimal 27-degree tilt and ensure long-term stability. These components were chosen for their crucial roles in the project's overall success. The details of each component are discussed in section 4.1.

### 4.2.5 Primary cost of the project

The table 4.3 below details the selected components, including their quantities and prices, which serve as the basis for calculating the primary cost of the project. This cost assessment provides a clear understanding of the initial investment required.

Table 4.3: Components of the 60kW SPV Power Plant

| No. | Components | No. of Units | Price/Units (BDT) | Total Amount (BDT) | Remarks (if any) |
|---|---|---|---|---|---|
| 1 | JA Solar JAM72D42-620/LB | 97 | 10,010 | 970,970 | [5] |
| 2 | Growatt MAX 80KTL3 LV | 1 | 413,000 | 413,000 | [6] |
| 3 | 3Ø 100 KVA 11/0.415KV X-former | 1 | 363,500 | 363,500 | [7] |
| 4 | Monitoring System and Display Screen | 1 | 40,000 | 40,000 | |
| 5 | Net Meter | 1 | 30,000 | 30,000 | |
| 6 | String Combiner Box | | | | |
| | SCB 4/2 | 1 | 21,000 | 21,000 | |
| | SCB 2/2 | 1 | 20,000 | 20,000 | |
| | SCB 1/1 | 1 | 12,000 | 12,000 | |
| 7 | Wiring | 3,196 meter | | 488,160 | |
| 8 | Lightning arrester | 2 | 1,500 | 3,000 | |
| 9 | Other Accessories | | | | |
| | Column | 154 | | 721,966 | |
| | Fasteners | 168 | | 101,929 | |
| **Total Cost (BDT)** | | | | **3,185,525** | |

# Chapter 5

# Design & Optimization

## 5.1 Preliminary Design

### 5.1.1 Overview: Selection of Conversion Technologies

The preliminary design of a 60 kW solar power plant was developed using PVsyst software [8], focusing on optimal component selection and system configuration. This process involved careful consideration of module characteristics, inverter capabilities, and array layout to ensure maximum efficiency and performance.

A flowchart is a visual representation of a process or system that shows the sequence of steps or actions involved. The block diagram of a solar power plant is shown in figure 5.1 below.

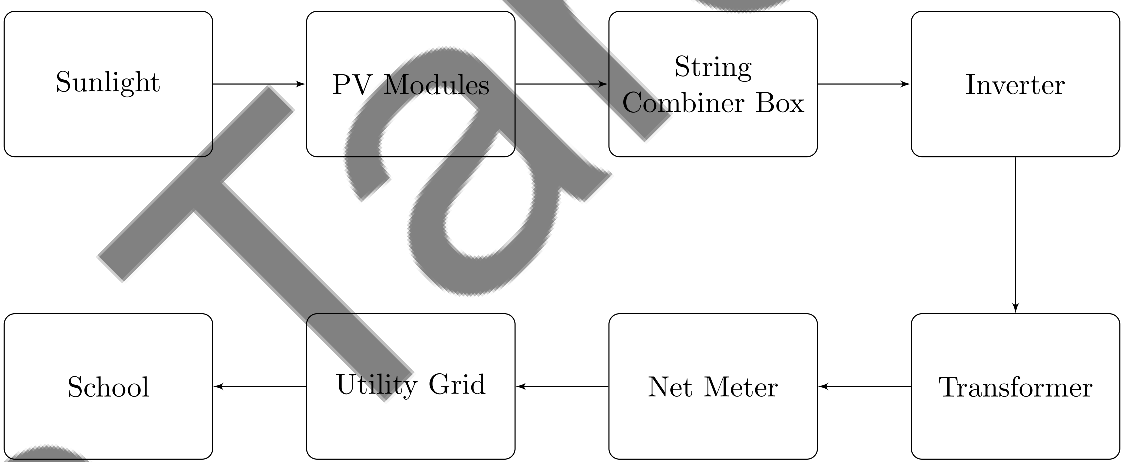



Figure 5.1: Block Diagram of On-Grid SPV system

It shows the flow of electricity starting from sunlight, which is captured by PV (Photovoltaic) Modules. The current is then passed through the String Combiner Box, then the Inverter. From the Inverter, electricity goes to a Transformer and then to a School. In addition, there is a connection from the Inverter to a Meter and then to the Utility Grid, which means that excess power can be measured and can be fed into the grid. This flowchart shows in detail how solar energy is converted and distributed for use in buildings such as schools, highlighting the key elements involved in this energy efficiency solution.

For this project, the JA Solar JAM72D42-620/LB module was selected, offering 620 Wp per panel. To achieve the target 60 kW capacity, we calculated the required number of modules as follows:

$$\text{Number of Modules} = \frac{60,000\,\text{W}}{620\,\text{W/module}} \approx 97\,\text{modules}$$

Using PVsyst, the array was optimized to include 98 modules arranged in 7 strings, with 14 modules per string. This configuration resulted in a Pnom ratio of 1.06 with 0.0% overload loss, indicating an efficient design without excess capacity or significant power clipping.

The Growatt MAX 80KTL3 LV inverter was chosen for its compatibility with the system size and voltage requirements. Key considerations included its operating voltage range of 200-1000 V and maximum input voltage of 1100 V. The array's operating conditions were verified to fall within these specifications, with Vmpp (60°C) at 563 V, Vmpp (20°C) at 628 V, and Voc (-10°C) at 826 V, ensuring safe and efficient operation across expected temperature ranges.

A critical aspect of the design was efficiently distributing the 7 strings across the inverter's 5 MPPT inputs. This was achieved using string combiner boxes (SCBs) in the following configuration:

- 3 MPPT inputs with 1 string each
- 2 MPPT inputs with 2 strings each

To implement this, three string combiner boxes were employed: SCB 1/1 managing a single string, SCB 2/2 combining two strings, and SCB 4/2 combining four strings into two outputs. This arrangement optimizes the use of available MPPT inputs while accommodating all 7 strings, ensuring maximum power point tracking for each sub-array.

### 5.1.2 Inter-row spacing and Pitch between two solar panels

Accurately determining inter-row spacing and pitch is crucial in solar panel design to ensure the panels receive optimal sunlight without shading, particularly during critical operating hours. These calculations are tailored to maximize energy generation during this period for a school-based solar power system, where the school day runs from 8 am to 2 pm. By considering the sun's position at the extremes of this time frame, we can optimize the layout for peak efficiency.

**Formulas:**

$$\text{[1] Height of the Panel } H_t = \text{Length} \times \sin(\text{Tilt Angle in radians}) \tag{5.1}$$

$$\text{[2] Horizontal Projection (M')} = \text{Length} \times \cos(\text{Tilt Angle in radians}) \tag{5.2}$$

$$\text{[3] Shadow Distance of the Panel } (d_1) = \frac{\text{Length} \times \sin(\text{Tilt Angle in radians})}{\tan(\text{Solar Elevation Angle in radians})} \tag{5.3}$$

$$\text{[4] Inter-row Spacing } (d_2) = \text{Shadow Distance of the Panel (d1)} \times \sin(\text{Azimuth Angle in radian}) \tag{5.4}$$

$$\text{[5] Pitch (Row Width)} = \text{Horizontal Projection (M')} + \text{Inter-row Spacing } (d_2) \tag{5.5}$$

In this solar panel layout design, the solar elevation angle and azimuth angle were determined using a solar path diagram, with a focus on the extreme points of 8 am and 2 pm. These times were selected because they represent the school's operating hours, ensuring that the solar panel system is optimized for when sunlight is most critical.

### Elevation angle (solar height) & Azimuth angle:

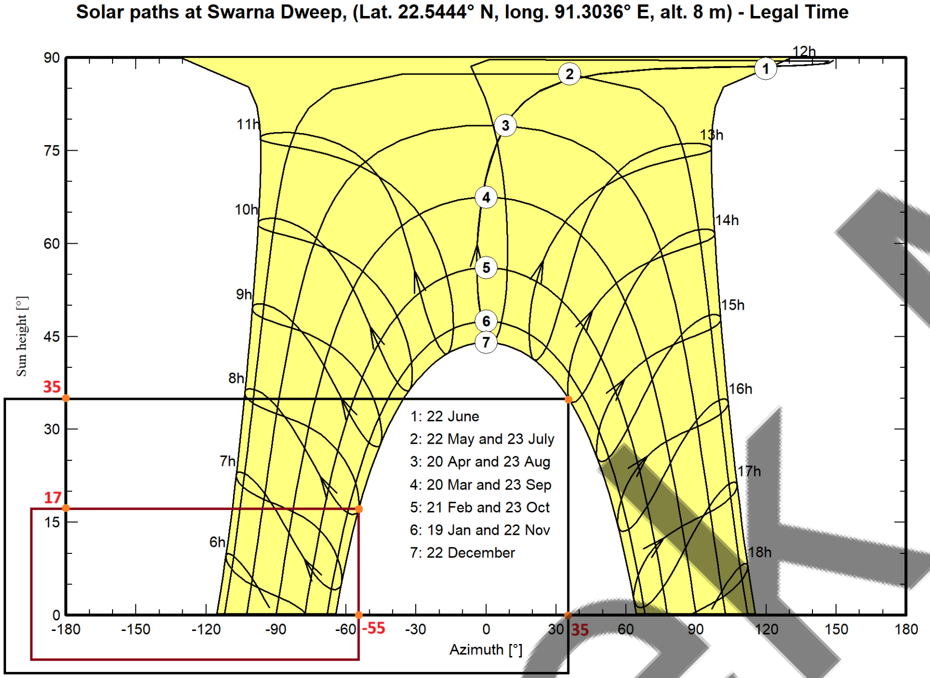



Figure 5.2: Finding Elevation & Azimuth angle using Solar Path at extreme points (8h and 14h)

As shown in figure 5.2, at the extreme point of 8h, the elevation angle is 17°and the azimuth angle is 55°, and at the extreme point of 14h, the elevation angle is 35°and the azimuth angle is 35°.

### Calculation Table

The following table, presented in Figure 5.3, is meticulously calculated using the formulas outlined in the preceding sections. As the shading limit angle we got from the PVsyst report is 20°, considering the 8 h timeline further ensures optimal sunlight without shading.

| Inter-row spacing between two solar panel | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Landscape setup** | | | | | | | | | | |
| Tilt angle, ° | Length | Hight of the panel, Ht | M' | Solar elevation angle, ° | Shadow distance of the panel, d1 | High Value, d1 | Azimuth angle, ° | Inter-row spacing, d2 | High Value, d2 | Pitch |
| 27 | 1.136 | 0.52 | 1.013 | 17 | 1.7008 | 1.70 | 55 | 1.39 | 1.39 | 2.41 |
| | | | | 35 | 0.7426 | | 35 | 0.98 | | |
| **Potrait Setup** | | | | | | | | | | |
| Tilt angle, ° | Length | Hight of the panel, Ht | M' | Solar elevation angle, ° | Shadow distance of the panel, d1 | High Value, d1 | Azimuth angle, ° | Inter-row spacing, d2 | High Value, d2 | Pitch |
| 27 | 2.467 | 1.12 | 2.199 | 17 | 3.6634 | 3.66 | 57 | 3.07 | 3.07 | 5.28 |
| | | | | 35 | 1.5995 | | 35 | 2.10 | | |
| The angles are in degree and the rest are in meter | | | | | | | | | | |

Figure 5.3: Inter-row spacing and pitch calculation between two solar panels

It also validates using the solar elevation angle for 17°. Portrait setup for solar panels is recommended as landscape orientation can render bypass diodes ineffective, reducing power output by up to 92% and potentially damaging PV modules [9]. Also, portrait installations typically require fewer mounting rails and brackets, resulting in lower material and labor costs. As the installation is quicker and simpler considering the portrait setup of solar panels is beneficial. However, we must analyze the location before going for a particular setup.

### 5.1.3 PV Array Configuration

#### General Parameter

The photovoltaic (PV) system utilizes a fixed plane with a tilt of 27°and an azimuth of 7°and consists of 98 sheds spaced 5.28 meters apart with a collector width of 2.47 meters, resulting in a ground coverage ratio of 46.7%. The system employs the Perez transposition model for solar radiation calculations, incorporating imported diffuse radiation and separate circumsolar modeling. Near shading effects are accounted for through linear simulations, while the user's energy needs are met by a fixed constant load of 6.11 kW and a total annual energy requirement of 53.5 MWh.

#### Characteristics

| **PV Module** | | **Inverter** | |
|---|---|---|---|
| Manufacturer | JA SOLAR | Manufacturer | GROWATT |
| Model | JAM72D42-620/LB | Model | MAX 80KTL3 LV |
| Unit Nom. Power | 620 Wp | Unit Nom. Power | 80.0 kWac |
| Number of PV modules | 98 units | Number of inverters | 5 * MPPT 14% 0.7 unit |
| Nominal (STC) | 60.8 kWp | Total power | 57.2 kWac |
| Modules | 7 string x 14 In series | Operating voltage | 200-1000 V |
| **At operating cond. (50°C)** | | Pnom ratio | 1.06 |
| Pmpp | 57.1 kWp | | |
| U mpp | 580 V | **Total inverter power** | |
| I mpp | 98 A | Total power | 57.2 kWac |
| **Total PV power** | | Nb. of inverters | 1 unit |
| Nominal (STC) | 61 kWp | Pnom ratio | 1.06 |
| Total | 98 modules | | |
| Module area | 274 m² | | |

### 5.1.4 MPPT Configuration

Proper Maximum Power Point Trackers (MPPT) configuration is crucial for maximizing the efficiency of a solar power system. MPPTs optimize the power output by adjusting each panel string to its ideal operating point under varying conditions. These tables highlight the importance of precise configuration, as mismatches or overloading in the MPPTs can lead to reduced efficiency, power losses, or even damage to the system. The inverter that is decided for the project has 7 MPPTs.

Table 5.1: Voltage Levels in Individual MPPT Channels

| **MPPT** | **Voltage** |
|---|---|
| MPPT 1: Strings 1 and 2 (Parallelly connected) | 614 V |
| MPPT 2: Strings 3 and 4 (Parallelly connected) | 614 V |
| MPPT 3: String 5 | 614 V |
| MPPT 4: String 6 | 614 V |
| MPPT 5: String 7 | 614 V |
| MPPT 6: This one remains unused | - |
| MPPT 7: This one remains unused | - |
| **MPPT Voltage Range** | 200 V - 1000 V |

Table 5.2: Current Levels in Individual MPPT Channels

| **MPPT** | **Current** |
|---|---|
| MPPT 1: Strings 1 and 2 (Parallelly connected) | 28.5 A (must be adjusted) |
| MPPT 2: Strings 3 and 4 (Parallelly connected) | 28.5 A (must be adjusted) |
| MPPT 3: String 5 | 14.25 A |
| MPPT 4: String 6 | 14.25 A |
| MPPT 5: String 7 | 14.25 A |
| MPPT 6: This one remains unused | - |
| MPPT 7: This one remains unused | - |
| **Max. Input Current per MPPT** | 26 A |
| **Max. Short-Circuit Current per MPPT** | 32 A |

In this analysis from table 5.1 and table 5.2, we reviewed the voltage and current characteristics of the MPPT system. Here, the solar panels are connected in series. The voltage of 614V across all MPPTs is within acceptable limits. However, the current readings for MPPTs 1 and 2 at 28.5A exceed the maximum input current rating of 26A, necessitating adjustments. Fortunately, the maximum short-circuit current of 32A allows for some leeway, indicating that immediate issues are unlikely.

### 5.1.5 Wire Size and Gauge Selection

In this section, we detail the wire size and wire gauge calculations for the solar plant, both of which are critical for ensuring the safety, efficiency, and reliability of the electrical system. Proper wire sizing helps prevent overheating and ensures compliance with electrical codes, while accurate wire gauging minimizes voltage drop and reduces energy losses. These calculations optimize current-carrying capacity, protect equipment from damage, and balance costs, ultimately contributing to the successful operation and longevity of the solar plant.

Each string consists of solar panels connected in series, with both positive and negative wiring running along the length of the string. For that, we need to multiply by 2. Given the following parameters:

- Length of each string: $L_s = 20\,\mathrm{m}$
- Number of strings: $N_s = 7$

The total wiring length for one string is calculated as:

$$W_{\text{string}} = L_s \times 2 = 20 \times 2 = 40\,\mathrm{m}$$

Thus, the total wiring length for all 7 strings is:

$$W_{\text{total strings}} = W_{\text{string}} \times N_s = 40 \times 7 = 280\,\mathrm{m}$$

#### Wiring from the closest panel to SCBs

For simplicity and to incorporate a safety margin, the wiring lengths from the strings to the SCBs are considered uniform. The SCB placement and string connection details are as follows:

SCB 4/2:

This SCB connects 4 strings. It is centrally located relative to these strings, with the distance from the closest panel to the SCB being 9 meters. Each string has both positive and negative wiring. Therefore, the wiring required for 4 strings is:

$$W_{4/2} = 9 \times 4 \times 2 = 72\,\mathrm{m}$$

SCB 2/2:

This SCB connects 2 strings with the same placement and wiring considerations as SCB 4/2. Thus, the wiring required is:

$$W_{2/2} = 9 \times 2 \times 2 = 36\,\text{m}$$

SCB 1/1:

This SCB connects 1 string. The wiring required, under the same assumptions, is:

$$W_{1/1} = 9 \times 1 \times 2 = 18\,\text{m}$$

### Total Wiring Calculation

The total wiring length from all strings to the SCBs is the sum of the individual calculations:

$$W_{\text{total wiring}} = 280 + 72 + 36 + 18 = 406\,\text{m} \approx 1332\,\text{ft} \tag{5.6}$$

For a single string, the total wiring length, including both within the string and up to the SCB, is:

$$W_{\text{single string}} = 40 + 9 \times 2 = 58\,\text{m} \approx 191\,\text{ft} \tag{5.7}$$

In conclusion, the total wiring length from all strings to the SCBs is approximately 406 meters (1332 feet), while the wiring length for a single string is approximately 58 meters (191 feet). These values provide a clear and safe estimate for the wiring required in the solar panel array. The cost of the total wirings needed for the project is provided in section 4.1.7, chapter 4.

### Wire Gauge Selection

Choosing the right wire gauge is vital in solar power systems. The Voltage Drop Index (VDI) method helps determine suitable sizes. It considers current, voltage, distance, and acceptable voltage drop. By calculating the VDI, you can select the appropriate wire gauge from standard tables, ensuring efficient power transmission and system safety.

The voltage drop in the electrical system behind the measuring equipment may not exceed 3% [10], in consideration of that, we will consider the voltage drop% to be 2, complying with IEC 60364-5-52. A graphical representation of different wire gauges is provided in the figure 5.4 to help us understand the design.

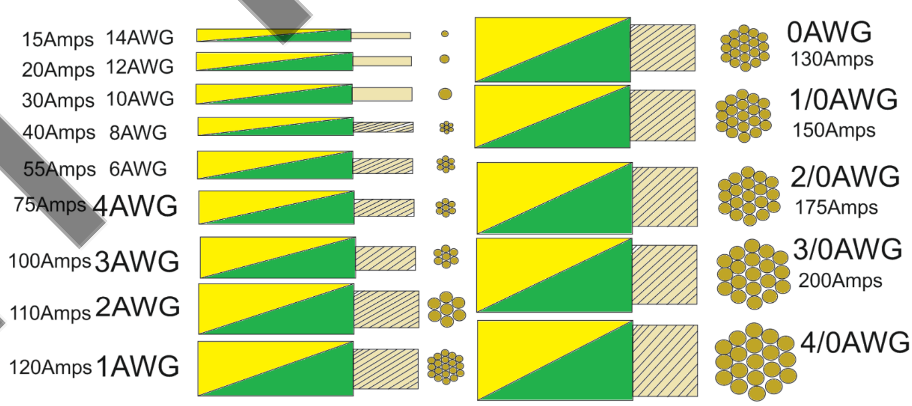



Figure 5.4: Wire size grounding conductors

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**Formula:**

$$V_{drop_{max}} = 0.02(2\% \text{ is acceptable}) \times V$$

For Single-Phase:

$$V_{drop} = \frac{2 \times I \times R(\text{from table}) \times L}{1000ft}$$

For Three-Phase:

$$V_{drop} = \frac{\sqrt{3} \times I \times R(\text{from table}) \times L}{1000ft}$$

### Wiring of single string to SCB

According to the datasheet, each panel has a maximum power current ($I_{mp}$) of 14.25 A and a maximum power voltage ($V_{mp}$) of 43.51 V. Equation 5.7 was used to calculation the distance.

Table 5.3: Single String to SCB

| Wiring | Current (A) | Voltage (V) | Distance (ft) | VDI | Wire Gauge (AWG) |
|---|---|---|---|---|---|
| Single String to SCB | 14.25 | 616 | 191 | 2.209 | 12 |

For ease of calculation and consistency, we approximate the voltage as 44 V. Given that each string consists of 14 panels connected in series, the total string voltage is calculated as:

$$V_{mp}(\text{string}) = 44\,\text{V} \times 14\,\text{panels} = 616\,\text{V}$$

### Wiring of SCB to inverter

This voltage is then used to assess the performance of different wiring configurations from the String Combiner Box (SCB) to the inverter.

Table 5.4: SCB to Inverter

| Wiring | Current (A) | Voltage (V) | Distance (ft) | VDI | Wire Gauge (AWG) |
|---|---|---|---|---|---|
| SCB 4/2 | 28.182 | 616 | 83 | 1.899 | 14 |
| SCB 2/2 | 14.25 | 609.14 | 83 | 0.971 | 16 |
| SCB 1/1 | 14.25 | 609.14 | 83 | 0.971 | 16 |

As the peak power for our solar panel is 620 W, taken from the model datasheet, we can calculate the power for each SCB. For the SCB 4/2 configuration, where two strings are combined, the total power is determined by:

$$P = 620\,\text{W} \times 14\,\text{panels} \times 2\,\text{strings} = 17,360\,\text{W}$$

Given that the voltage across this configuration remains at 616 V, the resulting current is:

$$I_{mp} = \frac{17,360\,\text{W}}{616\,\text{V}} = 28.182\,\text{A}$$

Similarly, for the SCB 2/2 and SCB 1/1 configurations, which handle a single string each, the power managed by each is:

$$P = 620\,\text{W} \times 14\,\text{panels} = 8,680\,\text{W}$$

With a slightly lower voltage of 609.14 V in these configurations, the current can be calculated as:

$$I_{mp} = \frac{8,680\,\text{W}}{609.14\,\text{V}} = 14.25\,\text{A}$$

### Wiring of inverter to transformer

The inverter specifications, taken from the datasheet of the Growatt MAX 80KTL3 LV inverter, are crucial for ensuring compatibility and optimal performance of the system.

Table 5.5: Inverter to Transformer

| Wiring | Current (A) | Voltage (V) | Distance (ft) | VDI | Wire Gauge (AWG) |
|---|---|---|---|---|---|
| Inverter to Transformer | 130 | 585 | 492.126 | 54.681 | 3/0 |

The inverter operates with a maximum power point voltage ($V_{mp}$) of 585 V and is designed to handle a current of 26 A per Maximum Power Point Tracking (MPPT) channel. Since the inverter utilizes five MPPT channels, the total current flowing from the inverter to the transformer is given by:

$$I_{mp}(\text{total}) = 26\,\text{A} \times 5\,\text{MPPTs} = 156\,\text{A}$$

### Wiring of transformer to net meter

The transformer employed in the system is a three-phase, 100 KVA unit with a voltage rating of 11/0.415 kV. As it is a three-phase transformer, the current at the transformer's output is calculated as:

$$I_{mp} = \frac{100,000\,\text{VA}}{\sqrt{3} \times 11,000\,\text{V}} = 5.25\,\text{A}$$

Table 5.6: Transformer to Net Meter

| Wiring | Current (A) | Voltage (V) | Distance (ft) | VDI | Wire Gauge (AWG) |
|---|---|---|---|---|---|
| Transformer to Net Meter | 5.25 | 11000 | 98.425 | 0.023 | 16 |

### Wiring of net meter to national grid

This current remains consistent for the wiring from the transformer to the net meter and subsequently to the national grid, with the voltage maintained at 11,000 V.

Table 5.7: Net Meter to National Grid

| Wiring | Current (A) | Voltage (V) | Distance (ft) | VDI | Wire Gauge (AWG) |
|---|---|---|---|---|---|
| Net Meter to National Grid | 5.25 | 11000 | 9459 | 2.257 | 12 |

### 5.1.6 Schematic Diagram

In addition to the system configuration details, a comprehensive schematic diagram of the entire solar power plant layout is provided. This diagram offers a visual representation of the system, incorporating all key components and their interconnections.

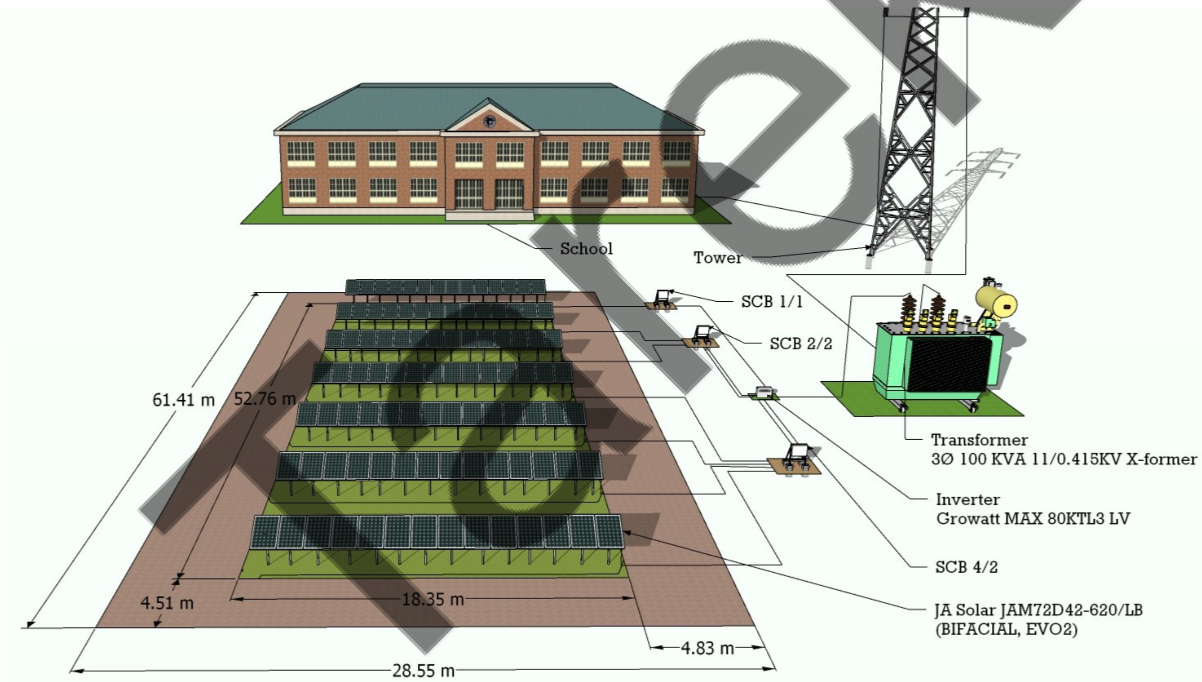



Figure 5.5: Schematic Diagram

The diagram from figure 5.5 was created using the SketchUp student version, with the Skelion extension used for solar panel design. This schematic serves as a valuable reference tool, providing a clear overview of the system architecture and facilitating easier understanding for stakeholders involved in the project's implementation and maintenance, offering a holistic view of the 60 kW solar power plant design.

## 5.2 Performance Analysis

### 5.2.1 Aging

Aging in photovoltaic (PV) modules refers to the gradual decline in performance due to factors like UV radiation, temperature changes, and humidity. This degradation can cause issues such as delamination and reduced electrical output. Understanding aging is crucial for predicting the lifespan and efficiency of PV systems, leading to better maintenance strategies and more durable designs.

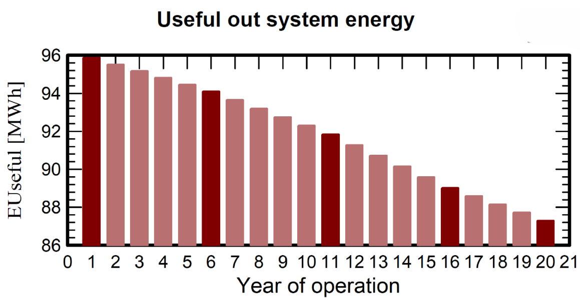



Figure 5.6: Useful system energy

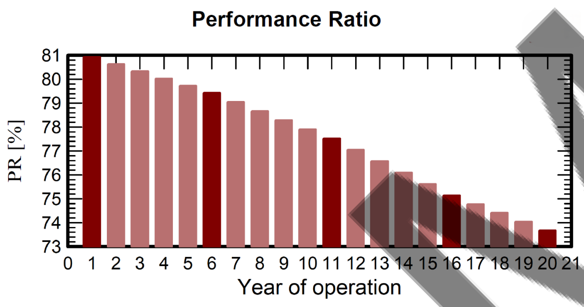



Figure 5.7: Performance Ratio

The aging simulation conducted with PVsyst software over a 20-year lifespan reveals a gradual decline in solar module performance, with degradation and increasing mismatch, as shown by rising RMS dispersion in Imp and Vmp, significantly contributing to performance loss.

Table 5.8: Energy Useful and Performance Ratio Over 20 Years

| Year | EUseful (MWh) | PR (%) | PR loss (%) |
|---|---|---|---|
| 1 | 95.87 | 80.63 | -0.19 |
| 2 | 96.81 | 80.03 | -0.60 |
| 3 | 94.58 | 79.73 | -1.30 |
| 4 | 94.81 | 80.03 | -1.30 |
| 5 | 94.45 | 79.73 | -1.67 |
| 6 | 94.10 | 79.43 | -2.04 |
| 7 | 93.65 | 79.05 | -2.51 |
| 8 | 93.19 | 78.67 | -2.98 |
| 9 | 92.74 | 78.28 | -3.45 |
| 10 | 92.29 | 77.90 | -3.92 |
| 11 | 91.84 | 77.52 | -4.39 |
| 12 | 91.27 | 77.04 | -4.98 |
| 13 | 90.71 | 76.57 | -5.56 |
| 14 | 90.15 | 76.09 | -6.15 |
| 15 | 89.58 | 75.62 | -6.74 |
| 16 | 89.02 | 75.14 | -7.33 |
| 17 | 88.58 | 74.77 | -7.78 |
| 18 | 88.15 | 74.41 | -8.23 |
| 19 | 87.72 | 74.05 | -8.68 |
| 20 | 87.29 | 73.68 | -9.13 |

The accompanying data table illustrates a consistent decrease in both energy useful (EUseful) and performance ratio (PR) over time, while the PR loss, calculated as the difference between the initial PR and subsequent annual PR values, also shows a steady downward trend, underscoring the significant impact of aging, driven by module degradation and varying weather conditions, on the long-term efficiency and energy output of solar systems.

### 5.2.2 Array loss

Based on the array design, the PV system experiences various array losses, beginning with a 3.0% loss due to soiling from dirt accumulation on the panels, reducing sunlight absorption. A 0.1% loss occurs at standard test conditions (STC) due to a 0.7V voltage drop across the series diodes, which block reverse currents. Module mismatch at the maximum power point (MPP) contributes to a 2.0% loss, resulting from differences in current output among individual modules. Thermal losses, influenced by module temperature constants ($U_c = 29.0\,\mathrm{W/m^2K}$, $U_v = 0.0\,\mathrm{W/m^2K/m/s}$), cause reduced efficiency due to overheating. Light-induced degradation (LID) adds another 2.0% loss, where sunlight exposure diminishes module efficiency, particularly in the early months. The system's DC wiring contributes a 1.5% loss at STC due to energy dissipation as heat, while an unexpected module quality gain of -1.3% slightly offsets these losses.

Over 20 years, module degradation at a rate of 0.4% per year leads to an 8.0% total loss due to environmental stress and material wear. Additional mismatch losses occur at 0.4% per year due to $I_{\mathrm{mp}}$ RMS and $V_{\mathrm{mp}}$ RMS dispersion. Modular degradation rate and mismatch losses are calculated through the aging tool from PVsyst, which are discussed in section 5.2.1.

$$\text{Total Losses} = 3.0\% + 0.1\% + 2.0\% + 2.0\% + 1.5\% - 1.3\% + (20 \times 0.4\%) + 0.4\% = 15.7\%$$

The total losses in the array design, calculated above amount to approximately 15.7% over the 20 years.

Using PVsyst, all kinds of losses from PV arrays have been accounted for. The losses of the IAM (Incidence Angle Modifier) loss factor and spectral correction coefficients have also been taken into consideration. These factors are critical for accurately predicting energy output, as they consider the effects of varying sunlight angles and atmospheric conditions on the efficiency of the solar panels.

Table 5.9: IAM Loss Factor

| Angle | 0° | 30° | 50° | 60° | 70° | 75° | 80° | 85° | 90° |
|---|---|---|---|---|---|---|---|---|---|
| IAM Factor | 1.000 | 0.998 | 0.981 | 0.948 | 0.862 | 0.776 | 0.636 | 0.403 | 0.000 |

Table 5.9 indicates that the efficiency of the solar panels decreases as the angle of incidence increases from 0° to 90°. This decline becomes significant at angles beyond 60°, with a sharp drop at 85° and 90°, where performance is almost entirely lost. This emphasizes the importance of optimizing panel tilt and orientation to minimize such losses.

Table 5.10: Spectral Correction Coefficients

| Coefficient Set | C0 | C1 | C2 | C3 | C4 | C5 |
|---|---|---|---|---|---|---|
| Monocrystalline Si | 0.85914 | -0.02088 | -0.0058853 | 0.12029 | 0.026814 | -0.001781 |

The spectral correction coefficients from Table 5.10 for Monocrystalline Silicon (Si) highlight how specific atmospheric conditions can slightly modify the panel's performance. While these corrections are relatively minor, they provide a more accurate prediction of energy output by accounting for local environmental effects, further refining the overall efficiency of the solar power system.

### 5.2.3 Loss Diagram

A loss diagram is a crucial tool in solar energy system design and analysis, providing a comprehensive breakdown of energy flows and losses throughout the system. It helps engineers and project managers identify efficiency bottlenecks, optimize system components, and set realistic performance expectations.

For the 60 kW solar plant, the loss diagram from Figure 5.8 shows that global horizontal irradiation of 1780 kWh/m² converts to 1827 kWh/m² on collectors, enhanced by optimal panel tilt and orientation. As the conversion efficiency of SPV is 22.25%, we get 1827 kWh/m² * 274 m² = 111,363 kWh worth of nominal annual production which is reduced to 96,419 kWh at the maximum power point (MPP) due to losses from module degradation, temperature, and other inefficiencies.

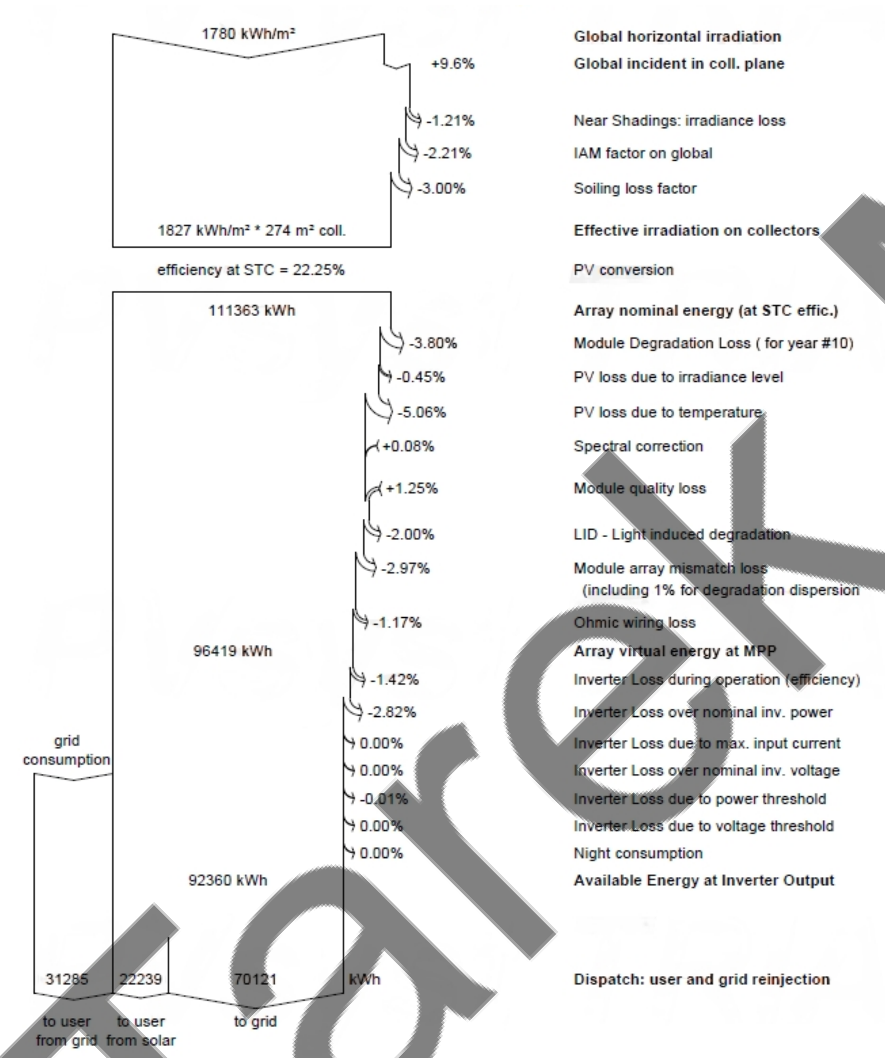



Figure 5.8: Loss Diagram

Energy distribution reveals that of the 92,360 kWh at the inverter output, 70,121 kWh goes to the grid and the rest of 22,239 kWh goes to the consumer from the sun. And 31,265 kWh worth of energy is imported back to the consumer from the grid with the help of a bi-directional meter, demonstrating a well-balanced system with strong self-consumption and net metering potential.

The system's overall performance appears robust, with effective utilization of produced energy and a significant portion available for grid export. This suggests the potential for both immediate energy cost savings and long-term financial benefits through net metering or feed-in tariff programs.

## 5.3 Optimization Process

In this section, we outline the optimization process for designing a grid-connected solar photovoltaic power plant for a school in Swarna Dweep. As discussed in Chapter 3, the optimal tilt and azimuth angles were determined using the Photovoltaic Geographical Information System (PVGIS). These parameters were then integrated into PVsyst software to analyze various losses, the expected annual electricity generation, financial viability, and $CO_2$ reduction.

### 5.3.1 Annual electricity production and performance ratio

The following table 5.12 shows the total electricity generated each month for the school which is our primary consumer.

Table 5.11: Annual Electricity Generation

| Month | GlobHor kWh/m² | DiffHor kWh/m² | T_Amb °C | GlobInc kWh/m² | GlobEff kWh/m² | EArray kWh | E_User kWh | E_Solar kWh | E_Grid kWh | EFrGrid kWh |
|---|---|---|---|---|---|---|---|---|---|---|
| January | 131.9 | 47.33 | 20.61 | 175.4 | 165.4 | 8534 | 4546 | 1794 | 6627 | 2752 |
| February | 145.7 | 49.90 | 23.17 | 177.4 | 167.4 | 8410 | 4106 | 1688 | 6611 | 2418 |
| March | 189.9 | 68.58 | 27.86 | 208.4 | 196.0 | 9818 | 4546 | 1983 | 7703 | 2563 |
| April | 189.1 | 74.66 | 28.57 | 187.4 | 175.3 | 8905 | 4399 | 1970 | 6809 | 2430 |
| May | 185.9 | 84.68 | 28.59 | 171.3 | 159.5 | 8264 | 4546 | 2063 | 6078 | 2483 |
| June | 128.9 | 75.51 | 28.37 | 116.0 | 107.3 | 5627 | 4399 | 1792 | 3731 | 2607 |
| July | 132.6 | 77.69 | 27.37 | 121.4 | 112.3 | 5897 | 4546 | 1864 | 3926 | 2682 |
| August | 128.4 | 72.15 | 27.67 | 124.0 | 115.4 | 5994 | 4546 | 1792 | 4092 | 2753 |
| September | 128.9 | 64.24 | 28.09 | 133.6 | 124.8 | 6438 | 4399 | 1752 | 4581 | 2648 |
| October | 140.1 | 61.73 | 28.13 | 161.8 | 152.0 | 7816 | 4546 | 1872 | 5834 | 2674 |
| November | 140.2 | 49.93 | 24.64 | 181.9 | 171.5 | 8863 | 4399 | 1824 | 6921 | 2575 |
| December | 138.0 | 44.05 | 20.30 | 191.2 | 180.3 | 9177 | 4546 | 1845 | 7210 | 2701 |
| Year | 1779.7 | 770.46 | 26.12 | 1949.8 | 1827.2 | 93742 | 53524 | 22239 | 70121 | 31285 |

## LEGEND

**GlobHor** Global horizontal irradiation

**DiffHor** Horizontal diffuse irradiation

**T_Amb** Ambient Temperature

**GlobInc** Global incident in coll. plane

**GlobEff** Effective Global, corr. for IAM and shadings

**EArray** Effective energy at the output of the array

**E_User** Energy supplied to the user

**E_Solar** Energy from the sun

**E_Grid** Energy injected into grid

**EFrGrid** Energy from the grid

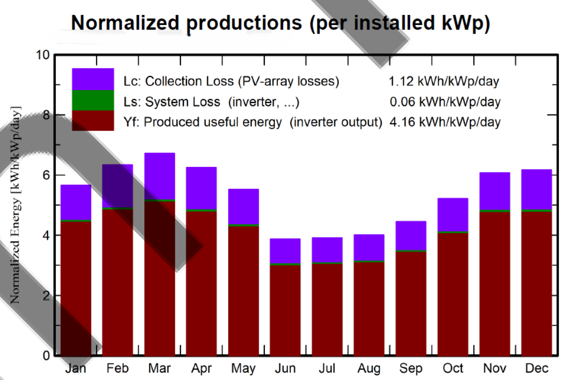



Figure 5.9: Normalized Production

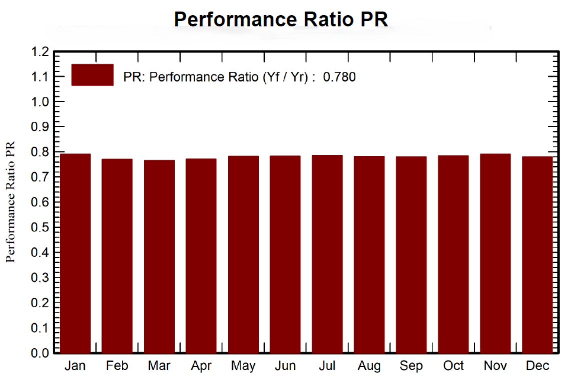



Figure 5.10: Performance Ratio

The solar plant's performance varies throughout the year, as shown in Figure 5.9. March yields the highest useful energy output (Yf), while July produces the least. The system's production generally peaks in the spring and summer months, with a noticeable drop in winter. Collection losses (Lc) are highest during summer, partially offsetting the increased production, while system losses (Ls) remain relatively constant year-round. In contrast, Figure 5.10 shows a stable performance ratio (PR) of 0.78 across all months, indicating that the overall efficiency of the system in converting available solar radiation to usable electricity remains consistent throughout the year, despite the variations in total energy production. These graphs suggest a well-designed system that adapts to seasonal changes while maintaining consistent overall efficiency, providing valuable data for performance assessment and potential optimization strategies.

### 5.3.2 Daily Input/Output Diagram and System Output Power Distribution

The daily input-output diagram reveals a strong positive correlation between incident radiation and system energy output, indicating high efficiency. The system output power distribution graph shows a typical right-skewed pattern, reflecting the plant's ability to handle varying production levels with the potential for high output on optimal days.

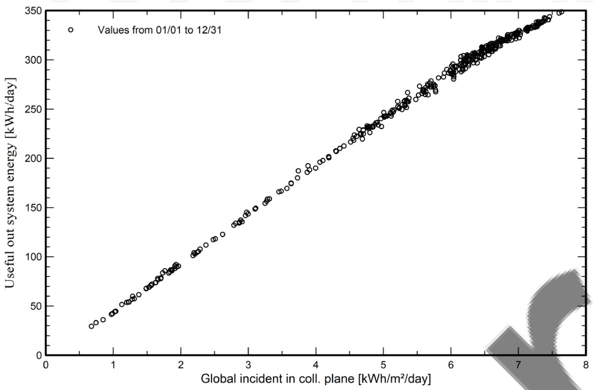



Figure 5.11: Daily Input/Output Diagram

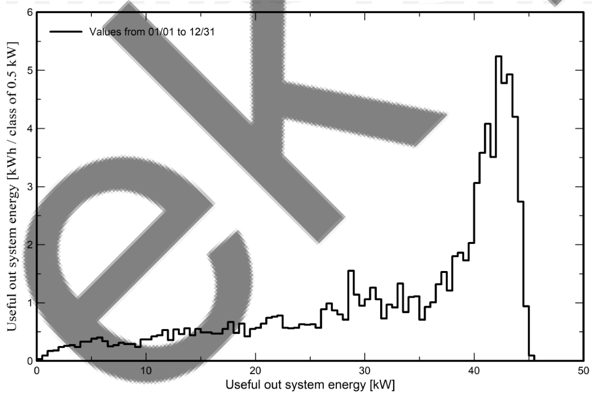



Figure 5.12: System Output Power Distribution

This versatility is crucial for year-round operation under different weather conditions. The consistent input-output relationship and the capability to produce significant energy during peak conditions suggest that the optimized design is well-suited for the chosen site. However, while these results are encouraging, a comprehensive assessment should also consider local climate patterns, seasonal variations, and specific energy demand requirements to fully determine the project's viability which are all discussed in Chapters 2 and 3 previously.

It's important to note that these graphs were generated using PVsyst software, a widely recognized tool in the solar industry for photovoltaic system design and simulation which adds credibility to the analysis [11].

## 5.4 Technical Specifications of the Final Design

The technical specifications provide detailed insights into the design, performance, and operational parameters, guiding engineers and stakeholders in the proper installation, maintenance, and optimization of the system.

Table 5.12: Technical Specifications

| **Parameter** | **Specification** |
|---|---|
| System Capacity | 60 kW |
| Tilt Angle | 27° |
| Azimuth Angle | 7° |
| PV Module | JA Solar JAM72D42-620/LB |
| Nominal Power | 620 Wp per panel |
| Efficiency | 22.18% |
| Number of PV Modules | 98 |
| Array Configuration | 7 strings with 14 modules per string |
| Inverter | Growatt MAX 80KTL3 LV |
| Maximum Output Power | 80.0 kWac |
| Efficiency | 98.8% |
| Number of Inverters | 1 unit (with 5 MPPT inputs) |
| Pnom Ratio | 1.06 |
| Ground Coverage Ratio | 46.7% |
| Inter-row Spacing | 5.28 meters |
| Collector Width | 2.47 meters |
| Annual Energy Production | Approximately 93,742 kWh |
| Performance Ratio | 0.78 (average) |
| Wire Gauges: | |
| Single String to SCB | 12 AWG |
| SCB 4/2 to Inverter | 14 AWG |
| SCB 2/2 and SCB 1/1 to Inverter | 16 AWG |
| Inverter to Transformer | 3/0 AWG |
| Transformer to Net Meter | 16 AWG |
| Net Meter to National Grid | 12 AWG |
| Transformer | Three-phase, 100 KVA, 11/0.415 kV |
| Expected System Lifespan | 20 years |
| Annual Degradation Rate | 0.4% |
| Module Operating Conditions: | |
| Vmpp (60°C) | 563 V |
| Vmpp (20°C) | 628 V |
| Voc (-10°C) | 826 V |
| Inverter Operating Voltage Range | 200-1000 V |
| Maximum Input Voltage | 1100 V |
| String Combiner Box Configuration: | |
| SCB 4/2: Combines 4 strings into 2 outputs | |
| SCB 2/2: Combines 2 strings | |
| SCB 1/1: Manages a single string | |
| Total Wiring Length | Approximately 406 meters (1332 feet) |
| Single String Wiring Length | Approximately 58 meters (191 feet) |

*Continued on next page*

| Parameter | Specification |
|---|---|
| Solar Radiation Data | |
| Annual Global Horizontal Irradiation | 1779.7 kWh/m$^2$ |
| Annual Diffuse Horizontal Irradiation | 770.46 kWh/m$^2$ |
| Average Annual Ambient Temperature | 26.12°C |
| Annual Global Incident in Collector Plane | 1949.8 kWh/m$^2$ |
| Annual Effective Global Irradiation | 1827.2 kWh/m$^2$ |
| Energy Supplied to User | 53,524 kWh/year |
| Energy Injected into Grid | 70,121 kWh/year |
| Energy Imported from Grid | 31,285 kWh/year |
| Module Temperature Coefficients: | |
| Uc (Thermal Loss Coefficient) | 29.0 W/m$^2$K |
| Uv (Wind Speed Coefficient) | 0.0 W/m$^2$K |
| System Losses: | |
| Soiling Loss | 3.0% |
| Mismatch Loss at MPP | 2.0% |
| Thermal Loss | Variable based on ambient temperature |
| Light Induced Degradation (LID) | 2.0% |
| DC Wiring Loss | 1.5% at STC |
| Module Quality Gain | -1.3% |
| IAM Loss Factors | Ranging from 1.000 at 0° to 0.000 at 90° |

In conclusion, the technical specifications of the final design for the 60 kW solar power system demonstrate a well-optimized and robust configuration, tailored to maximize energy production while ensuring system reliability. The selection of high-efficiency JA Solar PV modules coming from a Tier-1 manufacturer, coupled with the Growatt MAX 80KTL3 LV inverter, ensures that the system operates effectively across a wide range of environmental conditions. The careful consideration of wire gauges, thermal loss coefficients, and module operating conditions underscores the attention to detail in minimizing losses and optimizing performance. With a projected annual energy production of approximately 93,742 kWh and a performance ratio of 0.78, this design is poised to provide significant energy savings and contribute to sustainable energy goals.

Chapter 6

# Social Impact Assessment

## 6.1 Critical Analysis of Sustainable Development Goals (SDGs)

The Social Impact Assessment (SIA) evaluates the potential social effects of designing and implementing a grid-connected Solar Photovoltaic (PV) Power Plant for a school in Swarna Dweep. Swarna Dweep, being an island, faces unique challenges such as limited resources, vulnerability to climate change, and economic constraints. The following SDGs are particularly relevant to this project:

- **SDG 1: No Poverty**
  The construction and operation of the Solar PV Power Plant will create employment opportunities for residents, thereby providing a stable income source and reducing poverty levels within the community.

- **SDG 2: Zero Hunger**
  Increased employment leads to higher household incomes, enabling families to afford better nutrition and reducing instances of hunger. Additionally, improved energy access can support agricultural activities through the use of energy-efficient technologies.

- **SDG 3: Good Health and Well-being**
  Reliable electricity supply ensures the proper functioning of healthcare facilities, refrigeration of medicines, and operation of medical equipment, thereby enhancing the overall health and well-being of the population.

- **SDG 4: Quality Education**
  The primary beneficiary of the project is the educational sector. Enhanced energy reliability directly translates to better educational facilities, enabling the use of modern teaching aids and ensuring that educational activities are not disrupted by power outages. This leads to improved academic performance and better educational outcomes for students.

- **SDG 5: Gender Equality**
  The project promotes equal employment opportunities for all genders, empowering women through job creation and fostering an inclusive work environment.

- **SDG 7: Affordable and Clean Energy**
  Providing the school with a sustainable energy source not only reduces operational costs but also serves as a model for renewable energy adoption in the community. This promotes broader acceptance and implementation of clean energy solutions, contributing to long-term energy sustainability.

- **SDG 8: Decent Work and Economic Growth**
  The creation of jobs during both the construction and operational phases of the power plant stimulates the local economy. It provides meaningful employment opportunities, which contribute to economic stability and growth, fostering a more prosperous community.

- **SDG 12: Responsible Consumption and Production**
  The efficient use of solar energy encourages responsible consumption patterns within the school, minimizing energy wastage and promoting sustainable production practices.

- **SDG 13: Climate Action**
  By utilizing solar energy, the project significantly lowers carbon emissions associated with traditional energy sources. This proactive approach towards mitigating climate change impacts aligns with global climate action goals and enhances the community's resilience to environmental challenges.

- **SDG 15: Life on Land**
  The installation of the Solar PV Power Plant involves minimal land disturbance, preserving terrestrial ecosystems and biodiversity on the island.

- **SDG 17: Partnerships for the Goals**
  Successful implementation of the project relies on partnerships between government bodies, educational institutions, and private sector stakeholders, thereby enhancing collaborative efforts towards achieving sustainable development.

## 6.2 Benefits of the Project

The implementation of a grid-connected Solar PV Power Plant for the school in Swarna Dweep offers numerous benefits, including:

- **Enhanced Educational Facilities**
  Reliable and sustainable energy supply improves the educational environment by powering classrooms, laboratories, and digital learning tools.
- **Economic Growth**
  Creation of local jobs during the construction and maintenance phases stimulates the local economy.
- **Environmental Sustainability**
  Reduction in carbon footprint through the use of renewable energy sources, contributing to environmental conservation.
- **Health and Well-being**
  Reliable electricity supports essential services such as clean water systems and healthcare facilities, improving overall community health.
- **Energy Independence**
  Decreases reliance on fossil fuels and imported energy, promoting self-sufficiency and resilience against energy price fluctuations

The design and implementation of a grid-connected Solar Photovoltaic Power Plant for a school in Swarna Dweep align closely with several Sustainable Development Goals, particularly those related to education, clean energy, climate action, and economic growth. The project not only addresses immediate energy needs but also contributes to the long-term social and economic well-being of the community. By fostering sustainable practices and promoting inclusive growth, the project serves as a catalyst for broader sustainable development in Swarna Dweep.

# Chapter 7

# Environmental Impact Assessment

Environmental Impact Assessment (EIA) is a crucial tool for evaluating the potential environmental consequences of proposed projects. In the context of Bangladesh, especially remote areas, the significance of EIA is heightened due to the region's unique ecological and socio-economic conditions.

## 7.1 Environmental Benefits of the project

This project includes several environmental benefits which can be divided into three aspects. They are local, regional and global.

### 7.1.1 Local

- **Land Use and Habitat Disruption:**
  The project site on Swarna Dweep, controlled by the Bangladesh Army, requires a thorough assessment of its environmental footprint. It is vital to consider the potential disruption to the mangrove ecosystems nearby, which are critical for coastal protection and biodiversity. Additionally, potential impacts on local wildlife habitats, particularly for birds and aquatic species, should be carefully evaluated. An Environmental Impact Assessment (EIA) will help identify and mitigate any habitat disruption, potentially incorporating reforestation or other compensatory strategies to protect the natural environment.

- **Water Resources:**
  The project's proximity to water sources, including groundwater and surface water bodies, requires an evaluation of the potential effects on local water quality and availability. This is crucial to ensure that the project doesn't compromise the water needs of local communities and ecosystems.

- **Noise Pollution:**
  Both construction and operation of the solar power plant could generate noise, which may affect nearby communities and wildlife. It is essential to evaluate and implement noise mitigation measures to ensure that the project has minimal impact on the surrounding environment.

- **Waste Management:**
  The project will generate waste during construction and operation, including materials like solar panels that may require special disposal. A waste management plan must be in place to prevent environmental contamination and ensure the safe handling of any hazardous materials.

- **Community Engagement and Social Impact:**
  Involving local communities in the project is crucial. This can help address potential concerns, create employment opportunities, and mitigate any negative social impacts such as displacement. Ensuring that the project aligns with local development goals will promote both social and environmental sustainability.

This detailed assessment emphasizes the importance of balancing development with environmental and social responsibility, ensuring the solar plant project supports sustainable growth in Swarna Dweep.

### 7.1.2 Regional

- **Air Quality:**
  The transportation of materials and equipment to Swarna Dweep during the construction phase could temporarily increase emissions, affecting regional air quality. Minimizing this impact through strategies like using fuel-efficient vehicles, optimizing transportation logistics, or sourcing materials locally will reduce the carbon footprint of the project.

- **Climate Change:**
  The solar power plant will play a role in mitigating climate change by reducing the reliance on fossil fuels for electricity generation in the region. The reduction in greenhouse gas emissions contributes to regional efforts to combat climate change.

- **Water Quality:**
  The project's potential impact on regional water quality, including the potential for pollution from construction activities or equipment failure, requires careful evaluation to ensure that the project doesn't compromise regional water resources.

- **Biodiversity and Ecosystem Services:**
  Swarna Dweep's proximity to ecologically sensitive areas, such as the Sundarbans, necessitates careful consideration of the project's impact on regional biodiversity. Aligning with regional conservation initiatives can support biodiversity protection and preserve ecosystem services such as flood control and carbon sequestration.

- **Regional Energy Security:**
  The solar power plant will enhance regional energy security by contributing to a cleaner, more reliable electricity supply. Integrating renewable energy into the regional grid reduces dependence on imported fuels, supporting sustainable energy development in the area.

This comprehensive regional assessment ensures that the project not only mitigates potential negative impacts but also contributes positively to environmental sustainability and economic development at a broader scale.

### 7.1.3 Global

- **Climate Change Mitigation:**
  The project makes a significant contribution to global climate change mitigation by reducing greenhouse gas emissions. Our 60 KW solar project, operating 6 hours a day for 223 days, will produce a total of 93,742 kW of electricity.

Table 7.1: Comparison of $CO_2$ Emissions for Different Fossil Fuel Sources and Solar Energy Savings

| **Fossil Fuel Source** | **$CO_2$ Emissions (kg $CO_2$/kWh)** | **Total $CO_2$ Emissions (kg)** | **Emission Savings (tons)** |
|---|---|---|---|
| Coal Power Plants | 1.1 | 101,116 | 101.116 |
| Natural Gas Power Plants | 0.425 | 39,840.35 | 39.84 |
| Petroleum Power Plants | 2.4 | 224,980.8 | 224.98 |

According to table 7.1, it makes sense that by using solar power instead of fossil fuels, the project avoids significant $CO_2$ emissions, saving 88.3 tons compared to coal, 34.1 tons compared to natural gas, and 192.7 tons compared to petroleum. This substantial reduction in emissions highlights the critical role renewable energy plays in combating climate change and reducing the global carbon footprint, contributing directly to international efforts to limit global warming.

- **Global Energy Security:**

  By generating 80,280 kWh of clean, renewable energy, the project contributes to the diversification of global energy sources, reducing dependency on fossil fuels and enhancing global energy security. This transition toward renewable energy strengthens resilience against energy supply disruptions and price volatility, promoting a more sustainable and secure global energy framework.

- **Global Biodiversity Conservation:**

  Solar energy reduces environmental degradation from fossil fuel extraction, protecting global ecosystems and biodiversity impacted by climate change and pollution.

- **Water Resources:**

  Solar power requires minimal water, unlike fossil fuels, which consume large quantities. This contributes to global water sustainability by reducing water demand and preventing pollution.

- **Economic Development:** In addition to its environmental benefits, the project supports global economic development by creating jobs in the renewable energy sector, stimulating local economies, and promoting sustainable development. As part of the global transition to clean energy, the project fosters long-term economic growth and stability, benefiting both the environment and society.

This comprehensive global perspective demonstrates the far-reaching impact of the solar project. By avoiding $CO_2$ emissions from fossil fuel power plants and promoting renewable energy, the project contributes to climate action, energy security, biodiversity conservation, water resource management, and sustainable global economic development.

# Chapter 8

# Financial Analysis

Financial analysis involves evaluating various financial metrics to determine the potential profitability and sustainability of an investment. Key elements of financial analysis include calculating costs, revenues, cash flows and return on investment. By analyzing these factors, stakeholders can make informed decisions about the allocation of resources, the risk involved, and the expected returns. Financial analysis provides a clear picture of the financial health of a project, helping investors and decision-makers to understand whether the project is worth pursuing and how it aligns with their financial goals.

## 8.1 Financial Parameters

**Formulas:**

$$[1]\ \text{Total Yearly Cost} = \text{Operating Cost} + \text{Loan Annuities} \tag{8.1}$$

$$[2]\ \text{LCOE} = \frac{\sum \text{Cost over Lifetime}}{\text{Total Production over Lifetime}} \tag{8.2}$$

$$[3]\text{Fixed Feed-in Tariff} = \frac{\text{Total Cost over Lifetime}}{\text{Total kWh Produced over Lifetime}} \tag{8.3}$$

$$[4]\ \text{Payback Period} = \frac{\text{Initial Investment}}{\text{Annual Cash Inflow}} \tag{8.4}$$

These financial parameters are interconnected and essential for evaluating the viability and profitability of a solar energy project. The Total Yearly Cost includes operational expenses and loan repayments, providing investors with a clear view of the annual financial commitment required to sustain the project. This feeds directly into the LCOE, which measures the average cost per unit of electricity over the project's lifetime, allowing investors to compare cost-effectiveness with other energy sources. A lower LCOE enhances the project's attractiveness by indicating cost efficiency. The Fixed Feed-in Tariff is tied to the LCOE, as it determines the revenue generated from selling electricity to the grid, directly influencing the return on investment (ROI). Finally, the payback period, which indicates how quickly the initial investment can be recovered, is influenced by both the LCOE and the feed-in tariff. A shorter payback period signals quicker returns, making the project less risky and more appealing to investors.

## 8.2 Installation and Operating Costs Overview

A clear understanding of installation and operating costs is essential for assessing the project's financial feasibility. Installation costs encompass the initial expenses related to equipment and labor while operating costs include ongoing maintenance and operational expenses. Together, these figures provide valuable insight into the project's long-term economic sustainability, as illustrated in the following tables.

In the context of Bangladesh, particularly for a remote area like Swarna Dweep, the financial metrics highlighted in Tables 8.1 and 8.2 are critical. The total installation cost of BDT 4,560,713.60 (Table 8.1) and yearly operating costs of BDT 795,783.28, including inflation (Table 8.2), underscores the project's financial requirements.

Table 8.1: Installation Costs

| **Item** | **Quantity units** | **Cost BDT** | **Total BDT** |
|---|---|---|---|
| PV modules | | | |
| (JAM72D42-620/LB) | 98 | 10010.00 | 980980.00 |
| Inverters | | | |
| (MAX 80KTL3 LV) | 1 | 751660.00 | 533678.60 |
| Other components | | | |
| Accessories, fasteners | | 823895.00 | 823895.00 |
| Wiring | 1 | 17666.67 | 488160.00 |
| Measurement system, pyranometer | 3 | 53000.00 | 53000.00 |
| Combiner box | | | |
| Monitoring system, display screen | 1 | 40000.00 | 40000.00 |
| Surge arrester | 2 | 1500.00 | 3000.00 |
| Studies and analysis | | | |
| Engineering | 4 | 80000.00 | 320000.00 |
| Permitting and other admin. Fees | 2 | 80000.00 | 160000.00 |
| Environmental studies | 2 | 80000.00 | 160000.00 |
| Economic analysis | 2 | 80000.00 | 160000.00 |
| Installation | | | |
| Global installation cost per module | 98 | 1000.00 | 98000.00 |
| Global installation cost per inverter | 1 | 42253.52 | 30000.00 |
| Transport | 8 | 15000.00 | 120000.00 |
| Settings | 4 | 15000.00 | 60000.00 |
| Grid connection | 1 | 500000.00 | 500000.00 |
| | | **Total** | **4560713.60** |
| | | **Depreciable asset** | **2338553.60** |

Table 8.2: Operating Costs

| **Item** | **Total BDT/year** |
|---|---|
| Maintenance | |
| Provision for inverter replacement | 26845.00 |
| Salaries | 150000.00 |
| Repairs | 60000.00 |
| Cleaning | 30000.00 |
| Security fund | 40000.00 |
| Subsidies | -20000.00 |
| **Total (OPEX)** | **286845.00** |
| **Total (including inflation 9.72%)** | **795783.28** |

While Swarna Dweep's remote location may increase logistics and maintenance costs, the project's robust energy production—22.2 MWh/year for self-use and 70.1 MWh/year for grid sale—demonstrates strong economic potential. The LCOE of 11.9677 BDT/kWh is competitive within Bangladesh's energy market, particularly in remote areas where grid electricity is costly or unreliable. The fixed feed-in tariff ensures a stable revenue stream, offsetting initial investments and supporting long-term profitability. For investors, this analysis shows that despite logistical challenges, the project is economically viable and aligned with Bangladesh's renewable energy goals.

## 8.3 Key Financial Metrics

This section presents a comprehensive analysis of the project's key financial metrics, encompassing income variation, financing structure, electricity sale conditions, and investment returns. The data reveals significant potential for profitability, characterized by favorable regulatory support and robust financial indicators.

### 8.3.1 Simulated period

The project encompasses a 20-year lifetime, commencing in 2024. This extended duration signifies a substantial infrastructure investment for the solar plant site.

### 8.3.2 Income variation over time

The economic landscape is characterized by an inflation rate of 9.72% per annum and a discount rate of 9.00% per annum. These elevated rates suggest a potentially volatile economic environment. The slight disparity between inflation and discount rates may impact real returns over the project's lifespan.

### 8.3.3 Income-dependent expenses

Financial obligations include an income tax rate of 3.00% per annum and a dividend rate of 20.00% per annum. The modest income tax rate implies favorable taxation conditions, while the substantial dividend rate indicates that a significant portion of profits will be distributed to investors.

### 8.3.4 Depreciable assets

Table 8.3 offers a detailed breakdown of the depreciable assets involved in the project. All assets are being depreciated using the straight-line method over 20 years, with no estimated salvage value at the end of their useful lives.

Table 8.3: Depreciable Assets

| **Asset** | **Depreciation Method** | **Depreciation Period (years)** | **Salvage Value (BDT)** | **Depreciable Amount (BDT)** |
|---|---|---|---|---|
| PV modules (JAM72D42-620/LB) | Straight-line | 20 | 0.00 | 980,980.00 |
| Inverters (MAX 80KTL3 LV) | Straight-line | 20 | 0.00 | 533,678.60 |
| Accessories, fasteners | Straight-line | 20 | 0.00 | 823,895.00 |
| | | Total | 0.00 | 2338553.60 |

The total depreciable amount will be allocated as depreciation expense over the project's lifetime. It affects the project's tax liability (reduces it), cash flow (non-cash expense), asset valuation (decreases value over time), and financial ratios (affects calculations).

### 8.3.5 Electricity sale

The electricity sale framework includes a feed-in tariff of 19.12965 BDT/kWh (using equation 8.3), guaranteed for 20 years. An annual connection tax of 1000.00 BDT/kWh is applicable. The tariff structure incorporates an annual variation of +5.0% per annum, with a 15.00% decrease in feed-in tariff post-warranty. This guaranteed tariff for the project's entire lifetime, coupled with an annual increase, suggests a favorable regulatory environment for renewable energy investments.

### 8.3.6 Financing Structure

The project's financing comprises own funds of 4,160,713.60 BDT and subsidies amounting to 400,000.00 BDT when comes to the total investment in the project. This substantial subsidy effectively reduces the overall investment burden.

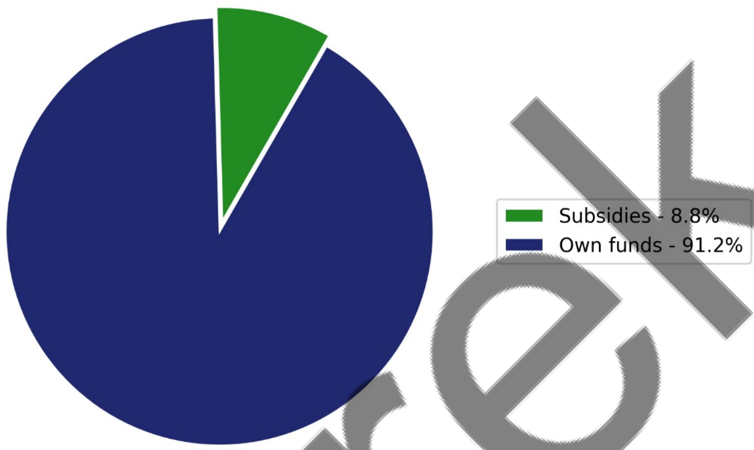



Figure 8.1: Financing Chart

### 8.3.7 Self-consumption

Self-consumption is priced at 7.50 BDT/kWh, with a projected tariff evolution of +5.0% per annum. These tariffs indicate that a portion of the generated electricity will be utilized on-site, with rising tariffs matching the feed-in tariff increases.

### 8.3.8 Return on Investment

These figures collectively suggest a highly profitable venture that was generated using PVsyst. The brief payback period indicates the rapid recovery of the initial investment.

| | |
|---|---|
| Payback period: | 4.1 years |
| Net Present Value (NPV): | 9,010,080.99 BDT |
| Internal Rate of Return (IRR): | 31.43% |
| Return on Investment (ROI): | 216.6% |
| Paid dividends: | 5,079,626.86 BDT |

The positive NPV demonstrates significant value creation, while the high IRR substantially exceeds the discount rate, indicating robust profitability. The impressive ROI implies the project will generate returns exceeding double the initial investment.

## 8.4 Detailed Economic Analysis

A detailed economic analysis for a solar plant project is about figuring out if it will make money or not. It looks at how much the project will cost to build and run, how much electricity it will produce, and how much that electricity can be sold for. The analysis also considers things like government subsidies and potential risks. The bottom line is determining whether the project will generate enough profit to justify the investment.

### 8.4.1 Comprehensive financial outcome

| Year | Electricity sale | Own funds | Running costs | Depreciation allowance | Taxable income | Taxes | After-tax profit | Dividend 20.00% | Self-cons. saving | Cumulative profit | % amortization |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 4160714 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -4160714 | 0,0 |
| 1 | 1338005 | 0 | 286845 | 116928 | 934232 | 28027 | 1023133 | 204627 | 166484 | -3069322 | 26.2% |
| 2 | 1399743 | 0 | 314726 | 116928 | 968089 | 29043 | 1055974 | 211195 | 174160 | -2033942 | 51.1% |
| 3 | 1464308 | 0 | 345318 | 116928 | 1002063 | 30062 | 1088929 | 217786 | 182188 | -1052407 | 74.70.% |
| 4 | 1531828 | 0 | 378883 | 116928 | 1036017 | 31081 | 1121865 | 224373 | 190583 | -122636 | 97.1% |
| 5 | 1602436 | 0 | 415710 | 116928 | 1069798 | 32094 | 1154632 | 230926 | 199362 | 757368 | 118.2% |
| 6 | 1676273 | 0 | 456117 | 116928 | 1103228 | 33097 | 1187059 | 237412 | 208542 | 1589519 | 138.2% |
| 7 | 1751667 | 0 | 500452 | 116928 | 1134287 | 34029 | 1217186 | 243437 | 217917 | 2374569 | 157.1% |
| 8 | 1830407 | 0 | 549095 | 116928 | 1164384 | 34932 | 1246380 | 249276 | 227707 | 3114364 | 174.9% |
| 9 | 1912639 | 0 | 602468 | 116928 | 1193244 | 35797 | 1274374 | 254875 | 237931 | 3810671 | 191.6% |
| 10 | 1998516 | 0 | 661027 | 116928 | 1220561 | 36617 | 1300872 | 260174 | 248608 | 4465188 | 207.3% |
| 11 | 2088197 | 0 | 725279 | 116928 | 1245990 | 37380 | 1325538 | 265108 | 259759 | 5079543 | 222.1% |
| 12 | 2179187 | 0 | 795776 | 116928 | 1266483 | 37994 | 1345416 | 269083 | 271072 | 5654260 | 235.9% |
| 13 | 2274053 | 0 | 873126 | 116928 | 1283999 | 38520 | 1362407 | 272481 | 282867 | 6190914 | 248.8% |
| 14 | 2372955 | 0 | 957994 | 116928 | 1298034 | 38941 | 1376020 | 275204 | 295164 | 6691010 | 260.8% |
| 15 | 2476060 | 0 | 1051111 | 116928 | 1308022 | 39241 | 1385709 | 277142 | 307983 | 7155993 | 272.0% |
| 16 | 2583540 | 0 | 1153279 | 116928 | 1313334 | 39400 | 1390862 | 278172 | 321347 | 7587246 | 282.4% |
| 17 | 2699585 | 0 | 1265377 | 116928 | 1317280 | 39518 | 1394689 | 278938 | 335775 | 7987110 | 292.0% |
| 18 | 2820773 | 0 | 1388372 | 116928 | 1315473 | 39464 | 1392936 | 278587 | 350843 | 8356780 | 300.8% |
| 19 | 2947328 | 0 | 1523322 | 116928 | 1307078 | 39212 | 1384794 | 276959 | 366578 | 8697404 | 309.0% |
| 20 | 3079484 | 0 | 1671389 | 116928 | 1291167 | 38735 | 1369360 | 273872 | 383010 | 9010081 | 316.6% |
| **Total** | **42026983** | **4160714** | **15915666** | **2338554** | **23772764** | **713183** | **25398135** | **5079627** | **5227881** | **9010081** | **316.6%** |

Figure 8.2: Economic outcome (kBDT)

Table from Figure 8.2 provides a detailed financial projection for a 20-year solar photovoltaic power plant project. Initially, the project experiences losses, indicated by the orange color. However, after four years, the project begins to generate profit, as shown by the transition to green. This shift marks the point where the revenue from electricity sales starts to exceed the running costs and other expenses, leading to a positive financial outlook for the remainder of the project lifespan.

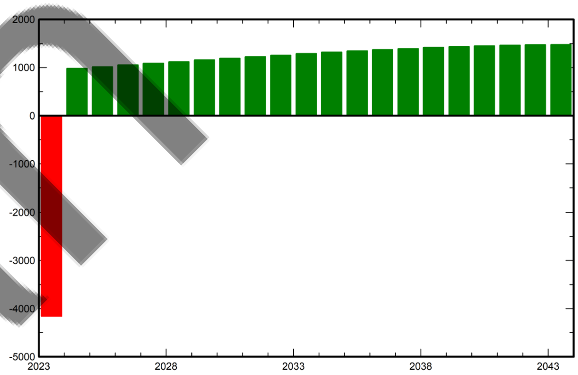



Figure 8.3: Yearly Net Profit (kBDT)

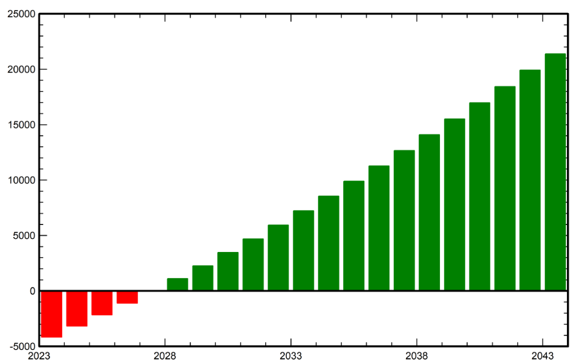



Figure 8.4: Cumulative Cashflow (kBDT)

The graph in Figure 8.3 shows that from the second year onwards, the project begins to make positive net profit by selling electricity generated from the solar plant. This indicates that the revenue from electricity sales starts to exceed the running costs and other expenses. The yearly net profit continues to increase steadily over the project lifespan, reflecting effective cost management and increasing efficiency or revenue generation from the solar power plant.

The graph in Figure 8.4 illustrates a similar trend. The initial years (2023-2026) are marked by negative cash flow due to the high initial investment and setup costs. However, the project reaches its break-even point in 2027, where the cumulative cash flow turns positive. This marks the point where the project starts to recover its initial costs and begins to accumulate profit. From this point, the cumulative cash flow shows a steady and significant increase each year, indicating that the project is not only recovering the initial investment but also generating substantial profits over time. By the end of the project lifespan in 2043, the cumulative cash flow will reach a high positive value.

### 8.4.2 Income Allocation

The pie chart shown in Figure 8.5 illustrates the average distribution of costs and profits over the project's lifespan. Net profit constitutes the largest portion at 47.1%, indicating strong financial returns. Maintenance costs are significant, making up 39.47%, reflecting the ongoing operational expenses. Dividends account for 11.78%, showing the portion of profits distributed to shareholders. Income tax represents the smallest fraction at 1.65%, highlighting the project's tax efficiency. This distribution underscores the project's profitability while balancing operational and shareholder commitments.

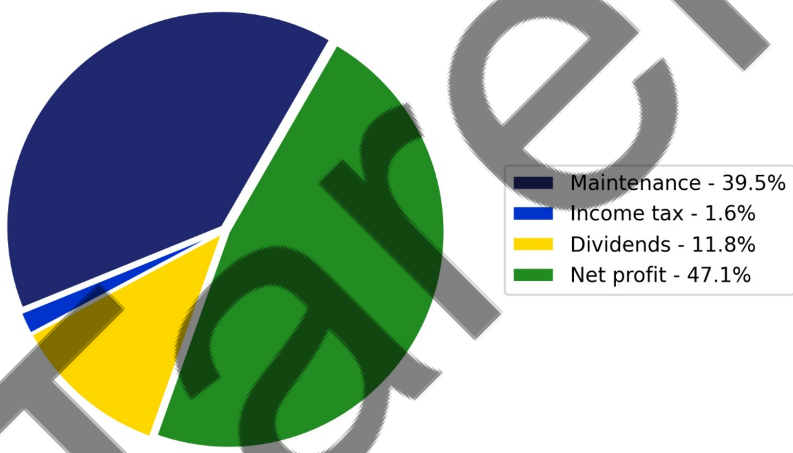



Figure 8.5: Income Allocation

Despite the initial financial burden, the solar photovoltaic power plant project shows a clear recovery phase followed by steady growth in both yearly net profit and cumulative cash flow. This consistent increase over the 20-year lifespan indicates the project's long-term financial viability and profitability, making it a sound investment with promising returns.

# Chapter 9

# Concluding Remarks

## 9.1 Conclusions

This report presents a comprehensive design and analysis of a grid-connected solar photovoltaic (PV) power plant for a proposed school in Swarna Dweep, Bangladesh. The project's objective was to address the critical issue of reliable electricity supply in remote island communities, which significantly impacts educational quality and operational costs.

Throughout this project, several key lessons emerged:

1. **Integrated Approach to Energy Solutions**: The need for a holistic approach in energy planning was evident. By considering factors such as local climate conditions, energy consumption patterns, and advanced technologies, the project successfully designed an efficient solar power system tailored to the specific needs of the school.

2. **Reliability of Renewable Energy**: This project illustrated that solar energy can provide a reliable and sustainable source of electricity, significantly reducing dependence on diesel generators, which are both costly and environmentally detrimental. The anticipated annual energy production of approximately 93,742 kWh demonstrates the potential of solar technology to meet the needs of educational institutions in remote areas.

3. **Importance of Performance Monitoring**: The performance analysis conducted using PVsyst provides valuable insights into the efficiency and reliability of the solar PV system. The consistent performance ratio (0.78) across operational months indicates that the system is well-optimized to adapt to varying environmental conditions.

4. **Community Engagement and Socio-Economic Development**: The project's design included not only technical specifications but also a strong focus on community impact, aligning with the Sustainable Development Goals. By creating jobs and enhancing educational facilities through reliable electricity, the solar power plant catalyzes socio-economic development in the region.

5. **Financial Viability and Investment Returns**: The financial analysis highlighted the project's economic feasibility, with a competitive Levelized Cost of Electricity (LCOE) and an attractive internal rate of return (IRR) of 31.43%. These metrics indicate that investing in renewable energy projects in remote areas can be profitable while contributing to long-term sustainability goals.

In summary, the project exemplifies a successful integration of renewable energy technologies in a practical application, providing reliable electricity to improve educational outcomes and stimulating economic growth in Swarna Dweep. The lessons learned from this endeavor can serve as a model for similar projects throughout Bangladesh and other regions facing energy challenges.

## 9.2 Recommendations

While the project demonstrates significant potential, several areas warrant further attention and improvement:

1. **Real-Time Monitoring and Maintenance Protocols**: The current design lacks a robust system for real-time monitoring of the solar PV plant. Implementing a comprehensive monitoring system that allows for real-time data collection and analysis would enable proactive maintenance strategies. Such systems can identify performance issues early, helping to minimize downtime and maximize energy production.

2. **Community Education and Training**: To ensure the long-term sustainability of the solar power system, it is crucial to engage the local community in training and educational programs. These programs should cover the operation and maintenance of the solar PV system, empowering community members to take ownership of the technology and its benefits.

3. **Exploration of Hybrid Energy Systems**: The current design focuses solely on solar PV technology. Future projects could benefit from exploring the integration of solar PV with other renewable energy sources, such as wind or biomass. Hybrid systems can provide a more reliable and resilient energy supply, leveraging the strengths of multiple technologies to meet diverse energy demands.

4. **Policy Advocacy for Renewable Energy**: Continuous engagement with policymakers is essential to fostering an environment conducive to renewable energy investments. Advocating for incentives, subsidies, and favorable regulations can encourage more schools and institutions to adopt solar energy solutions.

5. **Expansion of the Project Scope**: The project can be expanded to include educational components into the curriculum, focusing on renewable energy technologies and sustainability practices. This educational approach can inspire the next generation to embrace clean energy solutions and promote environmental stewardship.

6. **Enhanced Data Analytics and Predictive Maintenance**: The current design does not utilize advanced data analytics for predictive maintenance. Incorporating machine learning algorithms and data analytics can predict potential system failures and optimize maintenance schedules, thus improving the overall efficiency and lifespan of the system.

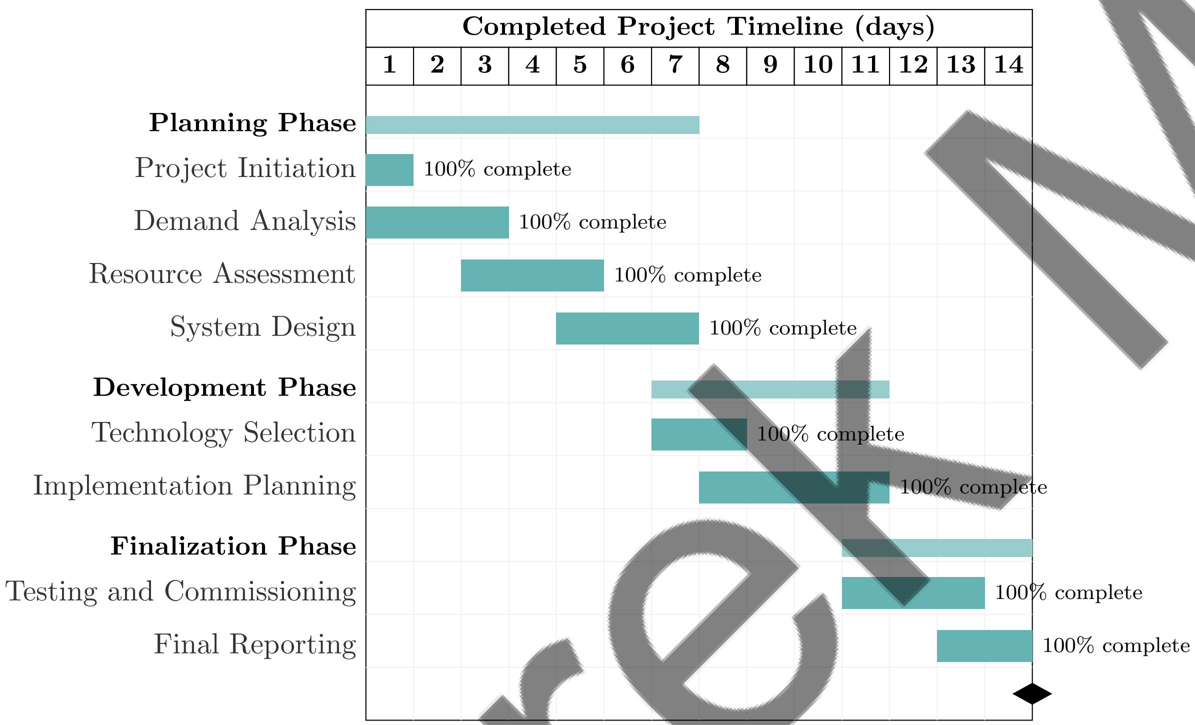
7. **Detailed Environmental Impact Assessments**: While the current design includes a basic environmental impact assessment, a more detailed analysis considering all environmental factors, such as local wildlife and ecosystem impacts, could be beneficial. This would ensure that the project aligns with environmental conservation goals and reduces negative ecological impacts.

8. **Advanced Weather Forecasting and Solar Radiation Prediction**: The system can be improved by integrating advanced weather forecasting and solar radiation prediction models. This would allow for better planning and optimization of the solar PV system's performance, ensuring maximum energy production even under varying weather conditions.

9. **Financial Risk Mitigation Strategies**: While the financial analysis considers basic costs and returns, incorporating risk mitigation strategies such as insurance for natural disasters and financial hedging strategies can provide a safety net against unforeseen events, ensuring the project's economic stability.

In conclusion, the grid-connected solar photovoltaic power plant project in Swarna Dweep is pioneering in renewable energy implementation. By addressing the outlined recommendations, subsequent projects can enhance their impact, further solidifying the role of renewable energy in driving sustainable development in Bangladesh and beyond.

## Gantt Chart


Completed Project Timeline (days)
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Planning Phase
Project Initiation
100% complete
Demand Analysis
100% complete
Resource Assessment
100% complete
System Design
100% complete
Development Phase
Technology Selection
100% complete
Implementation Planning
100% complete
Finalization Phase
Testing and Commissioning
100% complete
Final Reporting
100% complete

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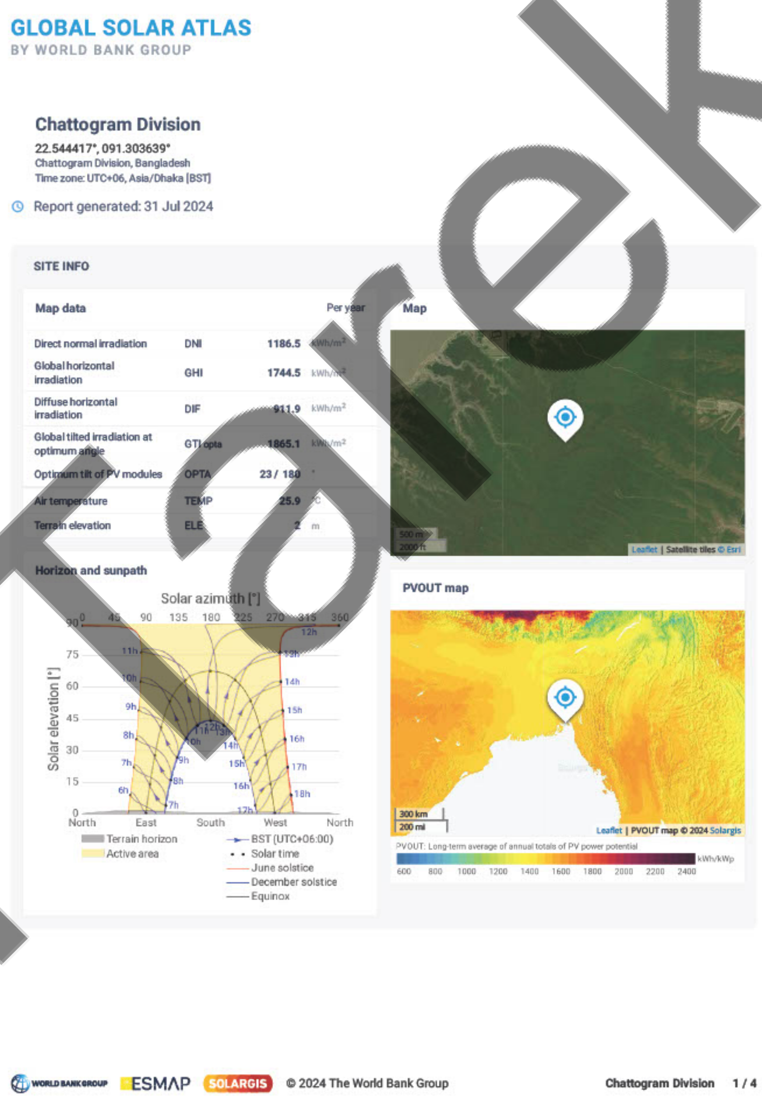
# Appendix A

# Report generated using Global Solar Atlas



GLOBAL SOLAR ATLAS
BY WORLD BANK GROUP

**Chattogram Division**

22.544417°, 091.303639°
Chattogram Division, Bangladesh
Time zone: UTC+06, Asia/Dhaka [BST]

Report generated: 31 Jul 2024

SITE INFO

Map data

| | | Per year | |
|---|---|---|---|
| Direct normal irradiation | DNI | 1186.5 | kWh/m² |
| Global horizontal irradiation | GHI | 1744.5 | kWh/m² |
| Diffuse horizontal irradiation | DIF | 911.9 | kWh/m² |
| Global tilted irradiation at optimum angle | GTI opta | 1865.1 | kWh/m² |
| Optimum tilt of PV modules | OPTA | 23 / 180 | ° |
| Air temperature | TEMP | 25.9 | °C |
| Terrain elevation | ELE | 2 | m |

Map

Horizon and sunpath



PVOUT map

PVOUT: Long-term average of annual totals of PV power potential

kWh/kWp

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Figure A.01: Page 1 of PDF

# GLOBAL SOLAR ATLAS
BY WORLD BANK GROUP

## PV ELECTRICITY AND SOLAR RADIATION

### PV system configuration

Pv system: **Ground-mounted large scale**
Azimuth of PV panels: **184°**
Tilt of PV panels: **27°**
Installed capacity: **60 kWp**

### Annual averages

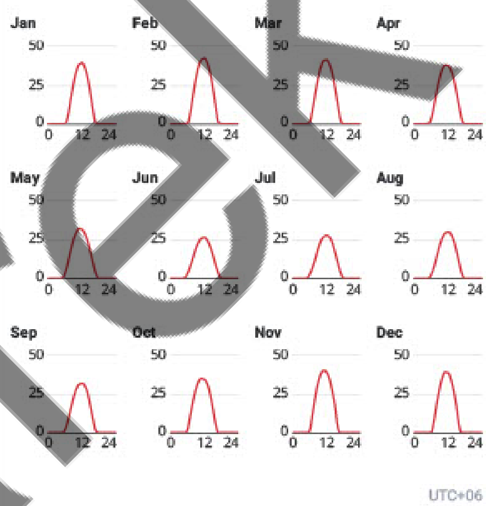
Total photovoltaic power output and Global tilted irradiation

**88.760** MWh per year

**1861.0** kWh/m² per year

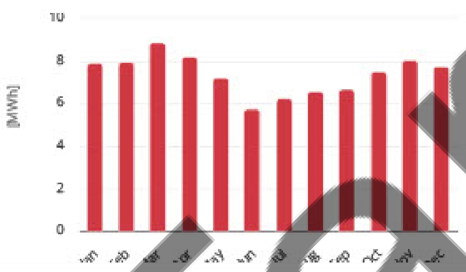
### Average hourly profiles

Total photovoltaic power output [kWh]




### Monthly averages

Total photovoltaic power output




### Average hourly profiles

Total photovoltaic power output [kWh]

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 - 1 | | | | | | | | | | | | |
| 1 - 2 | | | | | | | | | | | | |
| 2 - 3 | | | | | | | | | | | | |
| 3 - 4 | | | | | | | | | | | | |
| 4 - 5 | | | | | | | | | | | | |
| 5 - 6 | | | | 0.050 | 0.265 | 0.299 | 0.218 | 0.048 | | | | |
| 6 - 7 | 0.027 | 0.172 | 0.952 | 2.899 | 3.618 | 2.991 | 2.637 | 2.253 | 2.288 | 1.952 | 1.465 | 0.141 |
| 7 - 8 | 5.318 | 6.700 | 9.034 | 10.974 | 10.227 | 7.586 | 6.926 | 7.046 | 7.980 | 11.020 | 11.844 | 7.178 |
| 8 - 9 | 16.020 | 18.282 | 19.519 | 20.769 | 18.174 | 13.278 | 12.673 | 13.690 | 15.504 | 20.320 | 23.319 | 18.405 |
| 9 - 10 | 26.200 | 28.965 | 29.320 | 29.177 | 25.075 | 19.202 | 19.094 | 20.801 | 22.766 | 27.969 | 32.287 | 28.119 |
| 10 - 11 | 33.928 | 37.250 | 36.818 | 35.036 | 29.660 | 23.346 | 24.090 | 26.040 | 28.370 | 33.115 | 37.921 | 35.374 |
| 11 - 12 | 38.505 | 41.418 | 40.786 | 37.790 | 32.173 | 25.862 | 26.851 | 29.095 | 31.300 | 35.016 | 40.159 | 39.010 |
| 12 - 13 | 39.467 | 42.283 | 41.186 | 37.574 | 31.577 | 26.305 | 27.742 | 29.935 | 31.844 | 34.344 | 38.951 | 38.747 |
| 13 - 14 | 36.467 | 39.520 | 38.536 | 34.797 | 28.870 | 24.662 | 26.783 | 28.673 | 30.425 | 31.615 | 34.763 | 34.803 |
| 14 - 15 | 29.906 | 33.156 | 32.653 | 29.225 | 24.198 | 20.869 | 22.991 | 24.523 | 25.820 | 25.501 | 27.083 | 27.487 |
| 15 - 16 | 20.130 | 23.680 | 23.228 | 20.728 | 17.126 | 15.294 | 16.843 | 17.880 | 17.376 | 16.063 | 17.066 | 17.356 |
| 16 - 17 | 7.984 | 11.597 | 12.265 | 11.013 | 9.517 | 8.892 | 9.848 | 9.860 | 8.341 | 5.938 | 3.560 | 4.337 |
| 17 - 18 | 0.217 | 0.967 | 2.273 | 2.444 | 2.962 | 3.265 | 3.700 | 2.868 | 1.076 | 0.097 | | |
| 18 - 19 | | | | | 0.058 | 0.181 | 0.233 | 0.046 | | | | |
| 19 - 20 | | | | | | | | | | | | |
| 20 - 21 | | | | | | | | | | | | |
| 21 - 22 | | | | | | | | | | | | |
| 22 - 23 | | | | | | | | | | | | |
| 23 - 24 | | | | | | | | | | | | |
| Sum | 254 | 284 | 287 | 272 | 233 | 192 | 201 | 213 | 223 | 243 | 268 | 251 |

WORLD BANK GROUP ESMAP SOLARGIS  Chattogram Division 

Figure A.02: Page 2 of PDF

## GLOBAL SOLAR ATLAS
BY WORLD BANK GROUP

### PV ELECTRICITY AND SOLAR RADIATION

**Annual averages**

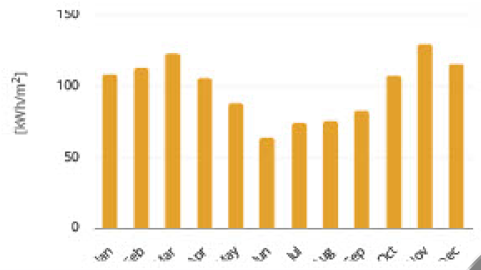
Direct normal irradiation

**1195.3**

kWh/m² per year

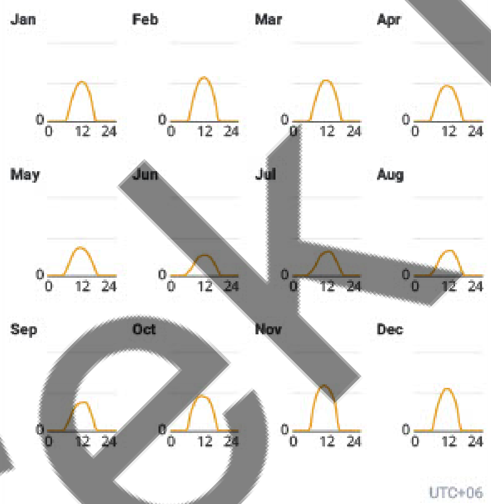
**Monthly averages**

Direct normal irradiation




**Average hourly profiles**

Direct normal irradiation [Wh/m²]




**Average hourly profiles**

Direct normal irradiation [Wh/m²]

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 - 1 | | | | | | | | | | | | |
| 1 - 2 | | | | | | | | | | | | |
| 2 - 3 | | | | | | | | | | | | |
| 3 - 4 | | | | | | | | | | | | |
| 4 - 5 | | | | | | | | | | | | |
| 5 - 6 | | | | | 2 | 5 | 7 | | | | | |
| 6 - 7 | | 2 | 19 | 45 | 52 | 45 | 40 | 32 | 39 | 42 | 41 | 2 |
| 7 - 8 | 96 | 127 | 160 | 163 | 134 | 84 | 85 | 81 | 111 | 217 | 270 | 141 |
| 8 - 9 | 243 | 288 | 286 | 275 | 222 | 140 | 140 | 150 | 195 | 321 | 421 | 302 |
| 9 - 10 | 354 | 411 | 394 | 370 | 300 | 202 | 216 | 228 | 275 | 401 | 517 | 414 |
| 10 - 11 | 443 | 506 | 479 | 432 | 347 | 246 | 275 | 282 | 328 | 442 | 567 | 495 |
| 11 - 12 | 495 | 552 | 523 | 457 | 369 | 266 | 299 | 315 | 357 | 448 | 585 | 538 |
| 12 - 13 | 511 | 564 | 527 | 454 | 361 | 272 | 313 | 328 | 364 | 438 | 565 | 538 |
| 13 - 14 | 488 | 536 | 508 | 434 | 339 | 269 | 318 | 328 | 368 | 422 | 523 | 499 |
| 14 - 15 | 424 | 471 | 455 | 387 | 298 | 241 | 288 | 296 | 337 | 369 | 448 | 424 |
| 15 - 16 | 323 | 372 | 358 | 296 | 230 | 192 | 219 | 227 | 247 | 270 | 335 | 308 |
| 16 - 17 | 147 | 215 | 226 | 187 | 151 | 130 | 144 | 140 | 145 | 126 | 77 | 87 |
| 17 - 18 | 4 | 16 | 44 | 43 | 57 | 55 | 68 | 45 | 19 | 1 | | |
| 18 - 19 | | | | | | 1 | 2 | | | | | |
| 19 - 20 | | | | | | | | | | | | |
| 20 - 21 | | | | | | | | | | | | |
| 21 - 22 | | | | | | | | | | | | |
| 22 - 23 | | | | | | | | | | | | |
| 23 - 24 | | | | | | | | | | | | |
| Sum | 3,527 | 4,061 | 3,978 | 3,543 | 2,860 | 2,148 | 2,413 | 2,451 | 2,787 | 3,498 | 4,351 | 3,749 |

WORLD BANK GROUP ESMAP SOLARGIS  Chattogram Division 3 / 4

Figure A.03: Page 3 of PDF

# Appendix B

# Report generated using PVGIS

European Commission

## Performance of grid-connected PV

PVGIS-5 estimates of solar electricity generation:

**Provided inputs:**

| | |
|---|---|
| Latitude/Longitude: | 22.544,91.304 |
| Horizon: | Calculated |
| Database used: | PVGIS-SARAH |
| PV technology: | Crystalline silicon |
| PV installed: | 60 kWp |
| System loss: | 14 % |

**Simulation outputs**

| | |
|---|---|
| Slope angle: | 27 (opt) ° |
| Azimuth angle: | 7 (opt) ° |
| Yearly PV energy production: | 89333.73 kWh |
| Yearly in-plane irradiation: | 1979.73 kWh/m² |
| Year-to-year variability: | 2971.51 kWh |
| Changes in output due to: | |
| Angle of incidence: | -2.64 % |
| Spectral effects: | NaN % |
| Temperature and low irradiance: | -10.18 % |
| Total loss: | -24.79 % |

**Outline of horizon at chosen location:**

**Monthly energy output from fix-angle PV system:**

**Monthly in-plane irradiation for fixed-angle:**



**Monthly PV energy and solar irradiation**

| Month | E_m | H(i)_m | SD_m |
|---|---|---|---|
| January | 8433.7 | 182.9 | 530.3 |
| February | 8265.5 | 182.2 | 406.8 |
| March | 9113.6 | 203.6 | 530.6 |
| April | 8381.6 | 186.7 | 513.7 |
| May | 7409.7 | 165.5 | 757.7 |
| June | 5873.7 | 130.7 | 685.1 |
| July | 5528.5 | 122.1 | 1864.3 |
| August | 6478.4 | 143.4 | 560.4 |
| September | 6367.5 | 142.1 | 442.9 |
| October | 7178.8 | 162.1 | 565.8 |
| November | 7930.7 | 177.2 | 534.3 |
| December | 8371.8 | 181.3 | 390.1 |

E_m: Average monthly electricity production from the defined system [kWh].

H(i)_m: Average monthly sum of global irradiation per square meter received by the modules of the given system [kWh/m²].

SD_m: Standard deviation of the monthly electricity production due to year-to-year variation [kWh].

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Joint Research Centre

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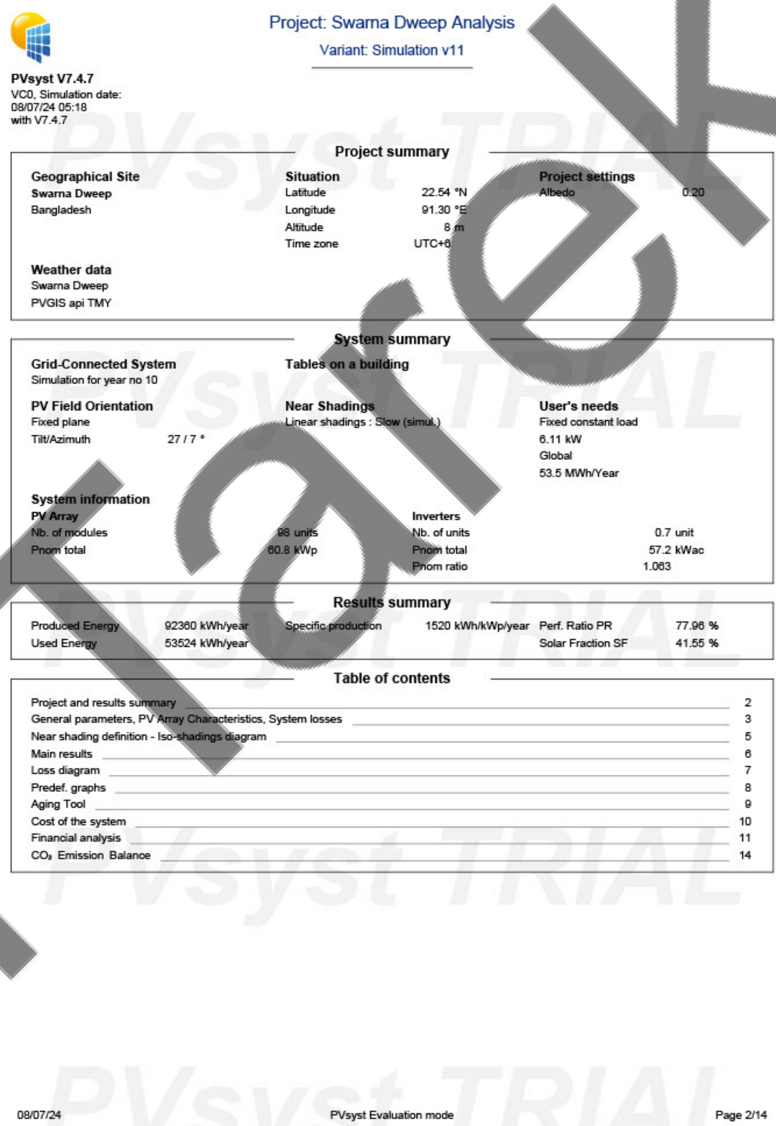
Report generated on 2024/09/09

Figure B.01: Page 1 of PDF

# Appendix C

# Report generated using PVsyst



PVsyst V7.4.7
VC0, Simulation date:
08/07/24 05:18
with V7.4.7

**Project: Swarna Dweep Analysis**
Variant: Simulation v11

**Project summary**

| Geographical Site | Situation | | Project settings | |
|---|---|---|---|---|
| Swarna Dweep | Latitude | 22.54 °N | Albedo | 0.20 |
| Bangladesh | Longitude | 91.30 °E | | |
| | Altitude | 8 m | | |
| | Time zone | UTC+6 | | |

**Weather data**
Swarna Dweep
PVGIS api TMY

**System summary**

**Grid-Connected System**
Simulation for year no 10

**Tables on a building**

| PV Field Orientation | | Near Shadings | User's needs |
|---|---|---|---|
| Fixed plane | | Linear shadings : Slow (simul.) | Fixed constant load |
| Tilt/Azimuth | 27 / 7 ° | | 6.11 kW |
| | | | Global |
| | | | 53.5 MWh/Year |

**System information**

| PV Array | | Inverters | |
|---|---|---|---|
| Nb. of modules | 98 units | Nb. of units | 0.7 unit |
| Pnom total | 60.8 kWp | Pnom total | 57.2 kWac |
| | | Pnom ratio | 1.063 |

**Results summary**

| | | | | | |
|---|---|---|---|---|---|
| Produced Energy | 92360 kWh/year | Specific production | 1520 kWh/kWp/year | Perf. Ratio PR | 77.96 % |
| Used Energy | 53524 kWh/year | | | Solar Fraction SF | 41.55 % |

**Table of contents**





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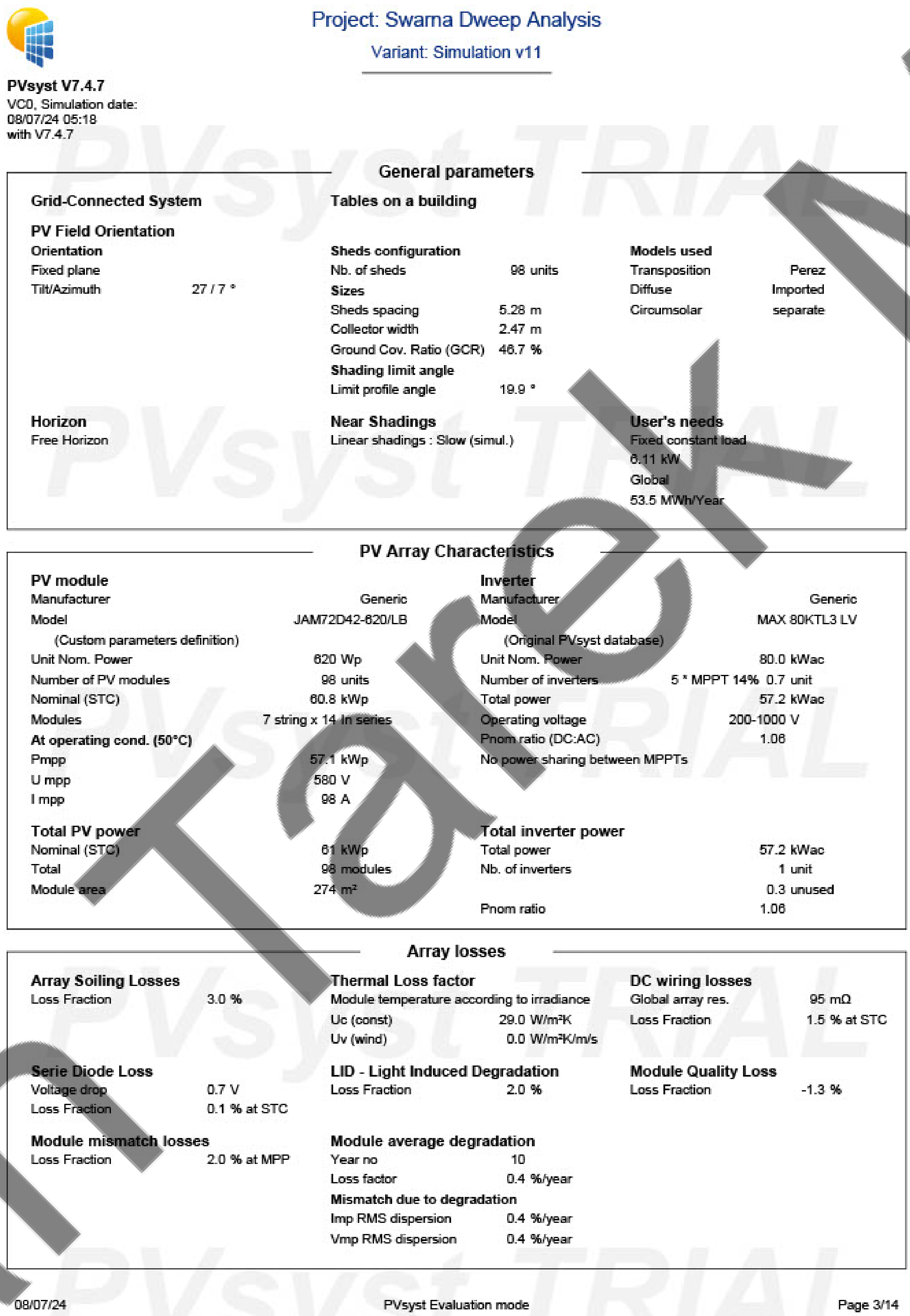
Figure C.01: Page 1 of PDF





## Project: Swarna Dweep Analysis

Variant: Simulation v11

### General parameters

**Grid-Connected System** | **Tables on a building**

**PV Field Orientation**

| Orientation | | Sheds configuration | | Models used | |
|---|---|---|---|---|---|
| Fixed plane | | Nb. of sheds | 98 units | Transposition | Perez |
| Tilt/Azimuth | 27 / 7 ° | **Sizes** | | Diffuse | Imported |
| | | Sheds spacing | 5.28 m | Circumsolar | separate |
| | | Collector width | 2.47 m | | |
| | | Ground Cov. Ratio (GCR) | 46.7 % | | |
| | | **Shading limit angle** | | | |
| | | Limit profile angle | 19.9 ° | | |

**Horizon**
Free Horizon

**Near Shadings**
Linear shadings : Slow (simul.)

**User's needs**
Fixed constant load
6.11 kW
Global
53.5 MWh/Year

### PV Array Characteristics

**PV module**

| | |
|---|---|
| Manufacturer | Generic |
| Model | JAM72D42-620/LB |
| (Custom parameters definition) | |
| Unit Nom. Power | 620 Wp |
| Number of PV modules | 98 units |
| Nominal (STC) | 60.8 kWp |
| Modules | 7 string x 14 In series |
| **At operating cond. (50°C)** | |
| Pmpp | 57.1 kWp |
| U mpp | 580 V |
| I mpp | 98 A |

**Inverter**

| | |
|---|---|
| Manufacturer | Generic |
| Model | MAX 80KTL3 LV |
| (Original PVsyst database) | |
| Unit Nom. Power | 80.0 kWac |
| Number of inverters | 5 * MPPT 14% 0.7 unit |
| Total power | 57.2 kWac |
| Operating voltage | 200-1000 V |
| Pnom ratio (DC:AC) | 1.06 |
| No power sharing between MPPTs | |

**Total PV power**

| | |
|---|---|
| Nominal (STC) | 61 kWp |
| Total | 98 modules |
| Module area | 274 m² |

**Total inverter power**

| | |
|---|---|
| Total power | 57.2 kWac |
| Nb. of inverters | 1 unit |
| | 0.3 unused |
| Pnom ratio | 1.06 |

### Array losses

**Array Soiling Losses**
Loss Fraction 3.0 %

**Thermal Loss factor**
Module temperature according to irradiance
Uc (const) 29.0 W/m²K
Uv (wind) 0.0 W/m²K/m/s

**DC wiring losses**
Global array res. 95 mΩ
Loss Fraction 1.5 % at STC

**Serie Diode Loss**
Voltage drop 0.7 V
Loss Fraction 0.1 % at STC

**LID - Light Induced Degradation**
Loss Fraction 2.0 %

**Module Quality Loss**
Loss Fraction -1.3 %

**Module mismatch losses**
Loss Fraction 2.0 % at MPP

**Module average degradation**
Year no 10
Loss factor 0.4 %/year
**Mismatch due to degradation**
Imp RMS dispersion 0.4 %/year
Vmp RMS dispersion 0.4 %/year





Figure C.02: Page 2 of PDF

## Project: Swarna Dweep Analysis

Variant: Simulation v11

**PVsyst V7.4.7**
VC0, Simulation date:
08/07/24 05:18
with V7.4.7

### Array losses

**IAM loss factor**

Incidence effect (IAM): Fresnel smooth glass, n = 1.526

| 0° | 30° | 50° | 60° | 70° | 75° | 80° | 85° | 90° |
|---|---|---|---|---|---|---|---|---|
| 1.000 | 0.998 | 0.981 | 0.948 | 0.862 | 0.776 | 0.636 | 0.403 | 0.000 |

**Spectral correction**

FirstSolar model

Precipitable water estimated from relative humidity

| Coefficient Set | C0 | C1 | C2 | C3 | C4 | C5 |
|---|---|---|---|---|---|---|
| Monocrystalline Si | 0.85914 | -0.02088 | -0.0058853 | 0.12029 | 0.026814 | -0.001781 |

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Figure C.03: Page 3 of PDF

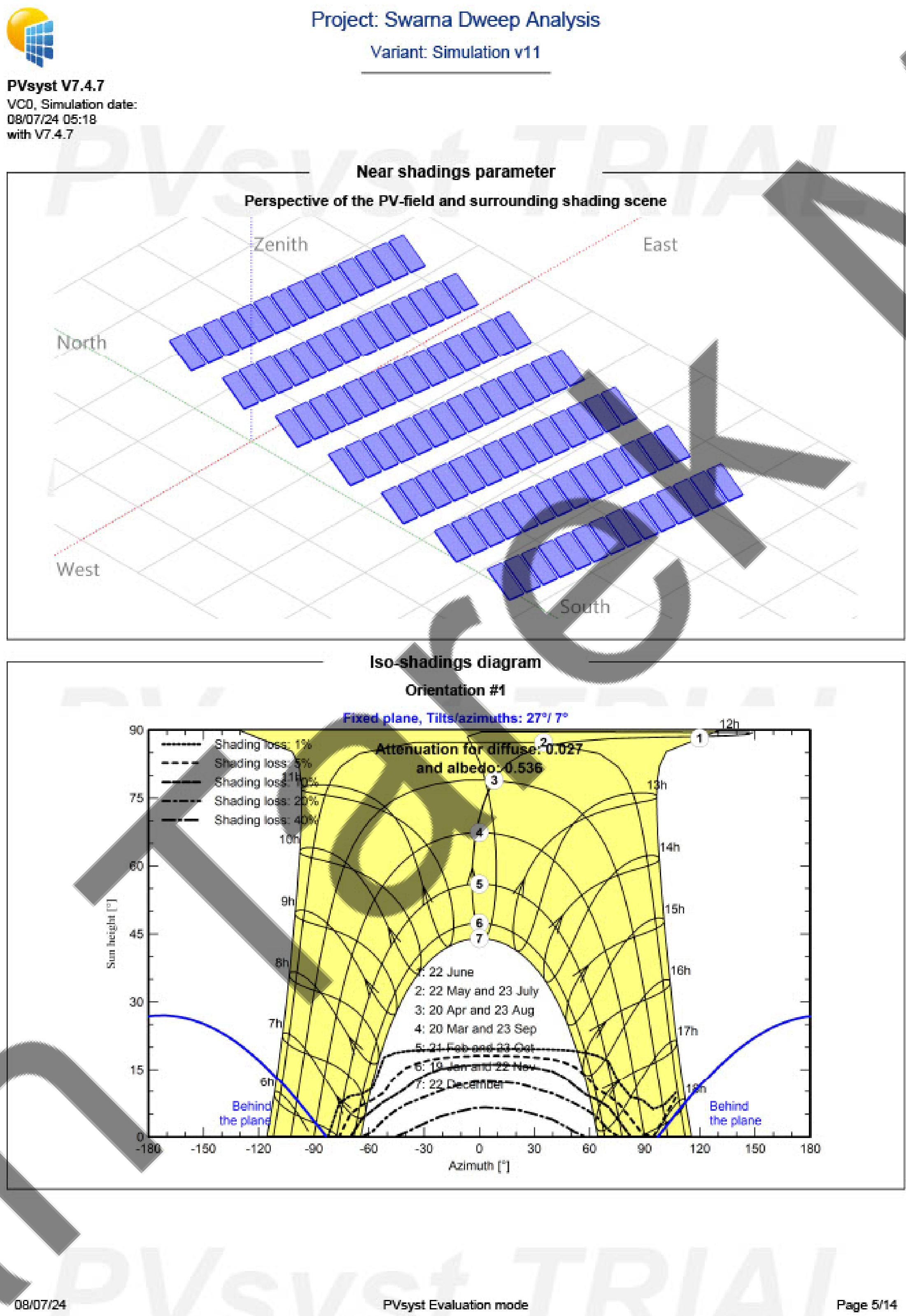



Figure C.04: Page 4 of PDF

**PVsyst V7.4.7**
VC0, Simulation date:
08/07/24 05:18
with V7.4.7

Project: Swarna Dweep Analysis

Variant: Simulation v11

## Main results

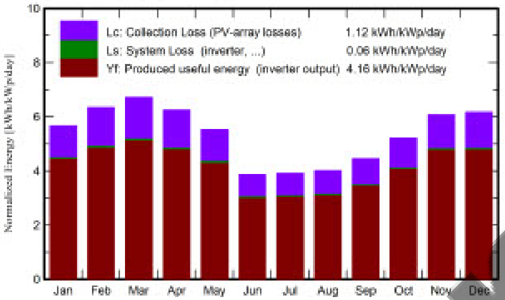
**System Production**

| | | | |
|---|---|---|---|
| Produced Energy | 92360 kWh/year | Specific production | 1520 kWh/kWp/year |
| Used Energy | 53524 kWh/year | Perf. Ratio PR | 77.96 % |
| | | Solar Fraction SF | 41.55 % |

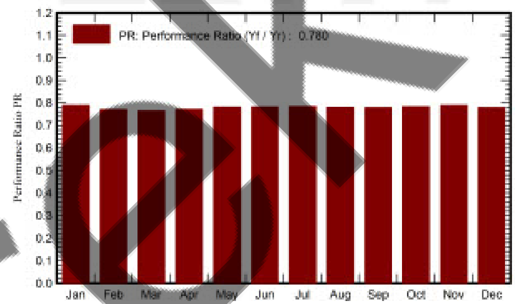
**Economic evaluation**

| Investment | | Yearly cost | | LCOE | |
|---|---|---|---|---|---|
| Global | 4560713.60 BDT | Annuities | 0.00 BDT/yr | Energy cost | 12.0 BDT/kWh |
| Specific | 75.1 BDT/Wp | Run. costs | 795783.28 BDT/yr | | |
| | | Payback period | 4.1 years | | |

**Normalized productions (per installed kWp)**




**Performance Ratio PR**




**Balances and main results**

| | GlobHor kWh/m² | DiffHor kWh/m² | T_Amb °C | GlobInc kWh/m² | GlobEff kWh/m² | EArray kWh | E_User kWh | E_Solar kWh | E_Grid kWh | EFrGrid kWh |
|---|---|---|---|---|---|---|---|---|---|---|
| January | 131.9 | 47.33 | 20.61 | 175.4 | 165.4 | 8534 | 4546 | 1794 | 6627 | 2752 |
| February | 145.7 | 49.90 | 23.17 | 177.4 | 167.4 | 8410 | 4106 | 1688 | 6611 | 2418 |
| March | 189.9 | 68.58 | 27.86 | 208.4 | 196.0 | 9818 | 4546 | 1983 | 7703 | 2563 |
| April | 189.1 | 74.66 | 28.57 | 187.4 | 175.3 | 8905 | 4399 | 1970 | 6809 | 2430 |
| May | 185.9 | 84.68 | 28.59 | 171.3 | 159.5 | 8264 | 4546 | 2063 | 6078 | 2483 |
| June | 128.9 | 75.51 | 28.37 | 116.0 | 107.3 | 5627 | 4399 | 1792 | 3731 | 2607 |
| July | 132.6 | 77.69 | 27.37 | 121.4 | 112.3 | 5897 | 4546 | 1864 | 3926 | 2682 |
| August | 128.4 | 72.15 | 27.67 | 124.0 | 115.4 | 5994 | 4546 | 1792 | 4092 | 2753 |
| September | 128.9 | 64.24 | 28.09 | 133.6 | 124.8 | 6438 | 4399 | 1752 | 4581 | 2648 |
| October | 140.1 | 61.73 | 28.13 | 161.8 | 152.0 | 7816 | 4546 | 1872 | 5834 | 2674 |
| November | 140.2 | 49.93 | 24.64 | 181.9 | 171.5 | 8863 | 4399 | 1824 | 6921 | 2575 |
| December | 138.0 | 44.05 | 20.30 | 191.2 | 180.3 | 9177 | 4546 | 1845 | 7210 | 2701 |
| Year | 1779.7 | 770.46 | 26.12 | 1949.8 | 1827.2 | 93742 | 53524 | 22239 | 70121 | 31285 |

**Legends**

| | | | |
|---|---|---|---|
| GlobHor | Global horizontal irradiation | EArray | Effective energy at the output of the array |
| DiffHor | Horizontal diffuse irradiation | E_User | Energy supplied to the user |
| T_Amb | Ambient Temperature | E_Solar | Energy from the sun |
| GlobInc | Global incident in coll. plane | E_Grid | Energy injected into grid |
| GlobEff | Effective Global, corr. for IAM and shadings | EFrGrid | Energy from the grid |

08/07/24 PVsyst Evaluation mode Page 6/14



Figure C.05: Page 5 of PDF

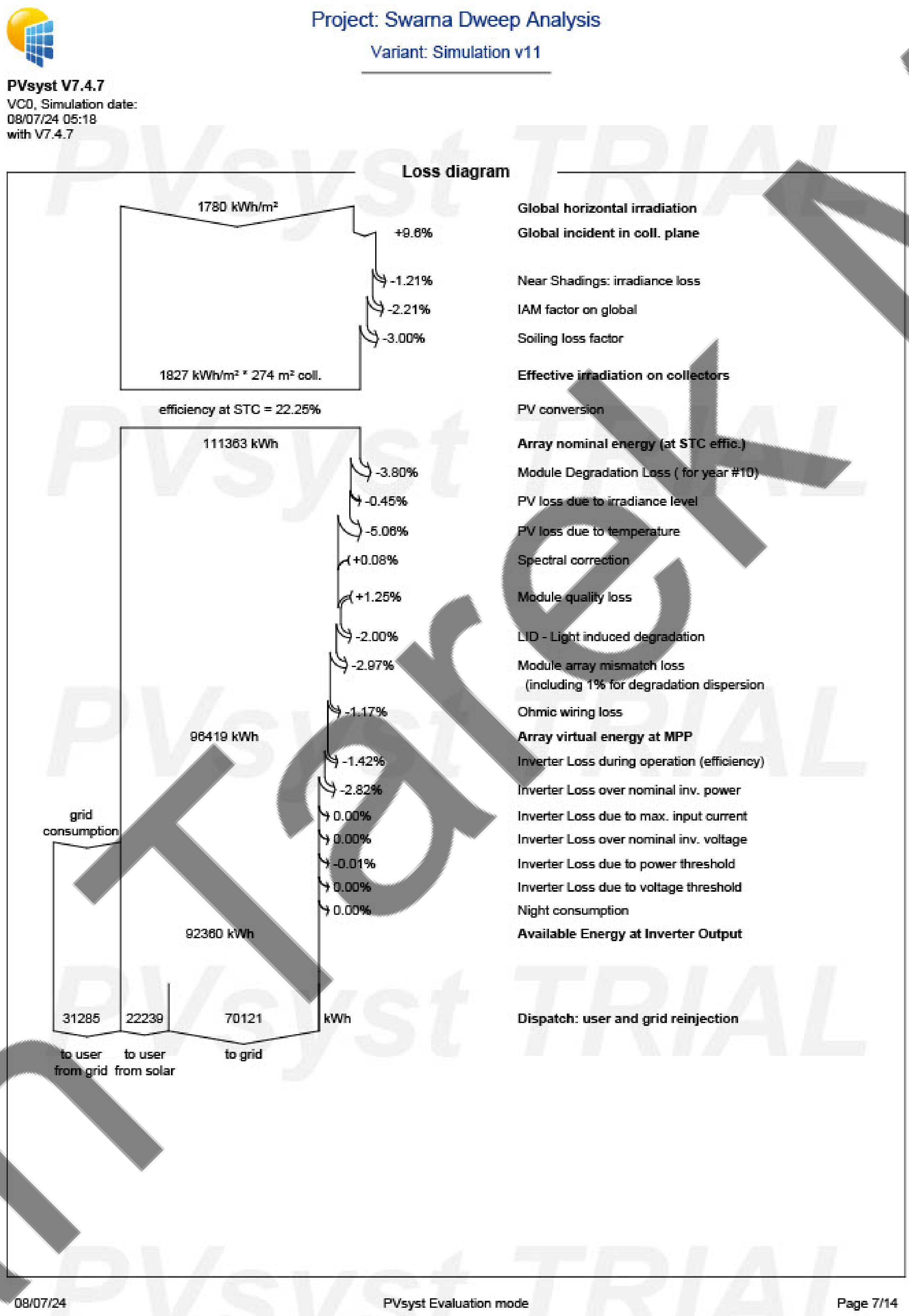



Figure C.06: Page 6 of PDF

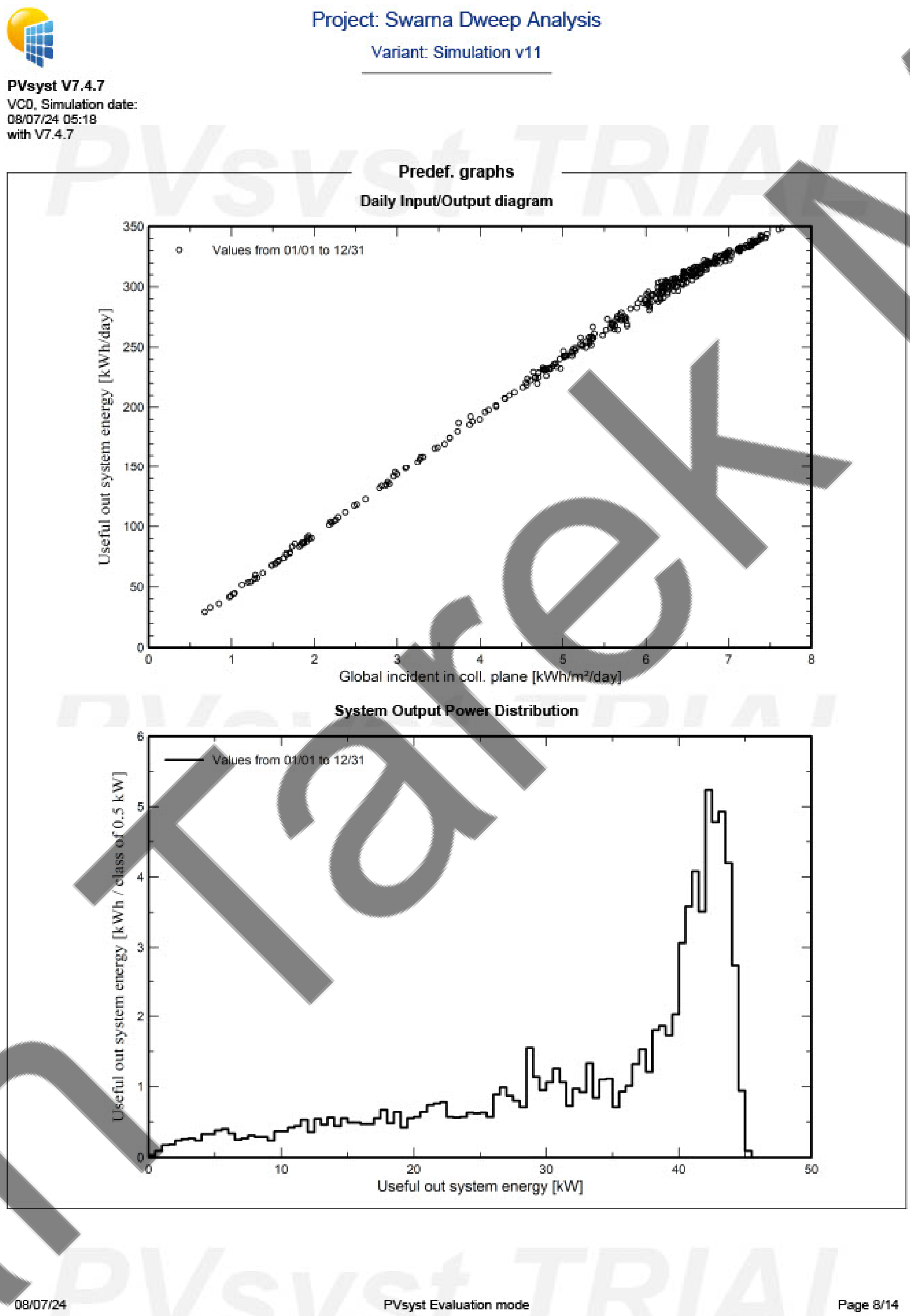



Figure C.07: Page 7 of PDF

PVsyst V7.4.7
VC0, Simulation date:
08/07/24 05:18
with V7.4.7

Project: Swarna Dweep Analysis

Variant: Simulation v11

## Aging Tool

**Aging Parameters**

Time span of simulation 20 years

**Module average degradation**

Loss factor 0.4 %/year

**Mismatch due to degradation**

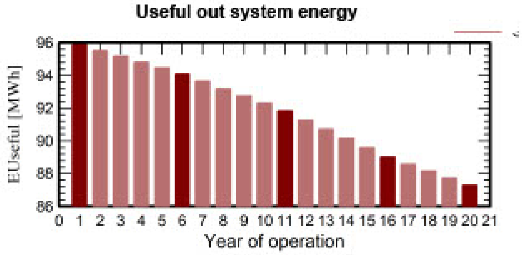
Imp RMS dispersion 0.4 %/year

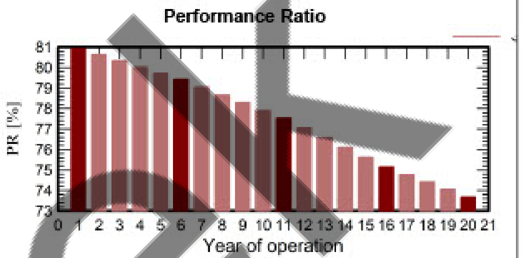
Vmp RMS dispersion 0.4 %/year

**Weather data used in the simulation**

**Swarna Dweep PVGIS API TMY**

Years reference year




| | EUseful | PR | PR loss |
|---|---|---|---|
| Year | MWh | % | % |
| 1 | 95.87 | 80.93 | -0.19 |
| 2 | 95.52 | 80.63 | -0.56 |
| 3 | 95.16 | 80.33 | -0.93 |
| 4 | 94.81 | 80.03 | -1.30 |
| 5 | 94.45 | 79.73 | -1.67 |
| 6 | 94.10 | 79.43 | -2.04 |
| 7 | 93.65 | 79.05 | -2.51 |
| 8 | 93.19 | 78.67 | -2.98 |
| 9 | 92.74 | 78.28 | -3.45 |
| 10 | 92.29 | 77.90 | -3.92 |
| 11 | 91.84 | 77.52 | -4.39 |
| 12 | 91.27 | 77.04 | -4.98 |
| 13 | 90.71 | 76.57 | -5.56 |
| 14 | 90.15 | 76.09 | -6.15 |
| 15 | 89.58 | 75.62 | -6.74 |
| 16 | 89.02 | 75.14 | -7.33 |
| 17 | 88.58 | 74.77 | -7.78 |
| 18 | 88.15 | 74.41 | -8.23 |
| 19 | 87.72 | 74.05 | -8.68 |
| 20 | 87.29 | 73.68 | -9.13 |

08/07/24 PVsyst Evaluation mode Page 9/14

Figure C.08: Page 8 of PDF

**PVsyst V7.4.7**
VC0, Simulation date:
08/07/24 05:18
with V7.4.7

## Project: Swarna Dweep Analysis

Variant: Simulation v11



### Cost of the system

**Installation costs**

| Item | Quantity units | Cost BDT | Total BDT |
|---|---|---|---|
| PV modules | | | |
| JAM72D42-620/LB | 98 | 10010.00 | 980980.00 |
| Inverters | | | |
| MAX 80KTL3 LV | 1 | 751660.00 | 533678.60 |
| Other components | | | |
| Accessories, fasteners | 1 | 823895.00 | 823895.00 |
| Wiring | 1 | 488160.00 | 488160.00 |
| Combiner box | 3 | 17666.67 | 53000.00 |
| Monitoring system, display screen | 1 | 40000.00 | 40000.00 |
| Measurement system, pyranometer | 1 | 30000.00 | 30000.00 |
| Surge arrester | 2 | 1500.00 | 3000.00 |
| Studies and analysis | | | |
| Engineering | 4 | 80000.00 | 320000.00 |
| Permitting and other admin. Fees | 2 | 80000.00 | 160000.00 |
| Environmental studies | 2 | 80000.00 | 160000.00 |
| Economic analysis | 2 | 80000.00 | 160000.00 |
| Installation | | | |
| Global installation cost per module | 98 | 1000.00 | 98000.00 |
| Global installation cost per inverter | 1 | 42253.52 | 30000.00 |
| Transport | 8 | 15000.00 | 120000.00 |
| Settings | 4 | 15000.00 | 60000.00 |
| Grid connection | 1 | 500000.00 | 500000.00 |
| | | Total | 4560713.60 |
| | | Depreciable asset | 2338553.60 |

**Operating costs**

| Item | Total BDT/year |
|---|---|
| Maintenance | |
| Provision for inverter replacement | 26845.00 |
| Salaries | 150000.00 |
| Repairs | 60000.00 |
| Cleaning | 30000.00 |
| Security fund | 40000.00 |
| Subsidies | -20000.00 |
| Total (OPEX) | 286845.00 |
| Including inflation (9.72%) | 795783.28 |

**System summary**

| | |
|---|---|
| Total installation cost | 4560713.60 BDT |
| Operating costs (incl. inflation 9.72%/year) | 795783.28 BDT/year |
| Useful energy from solar | 22.2 MWh/year |
| Energy sold to the grid | 70.1 MWh/year |
| Cost of produced energy (LCOE) | 11.9677 BDT/kWh |

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Project: Swarna Dweep Analysis
Variant: Simulation v11



## Financial analysis

**Simulation period**

Project lifetime 20 years Start year 2024

**Income variation over time**

Inflation 9.72 %/year
Production variation (aging) Aging tool results
Discount rate 9.00 %/year

**Income dependent expenses**

Income tax rate 3.00 %/year
Other income tax 0.00 %/year
Dividends 20.00 %/year

**Depreciable assets**

| Asset | Depreciation method | Depreciation period (years) | Salvage value (BDT) | Depreciable (BDT) |
|---|---|---|---|---|
| PV modules | | | | |
| JAM72D42-620/LB | Straight-line | 20 | 0.00 | 980980.00 |
| Inverters | | | | |
| MAX 80KTL3 LV | Straight-line | 20 | 0.00 | 533678.60 |
| Accessories, fasteners | Straight-line | 20 | 0.00 | 823895.00 |
| | | Total | 0.00 | 2338553.60 |

**Financing**

Own funds 4160713.60 BDT
Subsidies 400000.00 BDT

**Electricity sale**

Feed-in tariff 19.12965 BDT/kWh
Duration of tariff warranty 20 years
Annual connection tax 1000.00 BDT/kWh
Annual tariff variation +5.0 %/year
Feed-in tariff decrease after warranty 15.00 %

**Self-consumption**

Consumption tariff 7.50000 BDT/kWh
Tariff evolution +5.0 %/year

**Return on investment**

Payback period 4.1 years
Net present value (NPV) 9010080.99 BDT
Internal rate of return (IRR) 31.43 %
Return on investment (ROI) 216.6 %
Paid dividends 5079626.96 BDT



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Variant: Simulation v11



## Financial analysis

### Detailed economic results (kBDT)

| Year | Electricity sale | Own funds | Run. costs | Deprec. allow. | Taxable income | Taxes | After-tax profit | Divid. 20.00% | Self-cons. saving | Cumul. profit | % amorti. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 4160714 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -4160714 | 0.0% |
| 1 | 1338005 | 0 | 286845 | 116928 | 934232 | 28027 | 1023133 | 204627 | 166484 | -3069322 | 26.2% |
| 2 | 1399743 | 0 | 314726 | 116928 | 968089 | 29043 | 1055974 | 211195 | 174160 | -2033942 | 51.1% |
| 3 | 1464308 | 0 | 345318 | 116928 | 1002063 | 30062 | 1088929 | 217786 | 182188 | -1052407 | 74.7% |
| 4 | 1531828 | 0 | 378883 | 116928 | 1036017 | 31081 | 1121865 | 224373 | 190583 | -122636 | 97.1% |
| 5 | 1602436 | 0 | 415710 | 116928 | 1069798 | 32094 | 1154632 | 230926 | 199362 | 757368 | 118.2% |
| 6 | 1676273 | 0 | 456117 | 116928 | 1103228 | 33097 | 1187059 | 237412 | 208542 | 1589519 | 138.2% |
| 7 | 1751667 | 0 | 500452 | 116928 | 1134287 | 34029 | 1217186 | 243437 | 217917 | 2374569 | 157.1% |
| 8 | 1830407 | 0 | 549095 | 116928 | 1164384 | 34932 | 1246380 | 249276 | 227707 | 3114364 | 174.9% |
| 9 | 1912639 | 0 | 602468 | 116928 | 1193244 | 35797 | 1274374 | 254875 | 237931 | 3810671 | 191.6% |
| 10 | 1998516 | 0 | 661027 | 116928 | 1220561 | 36617 | 1300872 | 260174 | 248608 | 4465188 | 207.3% |
| 11 | 2088197 | 0 | 725279 | 116928 | 1245990 | 37380 | 1325538 | 265108 | 259759 | 5079543 | 222.1% |
| 12 | 2179187 | 0 | 795776 | 116928 | 1266483 | 37994 | 1345416 | 269083 | 271072 | 5654260 | 235.9% |
| 13 | 2274053 | 0 | 873126 | 116928 | 1283999 | 38520 | 1362407 | 272481 | 282867 | 6190914 | 248.8% |
| 14 | 2372955 | 0 | 957994 | 116928 | 1298034 | 38941 | 1376020 | 275204 | 295164 | 6691010 | 260.8% |
| 15 | 2476060 | 0 | 1051111 | 116928 | 1308022 | 39241 | 1385709 | 277142 | 307983 | 7155993 | 272.0% |
| 16 | 2583540 | 0 | 1153279 | 116928 | 1313334 | 39400 | 1390862 | 278172 | 321347 | 7587246 | 282.4% |
| 17 | 2699585 | 0 | 1265377 | 116928 | 1317280 | 39518 | 1394689 | 278938 | 335775 | 7987110 | 292.0% |
| 18 | 2820773 | 0 | 1388372 | 116928 | 1315473 | 39464 | 1392936 | 278587 | 350843 | 8356780 | 300.8% |
| 19 | 2947328 | 0 | 1523322 | 116928 | 1307078 | 39212 | 1384794 | 276959 | 366578 | 8697404 | 309.0% |
| 20 | 3079484 | 0 | 1671389 | 116928 | 1291167 | 38735 | 1369360 | 273872 | 383010 | 9010081 | 316.6% |
| Total | 42026983 | 4160714 | 15915666 | 2338554 | 23772764 | 713183 | 25398135 | 5079627 | 5227881 | 9010081 | 316.6% |

### Yearly net profit (kBDT)





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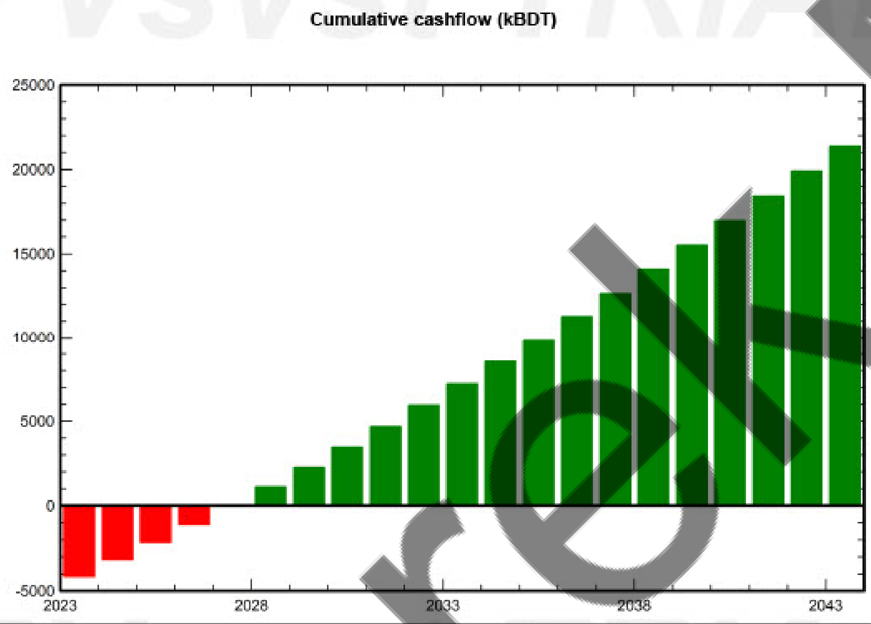
## Financial analysis

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Project: Swarna Dweep Analysis

Variant: Simulation v11

## $CO_2$ Emission Balance

Total: 877.6 $tCO_2$

**Generated emissions**

Total: 104.58 $tCO_2$

Source: Detailed calculation from table below

**Replaced Emissions**

Total: 1078.8 $tCO_2$

System production: 92.36 MWh/yr

Grid Lifecycle Emissions: 584 $gCO_2/kWh$

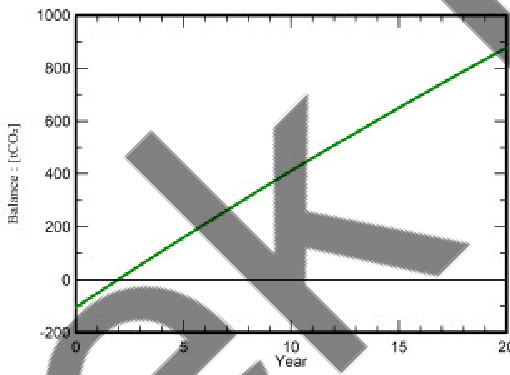
Source: IEA List

Country: Bangladesh

Lifetime: 20 years

Annual degradation: 1.0 %

**Saved $CO_2$ Emission vs. Time**




**System Lifecycle Emissions Details**

| Item | LCE | Quantity | Subtotal |
|---|---|---|---|
| | | | [$kgCO_2$] |
| Modules | 1062 kgCO2/modules | 98.0 modules | 104060 |
| Transport1 | 35.0 gCO2/km | 5.00 km | 0.59 |
| Transport2 | 59.7 gCO2/km | 5.00 km | 1.01 |
| Inverters | 522 kgCO2/units | 1.00 units | 522 |

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