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Development of a 10 kW Solar Photovoltaic Power Plant for Bonwary Lal Govt. High School

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Abstract: *This research paper proposes the development of a 10-kW solar photovoltaic (SPV) power plant for a high school named Bonwary Lal Govt. High School, is located near the Brahmaputra River in the Sirajganj district in Bangladesh. The school, with a land area of 3.65 acres and an annual enrollment of 1160 students, experiences significant power consumption due to its operation in two shifts. To address this challenge and promote sustainability, a solar PV power plant is designed to meet the school's energy demand while ensuring future development prospects in the region. PVGIS and RETscreen is used to simulate the solar data and feasibility of the powerplant. The paper explores the technical and economic feasibility of the project, emphasizing the advantages of solar energy, its environmental benefits, and the potential for reducing carbon emissions. The research highlights the importance of renewable energy adoption in educational institutions and presents the proposed solar PV power plant as a practical and sustainable solution for Bonwary Lal Govt. High School.*

Keywords: Solar photovoltaic (SPV) power plant, Bonwary Lal Govt. High School, sustainability, technical and economic feasibility, renewable energy.

1. INTRODUCTION

Bonwary Lal Govt. High School is a school situated beside Brahmaputra River near Sirajganj district having a land area of 3.65 acres [1]. It has three academic buildings and 1160 students are enrolled each year [2]. Huge power consumption is made to run the school in two shifts. As the land area is huge for the school, a solar PV powerplant can be developed to meet up the demand of the school. Solar energy is inexhaustible and pollution free [3]. The project "10 kW SPV Power Plant for School" is designed to meet up the power demand of the school individually. Assuming some parameters the project is designed indoor to open the future development scope in that area.

The location of the school is selected by observing the land area, academic buildings and availability of solar radiation. The location of our site is 24.45771°,089.70802° (latitude and longitude) beside Brahmaputra River near Sirajganj district. As land area of 3.65 aces is available for the school the implementation of SPV powerplant is expected to be tranquil. Also, solar project located near a river may have access to a reliable source of water for cleaning and maintaining the solar panels, which can improve lifespan of the project. A solar project located near a river may benefit from the cooling effect of the water, which can help to lower the temperature of the solar panels and improve their efficiency [4]. The location on google map is attached below [5]-

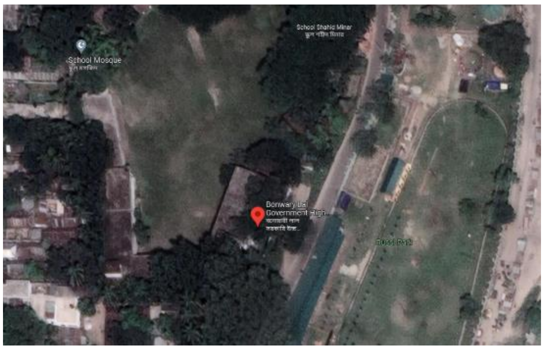

Figure 1: Location of Bonwary Lal Govt. High School [5]

A. Load Demand

Assuming a probable phenomenon's, the load demand of Bonwary Lal Govt. High School is estimated by gathering holding capacity. The components necessary for the institution and its laboratory are listed and calculated their power consumptions.

On the tables equipment's of the school classroom and laboratory uses is listed and total power consumption is calculated with few assumptions.

Table 1: Number of Components each room

Equip-ment's Name	Class Room	Teachers Room	Science Lab	ICT Lab	Multi-media Room	Wash-room & Pump
Fan	6	6	6	6	6	0
LED Light	4	4	4	4	4	1
Projector	1	1	1	1	1	0
Computer	0	0	0	9	1	0
Digital Display	0	0	0	1	1	0
Electric Pump	0	0	0	0	0	1

The equipment list with their total quantities and power consumption (in watt-hours) is as follows:

- Fan : 138 units, 11040 Wh each
- LED Light : 93 units, 2790 Wh each
- Projector : 23 units, 2450 Wh each
- Computer : 10 units, 2000 Wh each
- Digital Display : 2 units, 240 Wh each
- Electric Pump : 1 unit, 150 Wh

After calculating demand, total power required for Bonwary Lal Govt. High School is 168.030 kW if all the equipment is active for 9 hours of working time.

B. The Daily load Curve

The graphs are plotted by assuming that peak at two shifts of the school. Also, in winter season the load from the fans is deducted. Usually, the peak load at summer season is 168.03 kWh but in summer its just 68.67 kWh.

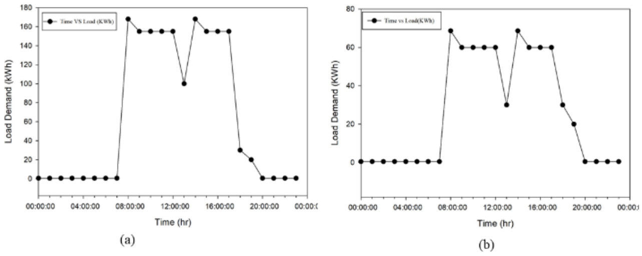

Figure 2: Load Demand Vs Time (a)Summer (b)Winter

Figure 2 illustrates the daily load curve for the school in summer season and winter season.

2. RESOURCE ASSESSMENT

C. Site Information

Project Location	B.L. School Road, Dhanbandhi, Sirajganj Sadar, Sirajganj, Rajshahi
Geographical Coordinates	24.45771°,089.70802° (latitude and longitude)
Time Zone	UTC +6, Asia/Dhaka (BST)
Elevation	19m

Map data			Per year
Direct normal irradiation	DNI	1032.6	kWh/m²
Global horizontal irradiation	GHI	1657.5	kWh/m²
Diffuse horizontal irradiation	DIF	931.4	kWh/m²
Global tilted irradiation at optimum angle	GTI opta	1772.3	kWh/m²
Optimum tilt of PV modules	OPTA	24 / 180	°
Air temperature	TEMP	25.4	°C
Terrain elevation	ELE	19	m

Figure 3: Map data of Banwari Lal Government High School, Sirajganj (per year) [6]

Data from figure 3 shows that for the selected site in Banwari Lal Government High School, Sirajganj, Direct Normal Irradiation is 1032.60 kWh/m2 per year. Global Horizontal and Diffused Irradiations are 1657.5 kWh/m2 and 931.4 kWh/m2 per year respectively. While for an optimum tilt angle of 24˚ and terrain elevation of 19 m, the Global tilted irradiation is 1772.3 kWh/m2 per year.

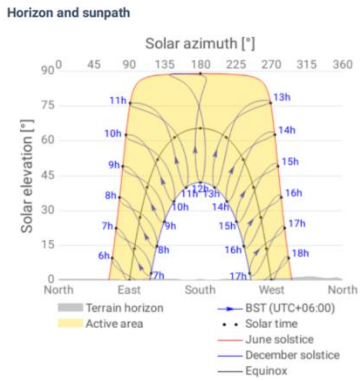

Figure 4: Sun path and Azimuth Diagram of the site [6]

The Sun path diagram is shown in figure 4 by plotting solar elevation angles and solar azimuth angles of a typical meteorological year for every hour of the day. It can be seen that in June maximum solar elevation (90˚) is found at noon and the azimuth direction is north. Whereas, in December noontime solar elevation angle is half of that.

D. PV Electricity and Solar Radiation

The PV system configuration used to acquire data from Global Solar Atlas [6] is given below

PV system	medium size commercial
Azimuth of PV panels	Default (180º)
Tilt of PV panels	24º
Installed capacity	10 KWp

Data from the Global solar atlas states that from a 10kW SPV system made of crystalline silicon solar panels, a total of 13.637 MWh of energy will be produced in a typical meteorological year and per day the average is 37.36 kWh.

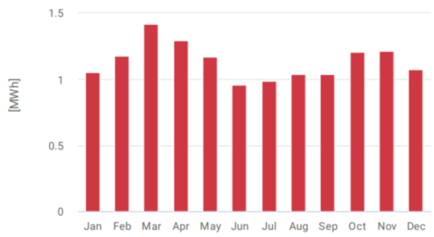

Figure 5: Monthly averages of total photovoltaic power output [6]

Figure 5 shows the amount of energy generated every month from a 10kW system. In March, the maximum power output is found about 1.4 MWh. In monsoon months the power output is relatively lower with the lowest being in June.

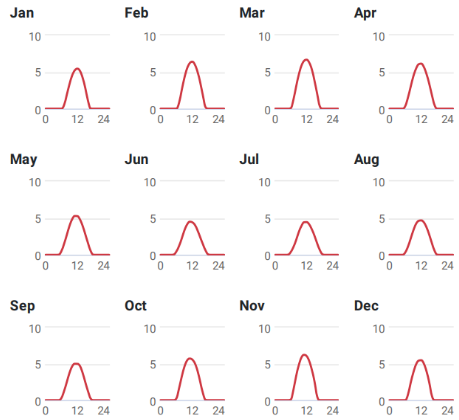

Figure 6: Average hourly profile of total photovoltaic power output for every month in kWh [6]

Figure 6 shows the PV power output of every month plotted against the hours of the day. From this curve, the peak power hours for every day throughout the year is noon.

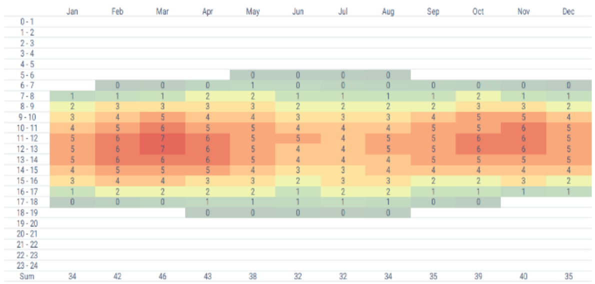

Figure 7: Average hourly profile of total photovoltaic power output in kWh [6]

Figure 7 shows how many units of energy are found per hour considering the system runs at full capacity. For example, in February from 6 am to 7 am no units will be produced, from 7 am to 8 am only 1 unit of energy will be produced, from 10 am to 11 am 4 units of energy will be produced, and so on.

Figure 8: Annual, monthly, and hourly average profiles of DNI the location [6]

From figure 8 the average annual global tilted irradiation is 1043.8 kW/m2 and 2.86 kWh/m2 per day. The monthly average DNI received is lowest in June and highest in November and average hourly profiles show the maximum amount of DNI will be received between November to march.

E. Sun Path Diagram

From sun path diagram, the azimuth angle and useful day length can be observed. We have found the sun path diagram for our location from PD: 3D Sun-Path - Andrew Marsh [7].

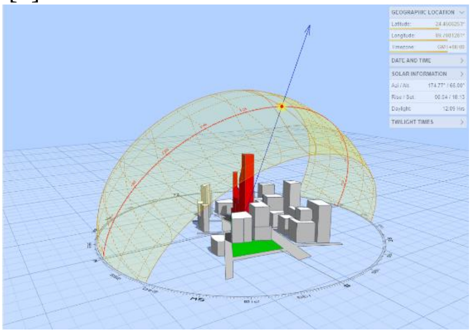

Figure 9: Sun Path Diagram of Sirajganj [7]

F. Key Findings

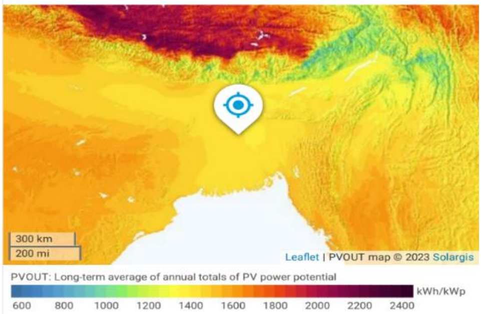

Figure 10: Satellite map and GSA PV output map of location [6]

The main findings from the preliminary resource assessment from Global Solar Atlas [6] of B.L. School Road, Dhanbandhi, Sirajganj Sadar, Sirajganj, Rajshahi, Bangladesh are listed below:

- The annual PV power potential is around 1350 to 1450 kWh/kWp [figure 10].
- The optimum tilt angle is 24˚ and the optimum azimuth angle is 180˚ [figure 3].
- The total annual PV power output is 13.367 MW and annual Global tilted irradiation is 1772.0 kWh/m2.
- The annual average DNI value is 1043.8 kWh/m2 [figure 8].

3. SELECTION OF CONVERSION TECHNOLOGY

G. Overall System

This system is a 10kW micro-grid solar PV as its capacity lies between 10kW and 100kW [8]. The system was designed on-grid. We decided to opt for DC-coupled power sources due to them being more efficient over AC coupled systems for a micro-grid system [9].

This system has 5 major components which are solar panels, charge controller, battery, inverter, and switch box

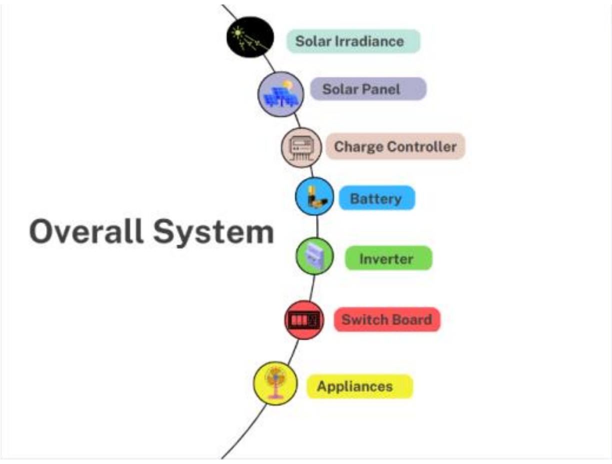

Figure 11: Diagram of the overall system

H. Selection of Components

While selecting the equipment's and components for the powerplant construction, we have conducted literature review. A life Cycle Assessment done by the National Renewable Energy Laboratory (NREL) shows that monocrystalline silicon modules are the most efficient [10]. High-quality solar panels provide better performance and service, but they are also more expensive. The premium panels would focus far too much on price. Considering all phenomenon including efficiency Loom Solar [11]. They provide a 10year manufacturer's warranty as well as a 25-year performance warranty [12]. IBC N-type silicon cells have the best efficiency (22%) when compared directly between other mono- and polytype silicon cells in a PV cell efficiency chart [13]. Between the solar panels and the storage must be a solar charge controller, also known as a charge regulator. There are two types of charge controllers, Pulse Width Modulation (PWM) and Maximum Power Point Trackers (MPPT). Compared to PWM controllers, MPPT significantly improves the ability of the panels to operate at the optimal voltage for maximum output [14]. Lead-acid batteries have been replaced with lithium-ion batteries. Additionally, modern deep-cycle lead-acid and lead-carbon batteries cost a lot of money [15]. For a 10kW system, 6units of batteries of 24V 300A is required. For the design, a 10kW 3-phase multi-mode inversion was chosen. Lastly, cables are needed to transport the received electricity. DC power would be transmitted from the solar panels to the charge controller, battery, and inverted input. DC solar cables or string cables are needed in this situation. Based on the system requirements and cost-effectiveness, every component was selected. Since the majority of the components are imported, table 4's prices already include the cost of delivery.

Table 2: Components of the 10kW SPV Power Plant

Component	No. of Unit	Unit Price (Taka)	Cost (Taka)	Sources
Solar PV Panel	22 pieces	8,500	2,20,000	[11]
MPPT Solar Charge Controller	1 piece	6,452	6,452	
Lithium-ion Po4 Battery	6 pieces	33,000	1,98,000	
Inverter	1 piece	1,03,207	1,03,207	
Switch Box	1 piece	10,269	10,269	
DC Wires	180 meters	82.36	14,825	[16]
AC Wires	100 meters	50	50000	
Mounting & Installation	-	94,072	94,072	
Sub-Total			6,96,825	
Maintenance	2% (per year)	13,940	3,48,500	
Total			1,045,325	

4. DESIGN & OPTIMIZATION

I. Preliminary Design

The method was created to produce as much as possible while keeping costs down. Therefore, all parts and the design of the plant were made with these factors in mind as well as Sirajganj climate. On a 5 by 5 grid, a total of 22 455W Monocrystalline Silicon cell-based solar panels will be installed. Following that, 180 meters of DC solar cables are used to connect the solar panels' output to the six units of 24V 600A lithium polymer batteries. Between the panels and the batteries, an MPPT solar charge controller is positioned to ensure effective charging and prevent overcharging. A 10KW multi-mode Inverter that transforms DC input into AC power output receives DC power from the batteries and transfers it over an additional 30 meters of DC solar wires. This AC output is subsequently transmitted to consumers via transmission lines, and the circuit switch box has control over it.

Figure 12: Schematic diagram of the 10kW Solar Powerplant

(All images used in this diagram were taken from the buyers' catalog and are free to use or share)

J. Performance Analysis

Performance analysis of the designed off-grid 10kW solar PV system for Bonwary Lal Govt. High School was done using Photovoltaic Geographical Information System (PVGIS) website [17]. After giving the latitude and longitude of the location in PVGIS, an off-grid system was selected. Then all necessary inputs (figure 13) were provided based on the design. Daily consumption was given for the total consumption calculated for summer. The battery discharge cutoff limit was set at 40% considering the default value [17].

Latitude/Longitude:	24.458,89.708
Horizon:	Calculated
Database used:	PVGIS-SARAH
PV installed:	10000 Wp
Battery capacity:	43200 Wh
Cutoff limit:	40 %
Consumption per day:	168030 Wh

Figure 13: Provided inputs in PVGIS [33] (Note: In PVGIS, 0˚is considered south)

Percentage days with full battery:	0 %
Percentage days with empty battery:	100 %
Average energy not captured:	0 Wh
Average energy missing:	131478.97 Wh

Figure 14: Stimulation outputs from PVGIS

Demonstrates that there would be 131 kW of energy missing and a total of 100 days with a depleted battery, which is not desirable.

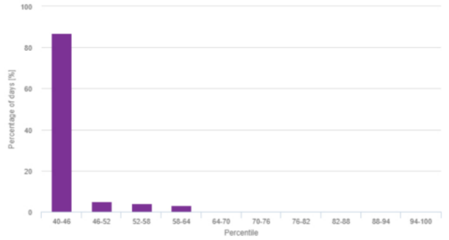

Figure 15: Probability of Battery Percentage at the end of the day

The daily consumption input was, however, made for the summer, when consumption is at its highest. Wintertime consumption drops by almost half. The results would be better and the average daily intake would be significantly lower. Additionally, figure 15 demonstrates that the battery will only be at 40% of capacity on more than 80% of the days. However, the battery percentage never stays more than 60% on any given day.

Figure 16: Power production estimate for the 10kW off-grid PV system

Figure 16 displays the preliminary design's 10kW off-grid solar PV powerplant's average monthly energy output. The monsoon season is when energy production is at its lowest, and spring is when it's at its highest. March has the highest daily average energy production, which is at 43.5 kW.

K. Optimization Process

Further investigation was conducted to optimize the performance of the 10kW roof-mounted solar PV plant after examining its performance. In an effort to improve the output results even more, the azimuth angle and tilt angle were optimized using the PVGIS website [17].
Since the optimization option was not accessible for off-grid PV systems, system inputs were provided under the grid-connected PV tab in order to optimize the slope angle and azimuth angle. Because it was the default figure, a system loss of 14% was taken into account. According to the simulation results, the panels' ideal tilt angles are 28° and 7°, respectively (south to west).

Latitude/Longitude:	24.458,89.708
Horizon:	Calculated
Database used:	PVGIS-SARAH
PV technology:	Crystalline silicon
PV installed:	1 kWp
System loss:	14 %
Slope angle:	28 (opt) °
Azimuth angle:	7 (opt) °
Yearly PV energy production:	1475.7 kWh
Yearly in-plane irradiation:	1975.36 kWh/m²
Year-to-year variability:	27.15 kWh
Changes in output due to:	
Angle of incidence:	-2.69 %
Spectral effects:	0.71 %
Temperature and low irradiance:	-11.36 %
Total loss:	-25.29 %

Figure 17: Provided inputs for optimization and stimulation outputs from PVGIS

The results of figure 17 were produced by entering the optimal azimuth and tilt angle values into PVGIS' off-grid PV performance section. The daily consumption value was calculated for this stimulation as the average of the maximum consumption values of summer and winter discovered through demand analysis.

Provided inputs

Latitude/Longitude:	24.458,89.708	Slope angle:	35 °
Horizon:	Calculated	Azimuth angle	0 °
Database used:	PVGIS-SARAH	**Simulation outputs**	
PV installed:	50 Wp	Percentage days with full battery:	0.02 %
Battery capacity:	600 Wh	Percentage days with empty battery:	99.95 %
Cutoff limit:	40 %	Average energy not captured:	110.53 Wh
Consumption per day:	300 Wh	Average energy missing:	117.27 Wh

Power production estimate for off-grid PV:

Probability of battery charge state at the end of the day:

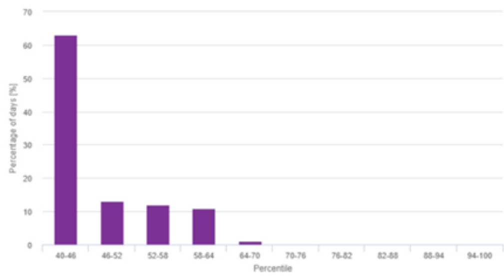

Figure 18: Given Inputs and stimulation results after optimization

These improvements result in an average energy missing value of 70.46 kW and a maximum monthly energy production of 44 kW. After optimization, the battery charge graph is also more evenly distributed (figure 18). Up to 80% of the batteries' charge is still present, however it is only for a few days.
Azimuth and tilt angle tuning thus yields marginally improved outcomes.

5. SOCIAL IMPACT ASSESSMENT

L. Social Benefits of the Project

The powerplant project is a beneficial project for a rural area like Sirajganj. Some points of Benefits from the Project are given below:

At the local level, create both direct and indirect jobs. Additionally, long-term income and money management in a place like Sirajganj, where there are little chances to build wealth. Energy prices for solar PV systems won't vary like they do for traditional electricity producing systems. Renewable energy installations attract visitors from schools and universities as well as student initiatives. They connect people to the source of their energy by offering opportunities for technical skill development, study spaces for a range of courses, and hands-on exposure to science and technology. Students and learners from that area now can attached to the online platform for higher knowledge gain easily without power outage.

6. ENVIRONMENT IMPACT ASSESSMENT

1) Local

The location is in Sirajganj Sadar, close to the Brahmaputra River. Which is 28.49 square kilometers. The likelihood of river corrosion and flood issues is increased in riverbank areas. Therefore, the power connection needs to be stronger for on-grid power plants. Due to the usage of heavy metals and chemical components during manufacture, solar PV and on-grid powerplants pose a health risk. Because to the power plant's development, the river's water may become contaminated. The project's land area requires the acquisition of the productive land where corps were grown, lowering the pace at which food is produced. A dam must be constructed to stop flooding, which will alter the river's flow and raise the likelihood of river erosion.

2) Regional

The goal of the Bangladeshi government is to reduce global warming by using only renewable energy to power Dhanbandi area. This objective would be partially attained by the 10kW solar PV micro-grid. Dhanbandi is mostly run by generators, as was already indicated. Depending on the engine and the fuel's properties, a diesel generator produces between 2.4 and 2.8 kg CO_2/L. A diesel generator is expected to emit 0.81 to 0.93 kg CO_2/kWh of carbon dioxide [18]. Therefore, even with the highest performance, a diesel generator would still produce around 299,000 kg of CO2 throughout its 25-year lifespan. The region's carbon footprint would be reduced thanks to this facility.

3) Global

Despite the negative impacts of burning fossil fuels on the earth's climate, the relevance of alternative energy sources will rise in the future even though the world now relies heavily on them. Fossil fuel reserves will be depleted by the beginning of the next century if utilization continues at its current rate. This suggests that human use of renewable energy sources will rise over time. And today, solar energy is seen to be the most promising renewable energy source. Every part of the world may access solar energy, which is carbon-free and renewable. Solar energy has the potential to significantly lower global GHG (Green House Gas) emissions. The reliance on traditional power sources may be significantly decreased by integrating solar PV with the on-grid. in the longtime use, Solar PV can be a great wastage but for some generation it'll gave a huge impact on the power plant sector. In the long run, solar energy can be a massive waste, but for some generations, it'll have a significant influence on the sector of power plants.

7. ECONOMIC/FINANCIAL ANALYSIS

M. Economic/Financial Analysis of the Project

The economic or financial analysis of this SPV powerplant for Bonwary Lal Govt. High School, Sirajganj is shown in table 9:

Table 3; Financial Parameters of the Project

Parameters	Values
Project life (years)	25 years
Investment Cost (Taka)	22,000
Yearly electricity production (kWh)	14,175.86
The production cost of electricity (Taka/kWh)	9.7
Expected Revenue during the project life (Taka)	4613
Simple payback period (years)	21.4

These data are provided using RETScreen Expert [19] and PVGIS [17] reports specifically imported for Bonwary Lal High School, Sirajganj. The project life here is considered as 25 years. Through the specific latitude and longitude value of the selected area the accuracy of SPV performance is ensured according to weather condition. Moreover, this software is reliable and acknowledged across the borders. The overall investment cost, taking into account the maintenance cost of 1% year, has been determined, as well as the cost of producing electricity and the payback period. Consequently, the complete investment cost will be refunded in 17.9 year.

This power station has been operational for approximately 18 years. Over this time, close to 29 lakhs taka in revenue are anticipated.

In present day Electricity is the most crucial form of energy. The modern Hi-tech world highly relies on electricity. But due to insufficient resource in production of electricity and sky-haunting price hike, electricity usage always tends to run out of reach. Here the Renewable Solar projects to produce energy or electricity works as blessing. Through some initial fixed cost these renewable energy sources can bear a huge portion of our daily demand of electricity. Due to the geographical location and the weather condition which is not within human control, Solar Photovoltaic Power Plants can be a very good partial source of electricity supply according to demand. It can certainly not meet up the huge demand over the period but can be a great support to the main source.

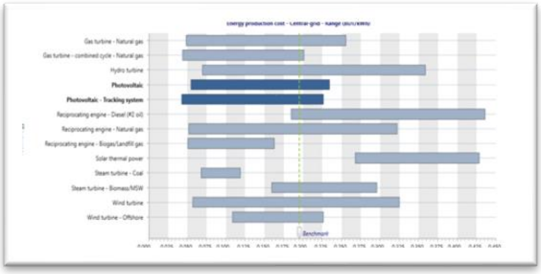

Figure 19: Power Plant technology feasibility

The figure 20 clearly depicts that the Photovoltaic and Photovoltaic tracking system technologies are just above per Energy production cost (BDT/kWh). Whereas Reciprocating Engine (Diesel) is the highest and does possess a range of 0.185-0.436 BDT/kWh. Solar Photovoltaic Powerplant technology provides 0.055-0.235 BDT/kWh. It clearly indicates that among the technology SPV might not be the best one as source but supplies moderate amount of energy.

Electricity exported to grid	MWh	14.2	T&D losses
GHG emission			
Base case	tCO_2	7.5	
Proposed case	tCO_2	0.53	
Gross annual GHG emission reduction	tCO_2	7	93%

Figure 20: Annual GHG emission reduction [19]

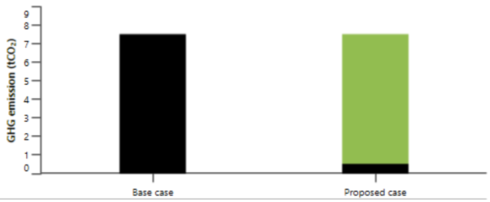

Figure 21: Annual GHG emission reduction [19]

The SPV powerplant project not only supports the nature by releasing 0.53% CO_2 also provides some financial benefits. From the graph below we can see that at 14th year the project overcomes its breakeven point and provides 1,411BDT. Then 1,439, 1,468, 1,497, 1,527 BDT is the profit earned consequently following years.

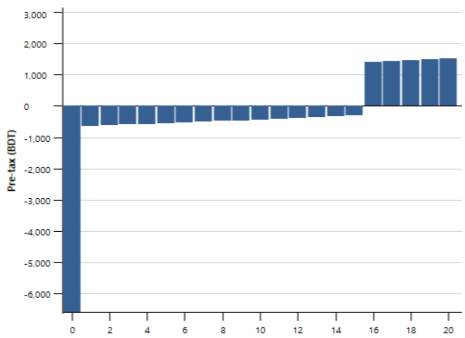

Figure 22: Payback period [25]

8. CONCLUDING REMARKS

The implications of 10kW PV (Photovoltaic) panels on grids is potentially substantial, and it ranges in accordance with numerous aspects such as system attributes, terrain, and the extent of the incorporation of green energy sources. PVGIS and RETScreen have had a significant impact on the renewable energy industry, providing accurate solar energy data and aiding project feasibility assessments. In this instance a few essential considerations to consider:

As the powerplant is set up to sustain the demand of the school at its running hour and store energy during off time. Powerplant is not connected to national grid so the frequency match up to national grid is not needed. The national grid frequency of Bangladesh is 50 hz. Voltage angle issues are not directly caused by PV panels. Still, if significant imbalances in the power supply and demand occur due to variable solar generation, it can affect the power flow and voltage angles in specific parts of the grid. Overall, the integration of PV panels can contribute to reducing power transmission losses, particularly if the panels are located close to the points of consumption, minimizing the need for long-distance transmission.

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