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Deploying Rooftop Solar PV System in an Educational Institution of Rural Bangladesh: A Software Based Case Study

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Abstract

Bangladesh, a country with a developing economy, grapples with significant energy hurdles, with rural areas like Netrokona experiencing acute electricity shortages. This research explores the deployment of rooftop solar photovoltaic (PV) systems as a sustainable solution to these energy issues, focusing on Netrokona Govt. Mohila College as a case study. Using simulation software, the study conducts a detailed assessment of the energy requirements and load profiles of the institution to determine the optimal size and configuration of the PV system. The designed system aims to generate 44.50 kWp, with a specific annual yield of 1226.83 kWh/kWp and a performance ratio of 82.21%, producing a total of 53,180 kWh annually. The implementation will significantly reduce grid dependency, with 5,460 kWh used on-site and 47,129 kWh exported to the grid, achieving a self-sufficiency level of 97.4% and minimal grid energy import of 163 kWh annually. An economic analysis over 20 years reveals the financial viability of the project, with an initial investment of \$66,750 offset by increasing annual returns from feed-in tariffs and electricity savings, resulting in positive cash flow from year 11 onwards. Additionally, the system offers substantial environmental benefits, reducing CO_2 emissions by 23,657 kg annually. Monthly performance variations due to irradiance and temperature fluctuations are also considered to optimize efficiency. This study underscores the potential of solar PV systems to address energy shortages in rural Bangladesh, offering significant long-term economic and environmental benefits.

Keywords

Rural Area of Bangladesh, Economic Analysis, Energy Access, Rural Development, Solar PV, Sustainability.

1. Introduction

Bangladesh, a South Asian nation undergoing development, faces significant energy challenges. Its energy infrastructure is struggling to keep pace with the demands of its growing population and expanding industrial sector. While urban centers have better access to electricity, rural areas often face significant energy shortages (Asian Development Bank, 2013). Netrokona, a rural district in northern Bangladesh, epitomizes this disparity, with many of its institutions, including educational and healthcare facilities, suffering from inadequate power supply. In this context, the deployment of rooftop solar photovoltaic (PV) systems presents a promising solution to bridge the energy gap, leveraging the abundant solar resources of the region (Bangladesh Bureau of Statistics, 2011).

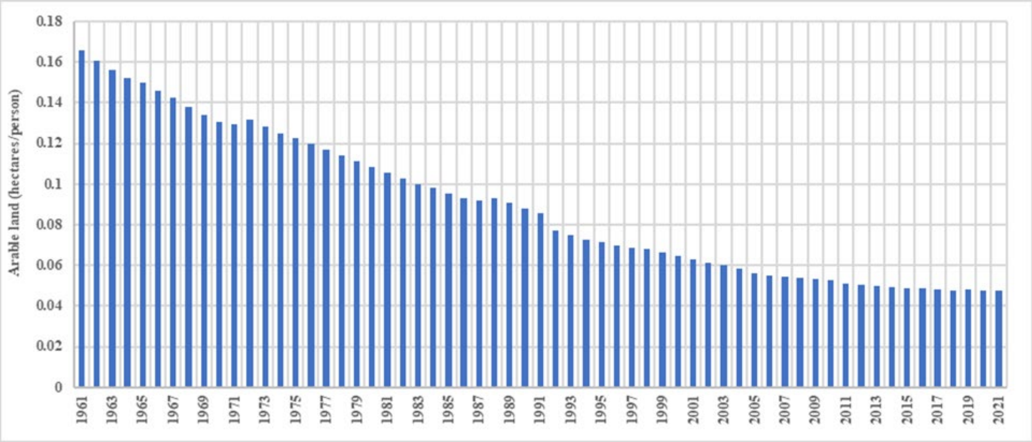


Figure 1. Decreasing per person arable land, in Bangladesh.

Research on photovoltaic (PV) system performance extensively utilizes simulation software to evaluate design, output (Figure 1), and economic feasibility across various regions. In India, simulations of a 10 MW utility plant using PVsyst demonstrated a capacity utilization factor (CUF) of 17.25% and a performance ratio of 86.12% (Kumar and Sudhakar, 2015), while residential system analysis indicated a yield of 1733 kWh/kWp/year (Shukla, 2016). In Nigeria, Aluko (2023) utilized PV*SOL for 3D design to determine a levelized cost of energy (LCOE) of $0.056/kWh with a high return on investment. Specific to Bangladesh, simulation studies have addressed coastal residential generation (Bhuiyan, 2020), the economics of net metering with a 5.9-year payback period (Hossain, 2021), and grid-connected feasibility focusing on cost reduction strategies (Chowdhury, 2021). Additionally, Lau (2010) explored the feasibility of PV-Diesel hybrid systems in Malaysia using HOMER software.

Experimental and analytical studies provide further insights into system efficiency, environmental factors, and broader economic metrics. Ayompe (2011) reported a 16.3% CUF for a 5 kWp grid-connected system in Ireland. In warmer climates like India, research has examined thin-film technology performance (Kichou, 2016) and the impact of high temperatures on 20 kWp systems (Padmavathi, 2013). Significant research has also focused on Bangladesh, covering solar irradiance assessments (Mondal, 2011), renewable energy scenarios (Islam, 2014), and solar potential across varied landscapes (Halder, 2015). Recent experimental work by Protya et al. (2025) highlighted the negative impact of dust, recording a 4.48% efficiency loss. Finally, global analytical studies have addressed the comparative LCOE of different sources (Branker, 2011) and PV grid parity dynamics (Breyer, 2009).

Bangladesh's renewable energy policies, which aim for 10% of electricity to be sourced from renewables by 2021, highlight solar power as a key contributor. Programs like the IDCOL Solar Home Systems initiative have demonstrated the feasibility of solar energy in rural areas. They are extending such efforts to institutional environments, such as Netrokona Govt. Mohila College, can further enhance energy access and contribute to regional socio-economic development (Uddin, 2019).This paper provides a detailed PV*SOL-based assessment of an institutional rooftop system in rural Bangladesh, where such case-specific studies are limited. Addressing shading, orientation, and system aesthetics provides a model for efficiently deploying grid-connected solar PV systems, supporting Bangladesh's transition toward a sustainable energy future.

1.1 Objectives

- To design a solar panel system for a rural college in Bangladesh.
- To check if the system makes financial sense and how long it takes to pay for itself.
- To calculate how much energy the system will produce and how much CO_2 it will save.
- To see if the institution can sell extra power back to the grid.

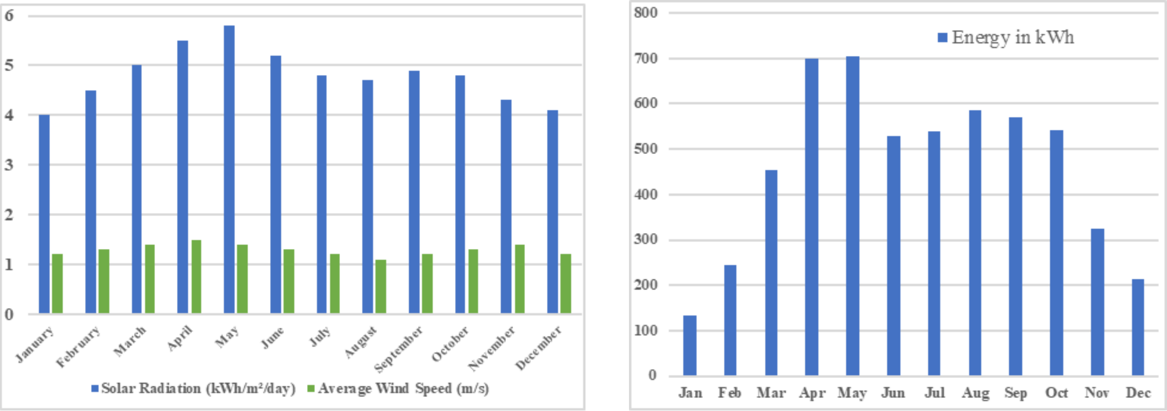
2. System design and simulation details

PV*SOL software streamlines designing, simulating, and optimizing PV systems, calculates performance metrics, and offers optimization and economic analyses, enabling efficient, cost-effective designs and clear client communication.

2.1 Site Selection and Data

Netrokona Govt. Mohila College in Netrokona, Bangladesh was chosen as the study site for this project. In the initial phase of using the PV*SOL software, essential project information and client details were entered (Figure 2-Figure 3).

Figure 2. Netrakona Govt. Mohila College



(a) (b)

Figure 3. (a) Monthly solar radiation data and average wind speed, (b) Monthly energy consumption of location.

2.2 System Type, Climate Data, and Energy Consumption

This research focuses on designing and implementing a grid-connected photovoltaic (PV) system to power electrical appliances at Netrokona Govt. Mohila College in Netrokona, Bangladesh. Accurate climate data is essential for simulating PV system performance, including geographical location ($24^{0}52.5'$ N $90^{0}44'$ E), weather data, solar radiation, temperature, and shading analysis. Detailed climate settings optimize system design, maximize energy yield, and evaluate feasibility. This comprehensive approach ensures maximum efficiency and cost-effectiveness, contributing to sustainable energy solutions in rural Bangladesh.

2.3 Module and cable design

The 44.5 kWp system, which uses 100 FS-6425 panels and covers 247.5 m², might be the maximum capacity that could be physically installed on the college's usable, unshaded roof space. The system uses four LG ESS Home 10 inverters from LG Electronics for seamless DC to AC conversion and grid connectivity. Additionally, it includes four LG ESS (97%) Home 10 units with LG HBC 15H batteries, offering a combined storage capacity of 14.2 kWh (A. R. Protya, 2025). PV module tilt angle 24° which is the standard optimal fixed-tilt angle, and azimuth 0° (due south). Annual panel degradation rate 0% was assumed.

3. Results & discussion

3.1 Simulation Results

After running the simulation, the project report generated the following results. The designed PV system has a capacity of 44.50 kWp and an annual specific yield of 1226.83 kWh with a performance ratio of 82.21%. It generates 53,180 kWh per year, of which 5,460 kWh is consumed on-site, and 47,129 kWh is exported to the grid. The system prevents 23,657 kg of CO_2 emissions annually. Total energy consumption for appliances is 6,214 kWh/year, with 5,460 kWh supplied by solar power and 163 kWh from the grid. The solar fraction, or the portion of energy met by solar, is 97.4%. The 88.6% grid export rate is a key finding, confirming the system is oversized for the college's 6,214 kWh annual load. This is compounded by the institution's limited daytime consumption on non-instructional days, making the project function more as a grid-tied power plant than a self-consumption system.

The system's simulated Performance Ratio (PR) of 82.21% aligns well with findings from similar studies in the region. For example, Sharma and Goel (2017) reported a PR of 80.7% for a rooftop system in Eastern India, and Goura (2013) found an on-field PR of 79.2% in South India. This comparison validates the simulation's accuracy.

3.2 Energy Flow Diagram

The energy flow diagram in Figure 5 illustrates the energy distribution and consumption in the PV system The solar panels generate 53,180 kWh, with 6,429 kWh stored in batteries and 4,338 kWh discharged for use. Energy losses from charging and discharging total 2,084 kWh, with an additional 85 kWh lost within the battery itself. The inverter consumes 677 kWh in standby mode. For direct consumption, 6,214 kWh is used on-site, 47,129 kWh is exported to the grid, and from the grid, and 163 kWh is drawn

3.3 Utilization of PV Energy & Coverage of Total Consumption

The graph in Figure 6(a) details how PV energy is utilized monthly. In January, out of 3,807.8 kWh generated, 55.6 kWh was used directly, and 3,752.2 kWh was exported to the grid. February shows 3,866.8 kWh generated, with 245 kWh used directly and 3,568.5 kWh exported. This trend continues throughout the year, with direct usage increasing slightly in the middle months. The graph in Figure 6(b) illustrates the proportion of energy consumption met by PV power and the grid. In January, appliances consumed 133 kWh, and the inverter 85.5 kWh, with 55.6 kWh covered by PV power and 162.9 kWh by the grid. February shows all 245 kWh of appliance consumption covered by PV power. This pattern reflects a high level of self-sufficiency, particularly from February to December, where PV power entirely covers the consumption, emphasizing the system's capability to meet energy demands.

3.4 Economic Analysis

In below Figure 7, the chart illustrates the Accrued cash flow (cash balance) of a project over 20 years, reflecting an initial substantial investment followed by growing returns from feed-in tariffs and electricity savings. In Year 1, a significant investment of $66,750 led to a negative cash flow of $62128.43. However, as the project progresses, annual returns from feed-in tariffs and electricity savings increase, leading to gradually improving cash flow. By Year 10, the accrued cash flow approaches neutrality. From Year 11 onwards, the project generates increasingly positive annual cash flows due to the rising feed-in tariffs and consistent electricity savings. By Year 15, the accrued cash flow turns significantly positive, reaching $42,447.83.

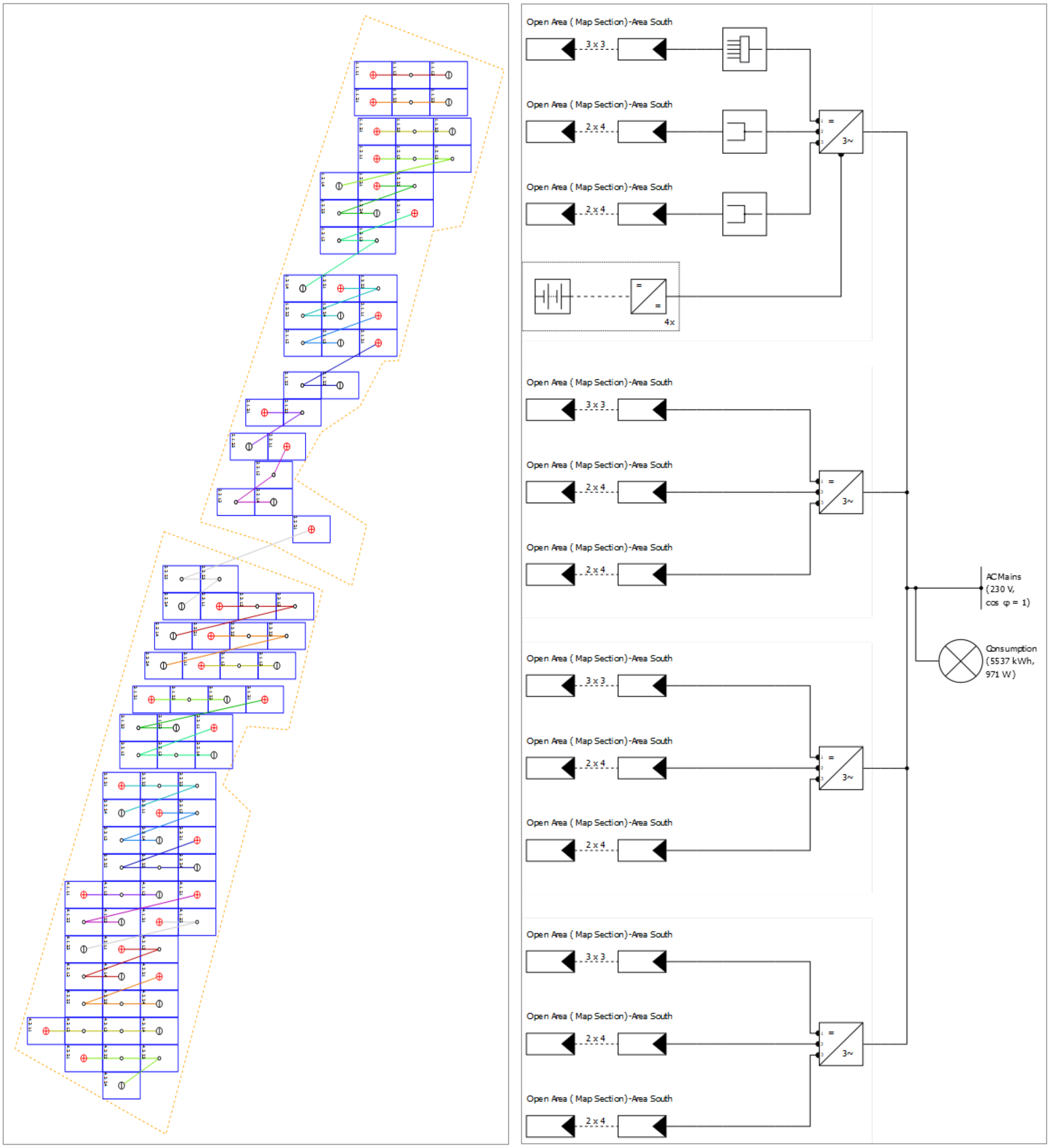


Figure 4. String plan of the module, cable design, and circuit diagram

The trend continues upward, with the cash balance hitting $107,650.73 by Year 20 (Figure 4). This indicates a successful recovery of the initial investment and substantial profit over the long term, highlighting the financial viability and profitability of the project, driven by steady revenue from feed-in tariffs and savings on electricity. It is important to note that this analysis assumes the battery system operates for the full 20-year project lifespan. However, the battery's 10-year warranty implies a significant capital replacement cost around Year 11, which is not factored into the current cash flow model and would reduce the long-term net profit (Table 1- Table 2).

Table 1. Simulation Outcomes

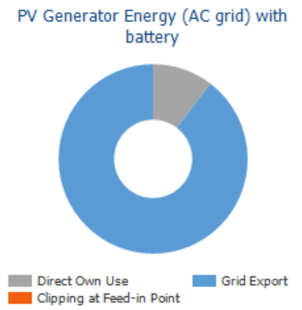
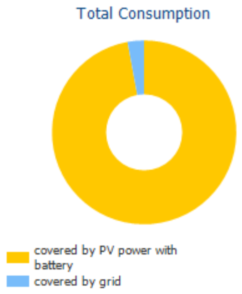
PV System		
Solar Panel Energy Production	44.50 kWp	
Expected Yearly Energy Output	1226.83 kWh/kWp	
Efficiency Ratio	82.21%	
Solar Panel Energy (AC) with Storage	53,180 kWh/Year	
Self-Consumption	5,460 kWh/Year	
Energy Supplied to the Grid	47,129 kWh/Year	
Personal Energy Use	10.2%	
Carbon Emissions Reduced	23,657 kg/year	
Total Consumption		
Energy Use by Appliances	5,537 kWh/Year	
Inverter Standby Power	677 kWh/Year	
Overall Energy Consumption	6,214 kWh/Year	
Energy Supplied by Solar and Battery	5,460 kWh/Year	
Energy Supplied by the Grid	163 kWh/Year	
Proportion of Energy from Solar	97.4%	
Energy Storage System		
Initial Battery Charge	78 kWh	
Battery Energy from Solar System	6,429 kWh/Year	
Battery Energy Used for Consumption	4,338 kWh/Year	
Charging/Discharging Energy Losses	2,084 kWh/Year	
Battery Energy Losses	85 kWh/Year	
Battery Charge/Discharge Cycles	0.3 %	
Battery Lifespan	> 20 Years	
Self-Sufficiency Level		
Level of Self-sufficiency	97.4 %	

Table 2. Economic Analysis Assumptions

Parameter	**Assumption**	**Value**
Costs	Initial Investment	$66,750
	Annual Maintenance Cost	$667.50 / year
Revenue Variables	Energy Tariff (Grid Feed-in & Savings)	$0.101 / kWh
	Tariff & Maintenance Escalation Rate	6.2% (annual)
	Project Lifespan	20 Years
	Panel Degradation Rate	0% (annual)
	Discount Rate	8.0% (annual)

3.5 Policy Implications and Recommendations

The findings from this case study offer significant policy implications for scaling rooftop PV in Bangladesh. The system's high grid export rate (88.6%) demonstrates that rural public institutions like Netrokona Govt. Mohila College can serve as distributed power plants, not just self-sufficient entities. We recommend that government bodies, such as

SREDA and IDCOL, develop programs that specifically incentivize this "prosumer" model by encouraging system oversizing on public buildings (Figure 5- Figure 7). The financial viability of this approach, however, is critically dependent on stable, long-term net-metering or feed-in tariff policies, which must be ensured to attract investment. Finally, to support widespread adoption and address the noted lack of rural technical expertise, these government programs should bundle installation with mandatory training for local technicians to ensure the long-term sustainability and performance of these vital energy assets.

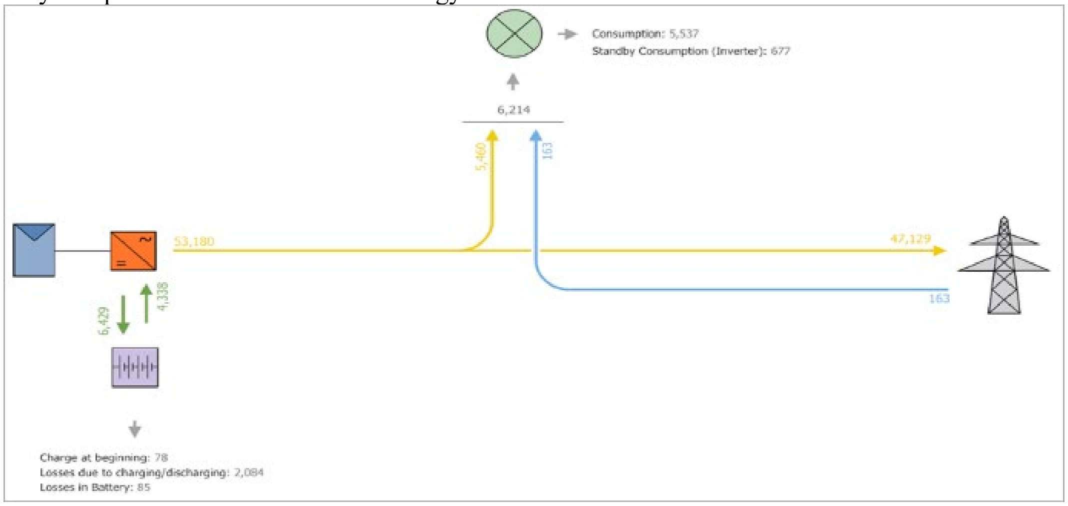


Figure 5. Energy Flow Diagram

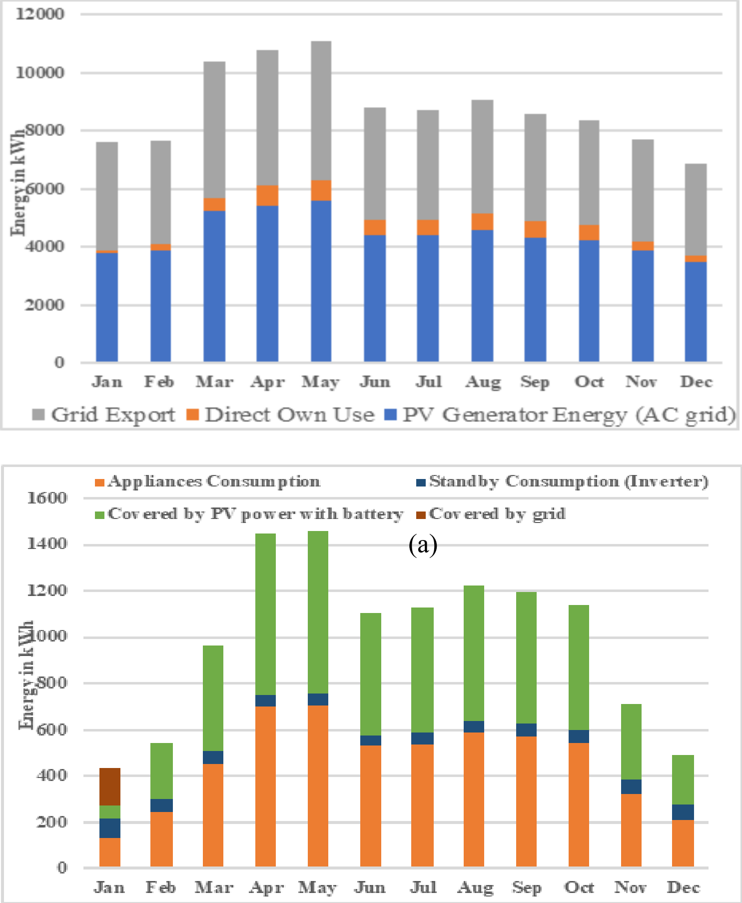


Figure 6. (a) Utilization of PV Energy, (b) Coverage of Total Consumption.

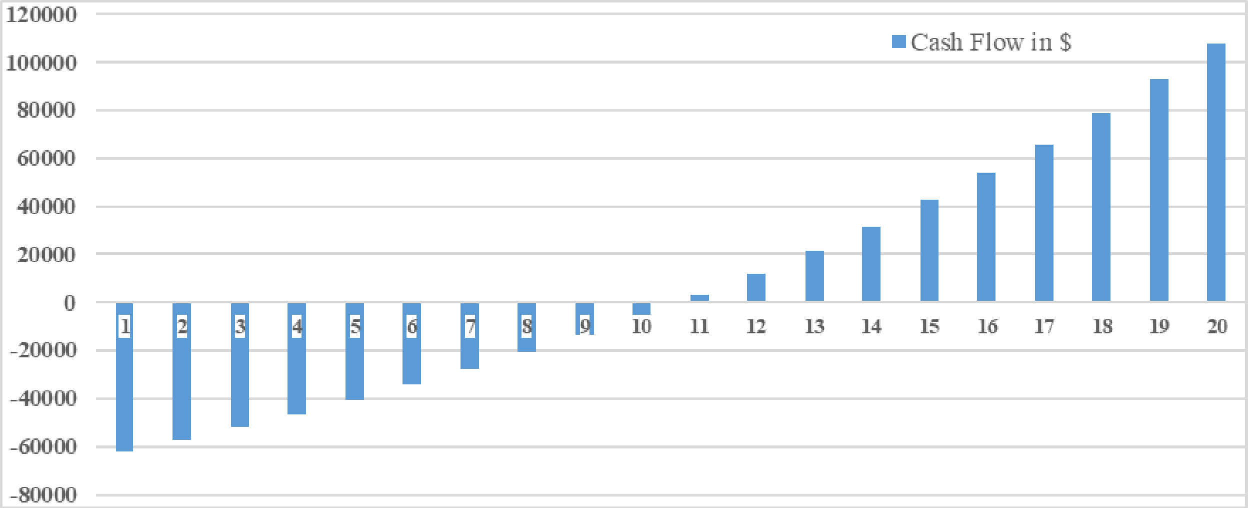


Figure 7. Accrued Cash Flow (Cash Balance).

Table 3. Key Financial Metrics (20-Year Project Lifespan)

Metric	**Value**
Net Present Value (NPV)	$5,128
Internal Rate of Return (IRR)	9.1%
Levelized Cost of Energy (LCOE)	$0.098 / kWh
Simple Payback Period	11 Years

4. Conclusion

This study evaluates the feasibility and advantages of implementing a grid-connected solar PV system at Netrakona Govt. Mohila College focuses on energy needs, costs, and potential savings. The PV system generates 44.50 kW of power, with an annual energy yield of 53,180 kWh. Around 5,460 kWh is consumed on-site, and 47,129 kWh is exported to the grid. The college imports only 163 kWh annually from the grid, with PV power fully covering consumption from February to December. Despite an initial investment of $66,750 leading to negative cash flow in the first year, the project generates increasing returns through feed-in tariffs and savings. By year 10, the cash flow approaches break-even, reaching $107,650.73 by year 20, and demonstrating long-term financial viability. The system reduces annual CO_2 emissions by 23,657 kg, aligning with climate change goals.

5. Future Work

To capitalize on this finding and enhance Bangladesh's rural electrification strategy, the following recommendations are proposed:

i. **Implementation of net-metering policies:** The financial viability of high-export systems like this one is critically dependent on robust net-metering policies. Government bodies should ensure these policies are in place to maximize the grid benefit and incentivize public institutions to install oversized systems.
ii. **Adoption of PV*SOL software for institutional energy audits:** The success of this study highlights the need for accurate pre-feasibility analysis. We recommend the adoption of simulation software like PV*SOL for all institutional energy audits to ensure optimal technical and financial design.
iii. **Establishment of rural technical training programs:** To address the lack of technical expertise in rural areas, government programs (such as those under SREDA or IDCOL) should fund training for local personnel to properly maintain and manage these solar PV systems, ensuring long-term sustainability.

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