

Techno-Economic Design and Analysis of a 10 MW Grid-Connected Solar Power Plant in Sirajganj, Bangladesh

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Abstract

In recent years, Bangladesh has been facing a steady rise in industrial energy demand, which makes it essential to look for power sources that are both sustainable and cost-effective. This paper explores the design and techno-economic performance of a 10 MW grid-connected solar photovoltaic (PV) plant planned for Chinabadh, Sirajganj. The analysis was carried out with NREL's System Advisor Model (SAM) by using local weather and solar data to estimate the system's performance and financial return. The plant is expected to generate around 19.4 GWh of electricity each year with a capacity factor of about 17.0%. From an economic view, the project shows promising results with an LCOE of 6.02 ¢/kWh, NPV of USD 556,000, and an IRR of 9.37%. A further advantage of the system is its potential to cut carbon emissions by a substantial amount—around 12.5 thousand ton each year, adding up to roughly 290 thousand ton over the project's lifetime of 25 years. Overall, the results indicate that the proposed solar plant could genuinely benefit the surrounding industrial sector by ensuring a steadier power supply, reducing environmental pressures, and supporting Bangladesh's long-term shift toward cleaner and more sustainable energy.

Keywords

Grid-connected solar photovoltaic (PV) system, Techno-economic analysis, System Advisor Model (SAM), Industrial energy reliability, Carbon emission reduction

1. Introduction

In the past few years, fossil fuel supplies have become increasingly uncertain, and the rapid rise in greenhouse gas emissions has only made the situation more worrying. These issues have pushed countries around the world to look more seriously at sustainable energy options. For developing nations, such as Bangladesh, the pressure is even greater because they must secure the rising demand of electricity that is both reliable and affordable while also trying to meet environmental commitments. Although much of this demand is being met with fossil fuels, the concerned authorities are more and more leaning towards sustainable alternatives. Among all the available alternatives, considering current circumstances, solar PV seems to be the most efficient one. Thus, in order to achieve the rising demands various solar PV based microgrids are being implemented as a reliable and sustainable source of energy.

Developing countries are leaning towards commercializing renewable energy sources specifically in the form of energy saving projects and microgrids (Hu et al., 2018). Microgrids are gaining more acceptability in order to meet the rising need of energy. Specifically, the requirement to meet local demand and to ensure sustainability as well to ensure socio-economic benefit these are being integrated not only into existing electrical network but also operating independently (Zia et al., 2018). Microgrids with grid-connections reduces fossil fuel usage as well as functioning as a support to the national electricity supply (Sumayli et al., 2023). For a developing country in Bangladesh such

microgrids with grid-connections offer reliable and continuous energy supply specially in local areas (Yeamin et al., 2024).

Various methods and designs have been implemented in order to achieve an environmentally friendly, reliable and sustainable grid connected system, for instance, a relevant study on designing a microgrid for an island in Bangladesh proposed a design on Pelican Optimization Algorithm incorporating solar PV, wind turbines, diesel generator and batteries. Furthermore, a comparative study has also been conducted based on LCC, COE and CO₂ emission of the system (Sagor et al., 2025).

Moreover, focused on designing an off-grid system using PVGIS for Char Jatin, Manpura Upazila, with key components such as solar panels, a charge controller, battery storage, a power inverter, and a supply box. The system was designed with the aim to provide continuous power to the remote island as well as to reduce the emission (Farzana Akter et al., 2023). The economic and environmental feasibility of a grid-connected photovoltaic system in Char Jazira, Bangladesh, was confirmed by a study that revealed an annual output of 2815 MWh, an LCOE of 2.82 BDT/kWh, and the potential to prevent 37,648 ton CO₂ emissions over a 25-year period, through PVsyst 7.1 simulation software (Ali et al., 2023).

Recent work has also explored CSP–PV hybrid systems using the System Advisor Model (SAM). These studies show that SAM is quite effective for evaluating location-specific performance and estimating financial outcomes. Even so, research on large, grid-connected PV projects in Bangladesh is still fairly limited, especially when viewed from an industrial or broader techno-economic perspective. Most available studies focus on small-scale or hybrid systems, and because of that, key aspects—such as long-term operational behavior, overall economic implications, and potential environmental benefits at utility scale—often receive little attention (Ali et al., 2024).

There is also a clear gap in the existing literature when it comes to understanding how large-scale solar projects might strengthen industrial energy reliability or support the country’s broader decarbonization goals. These issues are becoming increasingly important as Bangladesh continues to expand its industrial base and pushes toward meeting its national renewable-energy targets (Ali et al., 2023).

This study examines the techno-economic performance of a proposed 10 MW grid-connected solar PV plant at Chinabadh, Sirajganj, using the System Advisor Model (SAM) focusing on the gaps such as, lack of utility scale grid connected PV studies in Bangladesh, where most studies focused on small scale off-grid systems. Additionally, a lack of comprehensive SAM based techno economic analysis for large grid connected PV plant has motivated to conduct the whole research utilizing SAM. Furthermore, long-term decarbonization goals and financial liability haven’t been discussed much which has been highlighted here. This project also considers the potential industrial and operational benefits, IRR and detailed system losses all of which have a clear gap.

By linking simulation results with real-world energy needs, this research aims to fill the existing gaps in the literature and support Bangladesh’s ongoing move toward more sustainable industrial growth and long-term renewable energy development.

1.1 Objectives

The main goal of this research is to design and perform a comprehensive techno-economic assessment of a 10 MW grid-connected solar photovoltaic (PV) power plant at Chinabadh, Sirajganj, Bangladesh, using the System Advisor Model (SAM). The specific objectives are as follows:

- To design and optimize the configuration of a 10 MW grid-connected solar PV system based on local solar resources and site conditions.
- To evaluate the technical performance of the proposed system through annual energy yield, capacity factor, and performance ratio analysis.
- To conduct a detailed techno-economic evaluation using LCOE, NPV, and IRR to determine financial viability.
- To estimate CO₂ emission reductions and discuss the industrial and operational implications of large-scale PV integration in Bangladesh.

2. Literature Review

The world's heavy dependence on fossil fuels—combined with the steady rise in greenhouse gas emissions—has made the shift toward renewable energy not just important, but unavoidable. Among the different clean-energy options, solar photovoltaic (PV) technology has emerged as a leading choice because it is relatively simple to scale up, its cost has continued to fall, and it offers a clear environmental advantage. Grid-connected PV systems, in particular, have gained attention since they can provide reliable electricity while reducing the emissions associated with conventional power generation. According to the National Renewable Energy Laboratory's Annual Technology Baseline 2024, improvements in PV module efficiency and a continual drop in installation costs have helped make utility-scale solar projects far more financially attractive worldwide (NREL, 2024).

In Bangladesh, renewable energy development has been picking up momentum as the country works toward its 2041 target of generating 40% of its electricity from clean sources. Despite this direction, the national grid still depends heavily on fossil fuels, particularly natural gas, which creates long-term challenges for energy security and sustainability. A recent review by (Miskat et al., 2023) highlighted both the progress and obstacles within Bangladesh's solar sector—such as issues related to grid capacity, land availability, and maintenance practices. Even with these hurdles, the study strongly pointed out that grid-connected solar systems carry significant potential to support Bangladesh's growing energy needs and strengthen its future energy strategy.

Several techno-economic studies in recent years have focused on evaluating small- and medium-scale PV systems across Bangladesh. For example, (Ali et al., 2023) carried out a feasibility assessment of a 1.5 MW grid-connected PV plant in Natore and found an annual energy output of around 2.8 GWh, with an LCOE of 2.82 BDT/kWh—showing that smaller installations can still be financially promising. In another study, (Alam, 2022) examined solar-powered irrigation systems connected to the grid and highlighted a range of technical and policy-related barriers that continue to affect their long-term performance and operational reliability.

Recent performance-focused studies have taken a more practical angle, looking at how existing solar plants actually behave in the field instead of relying only on theoretical outputs. A useful example can be seen in the study by (Babu et al., 2024) on the 3.3 MW Sarishabari PV plant. While going through their results, it became clear that even the simpler adjustments—like slightly changing the panel tilt or getting the inverters to run a bit more efficiently—ended up improving the plant's yearly output by a noticeable amount. These tweaks also helped lower the overall emissions, which shows how much small operational decisions can matter in real projects.

These kinds of observations are important because they remind us that system improvement does not always depend on large design changes—sometimes routine optimization and better tuning can make a meaningful difference. In most of these evaluations, researchers end up using NREL's System Advisor Model (SAM). The reason is fairly straightforward: SAM allows them to work with actual weather data, realistic system losses, and financial parameters all in one place. Because of that, it has become the go-to tool for estimating not only the expected energy output but also the long-term financial performance of solar projects in Bangladesh (NREL, n.d.-c). Its flexibility makes it suitable for both academic studies and real project planning.

To estimate how much CO₂ a solar system can reduce, most researchers follow the national guideline from the Department of Environment. According to the 2023 Grid Emission Factor, Bangladesh uses 0.72 kg of CO₂ per kilowatt-hour. Using this standard makes it straightforward to calculate the carbon savings over the system's lifetime, and it also helps to compare results across different studies, since everyone is working from the same reference point (Islam et al., 2022).

The thorough literature review pointed towards the focus primarily being on small scale PV integration and general performance in different locations. Thus, this study decided to focus on large scale grid connected solar PV integration which hasn't been explored much. The project conducts configuration optimization and detailed loss analysis of various institution such as, hospitals, business institutions, schools, and so on of Sirajganj. This aspect differs from existing studies not just in terms of overall model but also the location itself. Implementing this project will definitely make financial impact in terms of creating jobs, ensuring reliable and continuous electricity supply so that every institution can run their operation smoothly and reduce the carbon dioxide emission significantly.

3. Methods

After finalizing the site selection, we designed the solar PV system by considering the local weather pattern and the daily variation of sunlight so that the plant can generate as much energy as possible. The proposed system is a grid-connected setup with a total capacity of 10 MW. For the main components—such as the module mounting structures, wiring layout, and necessary protection devices—we followed common industry practices to keep the design reliable and practical. To check how the system would actually perform, we used the System Advisor Model (SAM), which allowed us to estimate the yearly energy output, identify major losses, and evaluate overall system performance based on the site's irradiance and temperature data.

3.1 Proposed Location

The proposed location is Chinabadh, Sirajganj with a latitude of $24^{\circ} 27' 02.02''$ N and a longitude of $89^{\circ} 43' 08.38''$ E. The site's location, just north of the Tropic of Cancer has a significant impact on its solar irradiance, daylight length, and seasonal incident angles of sunray, all of which are critical variables for solar photovoltaic research (Figure 1).



Figure 1. Proposed Location for the plant (Chinabadh, Sirajganj).

3.2 System Schematic

A system schematic illustrating the arrangements of the components have been drawn. The components are solar PV array, inverters, transformers and switchgears which are all connected to the grid, each having their crucial function.

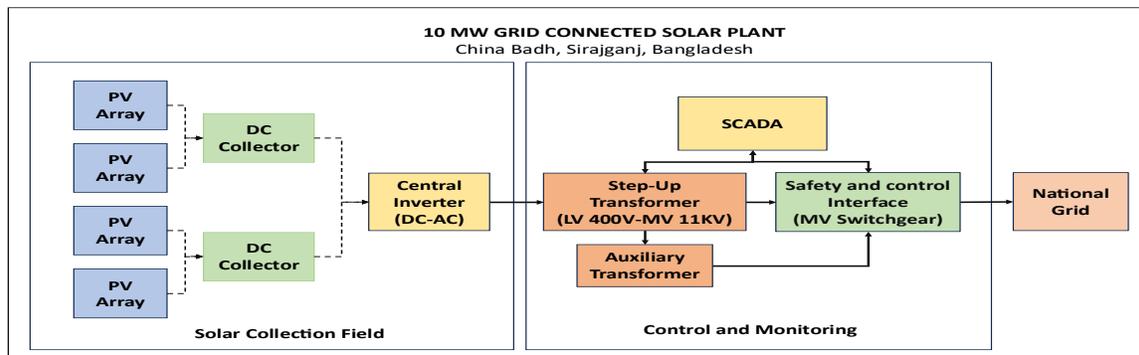


Figure 2. Schematic Diagram of the 10MW Grid-connected Solar Powerplant.

Figure 2 shows the schematic layout of a 10 MW grid-connected solar photovoltaic power plant located at Chinabadh, Sirajganj, Bangladesh. The system is made of PV arrays feeding DC power through inverters and a step-up transformer to the MV switchgear, which connects to the national grid, including auxiliary transformers for station services, weather monitoring, and earthing protection systems.

3.2 System Configuration

The proposed system includes a large-scale solar PV system with an array size of 13000KWdc with the total AC capacity of 10000KWac, providing it with 1.3 DC to AC ratio. A total of 24,066 TOPCO Solar Inc. TPM7-SHDB144-540/M module has been used arranged in 1,719 strings. The total module area is 61,609 m² without taking shading into consideration. The inverter used is CSI Solar Co-Ltd: CSI-25K-T480GL01-UB (480V) producing maximum AC power of 25.5KWac and a maximum of 800 voltage. The considered AC wiring loss is 1.5% of the output with an annual DC degradation rate of 0.50%. The system is estimated to require 15.3 acres of land for total module placement and a total estimated land area of 36.247 acres. From a financial perspective, the nominal discount rate for financial parameters is 9.59% with a PPA price of 0.07\$/KWh. The whole financial approximation was done considering an inflation rate of 3%.

4. Meteorological Data

The methodology adopted for this research is shown in the flowchart in Figure 3. The steps included in the flowchart are outlined below. Site assessment is a key initial phase in ensuring the effectiveness of a solar power project. It includes performing a detailed on-site evaluation of the proposed location in Sirajgang, Bangladesh. Basic information such as solar irradiance levels, shading conditions, local climate patterns, and site topography are collected through this assessment from The National Solar Radiation Data Base (NSRDB)(NREL, n.d.-a). The data is collected using global coordinate system and analyzed in the System Advisor Model (SAM). The assessment detects any site-specific challenges or shortcomings that must be taken into consideration during project planning and implementation.

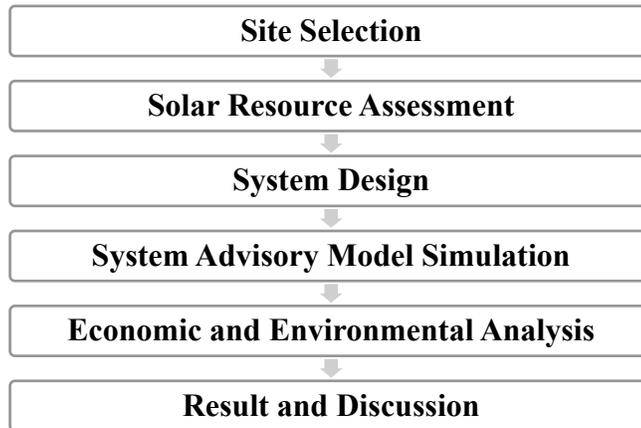


Figure 3. Flow diagram of the process

Meteorological data plays a significant role for SAM to analyze the climactic circumstances to design the most optimized solar power-based system. The SAM software depends on meteorological units especially solar irradiance data (Global Horizontal Irradiance, Diffused Horizontal Irradiance, and Direct Normal Irradiance) to ensure accurate calculation based on seasonal change of ChinaBadh, Sirajganj. The data set also includes Dry bulb temperature, wind velocity and relative humidity to reflect real climactic conditions. The meteorological data was collected from NSRDB as Typical Meteorological Year (TMY) with a stopgap of 60 minutes. The Meteorological data based on seasonal change is given in the following Table 1.

Table 1. Collected Typical Meteorological Data

Month	Direct Normal Irradiance (W/m ²)	Global Horizontal Irradiance (W/m ²)	Diffuse Horizontal Irradiance (w/m ²)	Dry- Bulb Temp (c)	Wind velocity (m/s)	Relative Humidity (%)
January	164	167	82	17	1.67	65.5
February	196	200	82	21.1	1.92	52
March	214	253	104	27.7	2.16	45.5
April	182	261	120	31	1.93	58
May	157	259	132	30.6	2.41	75.4
June	102	229	145	29.9	2.39	87.9
July	90	201	137	29.4	2.67	93.5
August	93	197	134	28.9	2.11	94.1
September	112	193	119	28.7	1.70	93.1
October	202	201	76	27.2	1.42	87.1
November	179	179	66	22.7	1.33	82.2
December	147	147	68	19.4	1.61	73.8

The solar irradiance is the key parameter for the yield of energy, directly determining the amount of electricity produced. Direct normal irradiance refers to the direct sunlight received on earth, an essential data for Solar PV systems. Global Horizontal Irradiance is the data regarding total solar energy which evaluates the prospect of the site. Diffuse Horizontal Irradiance is the radiation that gets scattered in the environment which a solar panel can utilize. All the parameters are measured in watt/meter square. During the months of March, April and May the average DNI, GHI and DHI are the highest. The GHI is March, April and May are 253, 261 and 259 w/m². The DNI and DHI are 214, 182, 157 and 104,120, 132 for the mentioned months respectively. Ambient temperature rising increases the efficiency of the system which is reflected in the 27.7, 31 and 30.6 temperature of March, April and May. Higher wind speed, on the other hand, cools down the modules and increases power output. RH affects the condition and the efficiency of the panels. When RH is higher, it can mean there is less solar radiation or even moisture build up on the panels resulting in lower power output. The comparatively lower RH value of March, April and May at 45.5, 58 and 75.4 ensures there won't be any cloud covering which may lower the energy output.

The SAM software accumulates the crucial meteorological data collected from NSRDB and simulates the most optimized system.

4.1 SAM Financial Model

The Single Owner PPA model in NREL's System Advisor Model represents a financial framework. In this model operation and maintenance of the entire solar PV system is conducted by a single entity as well as owning the establishment. It sells all the electricity to an off-taker through a long-term Power Purchase Agreement. The owner bears all capital and operational costs, has full financial risks. However, 100% of the PPA revenues and tax benefits, like ITC and MACRS depreciation is savored by the owner. Technically, the model embeds detailed system performance simulations of degradation rates, inverter efficiency, DC/AC ratio effects, soiling losses, availability factors, and weather variability to estimate annual energy output. Finally, SAM uses these performances parameters combined with financial inputs such as loan structure, discount rate, escalation factors, and O&M schedules to calculate project cash flows, NPV, IRR, and LCOE. This model is best suited for utility-scale or IPP projects that demands no more than a simple ownership structure with full control over technical and financial outcomes(NREL, n.d.-b).

5. Results and Discussion

5.1 Normalized Energy Production

Normalized energy production (NEP) is the metric used to determine the energy output of a system measured in kWh annually or per month. The given graph represents the NEP of the proposed system in Chinabadh, Sirajganj.

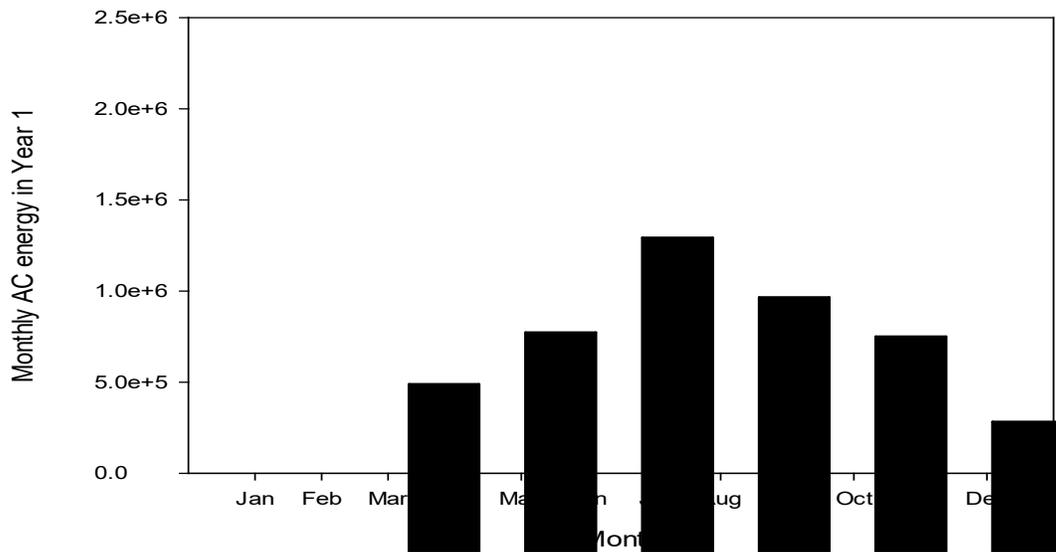


Figure 4. Normalized Energy Production

Figure 4 illustrates the monthly AC energy generation of the grid-connected PV system during the first year of operation. The results show noticeable seasonal variation, with higher energy output observed from February to April due to favorable solar irradiance conditions. Energy production declines during the monsoon months, particularly in June and July, as a result of increased cloud cover. Generation gradually recovers toward the post-monsoon and winter months, indicating stable annual performance of the system.

5.2 Financial Performance Analysis

The financial parameters calculated through SAM demonstrate not only the proposed project is environmentally sustainable but also financially viable. The economic prospects offer a socio-economic development as well as reliable supply of electricity for the area of Chinabadh, Sirajganj. The detailed expected economic annual result for the proposed microgrid have been calculated and displayed in the following Table 2.

Table 2. Simulated Results from SAM

Metric	Value
Annual Ac energy in Year 1	19,384,736 kWh
DC capacity factor in Year 1	17.0%
Energy yield in Year 1	1,491 kWh/KW
Performance ratio in Year 1	0.78
PPA price in Year 1	7.00 ¢/kWh
PPA price escalation	2.00 %/year
LPPA Levelized PPA price nominal	8.17 ¢/kWh
LPPA Levelized PPA price real	6.26 ¢/kWh
LCOE Levelized cost of energy nominal	7.85 ¢/kWh
LCOE Levelized cost of energy real	6.02 ¢/kWh
NPV Net present value	\$556,003
IRR Internal rate of return	9.37%
Year IRR is achieved	20
IRR at end of project	10.46%
Net capital cost	\$15,632,531
Equity	\$9,067,836
Size of debt	\$6,564,695
Debt percent	41.99%

The table represents principal financial and technical parameters where the annual generation of AC energy is 19,384,736 kWh and the plant produce 17.0% DC power compared to maximum capability. The efficiency of the plant is 1,491 kWh with an 78% performance ratio. PPA price starts at 7.00 ¢/kWh with a 2% annual increment, whereas LCOE is lower (6.02 ¢/kWh) confirming a profitable project. The project achieves an NPV net present value of \$556,003 and IRR of 10.46% achieving break even by year 20. The capital cost of \$15.7 M is financed through \$9.1 M equity and \$6.6 M debt (41.99%), reflecting a balanced structure that ensures both technical efficiency and financial viability.

5.3 Environmental and Industrial Impact

The 10 MW grid-connected solar PV power plant offers clean, reliable electricity while ameliorating environmental impacts and supporting industrial development. The project reduces primarily carbon di oxide emission along with other greenhouse gas emissions, conserves resources, and avoids air and water pollution by replacing fossil-fuel-based grid electricity with renewable generation. The plant makes the local supply chains stronger and resourceful, creates employment, and enhances national energy security simultaneously, making it both environmentally responsible and economically beneficial investment (Babu et al., 2024).

5.3.1 Projected Carbon Balance

The carbon balancing tool is an effective and proven method for calculating the reduction in CO₂ emissions that results from installing a PV system. This assessment is calculated based on the concept of life cycle emissions (LCE), which considers all carbon dioxide emitted from the plant during the production, operation, maintenance, and disposal of a system, providing a whole scenario of its impact on the environment (ELECTRUM, n.d.). The PV system's electricity generation can be compared to grid electricity with carbon balancing, showing how much conventional power (fossil fuel based), it can supplant. Overall CO₂ emissions are reduced, when the carbon footprint per kWh from the PV system is lower than that from the grid (PVsyst, n.d.). This method offers a pragmatic way to evaluate and illustrates the environmental benefits of solar energy, with the reduced CO₂ emissions (in ton CO₂) tracked over the system's lifetime.

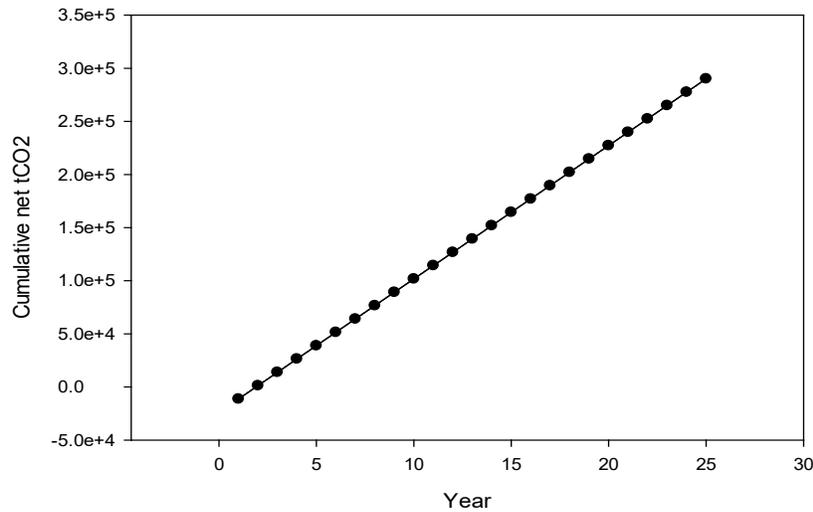


Figure 5. Cumulative CO₂ Emission Reduction Over Project Lifetime

Figure 5 shows the cumulative net CO₂ emission reduction achieved by the proposed grid-connected PV system over its operational lifetime. The results indicate a nearly linear increase in avoided CO₂ emissions with each year of operation, reflecting consistent annual energy generation. By the end of the project lifetime, the system achieves substantial cumulative emission savings, demonstrating its long-term environmental benefit. This trend highlights the effectiveness of large-scale solar PV deployment in reducing carbon emissions when displacing fossil fuel-based grid electricity.

Table 3 summarizes the life-cycle carbon emissions (LCE) associated with the main components of the proposed 10 MW grid-connected PV system. The analysis takes into account the embodied CO₂ emissions arising from manufacturing, transportation, and installation, which is the main contributor of carbon emission of the plant. PV module is mainly responsible for the system’s carbon footprint. Considering a life-cycle emission factor of 1,713 kg CO₂/kWp (PVsyst typical range: 1,500–1,900 kg CO₂/kWp for mono-Si, Asia-based manufacturing). For mono-crystalline silicon modules, for the installed 13,000 kWp DC capacity, 22,269 tCO₂ accounts for more than 90% of total system emissions.

The mounting structures (steel mountings) emit 1,624 tCO₂. The value is calculated using a steel emission factor of 3.9 kg CO₂/kg and a total structural mass of 416,530 kg. The total emissions from inverter are comparatively low due to lower material density which is 1.57 tCO₂. Overall, the total life-cycle emission of the PV system is estimated at 23,895 tCO₂ which accounts for 1.84 tCO₂/kWp when normalized.

Table 3. Carbon Emission of System

ITEM	LCE (Life Cycle Emission)	Quantity	Subtotal (LCE x quantity) tCO ₂
Modules (mono-C-Si)	1713KgCO ₂ / KWp	13000 KWp	22,269
Supports	3.90 KgCO ₂ /kg	416530 Kg	1624
Inverters	3.9 KgCo2/kg	401 Unit	1.57
		Total	23895 tCO ₂

Similarly to (Ali et al., 2023) the reduced carbon emission of the proposed plant is calculated by the methods followed stated below.

The LCE grid is expressed in CO₂/kWh and indicates the average CO₂ emissions per energy unit for grid-produced electricity. The LCE system is expressed in tCO₂ and represents the total CO₂ emissions brought on by the structure's construction and operation of the PV installation.

$$\begin{aligned} \text{Total Energy Generated} &= \text{Energy sold to grid} + \text{Energy consumed by auxiliary load} \\ &= (19384736 + 1491) \text{ kWh} \\ &= 19,386,227 \text{ kWh} \end{aligned}$$

Here,

Project lifetime=25 years

Projected LCE Grid for Bangladesh = 648 g CO₂/KWh (JAS, 2018)

LCE system= 23895,000,000 gCO₂

$$\begin{aligned} \text{Total Carbon balance} &= (\text{Total energy generated} \times \text{Project lifetime} \times \text{LCE Grid}) - \text{LCE System} \\ &= (19386227 \times 25 \times 648) \text{ gCO}_2 - 23895,000,000 \text{ gCO}_2 \\ &= 290,161,877,400 \text{ gCO}_2 \\ &= 290,161 \text{ tCO}_2 \end{aligned}$$

The calculation done above reaches a conclusion as the proposed design of the solar powerplant with the capacity of 10 MW is able to save a gigantic amount of CO₂ which is 290,161 tons of emission during its projected lifetime of 25 years. The calculation was done by taking the net supply to the grid and auxiliary power usage of the plant itself in mind.

5.3.2 Industrial Impact

The proposed 10 MW grid-connected solar PV plant is expected to provide a stable and cost-effective source of electricity along with empowering the local industrial development of Sirajganj. This reliable energy supply will minimize production downtime for local as well as national manufacturing and agro based industries while promoting uninterrupted operations assuring a green energy and mitigating energy dependence on the neighboring countries. The system incorporates modern SCADA-based monitoring, effective and low-maintenance PV infrastructure, enhancing grid stability and reducing operational expense for the utility and auxiliary consumption. The project directly contributes to the "Bangladesh's Renewable Energy Policy 2025" as well. The policy plans to install renewable energy to meet the nation's energy independency and climate goals by targeting 20% electricity from renewable sources by 2030 and 30% by 2041. Additionally, the projected long-term power output from the plant ensures sustainable industrial growth and galvanizes further renewable energy settlement in regional economic zones.

- Strengthen Local Manufacturing and Supply Chains
- Creating Employment
- Infrastructure
- Grid Modernization

5.3.3 Operational Outcome

While running at full capacity and routinely operation, the plant will have to provide with reliable industrial service. In order to gain an optimum service, a detailed O&M plan, grid interconnection studies, and periodic performance monitoring, sensitivity studies on LCOE, capacity factor and storage integration should be constantly updated to strengthen deployment case (Table 4).

Table 4. Simulated operational outcome

Annual Ac Energy (1 year)	19,384,736 kWh
Grid emission factor (Bangladesh)	0.648 kg CO ₂ /kWh (DOE GEF)
Annual CO ₂ avoided per year	12,561,308 kg ≈ 12561.3 tCO ₂
25-yr lifetime CO ₂ avoided	≈ 290,161 tCO ₂
LCOE (real)	6.02 ¢/kWh

5.4 Validation of the Work

There is a tabulated comparison of the completed and active solar projects in Bangladesh in Table 5. From the data of Ministry of Power and National Renewable Energy Database (Ministry of Power, n.d.; SREDA, n.d.), The comparison shows an overview of capacity, projected energy outcome and the reduced carbon emission of these projects of relatively similar capacity and global location.

Table 5. Comparison of different completed and running solar park projects and this proposed Solar Power Plant in Chinabadh, Sirajganj in Bangladesh

Project Name	Capacity (MW)	Location	Latitude/Longitude	Agency	Expected Energy (life)	Reduced Carbon Emission
30MW (AC) Solar Park by Intraco CNG Ltd. & Jiangsu Linyang Energy Co. Ltd.	30	Gangachara, Rangpur	25.82512° N, 89.28282° E	BPDB	654 GWh	309 kt CO ₂
Sirajganj 6.33 MW (AC) Grid-connected Solar Photovoltaic Power Plant	7.6	Sirajganj, Sirajganj	24.36127° N, 89.67549° E	NWPGCL	166 GWh	78 kt CO ₂
Kaptai 7.4 MWp (6.63 MW AC) Grid-connected Solar PV Power Plant	7.4	Kaptai, Rangamati	22.62382° N, 92.21836° E	BPDB	161 GWh	76 kt CO ₂
8 MW Solar Park by Parasol Energy Ltd.	8	Panchagarh, Panchagarh	26.70196° N, 88.95045° E	BPDB	174 GWh	82 kt CO ₂
20MW (AC) Solar Park by Joules Power Limited (JPL)	20	Teknaf, Cox's Bazar	20.90438° N, 92.25528° E	BPDB	436 GWh	206 kt CO ₂
10 MW Grid Connected Solar Power Plant in Chinabadh, Sirajganj (Simulated)	10	Chinabadh, Sirajganj	24° 27' 02.02" N, of 89° 43' 08.38" E	Proposed	484 GWh	290 kt CO ₂

6. Conclusion

This study represented a thorough techno-economic and environmental assessment of a proposed 10 MW grid-connected solar photovoltaic (PV) power plant at Chinabadh, Sirajganj, Bangladesh, using NREL's System Advisor Model (SAM). The analysis was conducted to fill the research gap in utility-scale, grid-connected PV system studies in barren lands existing in Bangladesh, where most prior work has focused on small-scale or off-grid applications.

From technical analysis, the proposed system demonstrates stable operation under local climatic conditions. The simulation results estimate an annual AC energy generation of approximately 19.4 GWh, with a DC capacity factor of 17.0% and a performance ratio of 0.78. There was periodical difference in energy output consistent with regional solar irradiance patterns, which validates applicability of the selected site for large-scale PV deployment. The economic analysis projects that the project is financially viable and beneficial under the assumed market and policy conditions. The plant can deliver competitive electricity prices while remaining attractive to investors as it offers a real LCOE of 6.02 ¢/kWh, combined with a positive net present value (NPV) of USD 0.56 million and an internal rate

of return (IRR) of 10.46%. With a mix of equity and debt, the balanced financing structure builds up the project's economic feasibility and lessens any long-term financial risk.

The projected carbon balance showcases the significant decarbonization prospect of the proposed PV plant. The total life-cycle carbon emission along with system construction, installation and component manufacturing was calculated at 23,895tCO₂. The operational phase enables substantial emission avoidance by displacing fossil-fuel-based grid electricity over a 25-year project lifetime. Over the projected lifetime the system is expected to avoid approximately 290,161tCO₂. This clearly demonstrates that the initial carbon investment is rapidly offset and that long-term environmental benefits are substantial from the proposed design.

Overall, this research concludes that large scale grid connected solar PV systems are both technically feasible and economically profitable in Bangladesh. At the same time, project like this delivers long-term environmental and industrial advantages. The methodology adopted in this study, combining SAM-based simulation, detailed financial modeling, and life-cycle carbon assessment, provides a framework that can be replicated for future utility-scale solar projects in similar climatic and economic condition. To further enhance system efficiency and grid flexibility, future work may focus on integrating energy storage systems and hybrid renewable configurations such as CSP-PV system along with policy driven incentives and grid integration to accelerate Bangladesh's transition toward a more sustainable and low-carbon energy future.

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