Paper ID: 62

Harvesting Kuakata's Solar Power: A Comprehensive Study on the Implementation of a 10 MW Solar Photovoltaic Power Plant

Syeda Tanjila Sarwar[1], Most Rubaiya Begum[1], Arup Das[1,a)]
[1]Department of Mechanical and Production Engineering,
Ahsanullah University of Science and Technology,
Dhaka-1208, Bangladesh

E-mail: syeda.tanjila33@gmail.com, rubaiyabegumema7586@gmail.com, dasarup184@gmail.com
a) Corresponding Author: dasarup184@gmail.com

Abstract

Solar energy, a clean, climate-friendly, and abundant energy resource, has been researched since the beginning for the development of an affordable, inexhaustible, and clean solar energy technology for longer-term benefits as it has incredible potential to power our daily lives. The present study has evaluated the design of a 10 MW grid-connected solar photovoltaic power plant in Kuakata, Bangladesh, which produced key findings such as the monthly photovoltaic power output, the average annual Performance Ratio (PR), and insights into identifying optimum locations and PV technology for the prominent adoption of solar photovoltaic systems in the region. Solar power is being considered as an alternative energy source, but probably should not be the exclusive energy source to rely on in the future. The research involved the use of various software programs such as Global Solar Atlas (GSA), Photovoltaic Geographical Information System (PVGIS), PVSyst, and RetScreen to acquire necessary details for the study. The knowledge obtained is valuable for evaluating the plant's operating advantages based on its net energy output and can be utilized in future large-scale projects. The analysis indicates a peak performance ratio (PR) of up to 84.60%, with a reduction in carbon emissions by as much as 93%. The project has the capacity to export 12,868 MWh of electricity annually, demonstrating a payback period of 11.3 years within its 25-year life cycle.

Keywords: Solar energy, Renewable energy, Grid-Connected, Sustainability.

1. Introduction

The world population is growing at an exponential rate, cities are becoming more and more urbanized, and technology is developing constantly. These factors are driving up the need for power globally. According to projections, there will be a roughly 50% increase in worldwide energy use by 2050 when compared to 2020 levels [1]. There is a growing emphasis on switching to renewable energy alternatives in response to the rising demand of the environmental effects of conventional energy sources. Wind, photovoltaic, biogas, ocean wave, hydro, and geothermal, are stand as infinite and environmentally cleaner alternatives to conventional energy sources [2, 3]. Governments worldwide are working hard to build renewable energy facilities that utilize their unique resources [4]. Among all renewable energy options, solar power plants stand out as the most common and frequently used. Their appeal lies in their adaptability and suitability for various geographic areas, making them a desirable option for many nations looking to expand their energy portfolios [5]. The significance of solar power plants highlights their critical role in meeting the changing energy needs in a sustainable and ecologically conscientious manner as the world navigates the dynamic terrain of energy demands. In light of this, there is a pressing need to address the specific energy requirements of regions facing unique challenges, such as Kuakata. The current energy situation in Kuakata, Bangladesh, is characterized by high electricity demand, frequent power outages, and reliance on fossil fuels for electricity generation. As a major tourist destination, Kuakata experiences power outages 10 to 12 times daily, leading to damage to electronic equipment and affecting businesses. The power sector in Bangladesh depends on fossil fuels like natural gas, furnace oil, diesel, and coal, though solar energy has significant potential in Kuakata [6-8]. The government of Bangladesh has set a target of generating 40% of its energy from renewable sources by 2041, with solar making up a significant portion. The country's installed renewable energy capacity is 650.53 megawatts (MW), with solar accounting for 416 MW. There is significant potential for solar and wind power in electricity generation, and the government aims for at least 10% of renewables in the total energy mix by the end of 2021 [9]. The longstanding issue of inadequate power supply in Kuakata has been overlooked for many years due to most of the energy from nearby Payra 1320 MW Thermal and Patuakhali 1320 MW Coal Fired

Power Plants being allocated towards the capital and larger cities which hampers tourist businesses. Both the aforementioned Power Plants rely on fossil fuels, and there are no renewable energy-based power plants in the vicinity. Establishing a renewable energy source in Kuakata leverage its plentiful sunlight, which will ensure reliable power, lessen dependency on fossil fuel. However, no research has been studied yet regarding this issue of Kuakata. So, this paper presents a comprehensive examination of the viability of establishing a 10 MW Grid-Connected Solar Photovoltaic Power Plant in Kuakata as a sustainable solution to the region's electricity challenges. Utilizing the abundant solar irradiation in the area, our analysis underscores the considerable potential for solar power generation. The proposed implementation of a grid-connected solar power plant aims to address the need for uninterrupted electricity in Kuakata, concurrently reducing dependence on fossil fuels. This initiative is aligned with and significantly contributes to the broader national objectives of emissions reduction and the promotion of renewable energy, aligning with the country's strategic targets in this regard [10].

2. Description of the Solar PV-Grid System

Kuakata, located in the Kalapara Upazila of Bangladesh's Patuakhali district, is a notable coastal town celebrated for its remarkable natural beauty. Situated near the southernmost tip of the Bay of Bengal, it boasts breathtaking views and natural splendor. Kuakata Beach, stretching 18 kilometers in length and 3 kilometers in breadth, is particularly distinguished for its unique geographical positioning, making it an exceptional natural attraction.

A. Project location

In terms of geographic location, the coordinates pinpoint the site at 21.8265° North latitude and 90.1348° East longitude. For a 10 MW solar power plant, the land requirement depends on factors like solar panel efficiency, technology, solar radiation, and layout design. A proposed 1.124 MW solar power plant necessitates 5 acres of land. To optimize land use, the project suggests installing solar panels on the sea bed near Kuakata Beach shown in figure 1. Choosing Kuakata for the 10 MW solar power plant offers advantages, serving local energy needs, contributing to the national grid, and emphasizing environmental stewardship [11]. This innovative strategy positions Kuakata as a role model for renewable energy, showcasing a win-win scenario for land preservation and sustainable energy production.



Fig. 1. Selected location for the plant, Satellite image of Kuakata.

B. Demand analysis

In this study, the number of units of appliances is taken into consideration, of 2065 houses. Every house is equipped with a refrigerator, a television, 5 LED lights, 3 fans, and a water pump. A daily load curve of both summer and winter is plotted in figure 2 depending on these hypothetical data. The curve shows the total consumed load per hour for a day. The maximum amount of consumed load was observed at the 9th hour (9 AM) and 17th hour (5 PM) during the summer season with the value of 1674 W and 1792 W and at the 9th hour (9 AM) during the winter season with 1674 W. The bi-daily utilization of the pump during the summer months is necessitated, whereas during the winter, a singular usage suffices owing to diminished water demand [12- 16].

During the summer season, the maximum electricity load was recorded at the 9th hour (9 AM) and the 17th hour (5 PM), with values of 1674 W and 1792 W, respectively. In contrast, during the winter season, the peak load of 1674 W was observed at the 9th hour (9 AM). The bi-daily operation of the water pump in the summer months is essential due to higher water demand, whereas a single daily operation suffices in winter owing to reduced water usage. Considering all 2,065 households in Kuakata, the total electricity demand for the residential area is 20 MW during the summer and 14 MW during the winter. The designed power plant, with a power output of 10 MW, is insufficient to meet the total electricity demand of all 2,065 households.

From the following estimated total load demand of an average household in a typical day during summer, the powerplant can distribute electricity to 998 households and 1447 households during winter (approximately) . It highlights the requirement for an additional power supply to effectively fulfil the demand.
From the following estimated total load demand of an average household in a typical day during summer, the powerplant can distribute electricity to 998 households and 1447 households during winter (approximately). It highlights the requirement for an additional power supply to effectively fulfil the demand.

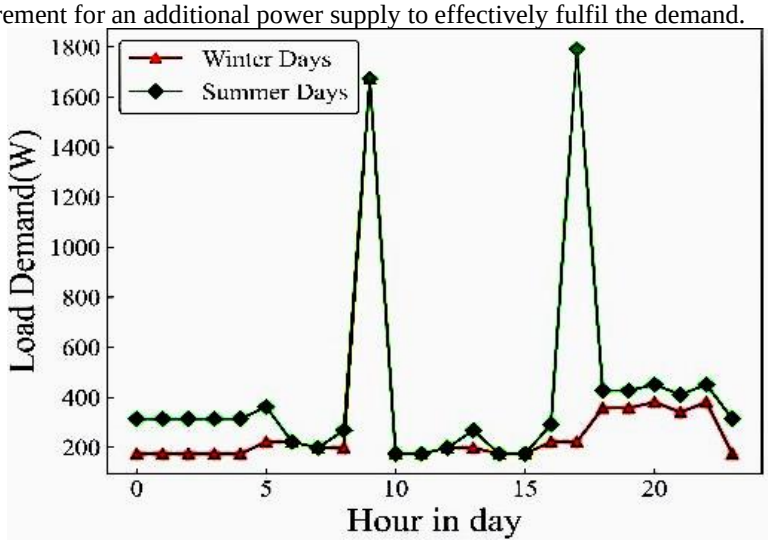


Fig. 2. Load curves of Summer and Winter

3. Resource Assessment

Using the geographic coordinates of latitude 21.8228181° and longitude 90.1219399°, the potential resources have been evaluated that may be accessible at the planned site of Kuakata. The goal of the resource assessment is to determine if the available resources are adequate to supply the necessary electrical demand. All of the information is collected from the Global Solar Atlas (GSA, provided by the Energy Sector Management Assistance Program), and the Photovoltaic Geographical Information System (PVGIS, commissioned by the European Union's Joint Research Centre (JRC) since 2001). The GSA solar map data for Kuakata are shown in Table 1 for each year.

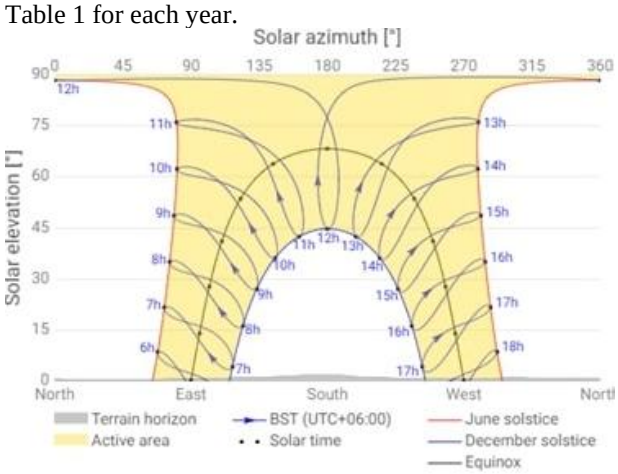


Table 1. Map Data of Kuakata Site (Per year)

Properties	Abbreviation	Value	Unit
Direct normal irradiation	DNI	1159.5	kWh/m^2
Global horizontal irradiation	GHI	1752.6	kWh/m^2
Diffuse horizontal irradiation	DIF	926.7	kWh/m^2
Global tilted irradiation at optimum angle	GTI opta	1865.7	kWh/m^2
Optimum tilt of PV modules	OPTA	22 / 180	°
Air temperature	TEMP	26.3	°C
Terrain elevation	ELE	5	m

Fig. 3. Monthly Solar Irradiation estimation graph from PVGIS

Figure 3 shows the sun path diagram. The sun path and azimuth angle are critical for assessing solar energy resources. They determine the trajectory and direction of the sun, leading to appropriate solar installation locations for efficient energy capture. These parameters are critical for forecasting energy generation patterns, mitigating shading impacts, and informing strategic decisions in solar project planning and design. From figure 3 it is illustrated that maximum solar elevation (90°) is found at noon in June, and the azimuth direction is north. In December, the noontime solar elevation angle is half of that. To construct a solar PV powerplant the estimation of the monthly solar irradiation is so crucial. The irradiation data help in determining the available solar energy resource at the selected site. The energy potential and feasibility of that solar PV powerplant can be assessed by understanding the amount of daylight that reaches the selected location every month. The graphs attached as figure 4 illustrate the average maximum irradiation occurs in March and December. This happens due to the earth is positioned in such a way that sunlight is more directly incident on the proposed location’s latitudes which results

in more solar radiation. Besides, from the perspective of our proposed location Kuakata, the atmosphere is tropical monsoon, with distinct humid and dry seasons. The weather is clearer during this period, with less cloud cover and lower humidity, enabling more direct sunlight to reach the Earth's surface as these months are transitional between seasons. Solar irradiance is a crucial aspect of estimating the energy potential of a solar power plant. The average annual global tilted irradiation is 1865.7 kWh/m2 and 5.11 kWh/m2 daily according to PVGIS [17].

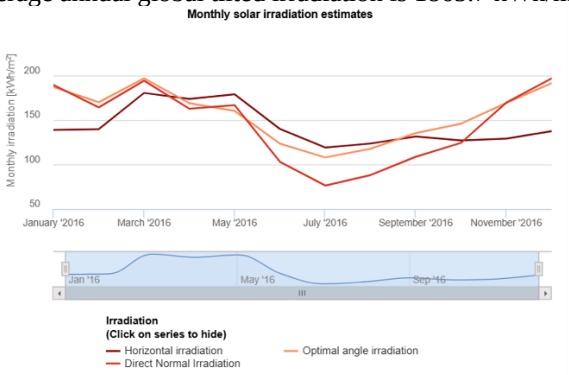


Fig 4. Monthly Solar Irradiation estimation graph from PVGIS [17].

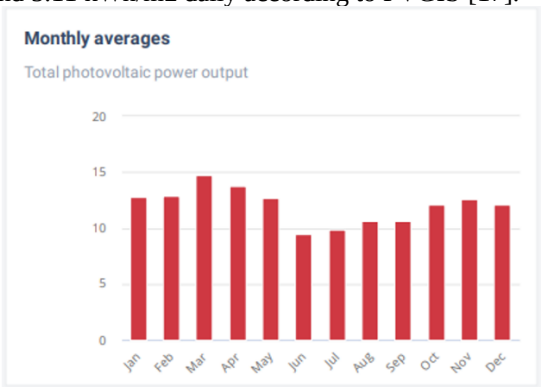


Fig 5. Monthly average profile of total photovoltaic power output from GSA.

The Global Solar Atlas provides information about a grid-connected 10 MW crystalline silicon solar panel system. The system is expected to generate 144.318 MWh per year or 395.39 KWh per day. Monthly energy generation, as shown in figure 5 from GSA, reaches a peak of 14.5 MWh in March, with reducing output in monsoon months, notably June.

4. Design and Optimization

The proposal foresees a 45-acre solar power facility on the sea bed near Kuakata Sea Beach to meet the energy needs of Bangladesh's underdeveloped coastal area. The design has its focus on a grid-connected photovoltaic system, with tilt and azimuth angles optimized for optimal energy generation. Excess electricity is supplied directly into the national grid, reducing storage losses and contributing surplus power to the grid when conditions are suitable.

A. System design

A grid-connected solar system comprises five major components that collectively harvest energy from sunlight and supply power to appliances once installed. Figure 6 illustrates the interaction and connections among these components, forming a grid-connected solar photovoltaic power plant. This system generates electricity from solar radiation, which can either be distributed to end consumers or returned to the grid. Solar panels capture solar energy and convert it into electricity. Inverters then transform this electricity from Direct Current (DC) to Alternating Current (AC). To manage excess electricity, a net meter is installed, allowing surplus power to be transferred to the utility grid. After sunset, any excess electricity exported to the grid can be drawn back as needed. Additionally, mounting structures, or mounting stands, are necessary for securing and positioning the solar panels [18]. The photovoltaic (PV) module used in this study has a nominal power rating of 240 watts peak (Wp), with a total nominal power output of 8279 Wp across all PV modules. The inverter has a nominal power rating of 75 kilowatts alternating current (kWac) and a total power output of 7700 kW. These details were collected from the PVSyst software.

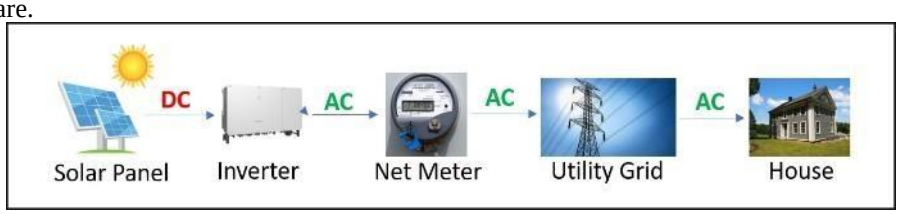


Fig 6. Schematic diagram of grid connected solar PV system Optimization.

This section delineates an overview of the optimization procedure employed for the proposed power plant, wherein the "PVGIS" software is utilized to gather the requisite data. Figure 7 and figure 8 below show how the solar irradiation varies with tilt angle and azimuth angle. They illustrate the fluctuation of solar radiation with tilt angle and azimuth angle. The tilt angle and azimuth angle of the solar panels are two essential parameters for optimizing solar irradiation and maximizing energy generation in a grid-connected solar photovoltaic powerplant. These angles are frequently modified based on the PV system's geographical location to ensure that the solar

panels receive the maximum sunlight throughout the year. The optimal value is 26° tilt angle and 4° azimuth angle, as determined by the optimization procedure.

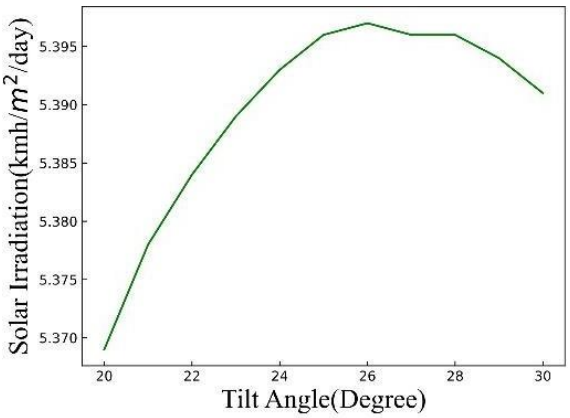


Fig. 7. Solar Irradiation vs Tilt angle (For 6◦ azimuth angle).

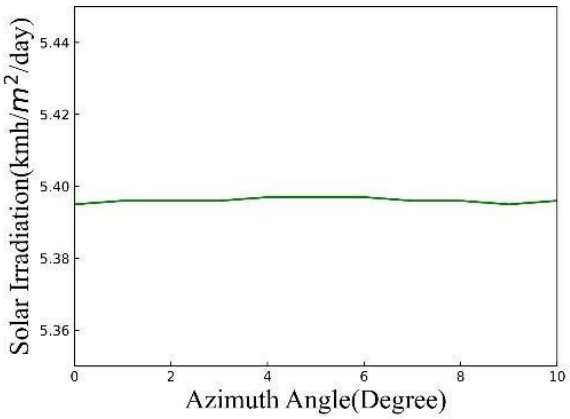


Fig. 8. Solar Irradiation vs Azimuth angle (For 26◦ tilt angle).

5. Result and Discussion

The information in this section is acquired through the utilization of PVGIS and PVSyst software.

A. Power output

Figure 09. Monthly PV output at optimum tilt angle. Figure 10 shows the monthly photovoltaic energy output which is simulated from PVGIS software. During the monsoon season June and July, energy generation is reduced, whereas peak output is observed in the spring. In March, the maximum daily average energy production is roughly 1544.482 MWh.

B. Performance Ratio

The PV (photovoltaic) plant performance ratio defines the relationship between the plant's actual and theoretical energy outputs. It represents the percentage of energy available for export to the grid after accounting for energy losses. The Performance Ratio (PR) values can be used to make deductions about system breakdown. A lower PR indicates problems such as inappropriate system operation and inverter malfunctions. **Figure 10** illustrates the annual average value of the PR ratio is nearly 81.70%. The highest value of PR was found to be 84.60% in January and the lowest PR was 80.10% in April and May. The information has been acquired through the utilization of PVSyst software.

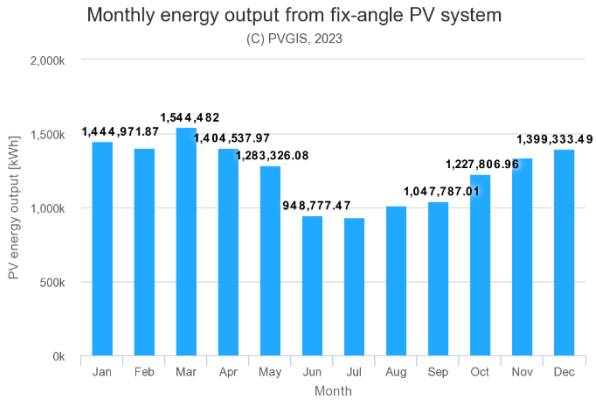


Fig. 9. Monthly PV output at optimum tilt angle.

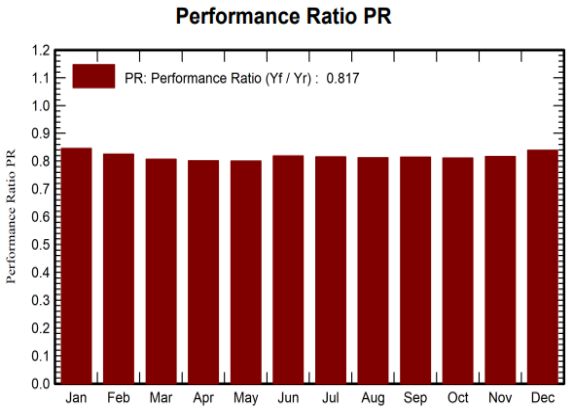


Fig. 10. Performance ratio for the 10MW grid connected solar PV system.

C. Emission Analysis

The Emission Analysis of a Solar PV Power Plant investigates the environmental impact of solar photovoltaic systems, evaluating aspects ranging from production to operation to end-of-life disposal. Understanding the emissions profile of solar PV is critical in evaluating its contribution to decreasing greenhouse gases in light of the global push for sustainable energy. The principal greenhouse gas (GHG) is CO2. In Bangladesh, the power

industry accounts for 40% of total CO2 emissions [19-20]. Total CO2 emissions are more than sevenfold to 1934 million tCO2 in 2050, up from 208 million tCO2 in 2005 [21]. Figure 11 below shows us the reduction of Greenhouse gas emissions. The gross annual emission reduction is 93%.

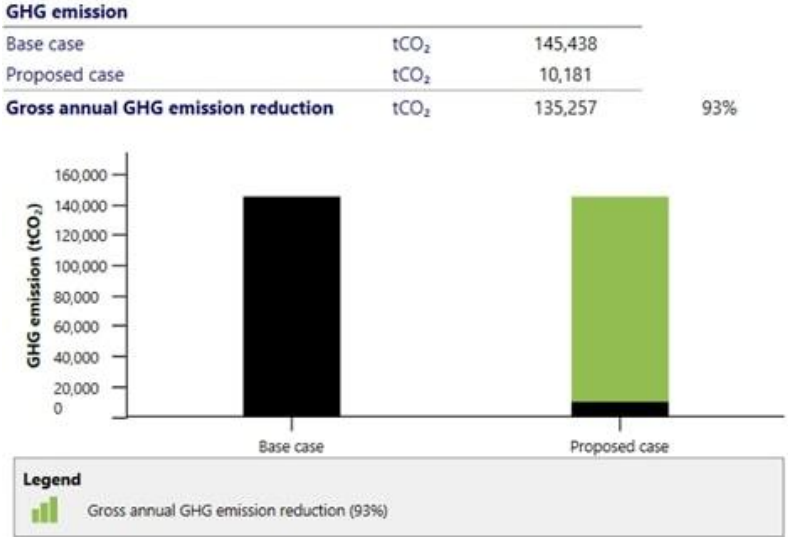


Fig. 11. Annual GHG emission reduction.

D. Financial Analysis

The "Renewable Energy and Energy Efficiency Technology Screen (RETScreen) Clean Energy Management" software, which is the world's top software for empowering cleaner energy decisions, was used to examine the financial elements of our project. This examines, among other things, production costs, revenue, and investment expenses.

Table 2: Financial Parameters of the Project

Parameter	Value
Project life (years)	25
Investment Cost (Taka)	457,884,194
Annual electricity generation (MWh)	12,868
Production cost of electricity (Taka/kWh)	8.84
Price of electricity (Taka/kWh)	10.84
Revenues expected over the course of the project (Taka)	139,459,748
Simple payback period (years)	11.3

This project has a 25-year life cycle. The annual amount of electricity that will be exported to grid is 12,868 MWh. The findings of a detailed analysis demonstrate that the payback period is 11.3 years. This demonstrates the potential of the proposed power plant. BDT currency is not supported by the software named “Retscreen Expert” used in this. In that case, the USD has been converted to BDT manually, and all computations use the BDT currency.

6. Conclusion

The deployment of a 10 MW Solar Photovoltaic Power Plant in Kuakata represents a promising solution to current energy challenges, aligning seamlessly with global priorities for sustainability. The plant's role in ensuring uninterrupted electricity delivery reflects a strategic move towards dynamic energy services, mirroring the global shift towards sustainable energy solutions. Despite cost competitiveness hurdles, the potential of solar energy to enhance local energy sufficiency and contribute to national emission reduction goals is unmistakable. This initiative not only addresses electricity access disparities but also fuels economic growth through job creation while minimizing environmental impact by sidestepping harmful particle emissions. The average annual Performance Ratio (PR) is 81.70%, demonstrating the solar power plant's efficiency and sustainability. This outstanding performance metric strengthens the plant's reputation as a reliable and consistent contributor to the energy environment. The study emphasizes the imperative for a multi-faceted strategy, blending innovation and supportive policies, to fully unlock the substantial potential of solar energy. These insights aim to empower decision-makers and guide future endeavors towards cultivating a resilient and sustainable energy landscape.

7. References

[1] U. S. Energy Information Administration, “International Energy Outlook 2016,” May 2016. [Online]. Available: www.eia.gov

[2] A. Al Mansur et al., “Electrical experimental data collection of polycrystalline and monocrystalline photovoltaic modules in an indoor environment using artificial sun simulator,” Data Brief, vol. 43, Aug. 2022, doi: 10.1016/j.dib.2022.108389.

[3] A. Amer et al., “Floating Photovoltaics: Assessing the Potential, Advantages, and Challenges of Harnessing Solar Energy on Water Bodies,” Journal of Ecological Engineering, vol. 24, no. 10, pp. 324–339, 2023, doi: 10.12911/22998993/170917.

[4] H. D. M. R. Perera, “Designing of 3MW Floating Photovoltaic Power System and its Benefits over Other PV Technologies,” International Journal of Advances in Scientific Research and Engineering, vol. 06, no. 04, pp. 37–48, 2020, doi: 10.31695/ijasre.2020.33782.

[5] G. K. Singh, “Solar power generation by PV (photovoltaic) technology: A review,” Energy, vol. 53, pp. 1–13, May 2013, doi: 10.1016/J.ENERGY.2013.02.057.

[6] Viktor Tachev, “Solar and Wind Power Potential in Bangladesh 2022.” Accessed: Dec. 13, 2023. [Online]. Available: https://energytracker.asia/solar-and-wind-power-potential-in-bangladesh/

[7] The Business Standard, “Hoteliers demand steady, decent power supply in Kuakata,” The Business Standard, Oct. 21, 2021. Accessed: Dec. 13, 2023. [Online]. Available: https://www.tbsnews.net/bangladesh/hoteliers-demand-uninterrupted- electricity-supply-kuakata-314992

[8] Sudarshan Varadhan and Carman Chew, “Bangladesh’s worst electricity crisis in a decade,” Reuters, Jun. 07, 2023. Accessed: Dec. 13, 2023. [Online]. Available: https://www.reuters.com/world/asia-pacific/bangladeshs-worst-electricity- crisis-decade-2023-06-07/

[9] M. N. Hoque, K. Nandi, and A. I. Journal, “Critical Review Feasibility study of a renewable power plant at Kuakata in Bangladesh Environmental Science Environmental Science.”

[10] Farzana Akter, Kazi Ahasan Ekram, Md. Araful Hoque, and Mohammad Joynal Abedin, “An Assessment of Solar Micro-Grid System in the Islands of Bangladesh for Sustainable Energy Access,” Malaysian Journal on Composites Science and Manufacturing, vol. 12, no. 1, pp. 31–42, Nov. 2023, doi: 10.37934/mjcsm.12.1.3142.

[11] Md. S. Sayem and Md. K. Hassan, “Designing Grid Connected 1.124 MW Photo-Voltaic System for Kuakata Coastal Area,” in 2021 Asian Conference on Innovation in Technology (ASIANCON), IEEE, Aug. 2021, pp. 1–4. doi: 10.1109/ASIANCON51346.2021.9544646.

[12] [Online]. Available: https://learn.pjm.com/three-priorities/keeping-the-lights-on/how-energy-use-varies.

[13] [Online]. Available: https://www.eia.gov/todayinenergy/detail.php?id=42915.

[14] [Online]. Available: https://www.cedengineering.com/userfiles/M06-004%20-%20Cooling%20Load%20Calculations%20and%20Principles%20-%20US.pdf.

[15] [Online]. Available: https://www.pdhonline.com/courses/m196/m196content.pdf.

[16] [Online]. Available: https://www.greenbuildingadvisor.com/article/seasonal-changes-in-electrical-loads.

[17] Photovoltaic Geographical Information System (PVGIS), developed by the European Union's Joint Research Centre (JRC)
- https://joint-research-centre.ec.europa.eu/photovoltaic-geographical-information-system-pvgis_en

[18] S. Mukherjee and M. A. Razzak, “Design, analysis and optimization of grid-connected solar photovoltaic system using RETScreen in eight divisions of Bangladesh,” in 2016 3rd International Conference on Electrical Engineering and Information Communication Technology (ICEEICT), IEEE, Sep. 2016, pp. 1–6. doi: 10.1109/CEEICT.2016.7873120.

[19] Md. A. H. Mondal, “Impacts of CO 2 Emission Constraints on Penetration of Solar PV in the Bangladesh Power Sector,” Nov. 2011, pp. 2698–2705. doi: 10.3384/ecp110572698.

[20] R. M. Shrestha, G. Anandarajah, and M. H. Liyanage, “Factors affecting CO2 emission from the power sector of selected countries in Asia and the Pacific,” Energy Policy, vol. 37, no. 6, pp. 2375–2384, Jun. 2009, doi: 10.1016/j.enpol.2009.01.032.

[21] R. M. Shrestha and S. Pradhan, “Co-benefits of CO2 emission reduction in a developing country,” Energy Policy, vol. 38, no. 5, pp. 2586–2597, May 2010, doi: 10.1016/j.enpol.2010.01.003.