Optimization of Solar PV System Efficiency in Bangladesh

Riad Mollik Babu[1*], Md. Shahidul Islam[2], Enamul Basher[3]

***Abstract*— This paper presents a comprehensive review and analysis of the Jamalpur Solar Plant Ltd., a 3.3 MW grid-connected solar photovoltaic (PV) system located in Jamalpur, Bangladesh. The study evaluates the plant's economic and operational performance, revealing a competitive payback period of 10.1 years and a levelized cost of energy (LCOE) of 0.11 USD/kWh. These metrics highlight the plant's financial viability, largely due to the low price of public land used for construction. However, profitability may be challenged if similar projects require significant investments in private land acquisition. Key areas for improvement identified include optimizing the tilt angle and integrating smart automation systems. Additionally, the potential for hybrid renewable energy systems combining solar and wind power is discussed. The paper also provides actionable recommendations for future renewable projects, emphasizing the importance of advanced technologies and supportive policies. These insights aim to inform the optimization of existing solar PV systems and guide the development of future renewable energy projects in Bangladesh, contributing to the country's sustainable energy goals.**

***Index Terms*— Solar PV, Renewable Energy, Hybrid Systems, Smart PV Systems, Performance Evaluation**

I. Introduction

Bangladesh is actively pursuing a sustainable energy future by leveraging its abundant solar resources and aiming for 40% renewable energy in electricity generation by 2041 to address its growing energy demand and environmental concerns [1]. The Jamalpur Solar Plant Ltd., a 3.3 MW grid-connected solar photovoltaic (PV) power plant, stands as a pivotal case study to assess the performance, economic viability, and potential enhancements of solar PV systems within Bangladesh.

This study delves into the operational efficiency, grid integration, and financial performance of the Jamalpur Solar Plant. Despite its success in harnessing renewable energy and contributing significantly to the national grid, the plant's performance ratio of approximately 71% indicates room for improvement compared to neighboring countries. Factors such as limited land availability, the necessity to preserve agricultural land, and technical and financial barriers impede the broader adoption of advanced solar technologies in Bangladesh. To address these challenges, this paper explores key areas for enhancement, including the optimization of the tilt angle and the integration of smart automation systems. Furthermore, the potential of hybrid renewable energy systems, particularly those combining solar and wind power, is examined as a viable solution to augment power generation and ensure sustainability.

In Bangladesh, the expansion of utility-scale grid-connected solar energy faces significant land challenges due to the country's limited land availability and the need to conserve land for agriculture [2]. Despite the vast potential for solar energy in Bangladesh, the slow diffusion of solar energy in rural areas highlights the need to overcome barriers such as land constraints, technical issues, and pricing challenges to ensure sustainable renewable energy market growth. The challenges facing the low number of smart solar PV systems and hybrid solar-wind plants in Bangladesh for integrating large-scale solar PV systems stem from various factors [3]. While Bangladesh has made significant progress in deploying Solar Home Systems (SHSs), the transition to more advanced systems like smart PV and hybrid plants faces obstacles such as high upfront costs, a lack of technical expertise, and limited awareness among stakeholders [4, 5, 6].

Smart solar PV systems offer significant cost-effectiveness compared to conventional solar PV plants [7, 8, 9]. By incorporating IoT for remote supervision and maintenance, smart systems can increase efficiency and yield while minimizing human intervention and costs [10]. Additionally, the implementation of innovative smart monitoring systems with electronic sensors enhances the performance monitoring of crucial components like PV arrays, leading to increased detection speed, improved efficiency rates, and higher quality operation of solar power plants [11]. The combination of these advancements showcases the superior cost-effectiveness of smart solar PV systems over conventional ones. By implementing innovative technologies such as smart monitoring with electronic sensors [12] for better energy management in smart grids [13], these systems can enhance performance, increase detection speed, improve quality, and reduce power loss due to factors like hot spots, soiling, and limited solar radiation capture [14]. However, the high initial cost is a significant obstacle to the wider adoption of solar energy systems [15].

The tilt angle of a solar PV system is crucial for maximizing energy generation efficiency [16]. Research has shown that the optimal tilt angle significantly impacts the performance of PV panels, affecting the amount of solar energy captured and the overall energy production [17, 18, 19, 20]. Studies have explored various tilt angles to determine the most efficient positioning, considering factors like dust accumulation, solar radiation utilization, and seasonal variations. However, many existing solar PV systems in Bangladesh, including the

Jamalpur plant, still rely on manual tilt angle adjustments, which can lead to suboptimal energy production and increased labor costs. Different studies have found that implementing automatic tilt angle adjustment systems could increase energy yield significantly, but the cost of these systems and the potential complexity of system setup and maintenance can be a barrier to adoption for project [21].

In Bangladesh, solar and wind potential is significant [22]. The integration of wind energy into solar PV systems could enhance the overall power generation sustainability [23, 24, 25] Therefore, coupling wind energy with solar PV systems, especially in coastal areas with sufficient wind resources, could provide a more reliable and sustainable power generation solution for Bangladesh [26]. Integrating wind energy into solar PV systems in Bangladesh has been a focal point for enhancing renewable energy generation and cost-effectiveness. Studies in Bangladesh have shown that hybrid energy systems combining wind and solar power can significantly reduce electricity costs and CO2 emissions [27]. A study found that the LCOE of hybrid wind solar power is 0.0725 and the payback period is 6.4 years [28]. However, the development of hybrid wind-solar projects in Bangladesh has been limited due to challenges such as the intermittent nature of wind resources [29], the need for additional infrastructure and technology, and the complexities of integrating wind power into the existing grid [30, 31]. A recent study [32] suggests that a supportive policy framework, including incentives for hybrid projects and streamlined approval processes, could accelerate the deployment of wind-solar hybrid systems in Bangladesh [33]. Additionally, another research [34] indicates that community engagement and awareness programs are crucial for the successful implementation of hybrid projects, as local acceptance and support can significantly impact project outcomes. Furthermore, the importance of accurate wind resource assessment and forecasting for the optimal design and operation of hybrid wind-solar systems in Bangladesh is highlighted [35].

Bangladesh is a small country with an area of 148,460 km². Due to its size, every part of the country receives almost equal amounts of solar irradiance. Therefore, studying the Jamalpur Solar Power Plant can provide valuable insights into the potential of solar PV systems throughout Bangladesh. This study is to optimize the efficiency and profitability of the Jamalpur Solar Plant and other solar PV projects in Bangladesh. This includes proposing recommendations for upgrading to a smart PV system with automatic tracking, optimizing the tilt angle of solar panels, and exploring the feasibility of hybrid wind-solar systems. By addressing the challenges of land acquisition and efficiency optimization, the research aims to contribute to the sustainable development of renewable energy in Bangladesh and provide valuable insights for policymakers, energy stakeholders, and investors.

II. METHODOLOGY

To comprehensively evaluate the performance, economic viability, and optimization options of Jamalpur Solar Plant Ltd. and future green projects, we employed a hybrid methodology. We integrated simulation techniques and software analysis. Additionally, we collected data on essential parameters from previous studies, plant officials, and government websites. Furthermore, we estimated the cost of the proposed hybrid system and automation by referencing existing hybrid systems and researching current equipment prices.

For economic analysis, we gathered crucial data from plant officials, including total installation costs, taxes, inflation rates, and other pertinent factors. We obtained vital parameters such as radiation values, average temperature, wind speed, and humidity by entering the coordinates of the chosen region. The procedure employed in PVSyst established the foundation for a thorough assessment of the solar power plant's performance and efficiency, considering actual environmental conditions. After completing the design phase, we calculated monthly energy production data for the power plant, utilizing its installed capacity of 3.3 MW, and determined the average performance ratio (PR) of the facility. PVSyst software played a crucial role in analyzing both overall electricity generation and the payback period, offering valuable insights into the economic feasibility and return on investment of the plant.

In the later part of the study, we designed a similar model, maintaining all parameters consistent with the first one. However, this time we experimented with different tilt angles to determine the optimal angle for solar irradiance capture. We also used educated assumptions and data from smart solar PV systems to estimate the benefits of integrating automation into the plant.

In the final part of the study, to evaluate the feasibility of hybrid renewable energy systems, we utilized HOMER Pro software, a tool designed for optimizing microgrid design. The simulation considered various configurations of solar PV, wind turbines, and energy storage systems to identify the most cost-effective and reliable setup for the given location and load profile. To analyze the feasibility of the hybrid wind-solar PV system in Bangladesh, we selected wind turbines, storage systems, and other essential equipment based on data from similar projects in Bangladesh and their cost-effectiveness.

Design of the solar PV system

Information about the PV array's orientation is shown in Table 1. The power plant incorporates a manual solar tracking system. The tilt angle is adjusted twice a year: to 5° in the summer and to 24° in the winter.

Table 1. Orientation of PV array

Tilt angle	Summer (April, May, June, July, August, September) tilt 5º
	Winter tilt 24º
Azimuth	180º

Table 2 provides a concise overview of key photovoltaic components utilized in the solar PV system, including solar panels and inverters.

Table 2. Details of the PV components

PV Component	Model Name	Manufacturer
PV Module	SUNMODULE PLUS SW 285 MONO	SOLARWORLD
Inverter	Sunny Tripower STP 25000TL-30	SMA Solar Technology AG

A summary of the main characteristics of the solar PV system is provided in Table 3. It outlines important characteristics such as the installed capacity, module configuration details including nominal power and total number, as well as inverter specifications including nominal power and quantity.

Table 3. Design details of the PV plant

Installed capacity	3000 kWh
Module Nom. power (Wp)	285
Total number of modules	11580
Nominal (STC)	3300 kWp
Modules	579 string x 20 In series
Inverter AC Nom. Power	25.0 kW
Number of inverters	123
Inverter AC Total power	3075 kW

Table 4 provides a concise overview of the financial investment required for the establishment and annual maintenance of the Jamalpur Solar Power Plant, highlighting both the initial capital expenditure and ongoing operational expenses.

Table 4. Installation and operating cost of Jamalpur Solar power plant

Total installation Cost	5,000.000 USD (Approximately)
Annual operating Cost	6,500,000 BDT (Approximately)

III. RESULTS

This section presents the performance evaluation of Jamalpur Solar Plant Ltd. and the simulations for a 3.3 MW solar PV plant in Jamalpur, Bangladesh. We analyze the current plant's economic and performance metrics as summarized in Table 5 and compare these with the simulated results to explore potential improvements and optimization strategies.

3.1 Evaluation of current plant performance

The performance of Jamalpur Solar Plant Ltd. is evaluated through a comprehensive economic and performance analysis. Key metrics of the system are summarized in Table 5.

Table 5. Economic and performance analysis of the Jamalpur Solar Plant Ltd

Metric	Value
Produced Energy	3132 MWh/year
Specific Production	949 kWh/kWp/year
Cost of Produced Energy	0.1132 USD/kWh
Feed-in Tariff	0.18970 USD/kWh
Electricity Sales	11,882,808 USD
Payback Period	10.1 years
Return on Investment (ROI)	92.3 %
Cumulative Profit	4,526,693 USD
Performance Ratio	0.7

The analysis demonstrates that Jamalpur Solar Plant Ltd. is performing efficiently, with a strong ROI and a reasonable payback period. However, the performance ratio of 0.7 suggests there is room for improvement in operational efficiency, potentially through optimizing maintenance practices or upgrading system components. Our study found that several factors contributed to this development. Firstly, the power system lacks automation, as it was established in 2017 when the available technology was not as advanced. Despite technological advancements since then, modern, sophisticated equipment has not been incorporated, adversely impacting efficiency. The system relies on manual solar tracking to adjust the tilt angle twice a year, which has multiple negative impacts. This practice not only involves considerable labor costs but also reduces energy generation and the system's longevity, resulting in higher maintenance costs. Furthermore, compared to similar projects in the country, the total installation cost is higher.

3.2 Financial analysis in ideal conditions

To estimate the annual energy generation of a 3.3 MW solar PV plant in Jamalpur, Bangladesh, under ideal conditions, we utilized an average solar irradiance of 5.4 kWh/m²/day, a system efficiency of 80%, and effective sunlight hours of 5.4 hours/day. These parameters, along with additional necessary information from Tables 1, 2, 3, and 4, were used to calculate the expected annual energy output based on the plant's rated capacity of 3.3 MW. The detailed calculations and results are presented in Table 6.

Table 6. Financial performance metrics for Jamalpur Solar Power plant in ideal conditions

Metric	Value
Effective Annual Energy Generation (MWh/year)	5201
Annual Revenue (USD)	986,695.97
Net Annual Revenue (USD)	931,695.97
Payback Period (years)	7.19
Levelized Cost of Energy (USD/kWh)	0.075

The simulation results indicate an effective annual energy generation of 5201 MWh/year. This value is higher than the current production, suggesting that there are opportunities to enhance the system's efficiency.

IV. OPTIMIZATION STRATEGIES

We propose the integration of smart PV systems, tilt angle optimization, and a hybrid wind-solar-smart system to maximize energy production and reduce operational costs. These strategies are supported by simulation results and comparative analyses, demonstrating their potential to significantly improve the performance and sustainability of solar energy systems in Bangladesh.

4.1 Introducing the Smart PV System

It is evident that effective operational management and smart automation of the plant can lead to optimal efficiency, enhancing its economic feasibility. To maximize efficiency and cost-effectiveness, we have developed a smart solar PV system.

Figure 1 illustrates the energy flow in our smart PV system. The process begins with the solar panels and ends with the grid connection and user interface. The system also integrates an energy storage component and is monitored and controlled via a communication network.

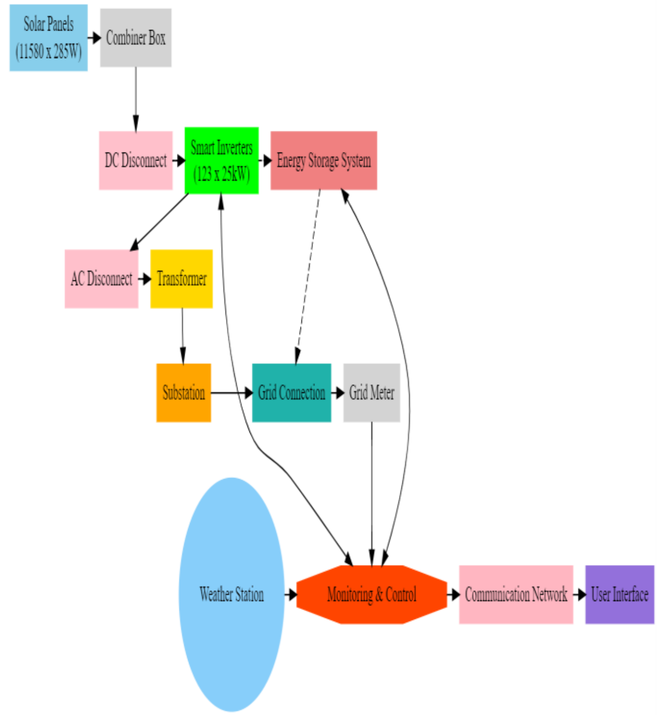

Figure 1. Energy flow diagram of the proposed Smart PV System

This system offers several advantages:

- **Predictive Maintenance:** Through data analytics and machine learning algorithms, smart PV systems can predict potential equipment failures before they occur. This proactive approach reduces maintenance costs and prevents unexpected breakdowns. By analyzing historical data, a smart PV system can predict when an inverter is likely to fail and schedule maintenance ahead of time, preventing costly emergency repairs and extended downtime.

- **Energy Storage:** Smart PV systems can integrate with energy storage solutions and demand response programs to optimize energy use. They can store excess energy during periods of low demand and release it during peak hours, improving energy efficiency and reducing costs.

- **Improved Data Collection and Analysis:** The data collected by smart PV systems can be used for detailed performance analysis, helping to identify patterns and trends that can inform future improvements and optimizations. By analyzing data from various sensors, a smart PV system can identify which panels are underperforming due to dirt accumulation and schedule cleaning operations to enhance overall efficiency.

- **Grid Interaction and Stability:** Smart PV systems can interact with the grid more effectively, supporting grid stability by providing ancillary services such as voltage regulation and frequency control. During times of high electricity demand, a smart PV system can supply additional power to the grid or reduce its consumption, helping to balance the load and prevent grid instability.

- **Monitoring and Control:** Smart PV systems are equipped with advanced sensors and IoT devices that allow for real-time monitoring of system performance. This capability enables operators to detect and address issues promptly, minimizing downtime and optimizing energy production. A smart PV system can detect a drop in performance due to shading on one of the panels and automatically adjust the power output of other panels to compensate, ensuring consistent energy generation.

These advantages of smart photovoltaic systems demonstrate their potential to significantly enhance the performance, reliability, and economic viability of solar power installations. By leveraging advanced technologies and data-driven insights, smart PV systems can address many of the challenges faced by traditional solar power systems, paving the way for a more efficient and sustainable energy future.

4.2 Tilt Angle Optimization

Jamalpur Solar Power Ltd. features a manual solar tracking system. These manual adjustments result in significant labor costs and, more importantly, reduce the plant's efficiency.

Through our PVsyst software simulations and comparisons with solar PV systems in our country and others, we have determined that the optimal tilt angle for solar panels corresponds to the latitude of the area. While a tracking system presents itself as an alternative, its widespread application is hindered by certain drawbacks.

Since Jamalpur is located at 24.7417°N, 89.8333°E, taking this into consideration, the tilt angle of our solar PV system should ideally be set at 24°. Readjusting the tilt angle will significantly enhance the plant's efficiency and reduce the payback period.

Table 7 presents a comparative analysis of solar panel installations at different tilt angles. The efficiency of each installation is assessed based on specific production, energy cost, payback period, and performance ratio. This comparison sheds light on the impact of tilt angles on the overall performance and economic viability of solar energy systems.

Table 7. Comparative efficiency analysis of solar panel installations at different tilt angles

Tilt Angle	Produced Generation	Specific Production	Energy Cost	Payback Period	Performance Ratio
Summer 5° and Winter 24°	3132 MWh/year	949 kWh	.11USD/kWh	10.1 years	70.62 %
Fixed 24° Tilt Angle	3886 MWh/year	1177 kWh	.10 USD/kWh	9.5 years	71.78 %

Optimizing the tilt angle of solar PV panels at the Jamalpur Solar Power Plant can significantly enhance energy efficiency and reduce costs. Adjusting the tilt angle to the optimal setting improves annual energy output by 5%, as indicated by the plant's performance data. This increase in energy production lowers the LCOE from $0.11/kWh to $0.10/kWh, contributing to a quicker return on investment. Additionally, optimizing the tilt angle reduces labor costs, leading to further cost savings and improved overall system performance.

4.3 Hybrid-Wind-Solar-Smart System

The Government of Bangladesh has set a target of achieving a wind power capacity of 1370 MW by 2030 and has encouraged private entities to invest in wind power projects [36]. A report on the country's technical capacity found that Bangladesh has around 20,000 square kilometers of land where wind blows at 5.75-7.75 m/s. It means wind farms covering these areas can produce a total of 30 GW of electricity [37, 38].

With the projected increase in land costs, future investors may find it challenging to ensure profitability for solar PV systems alone [39]. To address this challenge and enhance the economic viability of renewable energy projects, we propose the implementation of a hybrid wind-solar-smart system. By harnessing both wind and solar resources, this hybrid system aims to increase energy production while simultaneously reducing costs. The model is designed to be adaptable and can be applied to both the current Jamalpur solar PV plant and future renewable energy projects. It offers a flexible framework that can be tailored to the specific conditions and requirements of different locations, making it a valuable tool for optimizing energy generation in various contexts.

Hybrid system design

We've meticulously crafted a comprehensive design for the hybrid system tailored for Sarishabari, leveraging its abundant solar and wind resources. Our proposal centers on a wind-PV hybrid system poised to unlock the full potential of these renewable energy sources. Following a thorough assessment of horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT) for the power plant, we've determined that VAWT stands out as the optimal choice for this application. VAWT can be installed closer to the ground, it has a respected performance against lower wind speeds, and its effect on birds and aircraft is lower compared to HAWT [40].

Wind Turbine

This study uses a 100 kW vertical-axis wind turbine made by Nantong R&X Energy Technology Co., Ltd., China, since VAWT is the optimal option for this evaluation. Table 8 provides the technical specifications of the chosen wind turbine. This turbine is of the H-type.

Table 8 provides detailed specifications for the RX-HV100K wind turbine model. These specifications highlight the performance capabilities and operational requirements of the RX-HV100K wind turbine, offering insights into its suitability for various wind energy projects.

Table 8: Technical specifications of the RX-HV100K vertical axis wind turbine

Model	RX-HV100K
Rated power (kW)	100
Blades Length (M)	15
Wheel Diameter (M)	6
Rated Voltage	380
Start Up Speed (m/s)	2
Cut In Wind Speed (m/s)	3
Survival Wind Speed (m/s)	50
Number Of Blades	3
Lifespan (Years)	20
Gross Weight (kg)	250
Install Height (M)	2-12

Table 9 details the key characteristics and economic aspects of the components used in the hybrid solar-wind system at the Sarishabari Solar Plant.

Table 9. System components and economic information

Characteristic	Solar panel	Wind turbine	Inverter	Battery
Model	Sunmodule plus Sw 285 mono	RX-HV100K	Sunny Tripower STP 25000TL-30	100kWh Li-Ion
Power (kW)	.285	100kW	25	100kWh
Capital cost (USD)	328	49,000	4,057	40,000
Replacement cost (USD)	300	30,000	2,000	40,000
O& M cost per equipment/year	2	1,000	5	500

Table 10 presents cost and performance metrics for two configurations of renewable energy systems, as derived from the HOMER Pro software.

Table 10. Cost and performance metrics for different renewable energy system configurations

Sunmodule Plus Sw-285	RX HV 100 kW	100 kWh LA	Converter (Kw)	NPC ($)	LCOE ($/kWh)	Operating Cos ($/yr)	CAPX ($)
3300	20		25	$9.56M	$0.073	$75000	$8.7M
3300	20	20	20	$10.03	$0.1453	$80,500	$9.4M

Table 11 provides a detailed breakdown of the results derived from HOMER Pro software for a renewable energy system with an installed capacity of 5.3 MW, comprising 3.3 MW of solar and 2 MW of wind turbines.

Table 11. Breakdown of HOMER Pro results

Installed Capacity	5.3 MW (Solar 3.3MW+wind turbines 2MW)
Total Annual Generation	6,986 MWh
Total Initial Installation Cost	$8,700,000
Total Operation Cost	$75,000 per year
Annual Revenue	$1,325,154.2
Annual Profit	$1,250,154.2
Net Present Cost (NPC)	$9,560,250
LCOE	$0.073 per kWh
Payback Period	6.96 years
Ren Frac (%)	100

Although a hybrid system requires a higher initial investment, the land requirement challenge can be significantly mitigated by establishing a hybrid solar-wind power system. This approach will not only substantially increase profitability but also ensure optimal land utilization. The current plant has a payback period of 10.1 years and a LCOE of $0.11 per kWh. Transitioning to a hybrid system can reduce the payback period to 6.96 years, with an LCOE of $0.073 per kWh. While integrating a storage system will increase the LCOE, the payback period will still be shorter than that of the existing system. Additionally, the hybrid system's higher electricity generation capacity will have a more positive environmental impact. Our study has identified the Sarishabari Solar System as particularly feasible for a hybrid configuration due to its advantageous location. Moreover, the results indicate that hybrid systems could be effectively implemented in other regions of the country with ample wind resources.

V. CONCLUSION AND RECOMMENDATIONS FOR FUTURE DEVELOPMENT

This study assessed the performance and economic viability of Sarishabari Solar Plant Ltd., a 3.3 MW grid-connected solar PV system in Bangladesh. The plant's performance ratio of 0.7 indicates efficient operation, yet there is potential for further optimization. The analysis highlights a competitive payback period of 10.1 years and an LCOE of 0.11 USD/kWh, emphasizing the plant's financial viability primarily due to the low cost of public land used for construction. However, similar projects could face profitability challenges if significant investments in private land acquisition are required.

To enhance the plant's efficiency, this research recommends upgrading to a smart PV system with automatic tracking capabilities, optimizing the tilt angle of the solar panels to 24°, and integrating wind energy to create a hybrid system. Implementing these recommendations can reduce maintenance costs, increase energy generation, and potentially shorten the payback period to 7 years with an LCOE of 0.073 USD/kWh.

The findings have significant implications for policymakers, energy stakeholders, and investors. Policymakers should promote supportive policies and advanced technologies to foster the sustainable development of renewable energy. Energy stakeholders should consider the integration of smart technologies and hybrid systems to enhance efficiency and meet Bangladesh's renewable energy targets. Investors are encouraged to support projects incorporating these advancements for a more sustainable and cost-effective energy future.

To further enhance the sustainability and impact of renewable energy technologies, the following recommendations are proposed:

- Foster closer collaboration between policymakers, researchers, and academics to ensure that renewable energy policies are informed by scientific insights and innovative ideas.
- Create a dedicated research institution focused on renewable energy to conduct cutting-edge research, develop innovative technologies, and provide valuable insights for policymakers and industry stakeholders.
- Incorporate energy education programs into the national curriculum at all levels of education.
- Develop insurance schemes that offer affordable coverage for renewable energy investments.
- Remove import duties on tools and machinery for renewable energy plants to reduce the initial setup costs.
- Adopt modern energy modeling software, such as the Long-range Energy Alternative Planning System (LEAP), to analyze energy systems, forecast future energy consumption, and assess the potential of renewable energy sources.
- Allocate non-arable land at minimal or no cost to investors for the development of green energy projects.
- Encourage the development of hybrid power plants that integrate multiple renewable energy sources, such as wind and solar.
- Invest in smart energy infrastructure and grid technologies to optimize the integration of renewable energy sources into the electricity grid.
- Each renewable energy project should have a website providing detailed information for the public.
- Our study found that accessing information about renewable energy projects in Bangladesh is challenging, with officials often reluctant to share details. If there are no major security or

operational concerns, power plants should be more open and accessible, particularly for students, academics, and researchers.

- Researchers should focus on developing renewable energy projects that do not disrupt local biodiversity.
- Authorities should plan ahead for the recycling and disposal of solar and wind plant waste.
- Strengthen collaboration with neighboring countries to enhance renewable energy development.
- Explore ways to design renewable energy project sites for multiple uses, such as growing vegetables, seasonal foods, or integrating other forms of sustainable agriculture, to maximize land use efficiency.
- The government should prioritize the long-term environmental benefits of renewable energy over immediate profitability for the next 10–20 years.
- Universities should offer generous incentives, such as scholarships and research grants, to encourage students to major in or conduct research on renewable energy, addressing the current lack of enthusiasm and job opportunities in this field.

Adopting these recommendations will enable Bangladesh to significantly strengthen its renewable energy sector, ensuring its sustainability and boosting its contribution to the national energy mix.

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