

A Comprehensive Review of Renewable and Sustainable Energy Sources with Solar Photovoltaic Electricity Advancement in Bangladesh

Md. Naeem Hussain ^{1,*}, Md Rakibur Zaman ², Md Abdul Halim ³, Md. Sumon Ali ⁴, Md. Yakub Ali Khan ⁵
^{1,5} Department of Electrical and Electronic Engineering, World University of Bangladesh, Uttara, Dhaka, Bangladesh
² Department of Electrical and Electronic Engineering, Hubei University of Technology, China
^{3,4} Department of Electrical and Electronic Engineering, Prime University, Mirpur-1, Dhaka, Bangladesh
Email: ¹ naeemislam1007@gmail.com, ² rakibzumman@gmail.com, ³ halimabdul552@gmail.com,
⁴ marinersumon803@gmail.com, ⁵ yakub.bimt@gmail.com
*Corresponding Author

Abstract—With an emphasis on Bangladesh's accomplishments in solar photovoltaic power production, this extensive study offers a comprehensive review of sustainable and renewable energy sources. Bangladesh, a heavily populated country that depends heavily on energy, has a difficult time satisfying its rising electrical demand while also taking environmental issues into account. The assessment covers a wide range of topics related to renewable energy sources, including solar photovoltaic technology, how it fits into the nation's current energy infrastructure, legislative frameworks, and socioeconomic effects. The report emphasizes how solar photovoltaic power may play a key role in Bangladesh's sustainable energy future by lowering the country's reliance on fossil fuels, lessening the effects of climate change, and promoting economic development via the use of renewable energy sources. This comprehensive review explores the many facets of sustainable and renewable energy sources in further detail, with a particular emphasis on Bangladesh's ever-changing solar photovoltaic power market. The topic of discussion includes developments in solar panel technology, such as increased efficiency, lower costs, and novel ideas. It also looks at how solar energy may be integrated into the current energy system, discussing the benefits and problems related to energy storage and grid modernization. This paper has the potential to improve energy security, the environment, the economy, and the general well-being of the populace, with a focus on solar PV advancement in Bangladesh. It can act as a guide for decision-makers in government, academia, and business to work together to create a more resilient and sustainable energy future for the nation. The research explores how the expansion of the solar business might lead to the creation of jobs, the improvement of skills, and the enhancement of local economies. It also takes into account the advantages for the environment that come from using less fossil fuels, such as lower greenhouse gas emissions and better air quality. This thorough review highlights the importance of Bangladesh's progress toward solar photovoltaic electricity development as a way to guarantee a sustainable and environmentally conscious energy future, lower consumer energy costs, and improve energy security in a country with rising energy consumption and aggressive renewable energy targets.

Keywords—Renewable, Sustainable, Photovoltaic, Energy Sources, Advancement, Bangladesh

I. INTRODUCTION

With the world's fossil fuel supplies running low and climate change occurring, the switch to sustainable and

renewable energy sources has become critical. Under these circumstances, Bangladesh, a highly populous country that depends heavily on energy, has started a revolutionary path to fully use solar photovoltaic power as a major part of its portfolio of sustainable energy sources [1]. This thorough study aims to provide a thorough analysis of renewable and sustainable energy sources, with a focus on the developments and consequences of solar photovoltaic power in the particular context of Bangladesh [2]. This paper attempts to highlight the many aspects of this shift, including technical advancements, regulatory frameworks, financial implications, and environmental advantages, in light of the increasing awareness of the need for sustainable energy alternatives. This emphasizes how important it is for Bangladesh to move toward a more sustainable and energy-efficient future via the development of solar photovoltaic power, solving issues related to energy security and supporting international efforts to tackle climate change.

Bangladesh must diversify its energy sources, lessen its reliance on traditional fossil fuels, and lessen the negative environmental effects of energy production as it deals with a growing population and rising energy needs. With the region's tremendous resource potential, solar photovoltaic power offers an appealing alternative [3]. In addition to examining the possibilities of solar energy, this assessment looks at the several facets of its integration and deployment within Bangladesh's larger energy framework. Bangladesh's adoption of renewable energy has progressed via a number of steps, fueled by a combination of private sector involvement, government efforts, and technical innovation. The advancement of solar photovoltaic technology in particular has played a significant role in increasing the affordability and accessibility of solar energy. This analysis aims to provide a thorough overview of the technical advancements in solar photovoltaics, highlighting the rising domestic manufacturing sector, falling prices, and growing efficiency of solar panels.

In addition, this analysis explores the legislative and regulatory structures that have played a crucial role in forming Bangladesh's solar energy market. The encouragement of investment in solar infrastructure has been greatly aided by government regulations, subsidies, and incentives. In order to inform choices on energy policy in the

future, this analysis seeks to emphasize the achievements of these programs and identify opportunities for development. And just as important are the socio-economic aspects of this change. In addition to offering possible environmental advantages, solar photovoltaic power development may boost job possibilities, boost economic growth, and improve energy access in disadvantaged and rural regions. To assess the overall sustainability and efficacy of Bangladesh's renewable energy programs, it is essential to comprehend these wider implications [4].

This thorough analysis offers an all-encompassing look of Bangladesh's renewable and sustainable energy scene, with a particular emphasis on solar photovoltaic power [5]. Through an examination of policy dynamics, technology advancements, and socio-economic ramifications, it seeks to provide insightful information on the country's transition to a more energy-secure and sustainable future. Bangladesh's energy transformation presents both possibilities and problems, but solar photovoltaic power stands out as a glimmer of hope for the country's pursuit of a more resilient and environmentally friendly energy industry. Thoroughly examining sustainable and renewable energy sources can have a significant and diverse impact, especially when it comes to advancing solar photovoltaic (PV) electricity in Bangladesh. The review can give decision-makers a comprehensive grasp of the advantages and difficulties of incorporating solar PV into Bangladesh's energy system. Making well-informed decisions can result in the creation of long-term planning strategies, incentives, and regulations that promote the expansion of the renewable energy industry. By demonstrating the potential and viability of solar PV projects in Bangladesh, a well-documented review can draw in both domestic and foreign investment. Projects with a strong research base and a grasp of the local context may inspire greater confidence in investors.

II. METHODOLOGY

The present study's approach is intended to guarantee a thorough and exhaustive examination of renewable and sustainable energy sources, with a particular emphasis on the expansion of solar photovoltaic power in Bangladesh. The main elements of the technique are outlined in the paragraph that follows.

A detailed and methodical assessment of the literature, including a broad variety of academic journals, reports, government papers, industry publications, and scholarly articles, was done in order to undertake this review. The main emphasis was on research materials and sources that particularly discussed solar photovoltaic technology and advancements in renewable energy within the Bangladeshi setting. The thorough literature evaluation furnished the fundamental information required to comprehend the past and present conditions of renewable energy endeavors in the nation. Furthermore, both qualitative and quantitative data were gathered and examined from government agencies, business publications, and scholarly investigations to provide a deeper understanding of the regulatory frameworks, technical developments, and socioeconomic features of solar photovoltaic power in Bangladesh. The adoption of renewable energy has an influence on the country's energy sector, and this was evaluated by looking at statistical data on

energy production, consumption, and greenhouse gas emissions [6]. In order to ensure a thorough and efficient evaluation, the selection criteria for renewable and sustainable energy sources should take into account a number of factors, with a particular focus on the advancement of solar photovoltaic (PV) electricity in Bangladesh. First, an evaluation of Bangladesh's geographical setting and solar potential should be conducted, taking into consideration variables like solar radiation, climate, and land availability. Furthermore, a careful analysis of the solar PV projects' economic feasibility should take into account the expenses associated with technology, installation, and maintenance. One of the most important factors to take into account is how well solar PV systems can scale and adapt to the local energy grid and infrastructure.

Prioritizing social acceptance and community engagement is crucial for the successful integration of solar photovoltaic systems. Cultural considerations and potential social challenges should be taken into account. To make sure the selected technologies support sustainable development, it is also important to assess the environmental impact, including the life cycle analysis of solar PV systems. An environment that is conducive to the advancement of solar photovoltaics (PV) should be created by taking into account regulatory and policy frameworks, which include incentives and support mechanisms for renewable energy. In order to support a comprehensive and long-term strategy for Bangladesh's sustainable energy development, the review should also evaluate the potential for technological innovation and local capacity building. Researchers, business people, and legislators with knowledge of renewable energy in Bangladesh were consulted and interviewed as experts to supplement the literature study and data analysis. The interviews yielded significant qualitative insights and viewpoints that enhanced the review and gave a more all-encompassing comprehension of the topic. Moreover, a comparative evaluation of Bangladesh's advancements in renewable energy was conducted against global best practices and case studies. This aided in establishing standards and lessons that might be used to improve the nation's transition to sustainable energy. With a focus on the advancement of solar photovoltaic electricity in Bangladesh, the methodology for this thorough review was multidisciplinary and included data analysis, expert interviews, literature reviews, expert interviews, and international comparisons to provide a thorough and comprehensive examination of renewable and sustainable energy sources. This strategy guarantees the validity and dependability of the conclusions and suggestions made in the review. The paper is organized in the following ways.

- Introductory part of this review has been discussed in section I.
- Review structure has been explained in section II.
- Section III discussed about the sustainable energy and its features.
- In section IV, solar energy has been discussed with its appropriate block diagram.
- Solar energy scenario in Bangladesh has been explained in section V thoroughly.

- In section VI, largest solar power plants in Bangladesh have been discussed with location and capacity.
- Discussion and conclusion have been explained in section VIII & IX.

III. SUSTAINABLE ENERGY

Sustainable energy is a kind of energy that comes from sources that can be sustained and renewed endlessly, and is also often referred to as clean or renewable energy. It is essential to solving the problems of energy security and the environment in a world where fossil fuel supplies are running out and climate change is a reality. Renewable energy sources including solar [7], wind [8], hydropower [9], geothermal heat and mechanical vibrations [10] are the main sources of sustainable energy. These resources never run out since they are always being supplied by nature. Common examples are solar photovoltaic systems, wind turbines, hydroelectric dams, and geothermal power plants. When compared to fossil fuels like coal, oil, and natural gas, sustainable energy technologies provide electricity or other kinds of energy with far reduced greenhouse gas emissions and environmental pollutants. They are essential in reducing the effects of climate change and enhancing air quality.

Energy-efficient technologies that lower energy usage while preserving or even increasing productivity are often included into sustainable energy systems [11]. This helps ensure that resources are used more responsibly and sustainably. Numerous renewable energy sources, including sun and wind, are sporadic. Reliable and consistent energy supply is ensured by efficient energy storage systems, such as pumped hydro storage and batteries, which allow extra energy to be captured and used when it's available. Sustainable energy, often in the form of decentralized systems like small-scale solar panels, may enhance access to electricity in isolated or underserved locations. This may fundamentally alter how individuals in these areas live their lives. Continuous research and development efforts persist in enhancing the economic viability and efficiency of sustainable energy technologies, so making them more accessible and competitive. A key element of the worldwide endeavor to move toward a more resilient and environmentally conscious energy future is sustainable energy [12].

IV. SOLAR ENERGY

Solar energy is derived from the sun's rays and is a sustainable and renewable energy source. It is a plentiful and clean source of energy that may be used for a variety of purposes to generate heat and electricity [13]. The sun emits electromagnetic waves, such as visible light, infrared, and ultraviolet rays, which are the source of solar energy [14]. The main energy source for all solar devices is sun radiation. Solar photovoltaic cells, sometimes called solar panels, use direct solar energy conversion to produce electricity. Electrical current is produced by sunlight striking the solar cells, and this current may be utilized to power buildings, commercial establishments, and a variety of electronic equipment. Heat from solar radiation is produced by solar thermal systems and is useful for industrial activities, water heating, and space heating. Solar collectors are a component of these systems; they gather and focus sunlight to produce

thermal energy. Utilizing mirrors or lenses, Concentrated Solar Power (CSP) systems direct sunlight onto a tiny region, heating a fluid to make steam and power a turbine to produce energy [15]. Big power plants often employ this technique.

The electrical grid may include solar energy, enabling extra energy to be exported and utilized when the sun isn't out [16]. On the other hand, off-grid systems are independent power sources that are usually found in rural or isolated locations. Batteries and other energy storage devices are often used with solar systems to store extra energy produced during the day for use at night or in overcast conditions. Due to the sun's predicted billion-year lifespan, solar energy is both sustainable and almost limitless. Because of this, it is a dependable and durable power source. The solar energy industry has seen rapid expansion, resulting in the creation of employment and business possibilities as well as helping to improve energy security and lower consumer energy bills [17]. In the worldwide shift to greener and more sustainable energy sources, solar energy is essential. It supports initiatives aimed at lowering carbon emissions, halting global warming, and improving energy security. Solar energy is becoming a more appealing and practical choice for supplying energy demands globally as economies of scale are achieved and technology progresses [18]. A Block diagram of solar energy harvesting circuit is shown in Fig. 1.

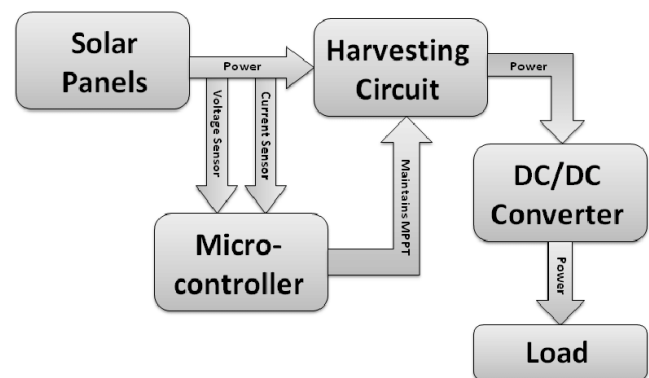


Fig. 1. Block diagram of solar energy harvesting circuit [19]

V. SOLAR ENERGY SCENARIO IN BANGLADESH

Bangladesh generates 99% of its energy from fossil fuels. However, it has several renewable energy targets for 2030 and 2040 that require significant financial and time investments. Bangladesh, being a densely populated country with a growing energy demand and limited fossil fuel resources, has been actively exploring alternative energy options, and solar power is one of the prominent choices. Renewable energy accounts for approximately 560 Megawatts (MW) of the total power production of 20,430 MW, and it has the potential to be a long-term solution to the demand-supply dilemma [20]. Solar power will play an essential role in reaching these targets, and Bangladesh can't afford to postpone the transition in favor of Liquefied natural gas.

There is significant potential for solar energy in Bangladesh. Not only is the low-lying country committed to growing its renewable energy capacity, but the population of over 170 million is growing at 1% annually. This growing population and its developing economy generate an average energy demand increase of 4.68% annually. Bangladesh, on

the other hand, is largely reliant on domestic and imported fossil fuels, resulting in a chronic energy problem. Rolling blackouts and load sharing have plagued the country in 2022, stifling the economy and emphasizing the dangers of reliance on fossil fuels. More than ever, it is evident that Bangladesh must invest quickly in renewable energy sources in order to build a resilient system capable of supporting the country's expanding capacity needs. Solar has the ability to lead these decarbonization initiatives, and its capacity is already expanding. Bangladesh is highly suited to decentralized and utility-scale systems. Its capital, Dhaka, is the world's fourth-most densely inhabited metropolis, while much of the country is rural and thinly populated. Looking at Bangladesh as a whole, it has an average theoretical solar potential of roughly 4.59 global horizontal irradiation (GHI), which places it in the middle of the pack when compared to other countries. In this example, the circumstance is favorable, indicating that solar is viable.

Bangladesh has been adopting solar energy with great success in order to meet its increasing energy needs and lessen its reliance on fossil fuels [21]. Bangladesh has led the way in using solar-powered residential systems to provide rural and off-grid communities with energy. Millions of solar household systems have been installed thanks to government programs and assistance from groups like the Infrastructure Development Company Limited (IDCOL). Remote areas now have better access to energy, which benefits rural families and fosters socioeconomic growth. Particularly in metropolitan areas, the usage of rooftop solar panels to generate power has been increasing. Businesses and households have been encouraged to invest in solar power systems by regulations and incentives that support feed-in tariffs and net metering. This has improved the national grid in addition to lowering power rates. Bangladesh has also started a number of sizable solar power projects to expand the capacity of its grid. Solar parks and utility-scale solar power plants are among these initiatives.

The goal of these advancements of solar energy is to lessen dependency on fossil fuels and diversify the energy mix [22]. In remote locations where it is not economically feasible to connect to the central grid, mini-grids powered by solar energy have been developed. These mini-grids sustain homes, small enterprises, and agricultural operations by supplying communities with dependable energy. Bangladesh's government has been aggressively promoting the use of solar energy via laws and subsidies [23]. Among these is the National Solar Energy Policy, which seeks to advance sustainable energy practices and raise the proportion of solar energy in the energy mix. Even with the advancements, problems still exist. These include problems with solar power's erratic nature, grid integration, and the need for energy storage devices to provide a steady supply of electricity. Concerns about funding and infrastructure development still exist. International organizations and donor agencies have provided Bangladesh with funds and help to further its solar energy endeavors [24]. Knowledge exchange and technology transfer have been made easier by this partnership.

VI. LARGEST SOLAR POWER PLANT IN BANGLADESH

The Rays Power Infra 275-MW solar plant at Sundarganj, Gaibandha, is currently Bangladesh's largest solar photovoltaic power plant. Bangladesh's geographical location is suitable for solar energy consumption, which can be harvested from everywhere in the country. Annual solar radiation can reach 1700 kWh/m², with a daily average solar radiation fluctuation of 4-6.5 kWh/m² [25]. As a result, solar irrigation could be an alternate approach to enhance crop production without putting additional strain on grid electricity or diesel fuel, while also helping to keep the environment clean. It is connected to the national grid and was finished in January 2023. Over 500,000 individual solar modules are scattered across 600 acres of land in the project. According to estimates, the facility will offset more than 375 billion tonnes of CO₂ emissions over its lifetime. Rays Power Infra has created 1.3 GW of solar energy capacity in the country and expects to expand capacity to 2.0 GW in the following two years. Some other noFig solar farms and future solar projects in Bangladesh shown in Table 1.

Table 1. Future solar projects in Bangladesh

Location	Generation Capacity	Project Status
Gangachara, Rangpur	30 MW	Ongoing
Dharmapasha, Sunamganj	32 MW	Ongoing
Gauripur, Mymensingh	50 MW	Ongoing
Chuadanga	50 MW	Future
Netrokona	50 MW	Future
Mongla, Bagerhat	100 MW	Ongoing
Feni	100 MW	Future
Narsingdi	120 MW	Future
Sundarganj, Gaibandha	200 MW	Ongoing

VII. ADVANCEMENT OF SOLAR ENERGY IN BANGLADESH

Bangladesh has been leading the way in solar energy development [26]. A number of things, such as foreign assistance, government regulations, and rising public awareness of the need for clean, sustainable energy sources, contributed to these breakthroughs. Bangladesh's solar energy industry has seen several significant breakthroughs. One of Bangladesh's best innovations is Solar Home Systems (SHS) [27]. When it comes to the use of solar-powered residential systems, Bangladesh has led the world. Millions of isolated and off-grid homes have been able to get energy thanks to these small-scale solar power plants. The spread of SHS in rural regions has been greatly aided by government programs and the backing of groups like IDCOL (Infrastructure Development Company Limited). Bangladesh has been increasing its capacity for solar electricity linked to the grid [28]. The nation has integrated solar parks and utility-scale solar power projects into the national grid to increase the amount of sustainable energy. In remote locations with difficult or impractical grid connections, solar mini-grids have been installed. In metropolitan areas, rooftop solar panels have become more and more common, and government regulations have incentivized companies and households to invest in solar power systems.

The National Solar Energy Policy and other regulatory frameworks have established aggressive goals for Bangladesh's increase in solar power capacity. To encourage investment in the renewable energy industry, the government has been aggressively pushing renewable energy sources and

providing incentives. International institutions, such as the World Bank and other donor agencies, have provided Bangladesh with financial assistance and financing to further its solar energy programs. The development of infrastructure and technology transfer has been made easier by this assistance. Reduced consumer energy costs and the development of jobs in the renewable energy industry are two economic advantages of Bangladesh's embrace of solar energy [29]. Additionally, the nation has made investments in solar energy technology research and development. The efficiency and affordability of solar panels and related equipment are two areas where this is being worked on [30]. The solar energy industry is dynamic and changing quickly, which is something to keep in mind. There may have been improvements and enhancements.

VIII. CHALLENGES OF SOLAR ENERGY HARVESTING

In order to be widely adopted and operate as efficiently as possible, solar energy harvesting while a promising and sustainable energy source must overcome a number of obstacles. It takes a multidisciplinary strategy that includes funding for research and development, encouraging legislation, technological innovation, and public involvement to address these issues. With the progress of solar technology, several obstacles are being steadily surmounted, making solar energy a more feasible and sustainable kind of energy [31].

- The amount of sunshine and the weather have an impact on solar energy. Energy output may decrease at night or on overcast days.
- Creating high-capacity, reasonably priced energy storage systems is a big task since the available technologies may be costly and have short lifespans [32].
- It may be difficult to integrate solar energy into the current electricity systems. Changes in policy and large investments may be necessary for this [33].
- Although the efficiency of solar panels has increased dramatically, maximizing energy production while lowering prices remains a problem in solar energy harvesting [34].
- Even if the price of solar panels has come down over time, installing solar still requires a sizable upfront payment [35].
- There may be environmental effects from the manufacture, disposal, and usage of solar panels [36].
- It is often necessary to combine solar energy with other energy sources, such wind or hydroelectric power, in order to make the switch to a solar-dominant energy system. Achieving a balanced and smooth integration might be difficult [37].

IX. DISCUSSION

With an emphasis on the development of solar photovoltaic power in Bangladesh, this study offers a critical analysis of a rapidly changing energy environment [38]. Renewable and sustainable energy sources are also covered in detail. Bangladesh, a highly populated country that struggles with energy security difficulties and environmental concerns, has been gradually adopting solar energy as a solution to these urgent problems [39]. Reviewing regulatory frameworks, technical developments in solar photovoltaics, and the socio-economic ramifications for the nation, the

paper delves into many facets of this shift [40]. Notably, the integration of grid-connected solar power, the exponential development of solar home systems in rural areas, and the promotion of rooftop solar installations in metropolitan regions have all contributed to a considerable expansion of clean energy availability. International cooperation and governmental policy have also been crucial in influencing this shift [41].

The paper also discusses the difficulties encountered, including energy storage and intermittency, and emphasizes the need of ongoing research and development. In the conclusion, this analysis shows how Bangladesh's transition to a more sustainable and energy-efficient future has been greatly impacted by the development of solar photovoltaic power, which has lessened Bangladesh's reliance on fossil fuels and helped the international community fight climate change [42].

The implementation of solar projects is uniquely presented by Bangladesh, given its growing energy demand and dedication to sustainable development. Understanding the nation's unique energy needs, economic climate, environmental issues, and regulatory environment is necessary for contextualization in this case. The operational features, design considerations, and specifications of solar PV projects are all included in the technical details [43]. It is essential to take into account both the cost-effectiveness of solar technology and the prevailing economic conditions in order to guarantee that projects are both financially feasible and contribute to the nation's overall economic development [44].

The urgency and significance of switching to sustainable energy sources like solar power are highlighted by the realization of environmental challenges like dependence on fossil fuels and vulnerability to climate change. Comprehending the current regulatory and policy framework, encompassing incentives, subsidies, and policies pertaining to grid integration, aids project developers in maneuvering through the legal terrain and guarantees adherence [45]. Optimizing the location and performance of solar installations requires a thorough evaluation of Bangladesh's solar resources, which can be achieved by assessing the country's solar potential in various areas. The identification and mitigation of potential environmental risks associated with solar projects necessitate the completion of a thorough environmental impact assessment (EIA) [46]. Solar projects are guaranteed to remain competitive and to continuously improve if research and development efforts are prioritized for technological innovation, such as smart grid solutions or advanced solar panel technologies.

The efficiency and long-term sustainability of solar PV projects are guaranteed by specifying the maintenance needs, operating procedures, and training courses for local technicians. It takes a careful attention to technical details and a thorough understanding of the local context to successfully advance sustainable energy sources, especially solar PV projects in Bangladesh. Through a comprehensive analysis of these factors, interested parties can design and execute solar projects that benefit the nation not just economically and socially, but also ecologically [47].

X. CONCLUSION

As a crucial part of its shift to renewable and sustainable energy sources, Bangladesh has achieved impressive strides in using solar photovoltaic power, as this thorough assessment concludes. The comprehensive research demonstrated the advancements in solar technology, the beneficial effects of policy, and the socio-economic changes that coincided with this change. Solar photovoltaic power has not only lit up houses but also Bangladesh's future, which is brighter and more sustainable, by increasing access to clean energy, cutting greenhouse gas emissions, and improving energy security. Bangladesh's embrace of renewable energy is undoubtedly a reflection of the country's will to fight climate change and promote economic development in the sustainable energy industry. Their broad adoption is beset by a number of difficulties. Solar PV generation is less predictable than conventional energy sources because it is intermittent and dependent on the availability of sunlight. A significant challenge is storing extra energy produced during times of high sunlight for use during times of low sunlight. Large-scale solar installations might need a lot of land, which could cause issues with land use and possible conflicts with natural areas or agriculture. As this analysis has shown, even if there are still obstacles to overcome, Bangladesh's progress in solar energy is encouraging and should serve as a model for the rest of the world as we work toward a cleaner, more sustainable energy future.

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