

Study on Solar Energy: Global and Local Perspective

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Abstract. Decarbonization is one of the most discussed topics today when it comes to environment, energy, and sustainable development. We need to know the effect of global warming and net-zero initiative. As we know that, fossil fuels are the major source of air pollution, and that is responsible for around five million premature deaths every year around the world. For both climate change and human health, we need to transition away from fossil fuels towards low carbon or clean energy sources. But question is, how quickly are we making progress on this? It is not just a technical concept, but a true global challenge that involves governments, businesses, and citizens. Reducing carbon dioxide emissions means embarking on a path that can ensure a cleaner, safer, and more resilient future for the next generations. Bangladesh, classified as a lower middle-income nation by the World Bank in 2018, stands at a critical juncture in its pursuit of sustained economic growth and development. As the country's economy expands at an unprecedented pace, the demand for electricity is surging, with forecasts predicting a net electricity demand of 61 GW by 2041. Today renewable energy technology offers advanced decarbonization solutions along with viable energy mix. However, major challenges remain, as implementing an effective decarbonization plan requires significant investments, innovation of energy networks, and supportive policies to facilitate the transition. There are also social and economic obstacles, like risk of job losses, people attitude, government perception in traditional sectors or the need to keep costs under control for households and businesses. In this analytical article authors will discuss and explore the present state, potential, prospect, major barriers or challenges and development strategy of solar energy of Bangladesh. Authors will try to propose a suitable strategy and framework by considering future of solar energy viability for Bangladesh. Authors will also discuss on its integration into sustainable rural, agricultural, and urban planning along with recommend to related issues for future study on viable implementation of solar energy solution for the nation.

Keywords: Global warming, net-zero, renewable energy, solar panel, energy transition, rooftop, net-metering, energy-mix

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I. Introduction

Electricity is a good that adds massive value to modern life, from having light at night to washing clothes, cooking meals, running machinery, heating or air-conditioning, general transportation, or connecting with people across the world. Most of the strategists and urban planners views that, it is a central and critical consideration for poverty alleviation, economic growth, development, national progress and improved living standards for every country.¹ Having low-carbon, or clean-fuels and sustainable technologies for cooking, washing, air-conditioning, transportation, meaning non-solid fuels like natural gas, liquid fuels, ethanol or even electric technologies, which make these processes more efficient, saving both time and energy. Moreover, it also

comes with massive health benefits. The use of solid fuels for cooking like charcoal, crop waste, or dung is a can led to premature deaths and ill-health from indoor air pollution.² We need to move towards low CO₂ emissions and reduce air pollution, by transformation of our energy systems from fossil fuels to low-carbon sources like renewable energy. Low-carbon energy sources mainly nuclear and renewable technologies. Renewable energy includes hydropower, wind, solar, geothermal, modern biomass and wave or tidal energy. Traditional biomass, charcoal, crop waste, and other organic matter may be omitted from this list. Nuclear energy alongside renewable sources is considering the major low-carbon energy foundation. Today those low carbon sources cover a large share of energy consumption for many countries. However, it is difficult to ascertain the energy mix changing pattern from year-to-year for the globe by looking from longer historical data. We need the answer of the question, like where do countries get their electricity or consume energy sources, such as fossil fuels (or coal, oil, gas) and low-carbon fuel (or nuclear power, renewable)? What is the suitable and viable energy-mix solution? Today, the electricity mix or the balance of sources of electricity in the supply is becoming significant as countries try to shift away from fossil fuels towards low-carbon sources for electricity generation by considering nuclear and renewable energy including hydropower, solar and wind. However, present day condition, electricity, transport and heating or air conditionings are the components of energy consumption. The electricity mix needs to handle wisely and not to be misunderstood with the total energy mix. After Industrial Revolution, fossil fuels have become the leading electricity source for most of the industrial countries across the globe. Today, the burning of fossil fuels like coal, oil, and gas is accountable for almost three-quarters of global greenhouse gas emissions.³

Today, rising sea levels and salinity intrusion are forcing many coastal families in Bangladesh to move to urban and semi-urban areas. This creates additional pressure on cities and generates new social and economic challenges. Climate migration affects education, health services, employment opportunities, and community stability. Addressing these challenges requires not only national efforts but also international cooperation and financial support. Although climate action is regularly discussed in international forums, implementation is often slowed by political and economic interests.⁴ Climate-vulnerable countries like Bangladesh continue to call for fair, transparent, and timely support from wealthier nations, rather than empty promises. The fundamental question facing the global community today is whether world leaders are willing to rise above short-term political interests and narrow economic considerations to prioritize humanity, ethical responsibility, climate justice, and the well-being of people.⁵ Across the world, including in Bangladesh, young people are increasingly demanding stronger and more effective action against climate change. Their movement is rooted in the principle of intergenerational justice, which recognizes that the decisions made today and the emissions produced by the current generation and that will directly shape the future of generations to come. In simple terms, if today's leaders fail to take timely and responsible action, it is future generations who will bear the greatest consequences. They will inherit a world facing greater environmental, social, and economic challenges. In Bangladesh, young people are not remaining silent.⁶ They are taking the lead in raising climate awareness, promoting large-scale tree plantation, protecting the environment, and advocating for renewable and solar energy solutions through various community and social initiatives. Their message to world leaders is clear and loud: climate change is not merely an environmental or scientific issue. It is a social, economic, and above all, a moral challenge that demands urgent and collective action.⁷ The future that young people inherit will depend largely on the choices we make today.

So, there is an urgent need to increase both the capacity and efficiency of energy generation. As part of this national strategic plan, the government of Bangladesh aims to achieve a total electricity generation capacity of 40,000 MW by 2030 and 60,000 MW by 2041.⁸ The energy sector, it is heavily reliant on conventional fuels such as natural gas, coal, and oil. Data from recent energy reports make it clear that over 85 % of total electricity generation is consistently sourced from fossil fuels, with natural gas alone contributing more than 50 % annually, supporting domestic and industrial sectors for decades.^{9,10} However, the extensive use of fossil fuels raises critical concerns about their long-term availability. Survey research and articles have anticipated that existing reserves of natural gas will be depleted within the coming decades.^{11,12} Despite having reasonable coal reserves, challenges such as high extraction costs, the location of reserves in densely populated regions, and the reliance on imported coal to meet local energy/fuel demand exacerbate the crisis. Again, Bangladesh lacks significant oil reserves, relying solely on imports to meet its energy needs.¹³ The rise in global fuel prices, driven by geopolitical conflicts and natural disasters, further strain the country's foreign reserves, making the reliance on fossil fuels unsustainable. In fact, an acute shortage of fossil fuels has already strained electricity production in recent years, resulting in frequent load-shedding and highlighting the need for a more sustainable energy strategy. The over-dependence on conventional fuels not only threatens energy security but also raises environmental concerns due to significant greenhouse gas emissions and a large carbon footprint. To address these challenges, diversifying the energy mix is imperative.¹⁴ So, efforts are needed to identify and implement alternative energy solutions in order to not only meet the country's ever-growing electricity demand, but also solve the geographic demand-supply mismatch across the country, enhance decentralization, reduce dependence on imports, and align with environmental sustainability goals.

The sun is classified among the brightest of the renewable energy sources in the world. It is now considered to be the long-term solution to many of the problems, such as national dependence on foreign fuels, environmental degradation, and economic development. The latter has been a sustainable resolution to a broad spectrum of issues linked to energy security, environmental degradation, and economic development. The growing concerns about global warming and the need to discover an alternative to the conventional fossil fuel-based sources of electricity have been added to the ever-growing data about the world's energy needs. Due to its cost-effectiveness, eco-friendliness, and endless potential, solar energy has been regarded as one of the most practical and expandable forms of power consumption in homes. Since a significant amount of energy demand in the world comes from domestic electricity consumption, the government has been promoting the use of solar photovoltaic (PV) systems by providing incentives, subsidies, and even raising awareness in different countries.¹⁵ Despite these steps, the transition from conventional electricity to solar energy is not uniform across all homes. While there are long-term savings on electricity bills, energy security, and a carbon footprint associated with solar adoption, the upfront cost and the cost of an opportunity factor that influences the decision-making process are important considerations. When compared to traditional grid-based electricity, solar energy systems continued to be seen negatively by many families due to financial risk or technological uncertainty.¹⁶ Solar energy is a potentially good but off-grid energy source that can help diversify Bangladesh's energy portfolio, as its energy potential is quite significant (4.0-6.0 kWh/m²/day). It has been integrated into the country to meet the growing demand.^{17, 18} Bangladesh has set challenging goals for renewable energy power, where the country hopes to achieve about 10% renewable energy by 2021, which will increase to 17% by 2041, and solar energy will be an unavoidable component.^{19, 20}

To reduce CO₂ emissions and exposure to local air pollution, we want to transition our electricity away from fossil fuels towards low-carbon sources. 'Low-carbon electricity' includes nuclear and renewable technologies. We can reduce emissions by using less energy; and/or by using lower-carbon energy.²¹ Due to the more than 1°C increase in temperature since 1950 and the ensuing climate change challenges, which are linked to an approximate 80% increase in carbon dioxide (CO₂) since 1970, industrial decarbonization has attracted international attention on the path to a net-zero carbon transition, as required by the Paris Agreement.^{22, 23} The primary causes of yearly CO₂ emissions are extensive deforestation and the use of fossil fuels for energy security.²⁴ The primary sources of global greenhouse gas (GHG) emissions, according to UN studies based on the EDGAR data repository, include energy sources for industrial sectors like transportation, manufacturing and construction, agriculture, and power and heat.²⁵ The electricity sector accounts for 38% of global CO₂ emissions caused by fossil fuels, followed by transportation (21%), non-combustion (10%), buildings (9%), and other industrial combustion (21%).²⁶ Over the past few decades, the share of renewable energy sources in the world's energy mix has grown gradually but steadily. Even while renewable energy sources have a lot of potential, their sporadic nature can cause power supply fluctuations in the event of an unexpected shortfall.^{27, 28} Therefore, it is clear that there are issues with the dependability of power systems that incorporate renewable energy sources. This is because most current power producing facilities are unable to react quickly enough to compensate for the losses brought on by renewable energy sources' intermittent nature.²⁹ On the other hand, any excess renewable energy must be limited in the absence of energy storage facilities, which immediately lowers the potential income of renewable energy farms. Energy storage devices are a feasible solution to the aforementioned problems in light of these factors.^{30, 31} Through their time-shifting function, which stores excess renewable energy for later use, energy storage devices can match renewable energy with real-time demand. The intermittency and loss issues that frequently arise while generating electricity from renewable energy sources are successfully resolved by this approach.³²

Today, solar Photovoltaic (PV) technology has emerged as one of the most rapidly expanding renewable energy technologies in Bangladesh. The commercial deployment of Solar PV began on a significant scale in 2003 under the Rural Electrification and Renewable Energy Development Project (RERED), particularly through the implementation of Solar Home Systems (SHS) in rural and off-grid areas. Since then, Bangladesh has progressively expanded the application of solar energy through Solar Home Systems, Solar Mini-grids, Solar Irrigation Pumps, Solar Street Lighting, Rooftop Solar Systems, Net-Metering, and Utility-scale Solar Power Plants. The Government of Bangladesh has undertaken several policy and institutional initiatives to accelerate the development of renewable energy and reduce dependence on conventional fossil-fuel-based electricity generation. Bangladesh's rapidly growing economy, industrialization, urbanization, agricultural modernization, and increasing commercial activities have resulted in a continuously rising demand for reliable and affordable electricity. Ensuring an adequate and uninterrupted supply of electricity has therefore become an essential prerequisite for sustainable economic development. At the same time, limitations in domestic fossil-fuel resources, dependence on imported fuels, volatility in international energy prices, and the growing impacts of climate change have created a strong need to diversify the country's energy mix and increase the use of renewable energy. In this context, Solar Photovoltaic technology represents one of the most promising, affordable, useful and user-friendly renewable energy solutions for

Bangladesh. The country receives substantial solar irradiation throughout much of the year, while significant opportunities exist for installing Solar PV systems on residential and commercial rooftops, industrial facilities, government buildings, agricultural and non-agricultural and, water bodies, and other suitable locations. The development of Solar PV in Bangladesh has therefore evolved from a primarily rural electrification initiative into a broader commercial energy transition program.

The Renewable Energy Policy 2025 of Bangladesh has further strengthened this direction by establishing ambitious targets for increasing the share of renewable energy in the national electricity mix. Despite significant progress, the large-scale commercial deployment of Solar PV in Bangladesh continues to face several challenges. These include limited access to affordable financing, inadequate grid infrastructure, land scarcity, lack of skilled technical manpower, inconsistent equipment quality, inadequate operation and maintenance practices, lengthy approval procedures, and uncertainties associated with project economics and long-term policy implementation. Bangladesh has ambitious solar and green energy goals including building best solar systems in Bangladesh. The country plans to generate 4,100 MW of clean energy by 2030, consisting of 2,277 MW from solar, 1,000 MW from hydropower, and 597 MW from wind power.³³ Furthermore, by 2041, Bangladesh aims to generate 40% of its power from clean sources and import 9,000 MW of renewable energy in Bangladesh from neighboring countries.³⁴ Considering the country's current total energy production capacity is around 25.5 GW including fossil fuels. Such plans includes projected growth demand over the same period. The government plans to provide more solar capacity to residential and business users and create stimuli for electric vehicle (EV) adoption.³⁵ These plans are may be ambitious, especially considering the country currently relies on fossil fuels for 99% of its energy needs. The paper will discuss major solar technologies like rooftop photovoltaic systems, home solar systems, solar irrigation pumps, floating solar plants, etc. along with suitability of solar power across urban and rural contexts. According to country reality and recent studies and policy frameworks, the author will try to identifies major challenges to large and scale solar implementation, along with financial, social and technical limitations. In this elaborate review paper, authors will discuss and explore the potential, present status, development strategy, major barriers or challenges, future market, public and private initiative for solar energy installation, proposed strategy and future of solar energy in Bangladesh along with effect of global warming and net-zero initiative. This article will also recommend related issues for future study of solar energy feasible installation of Bangladesh. This article may be useful to guide policymakers, researchers, stakeholders, practitioners and those who are working toward building a sustainable, progressive, resilient, and inclusive solar-powered Bangladesh.

II. Literature Review and Methodology

When comparing the total energy consumption of different countries, differences often reflect population sizes. It's useful to look at energy use on a per-person basis. Countries generate energy from coal, oil, gas, nuclear power, or renewables—in most cases, a mix of these sources. As nations transition from fossil fuels to low-carbon alternatives such as nuclear, hydropower, solar, and wind, the composition and proportions of these energy sources become increasingly important. Since the Industrial Revolution, fossil fuels have dominated global energy use, but burning coal, oil, and gas accounts for about 75% of greenhouse gas emissions and causes significant air pollution, leading to over 5 million premature deaths each year. To combat climate change and improve public health, shifting away from fossil fuels is crucial. Researchers are exploring solar PV systems in Bangladesh. For example, Podder (2021) provided a chronological review of the current state, challenges, and future prospects of solar PV in Bangladesh, including the distribution of different PV systems and an assessment of the viability of existing technologies.³⁶ In 2016, Halder conducted a feasibility study on solar home systems (SHSs) in Bangladesh, concluding that they are more economically suitable for small business enterprises than for household lighting. Meanwhile, Bangladesh is making rapid progress in deploying PV systems commercially to support a sustainable future and provide affordable energy.³⁷ Akash et al. (2024) examined Bangladesh's renewable energy options and identified major challenges to harnessing them. They noted that solar energy and biomass are the most abundant renewable resources in Bangladesh, underscoring the importance of using them to meet the nation's energy needs.³⁸

Anubhove et al. (2022) analyzed the feasibility of SHSs in rural Bangladesh and found them to be a viable option for substantially reducing GHG emissions. Consequently, the literature review shows that many recent studies focus on exploring renewable energy sources in Bangladesh and their future potential. Few studies have also examined the current state of solar energy utilization in Bangladesh.³⁹ While some studies have addressed advancements and future prospects of PV systems, the authors note that no recent comprehensive review covers the progress, challenges, and socio-environmental impacts of solar PV systems in Bangladesh. Additionally, research trends in solar PV systems have been analyzed using the 'Dimensions' search tool for improved insight.⁴⁰ Another study reported that the total global renewable energy generation capacity is around

2,838 gigawatts (GW).⁴¹ Solar energy is the most abundant renewable resource worldwide. Its main advantages are dependability, longevity, and its eco-friendly, discreet nature.⁴² Using photovoltaic (PV) panels to convert solar energy into electricity is the most prevalent method of capturing solar power. Past research has frequently focused on reducing energy use and operational costs.⁴³ Effective management of direct power and heat loads is essential for building energy flexibility. In the electricity sector, flexibility is achieved through controlling on-site generation, adjusting consumption plans, and managing energy charging and discharging. To reduce overall energy costs for buildings, Wei et al. introduced a co-scheduling approach that coordinates battery use, electric vehicle charging, and air conditioning.⁴⁴ Tang et al. classified flexible loads based on their purpose and potential roles in building response technologies.⁴⁵ The article describes flexible sources and control methods for building energy systems. It highlights how passive thermal storage in the building's structure or active thermal storage via charging and discharging offers thermal energy management options.

Extensive research has explored the technical and economic feasibility of various solar technologies in Bangladesh. This includes grid-connected photovoltaic (PV) systems, solar home systems (SHS), solar irrigation pumps, microgrids, floating photovoltaic setups, concentrating solar power (CSP), and newer applications like electric vehicle (EV) charging stations and virtual power plants.^{46, 47, 48, 49, 50} Many studies have shown that switching to solar energy in Bangladesh yields significant socioeconomic benefits, particularly in off-grid and rural communities lacking reliable electricity companies. The advantages are especially substantial in these rural areas.⁵¹ Interestingly, despite the achievements, several challenges remain, including funding gaps, limited policy support, technical difficulties in large-scale deployment, grid connection issues, and concerns about the environmental sustainability and waste management of solar PV.⁵² Furthermore, integrating smart grids and energy storage systems with advanced solar technologies is essential to enhance grid stability and increase solar energy penetration.⁵³ The chosen literature was analyzed thematically, organizing insights into technological progress, economic viability, policy measures, environmental and social advantages, and obstacles to adoption.⁵⁴ Where possible, quantitative comparisons were made, such as rooftop PV systems with a levelized cost of electricity (LCOE) between 0.08–0.12 USD/kWh, floating PV arrays from 0.10–0.15 USD/kWh, and CSP plants with higher LCOE values of 0.14–0.18 USD/kWh. Solar irrigation pumps showed energy efficiency improvements of 20–35% over diesel-powered pumps. These comparisons facilitated a critical assessment of the relative efficiency, cost-effectiveness, and scalability of various approaches. Incorporating differences between positive and null outcomes improves the review's robustness and broadens its scientific relevance.⁵⁵ Potential publication bias and limitations in the scope of the studies were mitigated by cross-validating with grey literature, technical reports, and policy documents from organizations such as SREDA and the World Bank.⁵⁶ Accounting for differences between positive and null outcomes improves the robustness and broadens the scientific relevance of the review.⁵⁷

This article is based on secondary and synthesized information from numerous academic sources published over the past decade, up to August 2026, and aims to provide a comprehensive overview of solar energy development in Bangladesh. The literature review involved systematic searches in scientific databases like Scopus, Web of Science, Google Scholar, and institutional repositories, focusing on topics such as renewable energy and specifically solar energy in Bangladesh; solar PV feasibility; renewable energy policies in Bangladesh; solar home systems; floating photovoltaic power; concentrated solar power; and solar irrigation pumps, including the global context.⁵⁸ The inclusion criteria covered peer-reviewed journal articles, conference papers, government and NGO reports on solar energy in Bangladesh and its socio-technical implications, published articles, news from print, electronic, and social media, and policy frameworks. Emerging technologies like floating PV arrays, CSP plants, solar integration with electric vehicles, and microgrids were prioritized.⁵⁹ Studies that are not relevant to Bangladesh or lack empirical or technical rigor were excluded. The author has gathered recent articles and reports on the topic, synthesizing the findings to analyze the current situation, challenges, policy landscape, technology, and prospects of solar energy in Bangladesh and globally.⁶⁰ It aims to address knowledge gaps by integrating technical, economic, social, and environmental perspectives. This will give policymakers, researchers, and other stakeholders the opportunity to collaborate to shape a sustainable, resilient solar energy future for Bangladesh.

This study provides a comprehensive review of the current status, progress, challenges, and future outlook of solar energy in Bangladesh. It explores various solar technologies like rooftop solar, solar home systems, floating photovoltaic systems, and solar irrigation. The review includes an analysis of policy development, regulations, and institutional frameworks, evaluating their effectiveness in encouraging both large-scale and decentralized solar adoption. It assesses the technical and economic viability of different systems through case studies, feasibility assessments, and comparisons across urban, rural, and industrial settings. Additionally, the study highlights research gaps and emerging trends in areas such as energy storage, smart grids, hybrid microgrids, digitalization, AI, lifecycle sustainability, and user-friendliness of solar technologies. It evaluates environmental and socioeconomic impacts, including energy access, employment, agricultural productivity, emission reductions, and public health. Key challenges, such as grid integration, financing, policy

fragmentation, capacity, land availability, social barriers, and public perception, are identified. The paper suggests strategic research avenues, policy priorities, and a framework for sector-specific solar energy deployment. It discusses global renewable energy issues, including climate change, net-zero targets, and the opportunities and challenges of solar energy. A sample project proposal for sector-specific solar installation, along with recommendations and future research needs such as advanced energy storage, smart grid integration, lifecycle assessments, and social impact analysis, will be included.

Global Warming, Climate Injustice and Consequences for Bangladesh

The primary reasons for the gradual shift toward renewable energy include rising global electricity demand, concerns about climate change, the depletion of fossil fuels, and the challenges of extracting them. As worldwide energy needs continue to grow quickly, they are expected to increase fivefold by 2100.⁶¹ Fossil fuels account for about 75% of the global energy consumption and are a major source of greenhouse gas (GHG) emissions.⁶² The move towards sustainable energy worldwide is accelerating due to growing urbanization, the depletion of fossil fuel reserves, and the pressing need to replace carbon-intensive, non-renewable resources with safe, zero-carbon alternatives.⁶³ Using wind, solar, hydropower, and other renewable energy sources can substantially reduce emissions of hazardous pollutants and greenhouse gases, thereby reducing our dependence on fossil fuels.⁶⁴ A recent study found that global renewable energy generation capacity reached approximately 2838 Gigawatts (GW).⁶⁵ Solar energy is the most abundant renewable energy source worldwide. The major advantages of solar energy are its reliability and durability, as well as its clean and discreet nature.⁶⁶ The most prevalent method of utilizing solar energy is through solar photovoltaic (PV) panels to generate electricity.

Bangladesh is at the forefront of experiencing climate change impacts. Over the past decade, it has faced some of the strongest storms, severe flooding, and extensive property destruction. Without proactive measures, these extreme weather events are expected to worsen. Already disproportionately affected, Bangladesh's large population of nearly 170 million amplifies the potential global consequences, including economic and social challenges. Therefore, adopting sustainable climate adaptation strategies is vital for the country.⁶⁷ Bangladesh faces significant climate change risks due to two main factors, beyond greenhouse gas emissions, namely its dense population. Firstly, its geographical features, including location, landscape, and urban centers, mean that over 50% of its people reside in areas highly susceptible to climate impacts. Secondly, its economic situation amplifies vulnerability; despite having the eighth-largest population, it ranks 137th in global GDP per capita. While climate change will bring severe economic challenges, the country's population currently lacks the preparedness to manage them.⁶⁸

Bangladesh is recognized as one of the countries most exposed to climate risks globally. Its efforts to build resilience rely not only on improving its capacity to manage specific climate threats but also on reducing systemic vulnerabilities that hinder good governance. Although the country has made progress in managing hazards such as cyclones and floods and has reduced social and economic vulnerabilities, ongoing political instability and rising violence threaten future development. As the second-most populous country facing very high exposure worldwide—after China—Bangladesh's low-lying delta region is particularly vulnerable to cyclones, storm surges, river flooding, and droughts. The dense population and widespread climate risks emphasize these vulnerabilities. A large portion of Bangladesh's 90 million residents live in areas highly exposed to climate hazards. Specifically, over 53 million people (33%) and 35% of the land experience very high climate exposure, with 56% living in areas with high exposure. Historically, communities have coped with seasonal floods and cyclones through periodic internal and international migration.⁶⁹ Despite this adaptation, the country's climate exposure renders some regions unsuitable for human habitation and agriculture, driving lasting demographic shifts and increasing pressure on urban areas that may outstrip the state's capacity to meet growing public needs.⁷⁰

Bangladesh's situation underscores how overlapping fragility and climate risks can heighten population insecurity by raising vulnerability to instability and humanitarian crises. Weaknesses in the country's political and security systems jeopardize livelihoods and survival, especially if the government does not enhance its capacity to manage rural conflicts over declining land resources and urban challenges. These issues are worsened by climate-related stresses and the movement of migrants fleeing rural hardships, as well as refugees escaping violence from Myanmar.⁷¹ Bangladesh's experience highlights how analyzing the intersection of compound fragility and climate risks can reveal new opportunities and strategies for both fragility reduction and climate adaptation. In the country, low state legitimacy—stemming from public perceptions is that the government is unwilling or unable to address needs—plays a major role in overall fragility.⁷² Therefore, government actions that address public needs to reduce climate vulnerabilities could concurrently reduce both climate risks and the legitimacy deficits fueling fragility in Bangladesh. Conversely, if the state fails to alleviate public concerns about climate threats, it could further weaken its political and security legitimacy, increasing overall fragility. In recent years, Bangladesh has made notable progress in strengthening state capacity to handle specific climate hazards, such as cyclones and floods, and in reducing societal and economic fragility.⁷³

Many people consider this as climate injustice. Bangladesh will be heavily affected by global issues, yet it is not a major contributor to carbon emissions. The country emits only 0.56 tons of CO₂ per person, compared to the United States at 15.52 tons and China at 7.38 tons. Such disparities are a major reason why developing nations are urging developed countries to finance their energy transition initiatives.⁷⁴ Bangladesh's position, where the rivers like Jamuna, Ganges, and Meghna are flow into the Bay of Bengal, and those make flooding and that is a major issue. Flooding already occurs annually, and scientists expect rainfall to rise by 10 to 15% over the next 100 years.⁷⁵ For example, in July 2021, more than 25% of Bangladesh faced flooding, impacting at least a million homes and 4.7 million people.⁷⁶ Flooding damages infrastructure, destroys agricultural land, and displaces residents. Consequently, a growing number of people migrate to Dhaka, with nearly 500,000 moving there annually. The city is expanding rapidly, but its infrastructure cannot accommodate the influx. Many of these climate refugees reside in Bangladesh's urban slums, which lack basic public services.⁷⁷

Despite the ongoing energy transition, the threats and impacts of climate change are already evident. These effects are expected to intensify over time. In Bangladesh, one notable consequence is the increased frequency and severity of extreme weather events, such as tropical cyclones. These storms bring more rain, higher winds, and storm surges. While such concerns are common for low-lying coastal regions worldwide, Bangladesh faces heightened risks due to its extensive river deltas and flat terrain. With an average elevation of less than 10 meters above sea level, the area can experience large storm surges that travel inland for hundreds of kilometers, causing widespread flooding. Since 2007, Bangladesh has faced a cyclone roughly every two to three years. Experts project that tropical storm intensity may increase by up to 10% in the coming decades.⁷⁸

Global sea levels are increasing at an alarming pace. Since 1880, they have risen 8 to 9 inches, with more than a third of this rise happening in the past 25 years.⁷⁹ Furthermore, scientists estimate that the coastal areas of Bangladesh will see sea levels rise between 0.4 and 1.5 meters by the end of the century, displacing up to 30 million people.⁸⁰ Although this appears severe, sea-level rise does more than destroy homes and displace people. It also causes salinization of agricultural land and drinking water.⁸¹ This will render some regions uninhabitable and land unsuitable for farming. These initial effects could trigger a chain reaction, leading to reduced food supplies and an increase in climate migrants. Bangladesh and other vulnerable nations, particularly in South Asia, will bear the heaviest climate impacts from global warming. This exemplifies climate injustice, as these countries are disproportionately affected relative to their greenhouse gas emissions. To mitigate these impacts, a collective effort to reduce emissions is essential. Developed nations, responsible for the majority of emissions, must take the lead. Achieving net-zero emissions is a crucial milestone towards meeting the Paris Agreement goal of limiting global warming to below 1.5°C.⁸²

Research shows that existing solar parks in Bangladesh could potentially cut CO₂ emissions by 1.91×10^4 kg over their lifespan. There are significant opportunities to expand solar park capacity if certain challenges are addressed and effective policies are implemented. Immediate actions such as incentivizing PV manufacturers, enforcing strict project timelines, and promoting rural PV electrification are vital to maximizing solar park development.⁸³ Across the globe, more individuals are facing what specialists identify as "climate anxiety" or "eco-anxiety"—persistent worry, stress, and unease about the effects of climate change. The World Health Organization (WHO) has recognized climate change as a significant threat to mental health and overall well-being. While concern for the environment is understandable given the real issues at hand, constant exposure to distressing news, record temperatures, and increasingly frequent natural disasters can become overwhelming. Young people, in particular, are experiencing heightened anxiety about the future, with many questioning whether future generations will be able to live safely and comfortably on a warming Earth.⁸⁴

Extreme weather events are a direct method by which climate change affects mental health. Floods, cyclones, droughts, and heatwaves can cause trauma that persists long after the physical damage has ceased. Individuals who lose their homes, livelihoods, or loved ones often suffer from stress, depression, anxiety, and sometimes PTSD. Major health reports, such as the Lancet Countdown, warn that climate-related disasters increase psychological stress worldwide. Heat itself can also harm mental wellbeing; studies indicate that prolonged exposure to temperature extremes can cause irritability, stress, sleep issues, and depression. As heatwaves grow more frequent and severe, the mental health toll is expected to rise alongside physical risks. Young people are especially vulnerable to climate anxiety. An international study in The Lancet Planetary Health reports that many young individuals feel scared, sad, and helpless about climate change.

Several participants shared that their worries impacted their daily life, education, and future goals. UNICEF has noted the emotional strain climate change causes among children and adolescents, particularly those in flood-prone, storm-affected, and very hot regions. Today's youth grow up immersed in constant news and social media alerts about environmental crises, a stark contrast to earlier generations. This relentless flow can lead to feelings of hopelessness and uncertainty, especially when young people believe that governments and institutions are not acting sufficiently. Climate-sensitive regions like South Asia—including Bangladesh, India, and Pakistan—regularly face floods, cyclones, rising temperatures, and other climate-related challenges. Research shows that such extreme weather events are associated with increased anxiety, depression, and

emotional distress. Experts warn that ongoing exposure to disasters can foster fears about the future and feelings of insecurity.

Psychologists highlight that residents in vulnerable communities often face "anticipatory anxiety," worrying not only about current hardships but also the possibility of future disasters. For those whose livelihoods rely on farming, fishing, or other climate-dependent activities, uncertainty about income and survival can heighten psychological stress. Limited access to mental health services in these areas further hampers their ability to cope. Despite these difficulties, experts emphasize that climate anxiety should not be ignored or dismissed. Recognizing these feelings and discussing them openly is a crucial first step. Strengthening community support networks, taking tangible steps to address climate issues, and limiting exposure to distressing news can significantly reduce feelings of helplessness. The WHO and mental health professionals urge governments to incorporate mental health support into climate adaptation and disaster plans. Climate anxiety extends beyond individual concerns; it is emerging as a significant public health issue. As global temperatures continue to rise, safeguarding mental well-being will be as vital as protecting homes, infrastructure, and ecosystems from the impacts of climate change.⁸⁵

Bangladesh has faced frequent cyclones, droughts, tidal surges, and floods, each of which has deeply impacted people, livelihoods, and landscapes. The rapidly rising temperatures pose a significant threat to the over 170 million residents. Annually, the country makes news due to devastating cyclones affecting coastal areas along the Bay of Bengal. However, the enduring effects of these disasters on public health, economic stability, and community resilience are often neglected. Though cyclones are a long-standing aspect of Bangladesh's climate, their severity and patterns have changed significantly. Research indicates that the increasing frequency and strength of extreme weather events are directly linked to climate change.⁸⁶ The coastal region near the Bay of Bengal in Bangladesh is among its most vulnerable areas, experiencing more intense and frequent cyclone activity. Tropical storms are equally destructive, and tidal surges can reach heights of up to 9 meters. For local communities, survival is a constant struggle as they face ongoing threats to their health.⁸⁷

Climate change's global impact and Bangladesh's progress toward sustainable development are crucial issues. Although climate change is a worldwide concern, Bangladesh ranks seventh among the most vulnerable countries and fifth among the most affected—a worrying situation for its delta region. In 2023, the Earth experienced its hottest year on record, confirming scientists' predictions about global warming driven primarily by human activity, particularly fossil fuel consumption. Urgent action towards renewable energy is imperative; delays risk worsening conditions. Approximately one crore families across more than 710 square kilometers of Bangladesh's coastal Bay of Bengal region face threats from flooding, cyclones, and landslides, with access to infrastructure and services severely compromised. The poorest households in 69% of coastal upazilas are at the highest risk, threatening Bangladesh's progress on SDGs 3, 4, 7, 8, and 13. Policymakers must prioritize pro-poor development in their strategies.

The study highlights that while poor and vulnerable communities do not cause climate change, they suffer the most from its effects and face a major existential threat. Climate change impacts have denied many poor families in coastal regions access to essential services such as food, shelter, education, and healthcare at higher rates than those of wealthier groups. These impoverished populations are 1.07 and 1.13 times more deprived of educational opportunities than middle or affluent groups, and this gap is widening. According to the Bangladesh Agricultural Information Service, rice production declines daily due to rising temperatures. Rice needs temperatures between 18 and 35°C, but in winter temperatures fall below 18°C, and in summer they exceed 35°C, causing fertilization issues and reduced yields. Rising temperatures also cause sea levels to rise as polar ice melts, increasing soil salinity in coastal areas. This salinization renders some arable land uncultivable, further decreasing yields and escalating economic losses; a Soil Resources Research Institute study reports that over 3 million tons of food grains are lost annually due to salinity in these districts.

Increasing agricultural land salinity leads to a 21% annual drop in agricultural income, rendering over half of coastal farmland unproductive and displacing many residents. Besides staple crops like rice, Bangladesh's production of jute, wheat, maize, peas, and chickpeas is slowly declining due to hail, storms, flash floods, drought, and other climate-related events. This decline reduces the per capita income of coastal communities, causing shortages in health, education, and nutrition. Climate change is affecting agriculture and the entire economy of Bangladesh, which is facing ongoing crises. For example, the country cultivates around 147000 hectares of ponds, 50488 hectares of fish ponds, and 11 million hectares of shrimp farms. Additionally, approximately 4.47 million hectares of rivers, haors, beels, and canals support about 250 fish species, but rising temperatures and climate shifts threaten these fish stocks. Experts note that when temperatures exceed 30 °C, water heats up, leading to oxygen depletion that significantly reduces fry production. Consequently, fisheries income declines, affecting fishermen whose livelihoods depend mainly on fishing. Moreover, frequent climate-induced natural disasters have left people with nothing and helpless, requiring government intervention for rehabilitation. This increases the budget deficit and hampers essential development projects. Many residents are also migrating to larger cities like Dhaka in search of work, often engaging in unplanned industries and informal labor systems.

The International Labor Organization (ILO) reports that Bangladesh's manufacturing sector currently loses 2.59% of working hours to heat stress, and that a figure expected to rise to 4.96% by 2030 due to climate change. Increasing reliance on air conditioning in garment factories to regulate temperature will boost greenhouse gas emissions, which are subject to international restrictions, especially since Bangladesh's electricity is predominantly fossil-fuel-based. Doctors warn that summer heat causes declines in productivity in Bangladesh due to headaches, dizziness, fatigue, and nausea, leading to higher absenteeism in workplaces. Currently, tropical cyclones cause about \$1 billion in economic damage annually. If these losses grow unchecked, by 2050 a third of agricultural GDP could be lost, with severe floods reducing GDP by up to 9% and displacing 13 million people. The EU Climate Service reports that last year, the global average temperature rose by 1.48°C above the long-term average, setting daily records since July and signaling that efforts to combat global warming are nearing failure.

To combat global warming, it's essential to rigorously limit greenhouse gas emissions and reliance on fossil fuels. Despite this, last year was the hottest on record, highlighting that the issue remains unresolved—a major concern worldwide. According to a report by Copernicus Climate Change Service (C3S), a European climate monitoring organization, October 2023 was significantly warmer than the pre-industrial average, reaching 1.7°C above it. Samantha Burgess, deputy director of Copernicus, noted that in 2023, six months and two seasons set new warmth records, making it the hottest year to date. In light of this, the push to phase out fossil fuels and keep global warming to 1.5°C has become more urgent. Since Bangladesh cannot directly influence global policies, it should lead by example—reducing fossil fuel use and pollution through national initiatives. To mitigate the adverse effects of climate change, all sectors of society, including individuals, must take proactive steps. Relying solely on government action is insufficient for future generations. Simple lifestyle changes, such as consuming more vegetables, fruits, grains, legumes, nuts, and seeds, and less meat and dairy, can substantially reduce environmental impact. Plant-based food production generates fewer greenhouse gases and uses less land, water, and energy. Additionally, avoiding flights for meetings and seminars by using video conferencing can significantly reduce fossil fuel consumption. Small individual efforts collectively can help sustain human civilization.

The world is increasingly divided over the future of fossil fuels. On one side are the interests of oil-producing nations, while the Alliance of Small Island States (AOSIS) fights to address climate risks. As COP-28 concluded, it became clear that the divide was vast. Despite widespread pressure, the issue remained unresolved, with some countries prioritizing pollution reduction over the elimination of fossil fuels. Saudi Arabia and Russia were notably active, with OPEC sending letters to member countries just before the summit, opposing any mention of fossil fuels in the conference agreements. This move suggested OPEC was struggling to reach consensus and attempting to influence climate negotiations, a rare and unprecedented action, especially as it avoided addressing the pollution caused by fuel oil and gas. During the conference, a controversial statement claimed there was no scientific basis for phasing out fossil fuels, prompting criticism. Eventually, countries agreed to gradually reduce fossil fuel use, following decades of climate negotiations that culminated in the successful Dubai Climate Agreement after the 2015 Paris Accord.⁸⁸

Carbon Emissions and Struggle to Achieve Net-Zero

Background. Understanding net-zero carbon emissions is essential for building a sustainable future. It involves balancing the amount of carbon released into the atmosphere with an equivalent amount removed, resulting in no net increase in carbon levels. Countries like the UK have legally committed to reaching net zero by 2050, and more than 70 other nations have set similar goals. Transitioning to a net-zero economy is one of the most urgent challenges of the 21st century, as climate change threatens ecosystems, economies, and human wellbeing worldwide. To meet decarbonization targets, governments, industries, and communities are increasingly focusing on energy efficiency, using less energy to deliver the same services or results. This strategy can significantly reduce carbon emissions across sectors such as industry, transportation, and residential and commercial buildings. Although decarbonization mainly emphasizes increasing renewable energy use, the crucial importance of energy efficiency is often overlooked, even though it can reduce emissions quickly and cost-effectively.⁸⁹In many countries, barriers such as inadequate policies, lack of financial incentives, high upfront costs, and limited public awareness continue to hinder the widespread adoption of energy-efficient technologies and practices.⁹⁰To address these challenges, policymakers need to adopt comprehensive, context-specific strategies that align with both national and global climate objectives. Multiple studies indicate that policy tools—such as subsidies, energy-efficiency standards, fiscal incentives, and market-based approaches like carbon pricing—are essential for encouraging energy-efficiency improvements.⁹¹Additionally, incorporating energy efficiency strategies into larger climate action plans can speed up the shift toward net-zero emissions and promote lasting sustainability.⁹²

Net Zero. The worldwide goal of reaching net-zero emissions by mid-century has become a central focus of international climate strategies. As the consequences of climate change become increasingly evident, governments, industries, and organizations worldwide are stepping up their efforts to achieve significant

decarbonization goals. Reaching net-zero emissions by 2050 is crucial to keeping global temperature rise within 1.5°C above pre-industrial levels, in line with the targets set by the Paris Agreement.⁹³ This transition is both a scientific and environmental necessity and an economic and social imperative, requiring large-scale changes across multiple sectors of the global economy. Recently, more countries have officially committed to reaching net-zero emissions by 2050. In 2019, the European Union became the first major region to establish a legally binding net-zero target for 2050 under the European Green Deal, initiated by the European Commission.⁹⁴ In 2020, China, the world's largest emitter, announced its goal of achieving carbon neutrality by 2060, marking a significant shift in global climate leadership. Likewise, other countries such as Japan, South Korea, and Canada have committed to achieving net-zero emissions by 2050. Additionally, corporate net-zero pledges are increasing, with multinational giants such as Microsoft, Amazon, and Google promising to achieve carbon neutrality in the coming decades.⁹⁵ These commitments highlight the growing role of environmental sustainability in corporate strategies and show how market solutions can support government efforts to meet global climate goals. The worldwide push to reach net-zero emissions by 2050 is gaining momentum as the need to combat climate change becomes more urgent. Despite challenges related to technology, economics, and politics, the drive for decarbonization remains strong. International agreements such as the Paris Agreement, national policies, technological advancements, and corporate pledges are all advancing sustainability. Nonetheless, achieving the targets requires unified action from governments, businesses, and individuals to prevent the most severe effects of climate change.

Net Zero Emissions Goal. The urgency behind the net-zero emissions goal is driven by the increasing scientific consensus regarding the risks of ongoing global warming. The Intergovernmental Panel on Climate Change (IPCC) warned in 2018 that exceeding 1.5°C of global warming could cause severe environmental shifts, including more frequent extreme weather, rising sea levels, and disruptions to ecosystems and agriculture. To prevent these outcomes, the scientific community emphasizes the need for a swift, coordinated global effort to significantly cut greenhouse gas emissions, aiming for net-zero by 2050. Several factors propel this push, notably the 2015 Paris Agreement, which has been instrumental in driving global decarbonization efforts. The Agreement urges signatories to limit warming to below 2°C, with efforts to target 1.5°C, requiring not only emission reductions but also substantial investments in clean energy, carbon capture, and energy efficiency. Nationally Determined Contributions (NDCs), which are country-specific climate action plans, have increasingly adopted ambitious decarbonization goals, with many targeting net-zero emissions by 2050. Alongside the Paris Agreement, other international initiatives, such as the United Nations Sustainable Development Goals (SDGs), emphasize the urgency of climate action. Specifically, SDG 13 calls for "urgent action to combat climate change and its impacts," reinforcing the global pursuit of carbon neutrality by mid-century, a goal endorsed by the United Nations in 2015.⁹⁶

Solution: Developing Policy Frameworks. To achieve the net-zero goal by 2050, countries are introducing various policies to cut emissions in major sectors. These include decarbonizing energy, boosting energy efficiency, shifting to renewable sources, and advancing CCS technologies, according to the IEA in 2020.⁹⁷ The International Energy Agency (IEA) estimates that reaching net-zero emissions will demand a fundamental overhaul of the energy sector, the main contributor to global emissions, responsible for over 70% of CO₂ emissions.⁹⁸ Therefore, the widespread adoption of renewable energy sources such as solar, wind, and hydropower, along with electrification, will be essential to reducing carbon emissions in the global energy sector (Hirth et al., 2015).⁹⁹ Policy frameworks are additionally emphasizing the promotion of energy efficiency in industries and buildings. According to Sorrell (2018), enhancing energy efficiency is one of the most cost-effective strategies for reducing emissions, leading to lower energy demand and more sustainable resource use.¹⁰⁰ Policies, including energy-efficiency standards, building codes, and subsidies for energy-efficient technologies, are being adopted both nationally and internationally.¹⁰¹ Alongside these sector-specific policies, numerous countries began implementing climate-neutral strategies in 2020, such as carbon pricing mechanisms, including carbon taxes and cap-and-trade systems, as promoted by the World Bank.¹⁰² These market-based tools offer financial incentives for companies to reduce emissions and adopt green technologies, thereby promoting a shift towards a low-carbon economy.¹⁰³

Solution: Implementing Advanced Technology and Innovation. For businesses and countries, the path to Net Zero emissions begins with a long-term strategy that involves setting incremental reduction targets. Many opt to collaborate with specialized organizations that help achieve these objectives. The process starts with data collection and monitoring to identify major sources of greenhouse gas (GHG) emissions and quantify their emissions. Once the carbon footprint is clearly understood, they can establish ambitious yet achievable reduction targets based on climate science. These targets then inform a strategic roadmap to achieve Net Zero emissions.¹⁰⁴ Technological innovation plays a vital role in the worldwide pursuit of net-zero emissions by 2050. For instance, carbon capture and storage (CCS) technology offers considerable potential to reduce emissions from hard-to-abate sectors such as heavy industry and fossil-fuel power generation.¹⁰⁵ Likewise, advancements in low-carbon hydrogen, electric vehicles (EVs), and advanced batteries are anticipated to reshape major parts of the economy by cutting direct emissions and decreasing reliance on fossil fuels.¹⁰⁶ The potential of digital

technologies such as smart grids, AI, and machine learning is being explored to enhance energy systems and increase energy efficiency. A 2020 McKinsey & Company study found that these technologies can support real-time monitoring and predictive analytics to better manage energy demand, facilitate the integration of renewable energy into grids, and optimize energy use in buildings and factories.¹⁰⁷ Scaling these technologies worldwide will necessitate significant investments in research, development, and deployment. According to the World Economic Forum (2020), reaching net-zero emissions by mid-century will demand annual investments of \$5-6 trillion in low-carbon clean energy and sustainable technologies.¹⁰⁸

Challenges. Achieving net-zero is challenging due to significant upfront investments, the need to develop emerging technologies, and the complexity of overhauling entire economic sectors. Additionally, it demands profound changes in daily routines, including energy consumption, transportation, diet, and waste practices.¹⁰⁹ Despite advances in many nations, reaching net-zero emissions by 2050 remains a significant challenge. A main hurdle is the persistent dependence on fossil fuels, particularly in developing economies with rapidly increasing energy needs. Although renewable energy is becoming more affordable, numerous countries still encounter infrastructure and technological obstacles to wide-scale implementation.¹¹⁰ Furthermore, in 2019, the International Monetary Fund (IMF) emphasized that subsidies for fossil fuel industries still hinder progress toward clean energy transitions in various regions.¹¹¹ Another challenge involves the socio-economic impacts of moving to a low-carbon economy. Moving away from fossil fuels may cause job losses in sectors like coal, oil, and gas. To manage this, a just transition is essential, including reskilling workers, creating green job opportunities, and protecting vulnerable communities from disproportionate impacts.¹¹² Furthermore, political and economic opposition to bold climate policies in certain countries and regions makes achieving net-zero emissions more challenging. As Grubb et al. (2020) note, entrenched fossil fuel industry interests and limited political commitment have hindered climate progress in many key economies.¹¹³

Way Forward. Reaching net-zero carbon emissions is vital to prevent global temperatures from rising more than 1.5°C above pre-industrial levels by mid-century. The Intergovernmental Panel on Climate Change (IPCC) considers this limit essential to avoid severe damage to ecosystems and to minimize the most disruptive effects of global warming. The 1.5°C goal and the aim of achieving Net Zero emissions were established in 2015 through the Paris Agreement, a legally binding treaty signed by 196 countries. To stay within this limit, emissions must be cut by 45% by 2030 and reach Net Zero by 2050. Implementing energy-efficient measures across sectors such as buildings, industry, and transportation has proven to be a cost-effective way to reduce carbon footprints while fostering economic growth. Leaders worldwide, including emerging economies, have demonstrated that a range of energy efficiency policies and technologies offer tangible benefits by supporting decarbonization strategies. However, challenges like financial constraints, technological hurdles, and low awareness still impede widespread adoption, especially in developing countries. To accelerate progress, governments need to improve financial mechanisms, enforce updated energy standards, and invest in public education on the benefits of energy-saving measures. The future of energy efficiency depends on innovative technologies, international collaboration, and policy improvements. Prioritizing energy efficiency in climate strategies can help countries lower emissions and build a sustainable, resilient energy system. Future research should explore long-term economic impacts, behavioral barriers, and the scalability of emerging solutions. Innovation remains the key to decarbonization—whether through smart grids, energy storage, industrial process improvements, or digital tools, each step accelerates progress. Though complex, this path opens new opportunities for sustainable growth and the development of new production chains.¹¹⁴

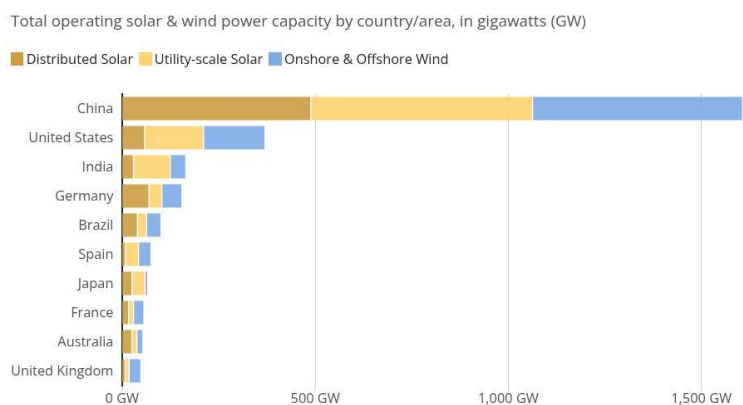
Policymakers need to regularly update energy efficiency regulations to keep pace with technological progress. This includes enforcing strict building codes and appliance standards to align new construction and manufacturing with energy-saving best practices. Governments should also improve financial mechanisms such as low-interest loans, energy performance contracting (EPC), and public subsidies to reduce the upfront costs of energy-efficient technologies. Innovative tools such as green bonds can further boost investment in these projects. Expanding public awareness campaigns is vital to educating consumers, businesses, and policymakers about the benefits of energy efficiency, including cost savings and environmental benefits. Incentive programs, such as rebates for energy-efficient appliances, should be promoted to encourage behavioral change. Incorporating energy efficiency as a key element in national and international climate strategies is essential to reaching carbon neutrality, with clear action plans to support these measures. Developing countries often face financial and technological hurdles in accessing energy-efficient technologies; international cooperation through technology transfer and capacity building must be prioritized to help these nations benefit from these advancements. Ultimately, energy efficiency is fundamental to the success of any strategy aimed at carbon neutrality. Scaling initiatives supported by robust policy frameworks and technological progress is crucial to achieve global climate targets and foster a sustainable future.

Global Initiative to Generate Solar Energy and Future Prospective

In 2025, the worldwide planned capacity for wind and utility-scale solar projects increased by 11%, from 4.4 TW to 4.9 TW, according to recent data from Global Energy Monitor (GEM). This represents a key milestone toward the global objective of tripling renewable energy capacity, as wind and solar are projected to account for 94% of the new additions.¹¹⁵ The global pipeline of 4.9 TW includes similar shares of wind and utility-scale solar, at 2.7 TW and 2.2 TW respectively. Currently, 758 GW of these projects are under construction worldwide, with China and India accounting for about 75% of the total. China leads with over half of these projects, totaling 448 GW, while India has 125 GW under construction as part of its goal to reach 500 GW of non-fossil capacity by 2030.¹¹⁶ The global shift to clean energy is happening at different rates around the world. China has over 1.5 TW of potential wind and large-scale solar capacity, nearly equal to the combined total of the next six countries: Brazil (401 GW), Australia (368 GW), India (234 GW), the United States (226 GW), Spain (165 GW), and the Philippines (146 GW). Despite their wealth, G7 nations lag significantly behind China and others in annual growth of prospective capacity, as illustrated in Figure 1 below.

Over the next five years, the IEA estimates that about 70% of all new renewable capacity in G7 countries will come from wind and utility-scale solar. This highlights a gap between current pipelines and the necessary progress.¹¹⁷ China leads the world in total wind and solar capacity, reaching at least 1.6 TW by December 2025, including 489 GW of distributed solar. The United States comes next, with over 368 GW of combined wind and solar capacity. In 2025, the U.S. added 4.9 GW of wind, 25.6 GW of utility-scale solar, and 5.5 GW of distributed solar. India ranks third, with over 163 GW of operating capacity. Despite controlling about half of global wealth, G7 countries represent only 11% of planned wind and large-scale solar additions. The focus for new clean power has shifted strongly toward emerging and developing economies. By 2025, their combined wind, utility-scale solar, and distributed solar capacity exceeded 1.6 TW, three times that of the U.S. and India. This growth is driven by rapid technological progress, significant cost reductions, solar's versatility—from small rooftop systems to large utility projects—and historically low prices due to global manufacturing overcapacity. Consequently, solar is increasingly outperforming other power generation methods.

China hosts three times more operating wind & solar than the United States and India combined



Source: Global Wind Power Tracker, Global Solar Power Tracker
Note: Data include only wind project phases with a capacity of 10 MW or more. All solar capacities are reported in MWac.



Figure 1: Global renewable energy users¹¹⁸

The latest report from the International Renewable Energy Agency (IRENA) highlights that solar energy is a leading source of renewable energy worldwide. China ranks first, with a solar capacity of 12,02,178.8 MW, followed by the USA at 2,11,610.1 MW, and India at 1,35,501.5 MW. Other major contributors include Germany with 106,272 MW, Japan with 92,211.3 MW, Brazil with 64,692.3 MW, Spain with 47,205.6 MW, Italy with 41,187.9 MW, Australia with 41,067.9 MW, and France with 31,226.2 MW. Regarding grid connections, Vietnam currently supplies 8700 MW of solar energy, the Philippines 2,600 MW, Sri Lanka 1000 MW, and Pakistan 800 MW. Sri Lanka aims to generate 70% of its electricity from renewable sources by 2030, with solar power particularly notable for its decentralized rooftop installations. Driven by the "Soorya Bala Sangramaya" (Battle for Solar) program, rooftop solar capacity in Sri Lanka has grown swiftly, surpassing 1,700 MW by May 2025.¹¹⁹ In South Asia, Pakistan has become one of the world's fastest solar energy producers, with an installed solar capacity of at least 32,000 MW. It also aims to generate 60% of its electricity from renewable sources by 2030. A UK-based analysis by The Guardian noted that after liquefied natural gas prices skyrocketed following Russia's invasion of Ukraine in 2022, millions of Pakistanis faced electricity and gas shortages during a severe heatwave. The Guardian highlighted that people soon recognized an alternative, as decreasing solar panel costs and government incentives to feed excess power into the grid made rooftop solar appealing. Pakistan's rapid solar adoption attracted CNN's attention last year, which reported on the country's remarkable

transition. Despite challenges like poverty and economic instability, Pakistan, with a population exceeding 240 million, is undergoing one of the fastest solar revolutions globally.¹²⁰

Government Initiative to Generate Solar Energy and Future Plan

According to a report by the Bangladesh Power Development Board (BPDB), 68% of Bangladesh's energy demand is met by natural gas. In addition to natural gas, Bangladesh relies heavily on diesel, coal, and furnace oil, leading to alarming levels of GHG emissions. Therefore, to meet the country's rising energy demand and achieve a sustainable environment, shifting toward renewable energy-based systems is mandatory, as only 0.05% of electricity demand is currently met by solar and wind energy.¹²¹ A recent BPDB report states that Bangladesh's annual electricity demand grows at about 10%, with expectations of further increase soon.¹²² Although approximately 94% of Bangladesh's urban population has electricity access, 60% experience frequent load shedding. As a result, solar PV systems present a practical solution to the power shortage. The government has launched multiple initiatives to deploy PV-based homes in off-grid areas, benefiting around 20 million rural residents. Additionally, ensuring energy security is seen as a crucial challenge for realizing Bangladesh's Vision-2041.¹²³ The majority of solar cells used in PV systems in Bangladesh and globally are silicone-based, capturing about 93% of the world market share in 2016.¹²⁴ However, the energy conversion efficiency of silicone PV cells remains inadequate, with 25.8% for mono-crystalline and 22.3% for multi-crystalline types. As a result, researchers have been exploring alternative materials for PV cells. Currently, perovskite solar cells, dye-sensitized solar cells, and quantum dot-sensitized solar cells attract attention because of their promising potential to replace traditional silicone solar cells.¹²⁵

In 2003, the government launched a program to extend electricity to off-grid communities through solar home systems installed by development organizations. Managed by Infrastructure Development Company Limited (IDCOL), this initiative resulted in nearly six million solar home systems being installed nationwide. While usage declined after Bangladesh became fully electrified, IDCOL reports that many systems are still operational. The agency now plans to seek new investments to expand residential solar power. IDCOL has received rooftop data from over 4,500 factories across various sectors, with these rooftops capable of generating up to 4,000 megawatts of electricity. Rooftop solar is more cost-effective than land-based systems; a 1-megawatt rooftop plant costs approximately Taka 40 to 45 million, about half the price of a land-based plant. Recent removal of import duties could cut costs by 25 to 30% for both options. While only one or two projects were typically undertaken annually in the past, interest has surged over the last three years, driven by rising fossil fuel prices, making rooftop solar increasingly attractive to businesses.

In 2025, approvals for projects to install 100 megawatts of rooftop solar capacity were granted. To date, 120 factories have been authorized to produce a total of 352 megawatts of electricity, with 308 megawatts already operational. By year-end, the operational capacity could reach about 350 megawatts, and an additional 80 to 100 megawatts might receive approval. Over the next five years, IDCOL aims to fund projects that generate 5,000 megawatts of solar power. A typical solar power plant provides electricity for 25 to 30 years, ensuring a relatively secure return on investment. Factories that have adopted rooftop solar and sources from IDCOL indicate that small industries currently pay Taka 12.73 per unit of electricity. For larger factories, the average tariffs are Taka 12.85 per unit for medium-voltage connections and Taka 12.75 for high-voltage connections. During peak nighttime hours, costs can rise to nearly Taka 16 per unit. Conversely, businesses financing rooftop solar through loans are producing electricity at Taka 4 to 8 per unit. Adding battery storage to save daytime electricity raises costs to about Taka 7 to 8 per unit, and operating the system for more than four hours at night could increase expenses further. Without batteries, rooftop solar electricity costs just Taka 4 to 5 per unit.

Jashore University of Science and Technology was the first among Bangladesh's universities to launch a rooftop solar project. A private company, funded by IDCOL, installed a 1 MW system on campus. The university purchases electricity at a rate 26.6% lower than the national grid tariff, significantly lowering its electricity costs. Any excess electricity is supplied to the Rural Electrification Board (REB). The university exports 24,000 to 38,000 units of electricity per month, offsetting its power bills, and earns Tk 2 per square foot per month in rooftop rental fees. Officials report the project is highly profitable. Subsequently, BUET installed a 2.4 MW rooftop solar system, and BRAC University added 1 MW of rooftop solar capacity. Both have reduced dependence on the national grid and lowered their electricity bills. United International University has also installed a 72-kilowatt rooftop solar system, supported by a private company, saving 250–350 kilowatt-hours daily. Bangladesh's 58 public universities, including 40 with permanent campuses, and 116 private universities with large campuses, could benefit from rooftop solar. Experts believe most universities can meet a significant portion of their energy needs this way. An IDCOL survey indicates that Rajshahi University could install up to 5 MW of rooftop solar capacity, and rooftops at Chittagong University could generate 5.5 MW against a demand of 6.5 MW.

Alternatively, by utilizing unused land on campus, an additional 5 MW could be generated, enabling the university not only to fulfill its own energy needs but also to contribute surplus power to the national grid. Energy experts emphasize that all universities should swiftly adopt rooftop solar. The current government aims to produce 10,000 megawatts of solar power by 2030 to enhance the country's energy security.¹²⁶ During a recent

meeting on April 16, 2026, the Cabinet Secretary Dr. Nasimul Ghani unveiled the Renewable Energy Policy 2025 at a press briefing held at the Secretariat. This announcement followed a cabinet meeting chaired by Prime Minister Tarique Rahman, which focused on ways to promote investment in renewable energy projects and on exploring options to expand renewable energy sources. The Cabinet Secretary explained that the policy seeks to enhance the investment climate by simplifying entry procedures for both public and private investors and by ensuring profitability.¹²⁷ He also stated that the policy intends to enhance the investment climate by simplifying entry for both public and private investors and ensuring profitability. Dr. Nasimul Ghani added that significant investment opportunities on government land will be made available not only to public entities but also to private entrepreneurs to support the target. The Renewable Energy Policy 2025 aims for at least 20% of electricity to come from renewable sources by 2030.

To reach this ambitious target, a committee has been established to finalize the policy and oversee its implementation. The current government has introduced a new policy framework to accelerate renewable energy development by permitting the use of unused or underutilized state-owned land for clean energy projects through a public-private partnership (PPP) model.¹²⁸ The cabinet also considered expanding other renewable energy sources, such as wind and biogas. During the briefing, the cabinet secretary mentioned ongoing efforts to modernize solar systems and boost domestic manufacturing to address current limitations. He also stated the government's goal to keep solar power tariffs between Taka 4 and Taka 8 per unit. On 29 Aug 2026, State Minister for Power, Energy, and Mineral Resources Anindya Islam Amit announced that Bangladesh aims to generate at least 3,000MW of solar power before next summer, which could alleviate the electricity shortage. He added that incentives for solar entrepreneurs will help increase capacity as part of the government's efforts to reduce the energy gap. Speaking as the chief guest at a meeting focused on improving education quality, ethics, and cleanliness at educational institutions at the Jashore PTI auditorium, he emphasized that the government is providing various incentives and support to solar sector entrepreneurs, enabling the country to reach the 3,000MW solar power target before next summer.¹²⁹

Private Initiative and Installation of Industrial Rooftops for Solar Energy

A recent survey by the Bangladesh Garment Manufacturers and Exporters Association (BGMEA) included 424 garment factories, all of which expressed interest in installing rooftop solar power systems. The main challenge cited was limited access to financing. Several factory owners noted that EU garment buyers have committed to cutting carbon emissions from production by 30% by 2030, pressuring manufacturers serving these buyers to adopt solar energy. Yet, high costs pose a barrier for medium-sized entrepreneurs. BGMEA President Mahmud Hasan Khan told Prothom Alo that loans for solar power are available at 5% interest from Bangladesh Bank's Green Transformation Fund and 6% from IDCOL. However, securing an IDCOL loan requires a 100% bank guarantee. To improve this, BGMEA suggested lowering interest rates or extending repayment periods from 7 to 9 years to make solar installations more feasible for medium-sized industries.¹³⁰ For instance, DBL Group, a major industrial player in the country, has installed solar power units with a total capacity of 5.5MW on the rooftops of seven of its garment and textile factories. Additionally, it aims to install 16MW of solar capacity in 10 more factories, including ceramics and garment facilities. Of this, 8MW is projected to be operational this year, with the remaining capacity coming online next year.

In an interview with Prothom Alo, MA Rahim, Vice Chairman of DBL Group, stated that their rapid investment in solar power is driven by energy security concerns at their facilities and demand from international buyers to lower carbon emissions. He explained that technological advancements have reduced installation times, and the cost of rooftop solar at their factories ranges from Tk 6 to Tk 6.50 per unit. Similarly, major industrial groups are increasingly adopting solar power. The adoption began about ten years ago due to government policies and international pressure. As the energy crisis worsens and fuel prices climb, these groups have significantly ramped up their solar investments over the past three years.¹³¹ Rising Group, a leading garment manufacturer, has installed 14MW of solar power across six industrial rooftops. These panels supply up to 60% of the electricity for two garment factories and 15% for two spinning mills. Mahmud Hasan Khan, the group's MD, explained to Prothom Alo that their Manikganj spinning mill faced a long gas shortage, prompting them to install solar power in 2019 out of necessity. Eventually, they expanded solar installations to other factories for business reasons, as solar power costs nearly half as much as grid electricity.¹³²

Several companies involved in solar power installation reported that most large solar plants on industrial rooftops have been built over the last two years. These units, totaling over 600MW of capacity, are predominantly at export-oriented garment factories. While rooftop solar cannot fully meet the electricity needs of these factories, it can generate power for three to four hours, covering 5% to 15% of their total demand—sometimes more. This has helped ease pressure on the national grid during daytime hours, according to industry officials. Notably, companies like Abul Khair Steel, Walton, Ha-Meem Group, PRAN-RFL Group, BSRM, Youngone Group, Meghna Group of Industries, Pacific Jeans, Team Group, DBL Group, Rising Group, Urmi Group, Microfiber Group, Palmal Group, Apex Footwear, Karnaphuli Shoe Industries, and Masco Group have already installed various capacities of solar units at their facilities.¹³³ A report by the US-based Institute for Energy Economics and Financial Analysis (IEEFA) evaluates the growth of rooftop solar capacity at industrial

and commercial sites in Bangladesh. The organization states that while government figures show 418.1 MW of rooftop solar installed by June 2026, IEEFA estimates actual capacity has reached 667 MW across 239 sites, including groups of companies. If units smaller than 0.15 MW were counted, Bangladesh's rooftop solar capacity could already be around 1,000 MW. This expansion has led to a slight decrease in daytime power demand, as observed in comparisons between 16 April–11 June 2024 and the same period in 2026.¹³⁴ PRAN-RFL, a leading industrial group in Bangladesh, aims to produce over 100MW of solar energy from its factory rooftops. Currently, it generates 35MW across 20 factories, with plans to add at least 30MW more this year. In addition to powering its own facilities, two factories are supplying electricity to the national grid.¹³⁵

Akij Bashir Group, a major industrial entity, is expanding rooftop solar capacity across its factories. It has established a 21MW plant at Janata Jute Mills, now fully powering the mill with rooftop solar. Additionally, a 13MW solar system with an 8MW battery has been installed atop Akij Glass in Habiganj, enabling night-time electricity supply. Since starting in 2022, Akij Bashir now produces 75MW from rooftop solar, with plans to add another 28MW. Similarly, Meghna Group of Industries (MGI) has installed 64.84MW of rooftop solar, covering about 5% of its energy needs, with plans for an additional 50MW to bring the total to approximately 115MW. MGI Director Tanveer Mostafa highlighted their focus on expanding renewable energy sources, including solar on facades and boundary walls. Meanwhile, Omera Solar, a subsidiary of East Coast Group, has installed rooftop solar units totaling 130-140MW on 100 factories since 2021, with ongoing projects in 12 facilities expected to generate an extra 20MW. Omera CEO Masudur Rahim noted that the recent surge in rooftop solar occurred mainly in the past two years due to the worsening energy crisis. These solar systems typically last 20-25 years.¹³⁶ After the initial investment, ongoing costs are minimal, primarily limited to maintenance. Additionally, the expense is at most half, and often less, than traditional grid electricity. As a result, more industrial entrepreneurs are showing growing interest in solar power.

Banglalink, a leading digital operator in the country, has reinforced its commitment to environmentally responsible digital infrastructure by installing a 50-kW rooftop solar power system at its Cumilla Data Center. Covering 2,500 square feet of previously unused rooftop space, this system is expected to produce around 85,000 kWh of clean energy annually, reducing grid electricity use during solar hours by about 6%. This initiative aims to cut carbon emissions by approximately 52 tons per year and save roughly Tk 1.2 million in energy costs annually. The system supports Banglalink's ESG objectives and helps maintain uninterrupted data center operations during emergencies and outages. Notably, Banglalink is the first mobile network operator in Bangladesh to incorporate solar power into a data center, following the installation of an 80-kW solar system at its Gazipur Data Center last year. Hüseyin Türker, Banglalink's Chief Technology and Information Officer, stated, "This is another step in our journey toward sustainable, resilient digital infrastructure. By integrating solar energy into our critical operations, we are reducing emissions, lowering energy costs, and enhancing the long-term sustainability of our network. At Banglalink, sustainability is not just an environmental duty; it is a business necessity." This project represents the company's effort to embed renewable energy into its digital infrastructure and expand clean energy use across its facilities and network, contributing to a greener, more resilient, and energy-efficient digital ecosystem aligned with broader ESG goals.¹³⁷

Contemporary Initiative and Future Perspective of Solar Energy in Bangladesh

Recently, various local researchers have studied the present situation and future potential of solar PV systems in Bangladesh. For example, Podder et al. provided a chronological overview of the current state, challenges, and future outlook of solar PV in the country.¹³⁸ Podder et al. stated that they were the first to illustrate the spread of various PV systems across the country and to conduct a feasibility analysis of current technologies. Hossain et al. outlined the current state of PV systems in Bangladesh and detailed the government's efforts to deploy them nationwide.¹³⁹ In 2016, Halder conducted a feasibility study on solar home systems (SHSs) in Bangladesh and found that SHSs are more economically viable for small business enterprises than for household lighting.¹⁴⁰ Bangladesh is advancing quickly in the commercial deployment of PV systems to promote a sustainable future and affordable energy. Akash et al. reviewed renewable energy options in Bangladesh and highlighted major challenges to tapping these sources.¹⁴¹ The authors highlighted solar energy and biomass as Bangladesh's most abundant renewable sources, emphasizing their potential to meet the country's energy needs. Anubhove et al. analyzed the feasibility of solar home systems (SHSs) in rural Bangladesh and concluded that SHSs can effectively reduce the nation's greenhouse gas emissions.¹⁴² Hence, the literature review shows that numerous recent studies have highlighted Bangladesh's potential renewable energy sources and their future prospects.¹⁴³

Although Bangladesh has discussed prioritizing renewable electricity for ten years, actual generation has seen little growth. The country aimed to generate 10% of its electricity from renewables by 2021 but missed the target and set a new one for 2025. Currently, the government plans to increase the share of renewables to 20% by 2030. As part of this effort, the government eliminated import, regulatory, supplementary duties, and advance tax on key solar equipment in this fiscal year's budget, though companies must satisfy certain conditions to qualify. Solar installation officials indicated that duty-free imports could cut costs by about 15%, potentially reducing the cost of installing 1MW of solar from Tk 40 million to approximately Tk 35 million.¹⁴⁴

A report by the Center for Policy Dialogue (CPD) highlights the potential to generate approximately 1,768MW of solar power from the rooftops of 3,320 garment factories nationwide. Notably, 500 factories are already prepared to begin producing solar energy, and with various incentives, an additional 1,300 could rapidly begin generating solar power. CPD Research Director Khondaker Golam Moazzem emphasized that for a long-term solution to the energy crisis, we need to increase domestic gas supplies, expand renewable energy, and electrify economic activities.* He stressed the importance of low-interest loans to help small and medium-sized factories adopt rooftop solar. During an interview with Daily Prothom, he suggested issuing green bonds on the stock market and utilizing international low-cost funds, which Bangladesh Bank would need to guarantee. He pointed out that two years ago, \$34 billion in such global funds were available for Bangladesh to access.¹⁴⁵ Shafiqul Alam, Bangladesh's lead energy analyst for South Asia at the Institute for Energy Economics and Financial Analysis (IEEFA), explained to Prothom Alo that rooftop solar holds significant potential not just for industries and universities but also across Bangladesh's 87,000 villages. He pointed out that rural residents are not currently benefiting from the import duty exemptions in the national budget and emphasized that these incentives should be available to all.

At a dialogue in Dhaka yesterday, speakers emphasized that Bangladesh should draw on international experience to secure energy, ensure affordability, and promote sustainability as it aims to expand rooftop solar. The event, titled "Solar Revolution in Pakistan: Lessons for Bangladesh from National Budget Perspective," highlighted Pakistan's rapid rooftop solar adoption and what Bangladesh can learn from it. Organized by the Center for Policy Dialogue at a city hotel, the keynote speech by Muhammad Basit Ghauri, Manager of Special Initiatives and China Program at Pakistan-based Renewables First, noted that Pakistan has seen one of the fastest growths in distributed solar power, driven mainly by consumers rather than government programs. In FY24, Pakistan imported 16 GW of solar panels, rising to 17.9 GW in FY25, with total solar capacity estimated at 28-38 GW. About 98 percent of this capacity has been installed at the distributed level, primarily on rooftops and behind consumers' meters.¹⁴⁶ Ghauri explained that the solar boom is driven by rising electricity tariffs, waning trust in grid reliability, declining global solar panel costs, and policies such as net metering and concessional loans. He emphasized that this solar expansion is not limited to urban areas, citing that about 7.3 million households had installed solar systems by 2025, with nearly 75% in rural regions. He also pointed out that during times of crisis, the grid became too expensive to compete with.

Pakistan's electricity tariffs have increased sharply in recent years, leading households, businesses, and industries to adopt solar systems. Simultaneously, a global glut of Chinese solar panels has significantly lowered equipment costs. The country also implemented simplified net-metering rules, concessional financing options, and competitive buyback rates for excess electricity. The State Bank of Pakistan's renewable energy financing program supported approximately 4,500 projects from 2016 to 2024, resulting in over 2,000 MW of renewable capacity through low-interest loans.¹⁴⁷ Ghauri noted that over 96% of solar adoption in Pakistan is funded by consumers themselves. Regarding Bangladesh, he pointed out similarities with Pakistan, such as reliance on imported fuel and overcapacity in the power sector. "Bangladesh may be nearing its own tipping point," he added. CPD Research Associate Atikuzzaman Shazeed mentioned that Bangladesh's solar development is moving from off-grid solutions to grid-connected renewable energy. He highlighted that the solar home system (SHS) program, once the world's largest off-grid solar project, provided electricity to over 20 million people, but installations declined sharply following extensive grid expansion into rural areas.¹⁴⁸

A CPD survey reveals that nearly half of the six million SHSs installed nationwide are now non-functional due to the absence of a strategic transition plan. Shazeed noted that Bangladesh has 4,551 net-metered rooftop solar systems with a total capacity of 213.3 MW, over 60 percent of which are in Dhaka division. About 98 percent of these systems are operational, and nearly two-thirds were financed by self-investment. CPD highlighted barriers to rooftop solar growth, including financing issues, high taxes on solar equipment, regulatory hurdles, and institutional fragmentation. Chief Whip Nurul Islam Moni, speaking as chief guest, said Bangladesh is seeking further opportunities for solar investment and collaboration. Asif Shahriar, senior assistant vice president at Infrastructure Development Company Limited, said the organization plans to launch smaller household solar schemes alongside industrial programs. David Hasanat, president of the Bangladesh Independent Power Producers' Association, warned against directly comparing Bangladesh with Pakistan, emphasizing decisions should reflect local circumstances. He pointed out that Bangladesh's electricity tariffs are lower than Pakistan's and stressed social sustainability's importance, noting, "Solar is not the only solution. We have to explore all available options." Moderating the session, CPD Research Director Khondaker Golam Moazzem urged Bangladesh to study international experiences to ensure energy security, affordability, and sustainability. Mostafa Al Mahmud of the Bangladesh Sustainable and Renewable Energy Association and Ashraful Alam of SREDA also spoke.¹⁴⁹

BPDB Chairman Engineer Rezaul Karim told BSS that the government aims to produce 809.5 MW of solar power by the end of 2028, as part of its green energy initiative. Currently, solar power accounts for 1451 MW, about 5.01% of the country's total installed capacity. This effort is part of a broader government plan to expand renewable energy, reduce carbon emissions, and enhance energy security. He noted that BPDB plans to add

809.5 MW to the national grid by 2028 and emphasized their commitment to the government's integrated strategy. Energy analysts suggest that rooftop solar and other renewable projects could significantly decrease Bangladesh's dependence on imported fuel. BPDB officials mentioned they have invited tenders for 13 solar projects generating 572.6 MW, and nearly 5 MW of rooftop solar panels are now installed and expected to be operational by September 2026. Additionally, 26 renewable power plants with a total capacity of 1,174 MW are under construction: six are government-led, and 20 are privately operated, with a total capacity of 1,062 MW. As of May 2026, Bangladesh's total grid-connected power generation capacity was 28,919 MW. Including captive power and off-grid renewables, the total capacity reaches approximately 32,332 MW.¹⁵⁰ The peak power demand is estimated to be between 18,000 MW and 18,500 MW during this summer. Bangladesh currently generates 1,450.7 MW of solar power, with 1,073.5 MW connected to the national grid and 377.17 MW off-grid. Renewable sources include 230 MW from hydroelectricity, 62 MW from wind, 0.69 MW from biogas, and 0.4 MW from biomass. According to studies by the Sustainable and Renewable Energy Development Authority (SREDA), Bangladesh has about 1,743.76 MW of installed renewable capacity, primarily from solar parks, rooftop net metering, and solar home systems (SHS).

The state-run Rural Power Company Limited (RPCL) is constructing a 100 MW solar park in Jamalpur's Madarganj, expected to be operational by December 2026. Additionally, private-sector or independent power producers (IPPs) are expected to contribute 132 MW to the grid. Recently, Energy Minister Iqbal Hasan Mahmood announced at the deputy commissioners' (DCs) annual conference that the government aims to generate 5,000 MW of solar power within the next five years. He also stated, "As a first step toward this goal, directives have been issued to install solar panels at the offices of all DCs nationwide within the next three months."¹⁵¹ The current electricity price for small industries is Taka 12.73 per unit. For large factories, the average cost is Taka 12.85 per unit for medium-voltage connections and Taka 12.75 per unit for high-voltage connections.¹⁵² During peak nighttime demand, the electricity price nears Taka 16 per unit, while rooftop solar generation costs between Taka 4 and 8 per unit. Superstar Renewable Energy has developed rooftop solar projects across 90 industrial sites, with a combined capacity of about 100 MW. They are now installing systems on more than 10 factories, which will produce an additional 20 MW once completed. CEO Mezanur Rahman told Prothom Alo that five years ago, installing a 1 MW rooftop solar unit cost Taka 50 million; now, it has decreased to Taka 40 million. In contrast, ground installations typically cost around Taka 80 million.¹⁵³

Leading energy analyst Shafiqul Alam, who serves at the independent Institute for Energy Economics and Financial Analysis (IEEFA), has recommended that the government develop a comprehensive energy master plan to ensure policy consistency and rebuild investors' confidence. He also added, "Bangladesh is currently facing a stagnation in renewable energy development, with no initiatives taken during the previous interim government." However, under the existing target, 20% of electricity will come from renewable sources by 2030 and 30% by 2041, in line with the UN's Sustainable Development Goal 7 (SDG 7). Coastal Livelihood and Environmental Action Network (CLEAN) chief executive and energy expert Hasan Mehedi said, "If the government installs a 1.0 MW solar panel, import costs could decrease by Tk 2.94-3 crore. He also mentioned that encouraging households to install rooftop solar panels could eliminate the need for government investment. Additionally, he pointed out that approximately 13,000 acres of land, previously acquired for coal-fired power plants, remains unused. Mr. Hasan Mehedi suggested that instead of acquiring new land, these existing sites could be repurposed for solar plants, which would reduce the cost per unit by 23-25 percent."¹⁵⁴ Bangladesh has recently taken a subtle yet significant role in expanding solar power in rural regions. The rapid increase in solar home system (SHS) installations has provided millions in off-grid areas with electric lighting for the first time, enabling children and adults to read and study after sunset and enhancing nighttime safety. Solar-powered TVs allow family members, including women, to access knowledge and information, empowering them and developing new skills. Additionally, families are earning income by offering mobile phone charging services, reducing the need to travel long distances to charging centers. This innovative policy approach is gaining recognition and holds promise not only for Bangladesh but also for other developing nations and the promotion of clean energy.

This innovative policy initiative has begun to attract attention and holds significant promise not only for Bangladesh but also for other developing nations and for the advancement of clean energy. It makes Shahidur Khandker, Hussain Samad, Zubair Sadeque, Mohammed Asaduzzaman, Mohammad Yunus, and Enamul Haque's new book particularly timely and significant. The advantages of replacing kerosene lighting are substantial. As shown in the book, kerosene lighting costs more than 35 times as much as solar home systems (SHS) for electric lighting, and SHS users consume about 3.5 times as much lighting as non-users. Replacing kerosene with SHS provides much better lighting quality, increases the quantity of lighting, and reduces health and safety risks associated with kerosene, especially for women and children. Additionally, about 160 million kilograms of CO₂ emissions are avoided annually. Since only around 10 percent of those in off-grid areas currently use SHS, there is significant potential to cut carbon emissions. Presently, many SHS units are being installed in rural Bangladesh through the second phase of the Rural Electrification and Renewable Energy

Project, supported by the World Bank and other partners. The Infrastructure Development Company Limited (IDCOL), which manages the project, aims to install an additional 3 million units in the next two years. A critical factor in the project's success is IDCOL's innovative, partially subsidized SHS delivery and financing scheme. This scheme offers incentives to partner NGOs to reduce unit prices for households and provides microcredit options, making SHS affordable for families unable to pay the high upfront costs. Given the rapid growth of SHS, the proven benefits to users, and the uncertain future of nationwide grid extension, policymakers must ask key questions now. They need to assess the potential market demand for SHS in off-grid areas and decide whether to continue subsidies to support further expansion.¹⁵⁵

Sustainable and Suitable Renewable Energy Solution for Bangladesh

Bangladesh has long identified itself as one of the most vulnerable nations to climate change, facing issues such as rising sea levels, intense cyclones, salinity intrusion, and flooding that are tangible realities, not just projections. The global community largely agrees that Bangladesh should receive climate finance and international aid, and this support remains justified. However, an uncomfortable question has arisen domestically: can Bangladesh continue to claim victimhood in climate change while simultaneously relying heavily on imported fossil fuels, which make the country susceptible to economic and geopolitical shocks? Recent energy crises have brought this issue into sharper focus, highlighting the fragility of fuel-importing economies amid global disruptions, including the war in Ukraine and instability in the Middle East. Bangladesh's energy infrastructure, which relies mainly on natural gas, coal imports, and purchased electricity, is at risk of sudden cost spikes, foreign-currency shortages, and supply disruptions. This has led to load shedding, weakened industrial confidence, and strained public finances due to energy subsidies. It's clear now that Bangladesh's energy dilemma extends beyond environmental concerns.¹⁵⁶ It is strategic. Energy security and economic sovereignty are now inseparable.¹⁵⁷

Until recently, Bangladesh's renewable energy policy advanced slowly. Solar goals were modest, implementation was inconsistent, and fossil-fuel power expanded rapidly to meet rising demand. The rationale was clear: rapid industrialization needed dependable baseload power, and fossil fuels were seen as the quickest fix. However, the global energy scenario has shifted. Imported fuel is no longer reliably cheap, with exchange-rate fluctuations directly impacting electricity costs. External shocks—like shipping delays or regional conflicts—now have domestic repercussions for factories, households, and government finances. In this environment, renewable energy is being re-evaluated not just for climate benefits but as a means of economic resilience. Since 2024, the key change has been more conceptual than technological, with policymakers increasingly considering solar energy, regional hydropower trade, and energy efficiency as strategies to reduce dependence on international fuel markets.

Rooftop solar panels on factories, commercial sites, and public institutions are becoming more popular because Bangladesh has limited land for large-scale renewable parks. Urban areas, once considered a challenge, could instead be an advantage if millions of rooftops are converted into small power stations. This shift won't be easy. Bangladesh has already invested heavily in traditional power plants under long-term contracts, so many of these facilities must keep running to avoid penalties. Additionally, grid infrastructure needs upgrading before high levels of renewable energy can be integrated. Significant funding gaps exist, and private investment depends on stable regulations. Energy transitions are also political, as electricity prices directly affect voters and industrial competitiveness depends on a stable power supply. Governments need to balance reforms with social stability, making it unlikely Bangladesh will quickly abandon fossil fuels. Natural gas and nuclear power will continue to be key parts of the energy mix for years, with a gradual diversification path rather than a sudden shift. The basic components of the solar unit are illustrated in Figure 2 below.

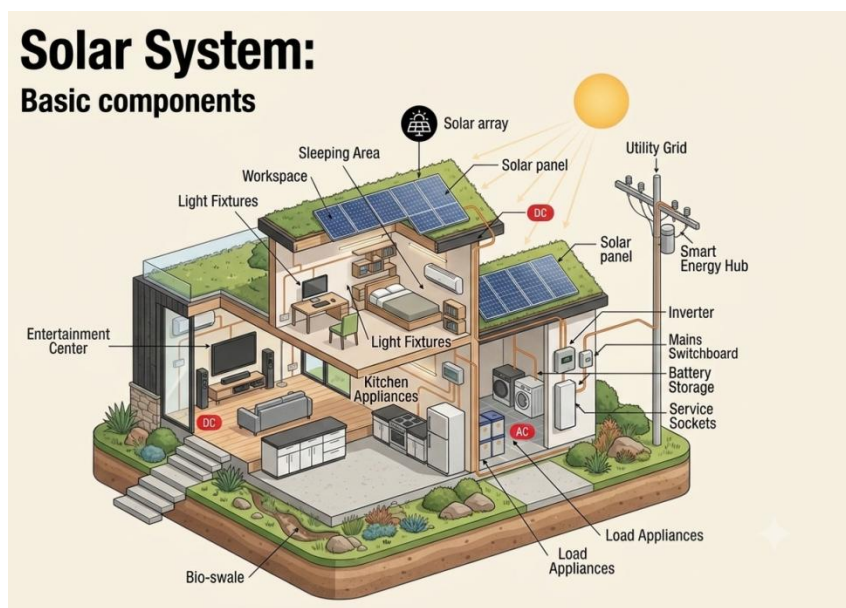


Figure 2: Sketch of basic solar PV technology

The current government in Bangladesh has a strategic opportunity to reshape its climate narrative. Instead of solely seeking compensation for damages caused elsewhere, Bangladesh could position itself as a country proactively reducing vulnerability through domestic innovation and resilience. This perspective is also significant internationally, as global supply chains are increasingly rewarding low-carbon manufacturing. Export sectors—such as garments and pharmaceuticals—will face stricter sustainability standards from European and North American markets. Cleaner electricity is now viewed as an economic advantage, not just an environmental virtue. Additionally, there is a generational aspect: Bangladesh’s young workforce will inherit an energy system built today. Relying on imported fuels poses risks, as dependence on external price cycles could hinder future growth. Investing in renewable capacity, enhancing efficiency, and regional electricity cooperation can lead to greater energy independence. Basic solar installation steps are illustrated in Figure 3 below.

The debate shouldn’t be about development versus climate responsibility. It’s a choice between dependence and resilience. Bangladesh can’t control global emissions or geopolitical conflicts, but it can influence how exposed its economy is to them. A practical energy transition—combining renewables, nuclear stability, smarter grids, and fewer fuel imports—would enhance economic security and boost its moral standing in global climate talks. Bangladesh’s leadership in adaptation has already earned international respect; leading on energy transformation could define its future role. The next decade is critical: will Bangladesh remain a victim of climate change or become a model for strategic adaptation? Solar energy offers prosperity, reliable power, and decarbonization. As a low-lying, climate-vulnerable country, we can’t delay this transition. It will help mitigate climate impacts and make the grid more resilient. Large solar projects can supply clean energy to densely populated areas, while mini-grids can power remote regions. With effective incentives and programs, Bangladesh can foster the growth of renewable energy nationwide.

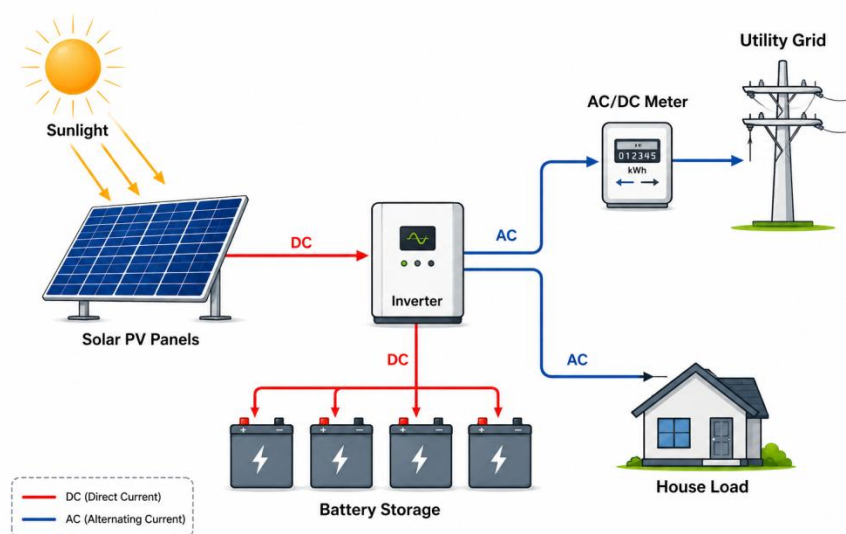


Figure 3: Basic solar installation process

As a developing country, Bangladesh's electric energy demand is rising sharply, driven by recent steady GDP growth. The Bangladesh Government has initiated several projects to address this increasing need, and new policies have been formulated to tackle challenges within the energy sector.¹⁵⁸ Bangladesh, a developing nation and the eighth most densely populated country in the world, is facing challenges in meeting the increasing demand for electricity.¹⁵⁹ Bangladesh is classified as a middle-income country with a GDP of US\$1.417 trillion, as reported in 2023. The level of energy consumption per person is closely linked to a nation's economy. As shown in Fig. 2, in 2019, Bangladesh's per capita energy use was only 344 kg of oil equivalent, which is below that of many other Asian nations. Additionally, the Bangladesh Power Development Board (BPDB) reports that natural gas supplies 68% of the country's energy demand.¹⁶⁰ In addition to natural gas, Bangladesh heavily depends on diesel, coal, and furnace oil, leading to high GHG emissions. To address the increasing energy needs and promote sustainability, it is essential to transition to renewable energy sources, as currently only 0.05% of the electricity demand is fulfilled by solar and wind power.

A recent BPDB report states that Bangladesh's annual electricity demand grows at about 10%, a figure likely to rise soon.¹⁶¹ Although around 94% of Bangladesh's urban population has access to electricity, 60% still suffer from regular load shedding.¹⁶² Therefore, solar PV systems present a viable solution for addressing the power crisis in Bangladesh. The government has initiated various projects to install PV-based systems in off-grid areas, benefiting around 20 million rural residents so far.¹⁶³ Furthermore, energy security is regarded as the key challenge for realizing Bangladesh's Vision-2041.¹⁶⁴ Most solar cells used in PV systems in Bangladesh and worldwide are silicone-based, capturing about 93% of the global market in 2016. However, their energy conversion efficiency remains unsatisfactory, with mono-crystalline silicone cells at 25.8% and multi-crystalline silicone cells at 22.3%. Therefore, the search for alternative materials for PV cells has been going on for quite some time, and perovskite solar cells, dye-sensitized solar cells, and quantum dot-sensitized solar cells are now under the attention of researchers due to their promising potential to replace conventional silicon solar cells.¹⁶⁵

Amid significant social, economic, and political pressures to resolve Bangladesh's power crisis, exploring energy solutions beyond traditional sources like gas, coal, and imported fuels has become crucial. Nuclear power, though promising, is costly, complex, and politically sensitive, with high initial costs. Depleting coal and gas reserves, coupled with environmental concerns, limit their viability. Hydropower is limited due to a lack of suitable water bodies, and biomass energy is restricted by the limited availability of organic waste. Climate change effects, such as rising sea levels and natural disasters caused by fossil fuel emissions, threaten low-lying Bangladesh. Conversely, the country receives abundant solar energy, with consistent sunlight for at least six hours daily, making solar power a highly feasible solution. Like other middle-income nations, Bangladesh faces an energy crisis driven by rapid population growth and industrialization. Solar photovoltaic (PV) systems hold significant potential to help address this crisis. This chapter offers an updated overview of Bangladesh's current solar PV energy landscape, highlighting challenges and future prospects. Studies show existing solar parks could reduce CO₂ emissions by 1.91×10^4 {1010} kg over their lifetime. There are substantial opportunities to expand solar capacity if key challenges are tackled and robust policies are implemented, such as incentives for

PV manufacturers, strict project timelines, and support for rural electrification, which are essential for maximizing solar park development.¹⁶⁶

Energy is essential for a country's progress, and Bangladesh must harness its resources. Among these, solar energy stands out as a safe and sustainable power source if produced responsibly. Solar energy is available worldwide, especially between 15° and 35° latitude north and south. Bangladesh lies between 20°43' and 26°38' north latitude, making it highly suitable for solar energy utilization. The country receives annual solar radiation ranging from 1840 to 1575 kWh/m², which is 50-100% higher than in Europe. With an average solar radiation of 1900 kWh/m², Bangladesh's total annual solar energy amounts to approximately 1010 x 10¹⁸ Joules. The current annual energy consumption is about 700 x 10¹⁸ Joules, indicating that just 0.7% of the incident solar radiation could meet the country's energy needs. Presently, Bangladesh uses roughly 0.15 watts per square meter of land, while the available potential exceeds 208 watts per square meter, highlighting the vast untapped potential of solar energy in the country.¹⁶⁷ Solar radiation in Bangladesh varies across different seasons, with an average daily value of 4-6.5 kWh/m². The monthly average solar radiation profile is presented in Figure 4.¹⁶⁸

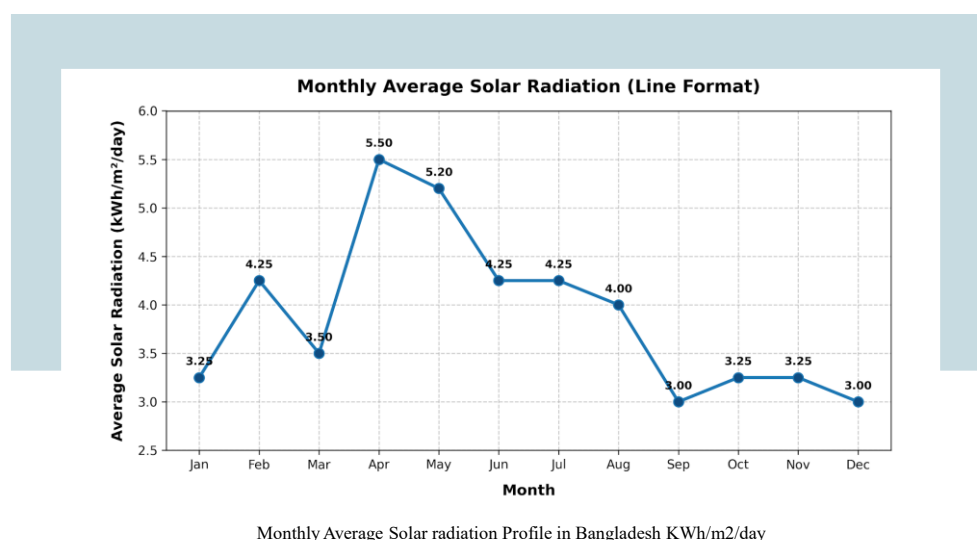


Figure 4: Monthly Average Solar radiation Profile in Bangladesh KWh/m²/day

From an economic perspective, solar energy is highly suitable for Bangladesh due to its lower cost compared to other power sources like nuclear energy. It requires only mechanical and technical assistance for power generation, and advancements in technology have significantly reduced costs. Solar energy can effortlessly supply electricity to coastal regions. Environmentally, solar power is a preferable choice over alternatives such as coal, oil, gas, and nuclear energy, which pose environmental hazards—examples include the Fukushima disaster in Japan, Chernobyl, and others. Germany's decision to shut down all nuclear plants by the end of 2020 highlights these concerns. For Bangladesh, solar power is both eco-friendly and cost-effective. Although it has some limitations, these can be addressed through new technologies, planning, and research. Regarding fuel stability, solar energy is more reliable for Bangladesh, with a potential lifespan of 20 to 25 years when properly maintained. Overall, solar power offers a high efficiency as a clean energy source, with solar cells reaching up to 30% efficiency.

Major Components and System of Solar Power System

Solar System Components. A complete solar photovoltaic system includes several essential components, with solar panels being the most crucial as they contain PV cells that produce DC electricity from sunlight. This generated power is then sent to an inverter, often called the “brain” of the system, which converts DC to AC for household use and the electrical grid. There are string inverters, which are centralized units managing multiple panels, and microinverters, installed on each panel to optimize performance at the panel level. Alternatively, power optimizers combine features of both by regulating the DC output at each panel before sending it to a central inverter for conversion.¹⁶⁹ Batteries play a vital role by storing surplus energy produced during the day for nighttime use or during grid failures, which makes them crucial for off-grid or hybrid setups. The system also includes a racking and mounting system that attaches the panels to the roof or ground, along with other balance-of-system (BOS) parts like wiring, combiner boxes, and fuses.¹⁷⁰

Types of Solar Panel. There are several types of solar panels. Solar energy collected via PV panels is central to global renewable energy efforts. These panels vary in efficiency, cost, and application, enabling users

to choose based on their energy needs and budget. The three main types are mono-crystalline, polycrystalline, and thin-film solar panels, each with distinct features affecting their performance and suitability. Mono-crystalline panels, with efficiency rates between 17% and 22%, are designed for maximum energy conversion. They feature a sleek black look and compact form, ideal for residential and commercial rooftops where space matters. They also tend to be highly durable with warranties often exceeding 25 years. Although their manufacturing costs are higher and more resource-intensive, their performance and durability offer significant long-term value. Figure 5 below illustrates different types of solar panels (created with AI assistance).

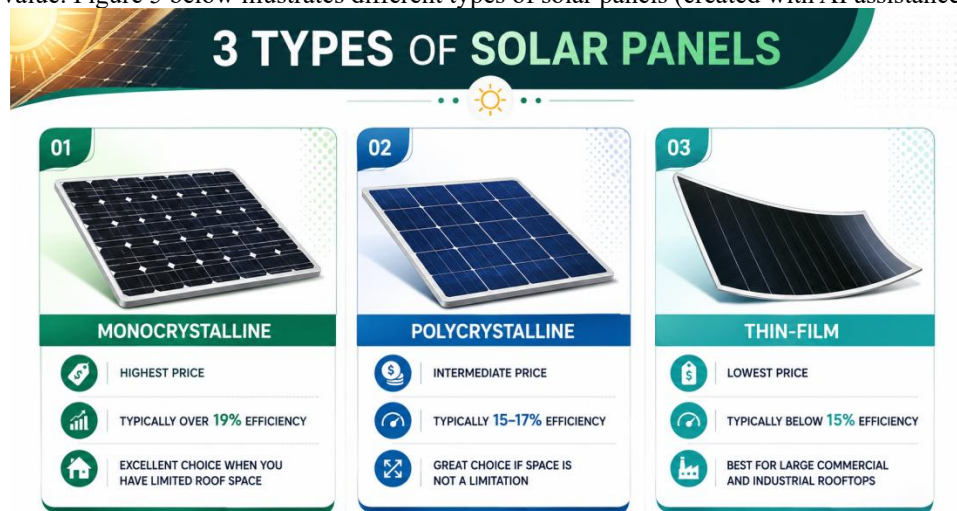


Figure 5: Different types of solar panel

In Bangladesh, only a limited variety of solar panels are available. Solar energy obtained through PV panels is a key part of global renewable energy strategies. Various types of solar panels have different efficiencies, costs, and uses, enabling users to choose according to their energy requirements and budget. The three most common types are monocrystalline, polycrystalline, and thin-film solar panels, each with distinct features affecting their performance and suitability for different environments. Monocrystalline panels are designed for the highest energy conversion rates, generally between 17% and 22%. They are recognizable by their sleek black look and compact form, making them suitable for residential and commercial rooftops where space is limited. These panels are also highly durable, often backed by warranties of 25 years or more. Although they are more costly to produce and resource-intensive, their superior performance and durability offer significant long-term value.¹⁷¹ Polycrystalline panels are made by melting together multiple silicon crystal fragments, giving them a distinctive blue, speckled look. They typically have efficiencies ranging from 13% to 17%. Their simpler manufacturing process lowers costs, making them popular among budget-conscious buyers and suitable for large installations with plenty of space. Although they are slightly less effective at high temperatures and have a marginally shorter lifespan, they remain a dependable and affordable option. Thin film solar panels are constructed by depositing layers of PV material onto flexible substrates, allowing versatile installation on curved or unusual surfaces. While their efficiency usually falls below 12%, they perform well in diffuse and shaded light conditions. They are the least costly to produce and lightweight but require more space for the same power output and tend to have a shorter lifespan and lower durability compared to crystalline panels. The fundamental components of a solar power system are illustrated in figure 6 below.

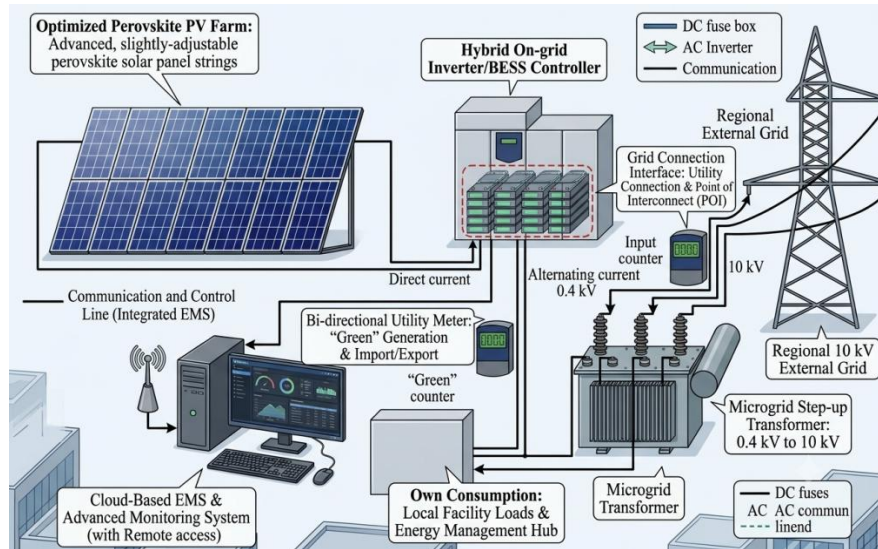


Figure 6: Basic components of solar power
Solar System Installation and Investment Process

Solar System Installation

Setting up a solar power system involves more than installing panels. It requires various interconnected parts that work together to capture sunlight and turn it into electricity. Whether you are designing an off-grid, on-grid, or hybrid system, understanding each component is essential for a safe, efficient, and durable solar energy solution. Figure 7 below illustrates a schematic of the solar photovoltaic (PV) installation process.

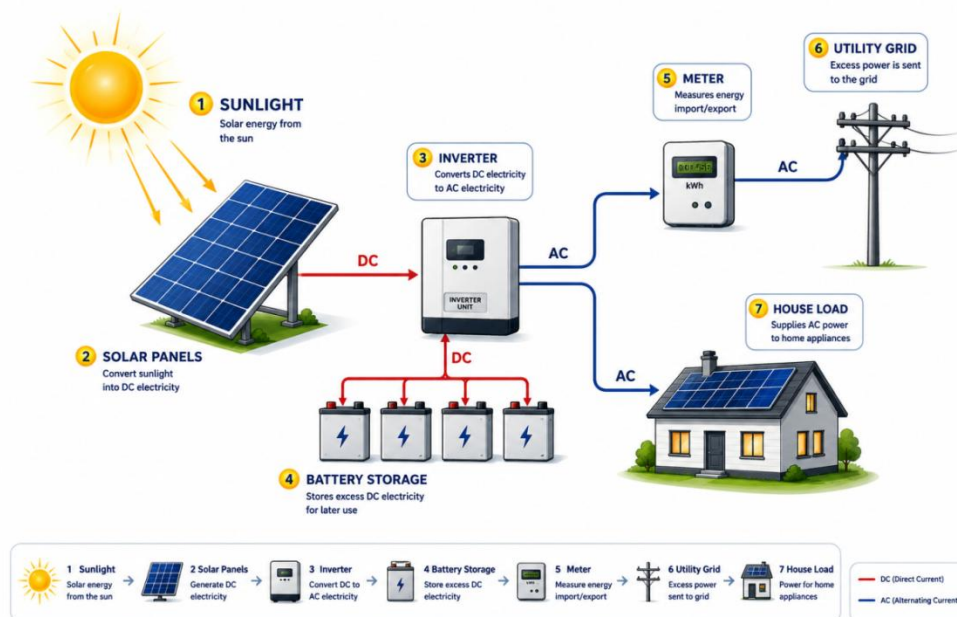


Figure 7: Basic installation process

a. Stand-alone Solar System

Installing Solar Systems is simple but demands precise technical execution to maximize energy production and ensure long-term reliability. EPC developers begin by qualifying customers. System sizing is based on essential loads, such as basic lighting, fans, device charging, and other electrical requirements, ensuring the system's capacity aligns with these needs. EPC technicians then install the mounting structure, choosing a design suited to the specific roof type, whether it be a concrete slab, corrugated roofing, or other surfaces, and secure it firmly to prevent movement and hold the panels securely. A detailed workflow for installing a stand-alone solar PV system is illustrated in Figure 8 below. The various types of standalone solar PV systems are also described.

- Roof-Mounted: Ideal for residential rooftops.
- Ground-Mounted: Useful for large-scale or rural installations with ample space.
- Pole-Mounted: Allows panel tilt adjustment; ideal in certain terrains and street lighting.

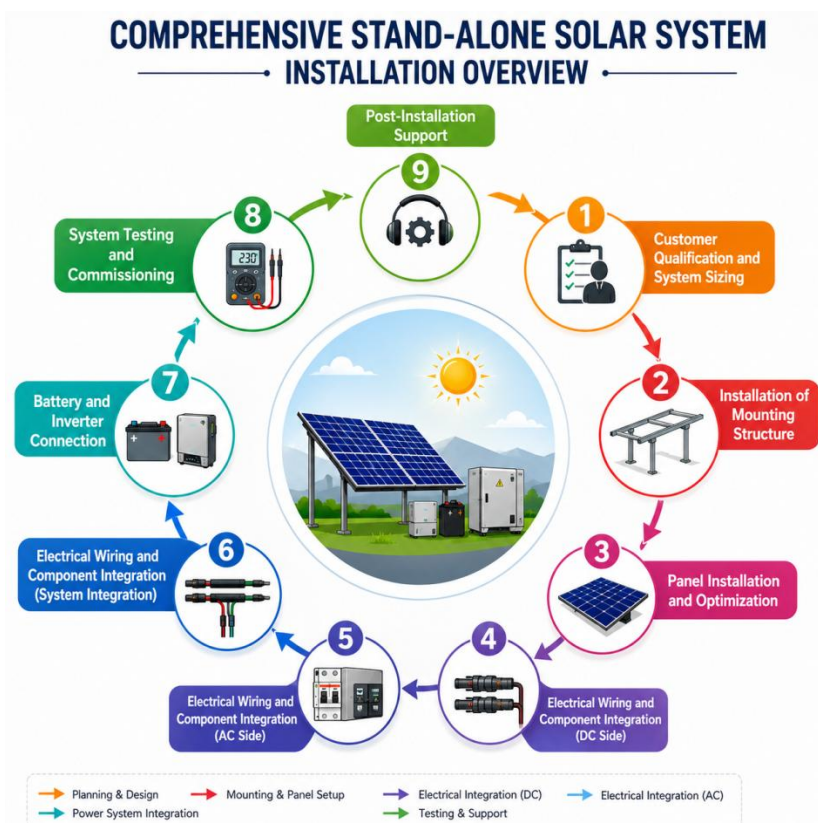


Figure 8: Comprehensive workflow of a stand-alone solar PV system installation

Installation of Different Components. The PV modules are securely mounted to the structure, with precise alignment and the correct tilt angle crucial for maximizing solar irradiation and ensuring efficient electricity generation by converting sunlight into DC power. To transform this DC electricity into usable AC power for homes or businesses, various inverters are employed. Solar batteries store excess energy generated during the day for nighttime use or emergencies, guaranteeing a continuous supply, especially in off-grid or hybrid systems. Commonly used batteries include Lithium-ion, which are compact, efficient, and long-lasting, and Lead-acid, which are more affordable but larger and require maintenance. The charge controller manages voltage and current from the panels to the batteries, preventing overcharging and protecting against voltage fluctuations and surges. There are two main types: PWM (Pulse Width Modulation), suitable for small, low-cost systems, and MPPT (Maximum Power Point Tracking), which is more advanced, efficient, and ideal for larger setups requiring higher energy conversion.

Electrical Wiring and Component Integration. The electrical wiring links the solar array to the charge controller, which is crucial for managing the current flow into the battery bank. In systems that operate independently of the grid, the integrity of the wiring is essential for safety and efficiency. The Junction Box serves as a key safety component, connecting multiple solar panels and organizing wiring within a protected enclosure. DC/AC cables and wiring are critical for system integration; using high-quality, solar-rated cables ensure efficiency and safety. Properly rated cables reduce energy loss, prevent overheating, and improve overall system reliability. MC4 Connectors, standardized and waterproof, connect solar panels securely and efficiently, enabling faster installation and greater resistance to moisture, dust, and faults. An earthing kit and lightning arrester protect the system from electrical surges and lightning strikes. Nowadays, monitoring systems provide real-time data, allowing users to analyze energy output, quickly detect faults, and optimize energy use. Lastly, the AC breaker or distribution box manages, controls, and protects the inverter's AC output, ensuring safety, stability, and adherence to electrical standards.

Today, in on-grid solar systems, the net meter is essential for measuring the amount of electricity exchanged between the solar system and the national grid. It tracks both energy consumption from and supply to the grid, enabling users to benefit from net metering. This system credits excess generated power against the electricity bill, encouraging cost savings and efficient energy use. Proper connection of the battery to the DC storage and the inverter is crucial: the negative wire from the panel connects to the inverter's negative terminal, and the positive wire to the inverter's positive terminal. A system check follows to verify power generation, where the EPC technician tests the system output (kWp) and confirms reliable battery charging. However, maintaining these systems in rural areas requires ongoing support, with EPC providers offering after-sales services for maintenance and user confidence. Successful solar installation depends on integrating all components

seamlessly—from capturing sunlight and storing energy to distributing and monitoring electricity safely. Every part, from panels to protection devices, influences the system’s reliability and performance. Various EPC providers in Bangladesh use high-quality components certified by IEC and TÜV standards to ensure maximum efficiency, durability, and safety. Whether for homes, offices, factories, or government institutions, investing in solar power is a smart, sustainable, and future-ready choice. The key components of the Solar System are illustrated in Figure 9 below.

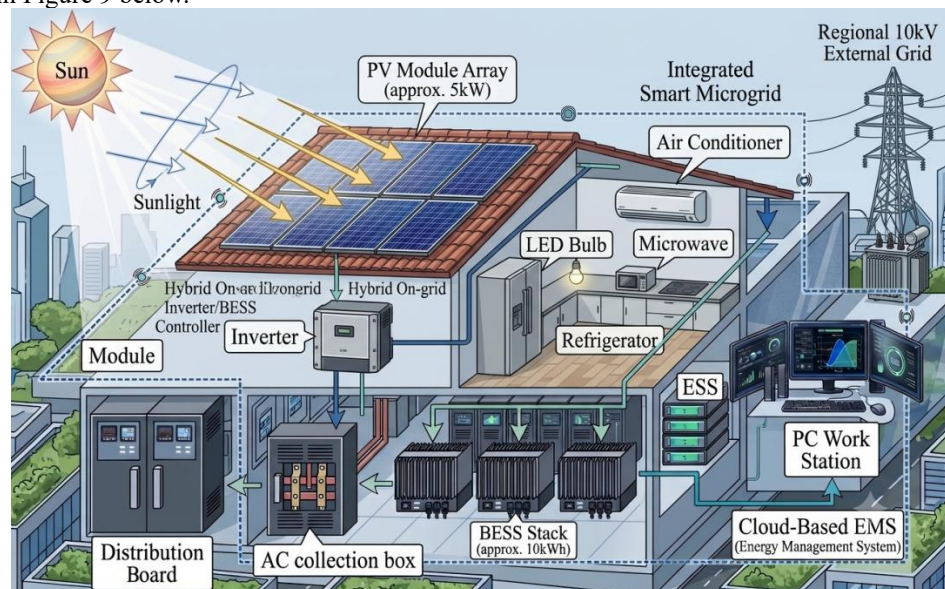


Figure 9: Elements of the Solar System

b. Grid-tied Solar Systems

The Grid-Tied Industrial/Commercial Net Metering process is subject to strict regulations to ensure grid stability and encourage responsible private investment. It is mainly used by industrial and commercial entities. An off-grid solar PV system and a schematic diagram of a unit package (with AI assistance) are shown in Figure 10 below. Setting up a grid-tied solar system requires several key steps.

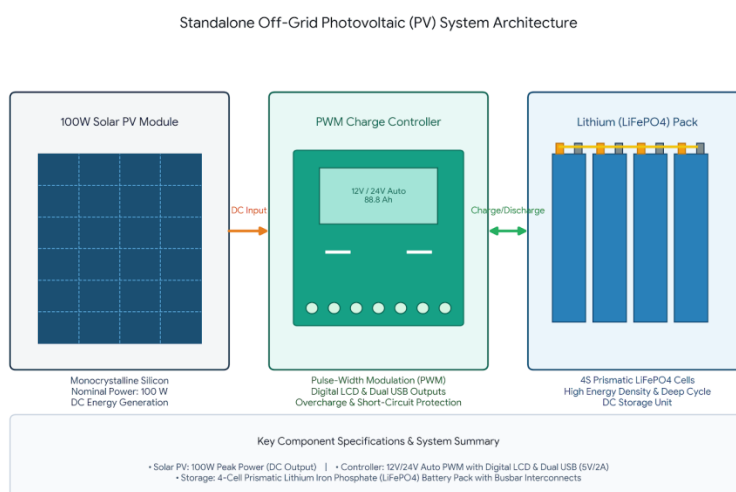


Figure 10: Schematic figure of the unit package

Initial Regulatory and Eligibility Assessment. The Net Metering Guideline of 2025 allows the installation of rooftop solar PV systems on industrial, commercial, and residential buildings. Owners can offset their demand, cut fuel costs, and store excess electricity on the grid. To participate in the scheme, the consumer must be a three-phase user with a sanctioned loads over 7 kW, which mainly limits residential participation to large users and targets large commercial and industrial consumers. Additionally, the solar PV system capacity must not exceed 70% of the sanctioned load to prevent reverse power flow and ensure grid stability. Despite these restrictions, the installation process for grid-connected solar systems is as straightforward as that for stand-alone solar systems.

Net-metering Process Flowchart. Solar system design calculation is essential before setting up the solar installation. There are a few key solar calculators available on the net, as mentioned below.

- Rooftop Solar Calculator.¹⁷²
- System Calculator.¹⁷³
- Net Metering Calculator for Initial Assessment of Rooftop Solar.¹⁷⁴
- Solar Inter-Row-Spacing Calculator.¹⁷⁵
- Location-wise solar panel calculator.¹⁷⁶

Investment in Solar Systems Installation

A typical 1 MWp DC rooftop solar system provides a dependable source of renewable energy for commercial or industrial buildings. Installation costs range from about 39.5 to 40 million BDT, mainly financed through an 80% debt loan at 5% interest over 8 years. The system produces approximately 1.2 million kWh annually, with the electricity tariff starting around 7.9 BDT/kWh and gradually rising. Over its lifetime, it reduces reliance on grid electricity via savings and earns additional income from carbon credits. The investment breaks even in roughly five years, with an IRR of 14.5% and an ROI of about 14.16%. Environmentally, the system reduces greenhouse gas emissions by decreasing fossil fuel use, aiding climate change mitigation and improving urban air quality. It promotes energy independence and decreases transmission losses by generating power onsite. Throughout its lifespan, it prevents significant CO₂ emissions, equivalent to planting hundreds of trees, showcasing economic and ecological benefits. These installations are especially advantageous in urban areas like Dhaka, supporting Bangladesh's renewable energy and climate goals. A schematic illustration of wide-scale home solar system integration, assisted by AI, is shown in Figure 11 below. The main steps for installing and investing in solar systems are outlined below.

a.Startup Business Module.As is well known, industrial projects must establish a solid legal foundation before working with distribution utilities.

- Company Incorporation: The initial step for investors is to register the business as a legal entity, usually a Private Limited Company, with the Registrar of Joint Stock Companies and Firms (RJSC). This step establishes the formal ownership, liability, and governance structure.
- BIDA Registration: After incorporation, the investment project must register with the Bangladesh Investment Development Authority (BIDA). BIDA registration is essential for gaining recognition, obtaining important licenses, and qualifying for government investment incentives.
- Environmental Assessment: The need for initial environmental clearance from the Department of Environment (DoE) depends on the project's size and type, and is intended to ensure compliance with environmental conservation regulations throughout all project phases.

b. Technical Application and Utility Clearance. During this stage, the grid interconnection application is submitted to the local Distribution Utility, which serves as the official approval authority.

- Application Submission: The applicant officially submits the necessary application, system checklist, and draft contract forms for Net Metering to the appropriate Distribution Utility office (such as DPDC or DESCO).
- Technical Design Submission: Please ensure that you provide comprehensive engineering documentation, including a clear and detailed description of the components and the Single Line Diagrams (SLDs) tailored to the specific voltage level of the consumer.
- Utility Review and NOC Issuance: The utility evaluates the technical submission for compliance and feasibility. If approved, a No Objection Certificate (NOC) is issued, which SREDA enables users to verify online.

c. Installation, Inspection, and Commissioning. This phase involves physically deploying the system using certified components, followed by integration and final sign-off by the utility.

- Procurement: All essential components, particularly panels and inverters, must be obtained from SREDA's Approved Products List and adhere to Bangladesh Standards (BDS).
- Structural and Electrical Installation: Installation starts with securing the mounting structure, then installing the panels at the proper angle. Electrical setup involves connecting the string output to the grid-tied inverter input. Safety measures dictate that the inverter must stay off during these connections.
- Grid Connection and Metering: The inverter's output connects to the main switchboard, supplying power to the facility and allowing energy export to the grid. The Distribution Utility is tasked with installing the bi-directional metering device, which is essential for measuring energy flow for net metering billing.
- Utility Inspection and Final Clearance: Utility officials perform a mandatory site inspection to confirm the installation matches the approved SLDs and component lists, ensuring safety protocols are followed.
- Commissioning and Synchronization: After a successful inspection, the system is officially commissioned. The utility signs the net metering contract, and the system is synchronized with the national grid, starting its operation.

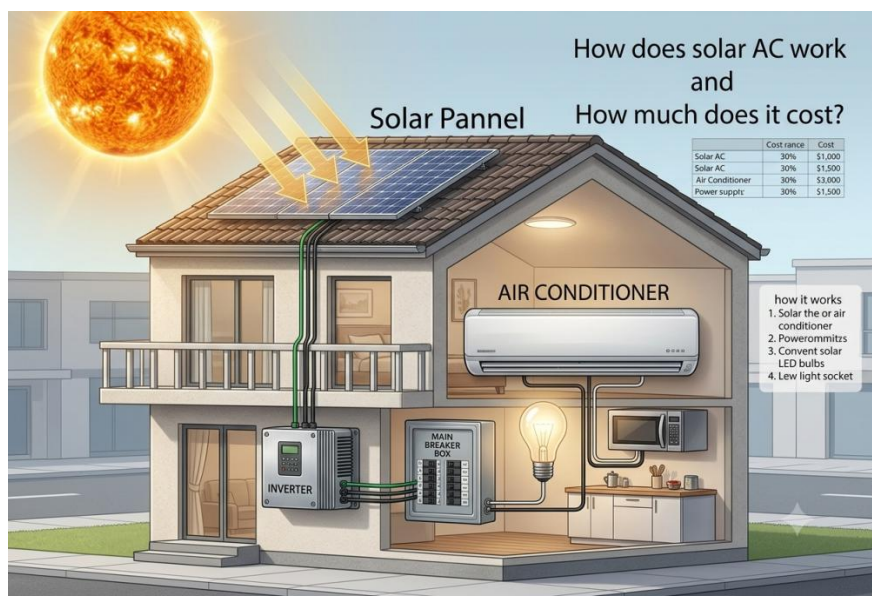


Figure 11: Extensive use of the solar system in the home

Solar power is the leading and most affordable technology driving Bangladesh's urgent need for clean, reliable energy. The country aims to generate 40% of its electricity from renewable sources by 2041. Economically, new solar installations in Bangladesh are already competitive with imported fossil fuels, providing stable, long-term savings and strengthening national energy security across various sectors. Solar panels, or Photovoltaic (PV) panels, convert sunlight into electricity. They operate by transforming photons into electrons using a silicon-based material. PV panels do not require direct sunlight; they only need daylight. The more daylight they receive, the more electricity they produce. PV panels are relatively easy to install and require minimal maintenance. Their costs have significantly decreased over the past decade, making them a highly cost-effective renewable energy option. A typical PV system can reduce homeowners' energy bills by up to 70%, depending on location-specific factors.¹⁷⁷ This solar power generation involves two main technological approaches: Photovoltaic (PV) technology and concentrating solar-thermal power (CSP). The PV technology is illustrated in Figure 12 below.

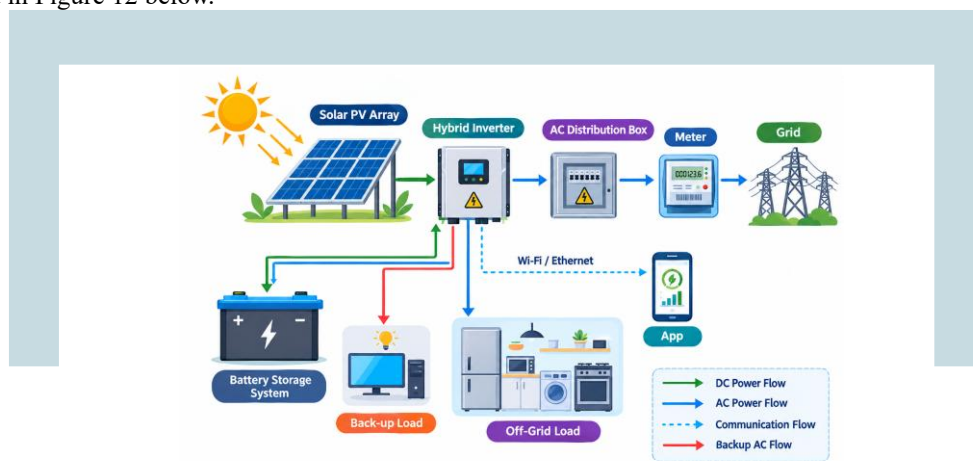


Fig: Solar Photovoltaic (PV) System Configuration

Solar Photovoltaic (PV) technology

Figure 12: Solar Photovoltaic (PV) technology

Photovoltaic technology, commonly used in rooftop solar panels and large-scale solar farms, convert sunlight directly into electricity through semiconductor materials. This direct conversion makes PV systems highly versatile and suitable for applications ranging from small residential setups to large-scale utility power plants. In contrast, concentrating solar-thermal power systems utilize mirrors to reflect and focus sunlight onto receivers, which then convert the solar energy into heat. This thermal energy is subsequently used to generate electricity, often by heating a fluid to drive a turbine. This process is illustrated in Figure 13 below. While both technologies harness solar radiation, PV has become the more widespread and recognizable method for most installations due to its direct, modular nature.

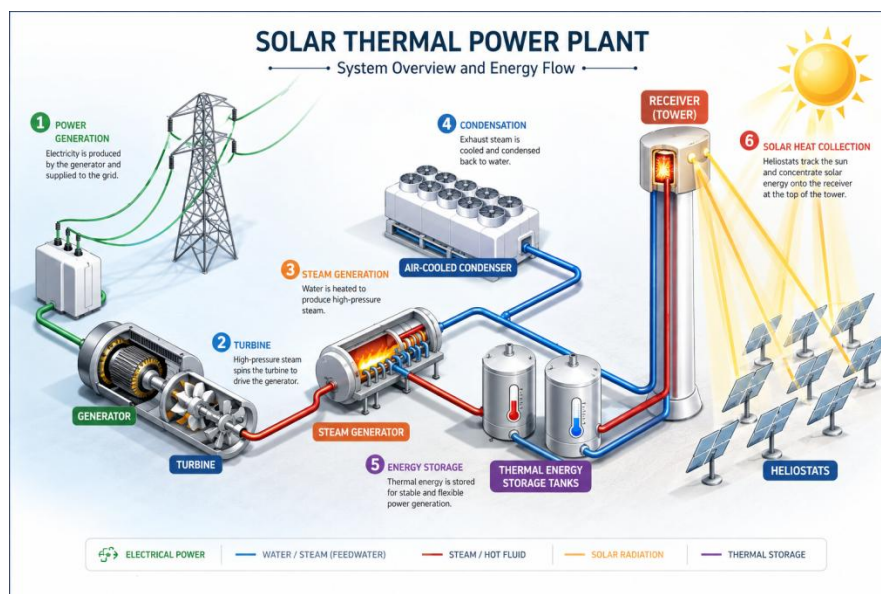


Figure 13: Solar-thermal power systems

Present Commercial Solar PV-Technology and Deployment in Bangladesh

Bangladesh's large-scale commercial Solar PV development began in 2003 with the Rural Electrification and Renewable Energy Development Project (RERED), primarily through the Solar Home System (SHS) program. Its goal was to deliver basic electricity to households and communities in rural and remote areas outside the national grid. Supported by financial and institutional backing from the Infrastructure Development Company Limited (IDCOL) and partners, the SHS program became a major renewable energy effort in Bangladesh. What began as a rural electrification initiative gradually transformed into a broad commercial ecosystem involving manufacturers, distributors, installers, financial institutions, technical service providers, and end users.

The success of the SHS program demonstrated that decentralized renewable energy systems can reliably supply electricity to populations outside the reach of traditional grid infrastructure. Gradually, the country shifted its focus from small household systems to more productive applications and larger-scale commercial and utility Solar PV projects.¹⁷⁸ Bangladesh's Solar PV development can be broadly divided into key application areas listed below. Each area has unique technical, economic, and operational features. Their long-term viability relies on proper system design, technology choice, financing options, operation, maintenance, and a supportive regulatory framework.

- SolarMinigrid
- SolarIrrigationSystems
- SolarStreetandSecurityLighting
- RooftopSolarPVsystemunderNetMeteringPolicy
- Utility-scaleSolarPowerPlants
- SolarHomeSystemsandOff-gridSolar
- HybridSolar SystemsandBatteryEnergyStorageSystems(BESS)

a. Solar Mini-grid: An Alternative for Remote and Off-grid Areas

Solar mini-grids have been crucial in delivering electricity to Bangladesh's remote regions where extending the national grid has been both technically challenging and costly. Numerous systems have been established in isolated char areas, islands, coastal communities, and other hard-to-reach locations. According to IDCOL, several Solar Mini-grid projects with a total capacity of several kilowatts have been implemented, supplying power to thousands of households and small businesses. A key benefit of solar mini-grids is their ability to offer fairly reliable electricity to communities that are difficult to connect to the main grid. In addition to household use, these mini-grids also support shops, small enterprises, educational facilities, and other productive activities.¹⁷⁹

Today, individuals can install solar power plants ranging from 1 kW to 1MW on land or rooftops. Installing net-metering at these sites links the system to the grid through the national electricity board or distribution

companies. Additionally, there is a 30% to 70% subsidy on solar panels for residential, institutional, and nonprofit organizations. The cost of a 1MW solar power plant in Bangladesh is approximately Taka 4 crore. Building a 1MW solar plant in Bangladesh costs between Taka 40 million (4 crore) and Taka 78 million (7.8 crore) for rooftop installations, whereas land-mounted systems typically cost twice as much or more, ranging from Taka 100 million to 150 million (10-15 crore), depending on land acquisition and infrastructure requirements. This research was presented during a seminar titled “Possibilities of solar energy and reality of land availability in Bangladesh” on Wednesday.

The Bangladesh Environmental Lawyers Association (BELA) and the Coastal Livelihood and Environmental Action Network (CLEAN) convened a seminar at the YWCA auditorium in the capital, where speakers discussed the potential of solar power. They highlighted that Bangladesh aims to achieve 100% renewable energy by 2050, though current progress stands at only 3%. Solar energy is presented as a promising solution for this challenge. A study indicated that 3,388 acres of unallocated government land in Dhaka Division could support ground-mounted solar plants capable of generating around 1,367 MW—covering 26% of the current energy demand. Moreover, utilizing just 10% of the water bodies in Dhaka Division's 148,235 acres could support a 5,985 MW floating solar plant, which could meet the entire energy requirement.

Research explores the potential to meet the country's electricity needs by utilizing Khas land, reservoirs, and the roofs of multi-storied buildings. During the seminar, speakers discussed various aspects of establishing solar power plants on these sites across the country. They acknowledged several challenges in installing solar plants on reservoirs but suggested that these can largely be overcome by empowering relevant government agencies. The role of policy-making was also emphasized. Additionally, the potential of both solar and wind power was highlighted. One speaker mentioned that achieving 100% renewable energy by 2050 is feasible if the conventional belief that space constraints prevent the development of solar plants is reconsidered. The seminar was attended by representatives from the Bangladesh Power Development Board, the Sustainable and Renewable Energy Development Authority, Palli Bidyut, and the Department of Environment, as well as private organizations, researchers, and academics. It is estimated that 10,779 MW of solar power could be generated by utilizing just 10% of Dhaka's rooftops.

- 'Solar energy can be one of the solutions to achieve this huge renewable energy target'
- Great opportunities for electricity generation from renewable energy on paddy fields, reservoirs, and rooftops
- Research has revealed that 10,779 megawatts of solar power can be generated on 10% of roofs in the Dhaka division.
- The research also showed strong opportunities for renewable electricity generation on paddy fields, reservoirs, and rooftops.

Solar mini-grids encounter several obstacles. A major long-term challenge is their sustainability when the national grid expands into areas previously served by these mini-grids. Since grid electricity often costs consumers less than power from off-grid mini-grids, users might gradually switch to the national grid. This decline in demand can threaten the financial viability of mini-grid projects. The ultimate goal should be to evolve mini-grids from basic electricity distribution systems into comprehensive local energy platforms. Consequently, future mini-grid development needs careful consideration:

- Potential future expansion of the national grid
- Grid-compatible business models
- Productive-use applications
- Agricultural and commercial loads
- Cold storage and agro-processing
- Potential future interconnection with the national grid.

b. Solar Irrigation: Opportunities, Installation and Challenges in Agriculture

Agriculture plays a vital role in Bangladesh's economy, with irrigation crucial to maintaining productivity, especially during the dry season. Historically, the country has relied heavily on diesel and grid-powered pumps. However, during electricity shortages and load shedding, irrigation can be interrupted, and frequent power outages can disrupt electric pump operations. Solar irrigation pumps offer a promising alternative, helping to decrease reliance on diesel and grid electricity while providing reliable daytime power for irrigation.¹⁸⁰ IDCOL has implemented numerous Solar Irrigation Pump projects as part of its renewable energy initiative, benefiting many farmers. However, solar irrigation encounters several challenges. Despite its promising potential, it faces technical and economic hurdles. The key issue is seasonality, with irrigation needs peaking only during certain months. Consequently, Solar PV systems often remain underutilized for the rest of the year.¹⁸¹ In certain cases, the choice of unsuitable

equipment and poor system design can cause a Solar Irrigation system to fail earlier than anticipated. Other challenges are listed below.

- Incorrect systemizing
- Poor-quality pumps and controllers
- Inadequate solar resource assessment
- Improper hydraulic design
- Lack of preventive maintenance
- Insufficient technical support
- Changing groundwater levels
- Lack of local spare parts and service facilities

As an agricultural nation, Bangladesh relies on irrigation. Specifically, 98% of the 11 million hectares used for rice cultivation depend on irrigation. During dry seasons, approximately 336,000 pumps are utilized for this purpose.¹⁸² In Bangladesh, numerous villages lack access to the main grid, with approximately 50% of the population living off-grid.¹⁸³ As a result, most irrigation is done with diesel generators. About 1.2 million diesel-operated pumps require 800 million liters of imported diesel per year. As global petroleum prices rise, this irrigation system becomes too expensive for farmers. So, it is important to explore alternative energy sources for irrigation to ensure both food and energy security. In this context, solar irrigation pumps have tremendous potential, especially to reduce dependence on diesel, an expensive liquid fuel. Solar-Powered Irrigation System: This irrigation system does not require highly sophisticated materials. Solar panels and solar submersible pumps are the main parts of this system. A solar panel produces electrical energy by using sunlight.

This energy powers the pumps used for irrigation, but it is on a small scale. A practical alternative is a microgrid system, in which small, standalone grids supply power to rural areas from a central station. These stations can be entirely solar PV or a hybrid of solar PV and diesel.¹⁸⁴ The proposed program aims to install 10,000 solar irrigation pumps across the country, replacing diesel-powered pumps. An 8 kW pump can lift 500,000 liters of water daily under average local solar conditions of 4.5 kWh/m²/day. This technology has the potential to lower irrigation costs and save foreign currency. Therefore, solar irrigation should be viewed as part of a broader Solar Agriculture Energy Platform rather than merely a water-pumping system. Figure 14 below illustrates a surface pump system powered by solar energy. When irrigation demand is low, excess solar electricity could be used for other agricultural needs. Such an integrated approach can enhance asset utilization and the financial sustainability of solar irrigation projects.

- Agricultural processing
- Crop drying
- Cold storage
- Rice milling
- Dairy and poultry operations
- Electric Vehicle Battery charging
- Grid integration facility under Net Metering Policy

Solar pump irrigation (SPI) has become more popular in Bangladesh as a sustainable alternative to traditional diesel and grid-powered pumps. This change is driven by the desire to improve energy security, cut greenhouse gas emissions, and lessen the environmental impact of irrigation. However, expanding solar pump use faces several hurdles, including high upfront costs, a shortage of technical expertise, slow progress toward government goals, ongoing infrastructure needs, weak policy support, and concerns about water scarcity and climate change. Addressing these issues proactively can help Bangladesh boost agricultural output, adopt eco-friendly practices, and move toward a more sustainable and greener future.¹⁸⁵

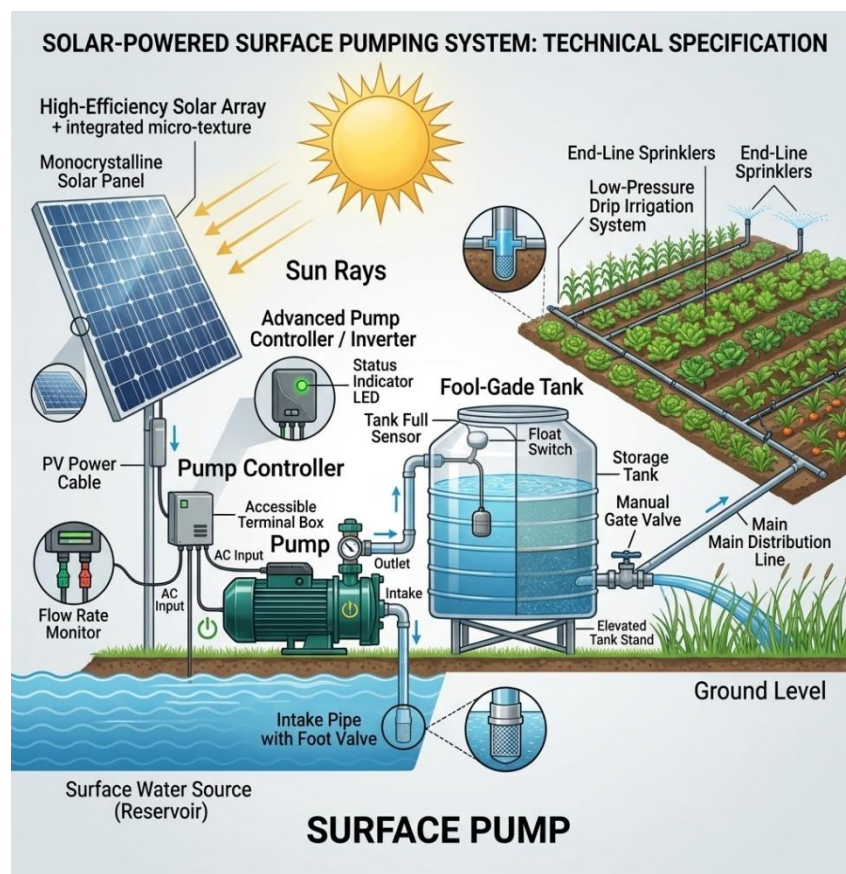


Figure 14: Solar irrigation system with surface pump powered by solar energy

c. Solar Street and Security Lighting

Solar Street Lighting has emerged as a prominent use of Solar PV technology in Bangladesh. These systems are suitable for rural roads, markets, schools, highways, industrial zones, public spaces, and security-critical sites. The key benefit of Solar Street Lighting is that each light can operate independently of the national grid, reducing the need for grid extensions and lowering infrastructure costs. Nevertheless, the long-term success of many Solar Street Lighting installations can be influenced by:

- Battery degradation
- LED failure
- Charge controller failure
- Poor-quality components
- Insufficient battery capacity
- Inadequate solar panel cleaning
- Poor maintenance practices
- Corrosion of mechanical structures

d. Solar LED Street light

Solar energy can play a vital role in street lighting. In the country, 11 City Corporations oversee approximately 5000 km of streets. The traditional lighting systems used are inefficient and consume more electrical power. Implementing solar PV LED (light-emitting diode) street lighting can reduce reliance on conventional power sources. These systems typically feature solar panels of 100 Wp, 75 Wp, and 40 Wp, which should be installed correctly to maximize sunlight absorption. During the day, the lead-acid batteries are charged with solar energy. A microcontroller manages various functions, such as switching, driver control, and sensor integration. Since the system relies on DC power, a DC-to-AC converter is necessary for the LED operation. Based on ADB's preliminary assessment, LED systems of 40 W, 30 W, and 15 W can be used. LEDs are highly efficient, have long lifespans, and operate at low voltage, making them suitable for solar applications. Approximately 33 LED units are needed to light up 1 km of street.¹⁸⁶ This street lighting system maintains functionality by reducing electricity consumption from the power grid. The system's circuit diagram for solar street lighting is illustrated

in Figure 15. When evaluating Solar Street Lighting projects, the focus should not be solely on the initial installation cost. Instead, consider the total life-cycle costs and the system's long-term dependability. A well-designed Solar Street Lighting system should include:

- High-quality Solar PV modules
- Longlife-cycle battery technology
- Appropriate charge controllers
- Proper lighting and energy calculations
- Adequate battery autonomy
- Robust mounting structures
- Preventive maintenance
- Long-term performance monitoring

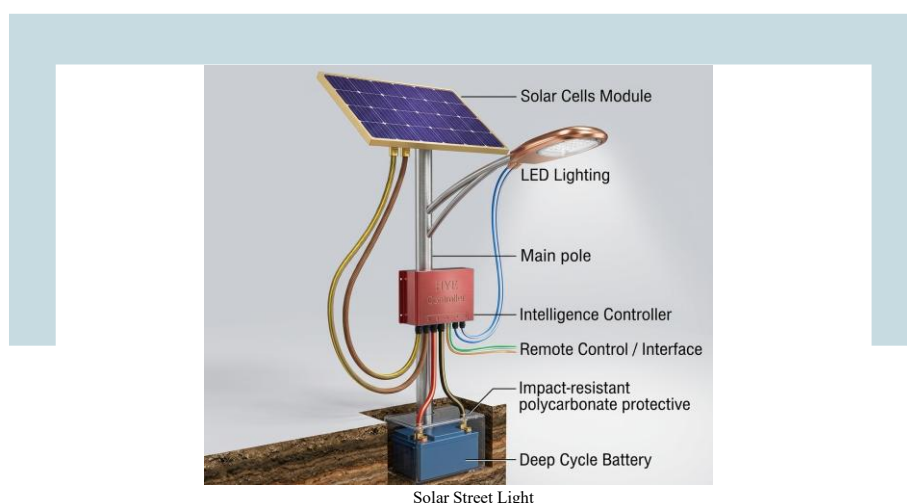


Figure 15: Solar Street Light

e. CSP (Concentrating Solar Power)

Concentrating Solar Power (CSP) is an emerging power-generation technology that harnesses direct normal irradiance (DNI) by concentrating sunlight to achieve temperatures between 400°C and 1000°C, used to produce steam in solar thermal power plants. Since the 1960s, CSP has been employed in large-scale solar power facilities. It uses lenses or mirrors, combined with tracking systems, to focus sunlight onto a small target area. The concentrated solar energy is then directed either onto high-efficiency photovoltaic cells or onto a heat transfer medium, similar to conventional thermal power plants.¹⁸⁷ The steam produced is in turn used to rotate a turbine coupled to an electric power generator. CSP systems work best at about 5.5kWh/m²/day. Currently, the cost of generating power with CSP technology is around 15-23 BDT per watt.¹⁸⁸ Some concentrating technologies even offer storage facilities, since normal operation at night time is not possible. Bangladesh receives an average annual DNI of nearly 1,900kWh/m² which is sufficient to operate a CSP plant. Studies show that by 2015, the capital cost of a CSP plant will be \$3800/kWe.¹⁸⁹ Because CSP requires no fuel, it can be an attractive option for mitigating Bangladesh's power crisis. Based on the process of collecting and concentrating solar radiation, CSP can be categorized into four major technologies: i) Parabolic Trough, ii) Solar Tower or Central Receiver, iii) Parabolic Dish, and iv) Linear Fresnel Reflector (LFR).

f. Solar Powered Vehicle

Solar energy can be highly beneficial for use in various small vehicles, such as e-bikes and rickshaws. The solar panel used in the solar vehicle has a rating of 140 Wp. However, the solar panel rating should be adjusted to meet the requirements. The solar panel should be positioned properly to maximize sunlight.¹⁹⁰ Multicrystalline cells are preferred over monocrystalline cells in solar-powered vehicles. The solar module installed on the car's roof charges the batteries through a charge controller. The output voltage of the 140 WP solar modules ranges from 24V to 25 V.¹⁹¹ The batteries start fully charged and are then connected to the solar module to maintain their charge. This process is necessary because the solar module's efficiency is only 15%, so the battery takes 3 to 3.5 hours to recharge under these conditions. The stored energy powers vehicles. Recharging an Easy-bike in Bangladesh requires about 300-500 MW of power. This technology can significantly save this large amount of electrical energy. Currently, around two million (or twenty lakh) people in the country earn their livelihoods as rickshaw pullers.¹⁹² The transport sector contributes 34% of Bangladesh's GDP, and the rickshaw sector is a

major part of that.¹⁹³In our country, rickshaws come in manual and electric-powered versions. The Bangladesh government has banned the import and assembly of electric motorized rickshaws due to their high power consumption of 300 MW daily from the national grid. Introducing solar-powered rickshaws could help conserve this energy. A solar rickshaw costs around BDT 80000 (with 1 USD equal to 79 Taka). A rickshaw puller can earn approximately BDT 1,000 per day. Since solar vehicles like e-bikes and rickshaws are eco-friendly and relatively easy to produce, utilizing solar energy is essential for conserving non-renewable resources.

g. Solar Home Systems with Off-grid Solar

Solar power systems deserve long-term power systems deserve serious consideration. There are two types of residential solar installations like grid-tied and off-grid systems. Each configuration offers distinct advantages and limitations. Off-grid solar systems operate completely separately from the utility power grid, and relying completely on solar energy. These installations provide complete self-sufficiency and that involves greater complication and higher costs than grid-connected alternatives. Here necessary components include; Solar charge controller, Battery bank, Off-grid inverter, Backup generator as optional item. Off-grid solar systems function by producing energy from solar panels and charging a battery bank via a charge controller. This controller protects the batteries from overcharging whereas managing electricity storage. The stored electricity undergoes conversion into AC current through an off-grid inverter, and making it suitable and useful for powering of our home. The battery storage component allows our home to operate completely on solar power, regardless of time and weather conditions.¹⁹⁴ However, if our location doesn't receive consistent sunlight throughout the year, we might require additional battery capacity or potentially and a backup generator to compensate for uninterrupted days with inadequate solar contact. A model of a basic house solar system has been shown in Figure16 below.

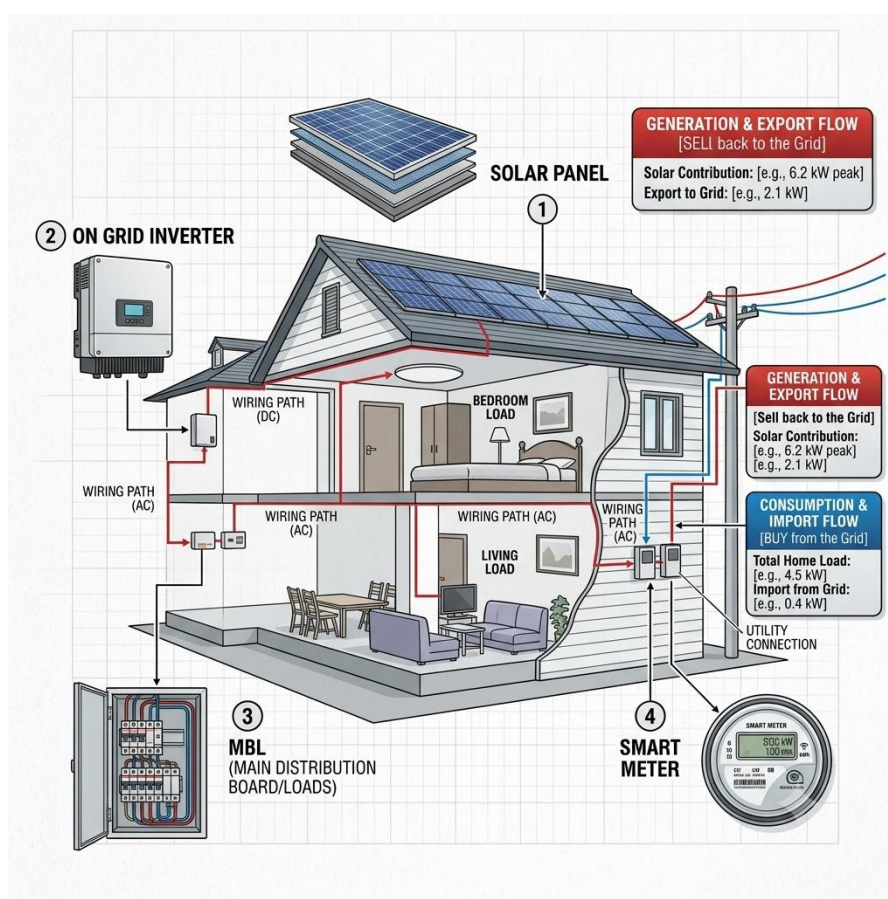


Figure 16: Basic house solar system

h. Solar Home Systems with Grid-tied Solar.

Grid-tied or on-grid or grid-feed solar systems, characterize the most common solar configuration for residential and commercial properties. As their name indicates, these systems connect directly with our local usefulness grid, establishing a reciprocally advantageous relationship between our solar panels and the existing

power infrastructure. The operational mechanism of a grid-tied solar system follows this sequence: Solar panels capture sunlight and transform it into direct current (DC) electricity. An inverter then converts this DC electricity into alternating current (AC), and which powers household appliances, devices and other utilities. After conversion AC electricity is flows through our switchboard to power our home. However, any excess energy generated is directed to the power grid, while a meter tracks electricity flow to ensure proper crediting for extra power production.¹⁹⁵ Here, distinct significant benefit of grid-tied solar systems lies in their integration with the utility network. When our panels generate more electricity than our household consumes, the surplus flows to the grid, earning us energy credits through net metering. During periods of reduced solar production, like nighttime or cloudy weather; the system automatically draws electricity from the grid to maintain continuous power supply. This dynamic exchange ensures our home and for all time has reliable electricity without requiring luxurious battery storage solutions. Grid-tied systems also offer greater affordability and reduced maintenance requirements compared to off-grid alternatives. Again by removing the need for backup batteries, homeowners enjoy lower initial costs as still reducing monthly electricity expenses. It's worth noting that grid-tied systems do have one notable limitation. During power outages, our solar system automatically deactivates to avoid back-feeding electricity into the grid. And this safety feature protects utility workers. Grid-tied solar installations provide many homeowners as an ideal balance between cost-effectiveness and sustainability. These systems enable reduced dependence on fossil fuels, lower utility bills, and contribute to environmental conservation efforts. Moreover, homeowners can GET profit from various incentives and tax breaks that make the initial investment more manageable. So, it not only enhances the homeowner's financial position but also promotes a greener community.¹⁹⁶

At present, grid-tied systems generally offer greater cost-effectiveness, allowing us to reduce monthly electricity expenses and potentially generate revenue through net metering credits. On the other hand, off-grid systems is providing complete independence, but involve higher initial costs due to additional required equipment, including battery banks and backup generators. So, by considering long-term objectives we need to determine, which option is the best aligns with our budget constraints. Again the suitability of either system often depends on our geographical setting and location. If we live in an urban environment with readily available power infrastructure, a grid-tied system can easily integrate with existing utilities. On the other hand, if our property or home is situated in a remote location or distant from the nearest utility connection, than an off-grid system may demonstrate more practical, eliminating the need for costly grid extensions.¹⁹⁷ Again, considering our household's electricity consumption patterns, when choosing between those two alternate systems, for larger residences or buildings with substantial power requirements, a grid-tied system provides the security of reliable backup, during periods of reduced solar production. Otherwise, if we maintain a smaller home or live in an area vulnerable to frequent power disruptions, an off-grid system can deliver reliable, stored power to satisfy our energy demands. Finally, our decision between grid-tied and off-grid solar depends on our specific circumstances and priorities. If budget is main concern and suitable grid access is our primary consideration, a grid-tied system likely represents our optimal choice. On the other hand, if we value complete energy sovereignty and freely invest in a more comprehensive setup, an off-grid system can deliver the self-sufficiency as we wish.¹⁹⁸ However, the fundamental goal remains embracing a sustainable and efficient lifestyle. The journey toward renewable energy represents a significant step toward a cleaner, more sustainable future powered by the plentiful energy of the sun.

Discussion on Present and Future Aspects of Solar Energy in Bangladesh

Bangladesh produces a large portion of its energy from fossil fuels. Nonetheless, it has set several renewable energy goals for 2030 and 2040 that demand substantial financial resources and time. Solar power is crucial for achieving these targets, and Bangladesh cannot afford to delay the shift in favor of LNG and other fossil fuels.¹⁹⁹ Bangladesh has significant potential for solar energy development. The country, which is largely low-lying, is committed to expanding its renewable energy capacity, and its population of over 170 million continues to grow at 1% per year.²⁰⁰ Bangladesh's growing population and economy drive an average annual increase in energy demand of 4.68%. The country's heavy reliance on domestic and imported fossil fuels has led to an energy crisis, with rolling blackouts and load-sharing throughout 2024. These issues have hampered economic growth and underscored concerns about dependence on fossil fuels. It is increasingly clear that Bangladesh must invest quickly in renewable energy to build a resilient grid capable of meeting rising capacity needs. Solar energy, in particular, has the potential to lead decarbonization efforts, and its capacity is already expanding.²⁰¹ Bangladesh is ideal for decentralized and utility-scale systems. Dhaka, the capital, is the fourth-most densely populated city globally, while much of the country remains rural and sparsely populated.²⁰² Bangladesh's overall solar potential averages about 4.59 GHI, placing it around the middle globally. This indicates that solar energy is a viable option for the country. Figure 17 below illustrates the annual change in primary energy consumption in Bangladesh from 1971 to 2021.²⁰³

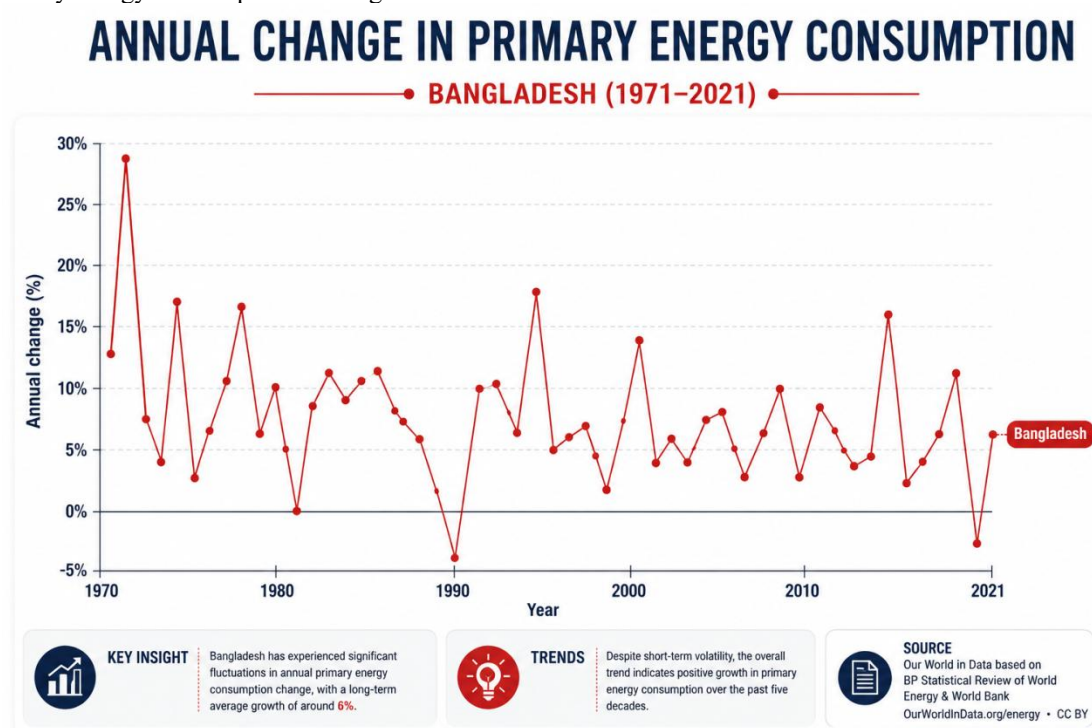


Figure 17: Annual change in primary energy consumption in Bangladesh, 1971–2021²⁰⁴

The World Bank has published the study 'Global Photovoltaic Power Potential by Country,' offering a comprehensive overview of solar resources and the potential for developing utility-scale photovoltaic (PV) power plants across different countries and regions. Using consistent, high-resolution, and reliable data, along with a replicable methodology, the study reveals that 93% of the global population resides in countries where the average daily PV potential ranges from 3 to 5 kWh/kWp. Approximately 20% of the world's population lives in 70 countries with excellent PV conditions, where the long-term PVOUT exceeds 4.5 kWh/kWp per day. Conversely, 30 countries—representing only 9% of the global population—have an average PVOUT below 3.5 kWh/kWp. These include many European countries (excluding Southern Europe), as well as Japan and Ecuador. Even in countries with lower PV performance, the potential remains reasonably high compared to top-tier regions. Notably, less developed nations, based on human development, electricity reliability, and rural access, often possess significant untapped PV potential. This presents a unique opportunity for PV technology to deliver affordable, reliable, and sustainable electricity to large populations lacking adequate access, thereby improving economic prospects and quality of life.²⁰⁵ Figure 18 below illustrates Bangladesh's solar energy potential based on GHI and PVOUT, with an average theoretical capacity of 4.596 kWh/m.

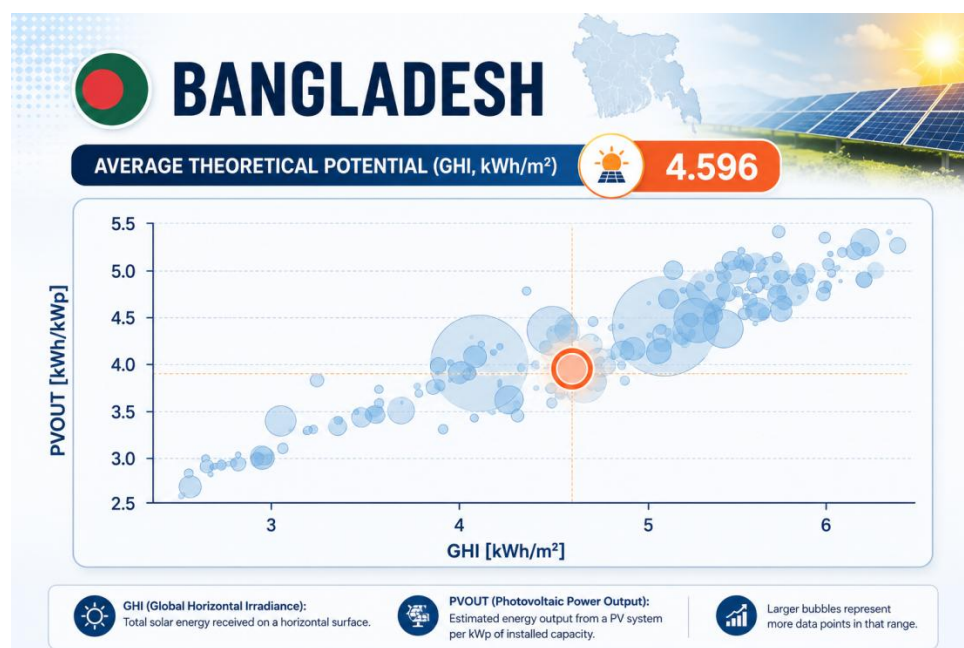


Figure 18: Solar energy potential of Bangladesh based on GHI and PVOU, with an average theoretical potential of 4.596 kWh/m²²²⁰⁶

Bangladesh has a significant theoretical solar potential compared to many countries worldwide. The country heavily invests in distributed solar systems, notably through the world's largest off-grid solar initiative, the Rural Electrification and Renewable Energy Development (RERED) Project. Since 2003, this solar home system program has brought electricity to areas with over 20 million residents nationwide. Experts consider it an excellent example of rural electrification. However, rural communities generally have lower energy needs than industrial urban centers, so solar capacity remains a small part of total power generation. Utility-scale solar remains largely undeveloped. Bangladesh, being low-lying with high sunlight exposure, has the potential for large PV farms. Its location in the Ganges Delta, the world's largest river delta, offers abundant water resources amidst a mostly flat landscape.²⁰⁷ Under these conditions, large solar farms show significant potential. Floating solar farms, such as those in Singapore and China, in river or lake regions, also hold considerable promise.²⁰⁸ In 2021, renewable energy accounted for just 1% of Bangladesh's total power generation.²⁰⁹ While the total generation numbers are modest, solar energy has significantly contributed to overall electrification. The government's RERED program reaches 12% of rural communities, and solar capacity continues to grow.²¹⁰ Once again, small-scale solar farms generate sufficient electricity to power 4 million households, and the country has 21 independent solar mini-grids.²¹¹ This infrastructure comprises 1,000 solar-powered irrigation pumps distributed by the government to farmers, reducing dependence on rainfall and supporting higher crop yields and incomes in poor regions. Although overall solar capacity remains limited, solar PV power plants are starting to demonstrate success nationwide. This progress is expected to encourage the development of larger, more extensive renewable energy projects.²¹² Despite multiple electricity tariff increases, Bangladesh still spends about USD 3.3 billion (Tk 40,000 crore) annually on power subsidies. Consumers face shortages during peak times despite higher prices. Energy experts highlight an easy and affordable solution: unused rooftops. Sector insiders reveal that electricity from rooftop solar systems is cheaper per unit than grid power. Several large industrial firms are already using rooftop solar to meet a substantial part of their electricity needs, with many more adopting this approach.²¹³

The Bangladesh Sustainable and Renewable Energy Association (BSREA) claims that recent tax exemptions primarily benefit a select few businesses. During a press conference on 14 June 2026, BSREA President Mostafa Mahmud emphasized that without a revision of the NBR's notification, Bangladesh may find it difficult to grow its solar sector and meet its 2030 renewable energy goals. He pointed out that although current incentives favor industrial consumers, they offer limited support to residential, agricultural, and rural users, and suggested that benefits should be accessible to all. In an interview with Prothom Alo, he also mentioned that imported solar equipment still faces a combined 17% tax, including 15% VAT, and that removing VAT would greatly support sector development. According to BSREA, Bangladesh's renewable energy market is largely driven by importers, distributors, dealers, retailers, and EPC companies, which receive minimal advantages from existing policies. Since 63% of electricity consumers are in the residential, agricultural, or small commercial sectors, they are unlikely to benefit significantly. The association warns that if the NBR notification remains unchanged, Bangladesh will fall short of its 2030 renewable energy targets. Conversely, extending zero customs duty and tax benefits to all industry players, including importers, EPC firms, and distributors, could enable

rooftop solar installations on just 25% of buildings in Dhaka and other major cities, potentially generating between 6,000 MW and 8,000 MW of electricity.²¹⁴

Most industry experts agree that removing tax barriers is crucial to making rooftop solar more appealing. Since homeowners usually purchase solar equipment locally rather than importing it, lowering market prices is vital. They also observe that although the official process for feeding excess rooftop electricity into the grid is supposed to take 15 days, it often takes three or four months. To address this, they recommend simplifying approval procedures and expanding tax incentives to all consumers. M. Shamsul Alam, energy adviser to the Consumers Association of Bangladesh (CAB), told Prothom Alo that the government is developing a strategy to generate 20% of Bangladesh's electricity from renewable sources by 2030. He noted that the universal incentives announced in the budget could reduce the cost of solar electricity to Tk 4.29 per unit, making rooftop solar widely accessible. However, he criticized the NBR notification as "a farce" that has undermined these goals. State Minister for Power, Energy and Mineral Resources Anindya Islam Amit told Prothom Alo that the government has taken comprehensive measures, ensuring private-sector involvement, to reach its renewable energy goals. He emphasized that this commitment is reflected in the current policy. Additionally, he mentioned that the government granted import duty exemptions for renewable energy equipment following stakeholder consultations, with some stakeholders requesting additional incentives. Nonetheless, he stated that 90% of these demands have been fulfilled and that work should now commence. If further measures are needed later, the government will consider them based on practical realities.²¹⁵

Bangladesh's renewable energy transition is on track. Cost-competitive renewable energy can help Bangladesh reduce its high fossil fuel import costs. The country can immediately reduce costly oil-based peak power generation during the day and at night by using solar energy with battery storage. Industries and large corporations aiming for sustainability could also reduce fossil fuel consumption by switching to renewable energy sources. However, limited success in exploiting domestic renewable resources has led to a 57% dependence on energy imports, increasing financial strain (focused on commercial energy). As of November 2025, the Bangladesh Power Development Board's payment arrears for power bought from independent producers exceeded Tk 270 billion (USD 2.21 billion).²¹⁶ In November 2024, the country's credit rating dropped to B2, adding to existing difficulties with fossil fuel imports. Consequently, the World Bank issued a repayment guarantee to assist Bangladesh's liquefied natural gas imports.²¹⁷ The country also finalized a USD 2.75 billion (Tk336 billion) agreement with the International Islamic Trade Finance Corporation to facilitate fossil fuel imports.²¹⁸ The increasing financial difficulties in the energy sector highlight the importance of implementing proactive strategies to accelerate renewable energy deployment. This involves creating a supportive environment for utility-scale projects by allocating land and establishing corporate power purchase agreements (CPPAs). Additionally, the country should promote the adoption of rooftop solar systems to ease pressure on limited land resources.²¹⁹

The present situation can accelerate renewable energy projects. When Bangladesh adopted its initial renewable energy policy in December 2008, its total renewable energy capacity was around 244.4 megawatts (MW), comprising 230MW from hydro and 14.4MW from solar home systems; other sources contributed minimally.²²⁰ As of December 2025, the country's renewable energy capacity was only 1,690.7MW, indicating sluggish progress. To reach its 2030 target of 20% renewable energy, Bangladesh must implement about 760MW of renewable energy projects annually from January 2026 to December 2030.²²¹ The current renewable energy capacity is 1,690.7 MW, with 358 MW of projects under construction. To meet the 20% target, approximately 5,851 MW are needed. However, as of 06 Sep 2026, the country's renewable energy capacity is 1850.04 MW, as shown in Table 2 below.²²²

Technology	Off-grid (MW)	On-grid (MW)	Total (MW)
Solar	377.47	1179.49	1556.95
Wind	0	62	62
Hydro	0	230	230
Biogas to Electricity	0.69	0	0.69
Biomass to Electricity	0.4	0	0.4
Total	378.56	1471.49	1850.04

Table 2: Country's renewable energy capacity in 2025

Allocating land through economic zones and mapping. Over the past fifteen years, utility-scale solar projects in Bangladesh have encountered major hurdles due to land scarcity, especially in densely populated and agriculture-dependent areas. However, the country can designate land for these projects by developing strategic economic zones and conducting resource mapping. For example, the government-controlled National Special Economic Zone (NSEZ) covers 33,805 acres (13,680.4 hectares)²²³, including 5,980 acres (2,420 hectares) designated as open space (17.7%), and the Bangladesh Economic Zones Authority signed a Transaction Advisory Services Agreement.²²⁴ In collaboration with the Asian Development Bank, a 100–200MW solar project with a battery energy storage system is planned for the NSEZ. The available free space allows for additional renewable energy development. Allocating 1,000 acres (404.7 hectares) through a Public-Private Partnership, the NSEZ could host approximately 350MW of solar capacity. This would raise the total utility-scale solar capacity to about 550MW, which is roughly 17% of the NSEZ's projected maximum demand of 3,248.7MW.²²⁵ The government might consider applying a similar strategy in other specialized economic zones. Additionally, land-resource mapping can help identify suitable public lands for utility-scale projects within the same framework, thereby encouraging private investment. Furthermore, the government should plan and issue tenders in stages for the previously identified char areas (islands) in Jamalpur district, which can support solar plants with capacities up to 6,000MW.²²⁶ These strategies can help overcome the country's land-related challenges for renewable energy initiatives.

Harnessing the potential of CPPAs. The growing emphasis on environmental sustainability drives industries and businesses to seek alternative ways to make their operations greener, especially given Bangladesh's limited access to clean energy on the grid. For example, Pran-RFL, with support from the International Finance Corporation, plans to establish a solar power plant to supply green energy to H&M's chosen apparel suppliers through a Power Purchase Agreement (CPPA).²²⁷ Similarly, telecom operator Robi, in collaboration with FloSolar Solutions Ltd and Green Power Asia, aims to develop a 100MW solar project to reduce its carbon footprint.²²⁸ With the approval of the new Merchant Power Policy, Bangladesh now has a broader framework for the CPPA. The next step is to finalize the service-level agreement, focusing on areas like wheeling charges and dispute resolution. This will enable project implementation under the CPPA, offering three benefits: increasing the share of on-grid renewable energy without complex procurement involving government agencies; generating wheeling charges for transmission and distribution companies; and helping industries meet sustainability goals. Successful initial projects could motivate other organizations to use the CPPA for decarbonization efforts.²²⁹

Rooftop solar is essential to overcoming Bangladesh's land constraints, yet its adoption is hindered by high import taxes and limited access to financing. Solar panels and inverters used in rooftop projects are subject to 28.73% import duties.²³⁰ Export-focused manufacturing sectors can import these accessories at a 1% duty under the capital expenditure approach. However, projects under the operational expenditure model face higher import duties, increasing overall costs. Additionally, industries and businesses face a complicated process to access Bangladesh Bank's low-cost green loans. For instance, a financial institution first approves a loan at a commercial rate and then submits documentation to Bangladesh Bank to access low-cost funds, which causes delays in approval and disbursement. This often discourages industries from applying. Moreover, financial institutions are hesitant to lend for small rooftop solar projects.²³¹ Furthermore, the Bangladesh government might consider temporarily waiving duties on rooftop solar accessories. This could enable a 1MW rooftop solar plant to save about Tk22.4 million (USD0.18 million) annually on fuel import costs, excluding capacity charges, based on furnace oil at Tk16/kWh (USD0.13/kWh) and the solar plant operating four hours daily for 350 days each year. To facilitate access to affordable financing, Bangladesh Bank could establish a dedicated fund for rooftop solar projects with a streamlined approval process to minimize disbursement delays. Although the ongoing energy crisis poses a significant challenge for Bangladesh, implementing strategic measures to overcome existing barriers—especially with active private-sector involvement—can help improve the situation.²³²

Present Trend and Future Prediction of Solar Energy Growth or Market for Bangladesh

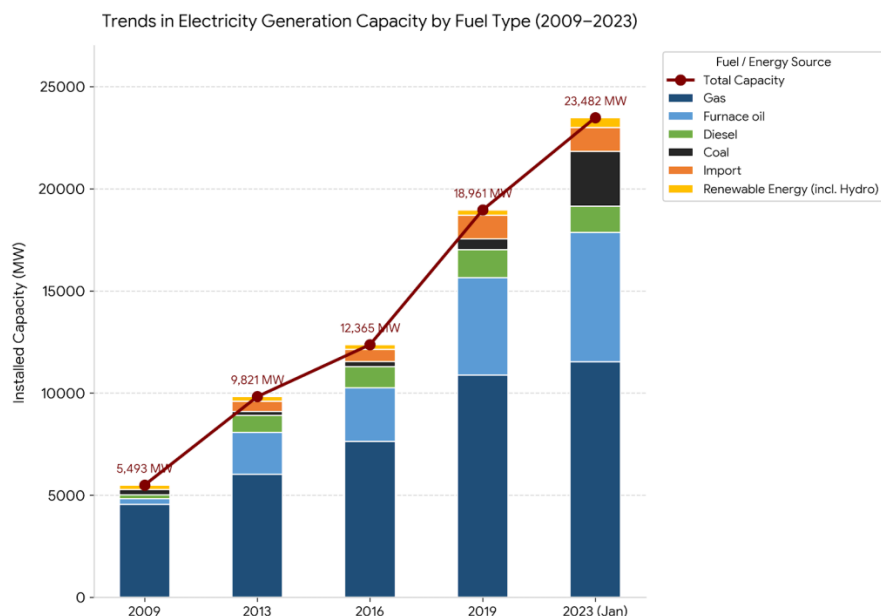


Figure 19: Historical Trajectory/trend and Fuel-Mix Breakdown of Power Generation Capacity (2009–2023)²³³ Bangladesh aims to meet 20% of its electricity needs from renewable sources by 2030. While this goal is technically feasible, achieving it requires faster solar project development, significant grid upgrades, energy storage solutions, affordable financing, and minimal delays from project approval to operation. Current challenges include gas shortages, strained foreign exchange reserves, and volatile prices for LNG, coal, and oil, highlighting the financial risks in the power sector. The Renewable Energy Policy 2025 sets targets for renewables to supply 20% of the nation's electricity by 2030 and 30% by 2040. By mid-2026, Bangladesh's renewable capacity was approximately 1.8 GW, primarily solar, hydropower, wind, and smaller technologies. The government has also set an ambition to develop around 10,000 MW of solar power by 2030, a goal that requires several times the current capacity in a short period. While other Asian countries have achieved similar solar installations, Bangladesh has yet to match their speed in land acquisition, grid connection, procurement, and financing. Declaring capacity does not equal generating electricity; a project only contributes after land is secured, funding is secured, equipment is delivered, construction is completed, and the grid is prepared. The historical trajectory and fuel-mix breakdown of power generation from 2009 to 2023 are shown in Figure 19 above. Additionally, the projected solar energy market in Bangladesh is depicted in Figures 20 and 21 from three different perspectives.

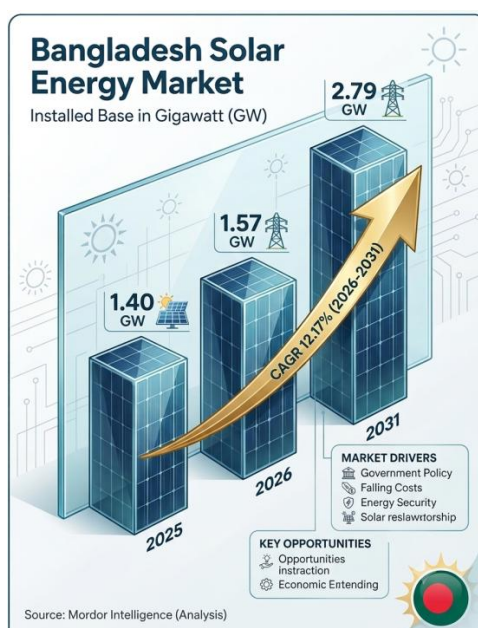


Figure 20: Forecasted Installed Solar Energy Market in Bangladesh (2025–2031)²³⁴

20% of Renewable energy is Achievable. Technically, yes, but under current conditions, it's still uncertain. Bangladesh has sufficient sunlight, rooftops, and investor interest, and solar costs are no longer the main barrier.

The key challenges are institutional, including project delays, grid readiness, financing, land use, and coordination among government agencies. Achieving the target depends on a clear increase in completed projects each year, not just approval pipelines that never materialize. A feasible approach involves leveraging industrial and public rooftops, conducting competitive tenders for solar parks, investing in battery storage, importing renewable energy from the region, and strengthening energy-efficiency measures. Reducing unnecessary electricity demand will also help reach the 20% share. The critical period isn't the final year but the next two to three years. Rapid deployment of rooftop projects, completion of solar plants through competitive bidding, and substantial grid-storage investments are essential; otherwise, the 20% goal risks further delay, as has happened before. Bangladesh's renewable resources are abundant, but slow execution leaves little time to achieve these goals.

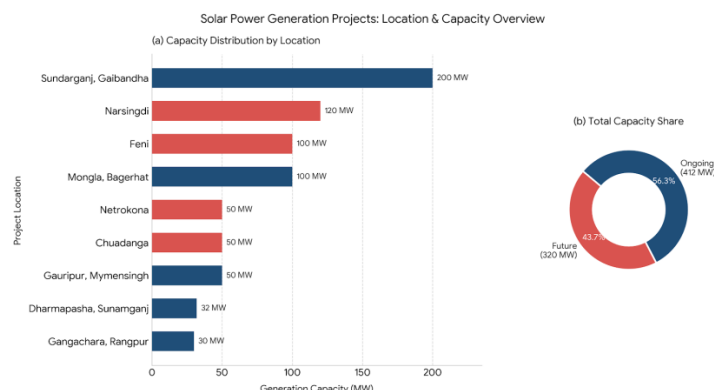


Figure 21: Forecasted Installed Solar Energy Capacity Growth in Bangladesh (2025–2031)²³⁵

Rooftops Offer the Fastest Route. While large solar parks remain important, rooftops offer Bangladesh a quick, practical opportunity. Existing structures like factories, warehouses, hospitals, universities, shopping centers, and public buildings already have suitable surfaces for panel installation. Rooftop solar projects can sidestep many debates over agricultural land use and are often quicker to implement than large-scale power plants. They also generate electricity close to where it is used, reducing strain on transmission grids. Industrial facilities are particularly suitable because they tend to use most of their energy during daytime. The National Rooftop Solar Program and initiatives to convert public buildings are more than symbolic—they could create a widespread power network if implemented across thousands of sites. The main obstacle isn't the availability of roofs but project planning, including structural surveys, clear ownership agreements, reliable net-metering approval, and affordable financing.

Utility Solar Still Has to Deliver. Rooftops alone cannot fulfill the electricity target; Bangladesh must develop large grid-connected solar plants. The transition from expensive negotiated contracts to competitive bidding has begun, which should reduce tariffs and enhance transparency. New solar tenders are being planned near existing substations, a practical approach as it minimizes the need for extensive transmission lines. However, Bangladesh has a history of postponing approved power projects. Alternatively, unused land from previously canceled coal projects could help fill this gap. Additionally, floating solar, reservoirs, industrial land, and well-planned agri-voltaic initiatives might alleviate pressure on farmland. Nonetheless, the deployment of utility-scale solar faces further challenges:

- Suitable land is scarce and expensive.
- Agricultural land cannot be treated as empty space.
- Developers face currency and financing risks.
- Imported equipment can be delayed by foreign-exchange constraints.
- Local substations may not have enough capacity.

Twenty Percent Capacity Is Not Twenty Percent Electricity. A 100 MW gas plant can operate overnight and under cloudy conditions if fueled, whereas a 100 MW solar plant produces power only when sunlight is available. As a result, its annual output is less than its capacity suggests. To meet the policy goal of meeting 20% of actual electricity demand, Bangladesh must install more renewable capacity than a simple capacity percentage would suggest. Contributions may come from hydropower imports from Nepal and Bhutan, domestic wind projects, and other renewable sources, but solar will be the primary focus. Hence, careful planning is essential.

The Grid Could Become the Main Constraint. Adding thousands of megawatts of solar without upgrading the grid could lead to new issues. Solar output peaks around midday and drops quickly before evening demand rises. Monsoon clouds can also cause rapid fluctuations in output. The Power Grid Company of Bangladesh and utilities will require better forecasting, stronger substations, flexible power sources, and

advanced control systems. Battery Energy Storage Systems will grow in importance, as they can store excess solar energy during the day and release it when demand increases. They also help with frequency regulation and reduce renewable curtailment. However, storage adds cost, and mandating batteries without a clear payment system might hinder project financing. Bangladesh needs transparent rules on storage ownership, service valuation, and recovery of investments through tariffs.

Financing Will Decide the Outcome. While solar equipment has become more affordable worldwide, capital costs in Bangladesh remain high. Factors such as interest rates, currency risk, and short loan durations can render otherwise viable projects financially unfeasible. Large corporations might fund rooftop solar systems from their own resources, but smaller factories, farms, and households lack that capacity. Development banks can offer support, yet public funds alone cannot finance the entire transition. Private investors require assurance that contracts will be fulfilled and that payments will be made punctually. Consequently, Bangladesh needs:

- Long-term local-currency loans
- Credit guarantees for smaller projects
- Transparent tariff and net-metering rules
- Faster approvals
- Predictable import and tax treatment
- Financing models in which investors own and operate rooftop systems

Problems and Challenges to Scaling Solar Energy

Scaling solar energy in Bangladesh faces several challenges, including land scarcity, financial constraints, market constraints, and infrastructure limitations. The shift to renewable energy has become a strategic and economic priority due to rapid industrialization, urbanization, and rising electricity demands, which have increased reliance on imported fuels such as LNG, coal, and petroleum. This reliance leaves the economy vulnerable to global fuel price fluctuations, foreign-exchange pressures, and fiscal strains. Climate change worsens these risks through heat waves, unpredictable rainfall, rising sea levels, and extreme weather that threaten agriculture, infrastructure, and livelihoods. Transitioning to a cleaner, diversified energy system can strengthen environmental sustainability, energy security, and economic stability. However, a gap exists between renewable energy potential and actual deployment, primarily due to land scarcity. Protecting agricultural land is essential for food security, and large solar projects often compete with agriculture, making widespread farmland conversion neither desirable nor sustainable.²³⁶

The solution involves prioritizing non-agricultural land, unused public land, industrial zones, railway and highway corridors where suitable, water bodies appropriate for floating solar, and rooftops. Agro-voltaic systems, which combine agriculture with solar power, may offer an innovative option where technically and economically viable. Three key obstacles are investment, finance, and the electricity grid. Renewable projects need significant initial funding, despite their low operating costs. Challenges such as high interest rates, lengthy approval processes, uncertainties around tariffs and land acquisition, and difficulties in securing long-term financing can deter investors. The grid poses another major hurdle, as solar and wind output depend on weather conditions. A modern renewable energy system requires flexible transmission networks, digital monitoring, demand management, energy storage, and better forecasting. Technologies such as Battery Energy Storage Systems (BESS), smart grids, and stronger interconnections can help reliably integrate variable renewables. The 2025 Renewable Energy Policy emphasizes the importance of grid stability and storage. Therefore, the country must recognize that renewable energy involves more than just installing solar panels; it requires grid modernization and comprehensive system planning.²³⁷

Economic and Financial Barriers: A significant economic obstacle to renewable facilities is the high cost of PV technology, particularly in rural Bangladesh. Many rural residents cannot afford expensive solar panels and often settle for low-quality, inexpensive solar solutions. As a result, their energy needs are often unmet. This situation leads to resistance to adopting renewable energy, as they continue to rely on grid power.²³⁸ Renewable energy can be sustainable and cost-effective when utilized at its peak, but its efficiency heavily depends on natural phenomena. For instance, an overcast sky reduces solar energy output, and a windless day renders wind power ineffective. To address periods of low energy output, it is recommended to use batteries or other storage solutions. Battery backup can mitigate the intermittency issues of solar and wind power worldwide. However, in Bangladesh, access to such batteries remains limited, and there is a lack of infrastructure for their processing and disposal. Additionally, a viable business model for solar energy is missing. The progress of grid-connected solar in Bangladesh faces challenges due to the absence of a large-scale solar industry and a lack of a market-driven environment. Linking incentives to market prices adds further complexity. The commercialization of renewable energy, along with high initial costs and competition from Independent Power Producers (IPPs), hampers financing. Also, the underdeveloped financial system and limited financial support hinder private investment in renewable projects, creating new barriers.²³⁹

Technical Barrier: Successful technology adoption requires extensive research and innovation. However, research on renewable energy in Bangladesh is limited. The level of innovation across different renewable

technologies remains unclear, which hampers grid integration, especially for solar power. Most renewable technologies used are imported, making them costly.²⁴⁰

Institutional Barrier: Multiple institutions involved lead to fragmentation and duplication of renewable technologies. In Bangladesh, the expansion of renewable energy is limited by poor coordination among agencies and the absence of a centralized monitoring authority. Additionally, bureaucratic approval processes and delays hinder the adoption of renewable energy. Institutions also fail to proactively involve key stakeholders, such as local entrepreneurs, investors, and end-users, in the development of renewable energy sources. Limited guidance and support restrict prospective beneficiaries' participation, while inaccurate demand estimates further impede growth. Historically, in South Asia, barriers such as a scarcity of NGOs, financial exclusion, and weak institutions have hindered renewable energy adoption. Many rural pilot projects originated from partnerships between multilateral funders and local entities. Currently, however, numerous NGOs and financial institutions support these efforts.²⁴¹

Informational Barrier: The primary obstacle to adopting renewable energy is the lack of information. In rural areas of Bangladesh, renewable technologies are rarely known or understood. Even in urban regions, most people are accustomed to grid-supplied electricity and are unfamiliar with renewable energy. This results in a general lack of knowledge and awareness about renewable options. Potential users are often hesitant to switch because they don't understand how these technologies work. Additionally, industries, government agencies, policymakers, and financial institutions are underserved in the development of renewable technologies. Since users are unfamiliar with how to operate renewable energy systems and there's often no guidance, they tend to make mistakes, which diminishes the technology's effectiveness and increases costs. Such experiences reinforce the perception that investing in renewables is risky, further discouraging adoption.²⁴²

Bangladesh faces significant supply-side and demand-side informational barriers to renewable energy adoption. A major issue is the insufficient supply-side data, including resource potential, site-specific ground data, wind maps, technical specs, and cost analyses, which hampers full utilization of renewable resources. Additionally, there is no centralized source; information is scattered across government, private sector, and research entities. On the demand side, challenges include a lack of data on cultural traits, local demands, and awareness of alternative energy sources. Many locals believe solar PV is the sole renewable option, and there's limited knowledge or training in solar PV operation, maintenance, battery management, and handling seasonal output variations.²⁴³

Human Capacity Barrier: One of the most daunting obstacles to adoption is the human resource limitation. There aren't enough personnel to establish a large, efficient renewable energy facility. While experts and skilled engineers exist, their focus is usually on high-level projects. For the general public, there is a shortage of technicians. Most local solar providers focus on small-scale installations. Solar energy is especially needed in rural areas, but there are very few, if any, experts available to install solar panels there.²⁴⁴

Policy and Government Barrier: Bangladeshi policies tend to be formulated top-down. Typically, the government sets policies, and actions follow accordingly. The participation of professionals, producers, consumers, and engineers is limited, with inadequate engagement and communication between policymakers and experts. Additionally, stakeholders in the energy sector are loosely organized, resulting in their opinions being less considered in policy decisions. Citizen involvement in renewable energy initiatives, especially in rural areas, remains extremely low. Moreover, policymakers often view renewable energy as an unviable option due to its intermittency. The slow upgrade of existing grid networks to accommodate intermittent renewables is hindered by a lack of prioritization, which restricts overall adoption.²⁴⁵

Resource and infrastructural barriers pose challenges for Bangladesh's renewable energy development. The country has a growing demand for land to install solar panels, but limited non-cropped land hampers expansion. Natural disasters such as heavy rainfall, floods, and riverbank erosion frequently disrupt solar energy production. Regarding biomass, a lack of awareness and confusion about available resources limit the advancement of biomass energy projects. Wind energy potential remains modest overall, largely confined to coastal areas, and grid-scale generation is constrained by low wind speeds.²⁴⁶

These are the barriers to adopting renewable energy. However, Bangladesh's government has a comprehensive plan to boost reliance on renewables and cut fossil fuel use. This plan should involve establishing stable markets for renewable technologies, building robust infrastructure, engaging experts, enhancing communication between policymakers and specialists, raising awareness, supporting research and innovation, organizing workshops and training, encouraging local participation, and providing grant funding for renewable plants. With such measures, Bangladesh is poised to advance in increasing its use of renewable energy and becoming more self-sufficient.²⁴⁷

Despite the government's commitment, progress in increasing the share of renewable energy has been slow. Several factors contribute to this, including: (i) a need for more project implementation experience and stronger institutional capacity, as Bangladesh has only a few large solar projects so far, and the rooftop PV market remains in its early stages; (ii) challenges in the financing market, such as limited domestic long-term funding, poor due diligence expertise, and an underdeveloped syndication market; (iii) land scarcity, since utility-scale

solar and wind require significant land, which is a major obstacle in a densely populated country; and (iv) project development issues, like limited data on resource availability, lack of technical studies, and insufficient project preparation and due diligence.

Despite notable technological advances and positive economic trends, Bangladesh's extensive solar energy expansion still encounters a complex array of interconnected challenges. Technically, grid integration is a key obstacle, hindered by intermittent solar output, limited grid adaptability, and insufficient energy storage to manage fluctuations.²⁴⁸ These issues are worsened by the country's aging grid infrastructure, which was not built to handle high levels of variable renewable energy. Reliability concerns are also raised by the degradation and aging of photovoltaic panels. Studies highlight that unmanaged long-term performance declines and can threaten the economic viability and sustainability of solar systems.²⁴⁹ This underscores the importance of establishing standardized maintenance protocols, performance monitoring, and life cycle management strategies, which are still underdeveloped in the current deployment landscape.²⁵⁰

Institutional and policy barriers exacerbate these technical issues. Fragmented policies, conflicting mandates, and limited institutional capacity obstruct effective implementation and cross-sector coordination.²⁵¹ Although various incentives and programs are available, inconsistent implementation can create regulatory uncertainty. This often hinders private investment and delays project progress. In such cases, weak governance becomes a major obstacle, even when technology and market demand are robust.²⁵² Financial constraints remain major barriers, especially for small users and low-income families. High initial costs, limited access to affordable credit, and underdeveloped financial tools hinder wider involvement in the solar industry.²⁵³ These constraints are particularly strong in rural regions, where income instability and risk aversion further hinder adoption, even though solar systems offer long-term cost savings.²⁵⁴

Apart from technical and financial challenges, social acceptance and human capacity development are often overlooked but crucial for ongoing adoption. Literature consistently emphasizes the significance of engaging communities, providing local technical training, and conducting awareness campaigns to promote system ownership, ensure proper maintenance, and support long-term operation. Without adequate social integration, even well-designed solar projects risk underutilization or premature failure.²⁵⁵ Synthesizing these findings, it is clear that barriers to expanding solar energy in Bangladesh are systemic rather than isolated. Technical issues, financial constraints, institutional weaknesses, and social factors reinforce one another, creating a cycle that hampers deployment despite favorable market conditions. Addressing these challenges necessitates coordinated solutions that include grid modernization, financial innovation, institutional reforms, and community-focused approaches, rather than isolated efforts.²⁵⁶

Strategy, Policy Framework and Challenge to Achieve Target of Solar Project

Energy is essential for human life, and ensuring a reliable and accessible energy supply is vital for the sustainability of modern societies. The ongoing reliance on fossil fuels faces several challenges: reserves are depleting, environmental issues like global warming are intensifying, geopolitical and military conflicts persist, and recent fuel price increases remain significant. These issues highlight an unsustainable situation.²⁵⁷ Renewable energy offers a solution to increasing energy challenges. Resources like solar, wind, biomass, and wave and tidal energy are plentiful, sustainable, and eco-friendly.²⁵⁸ The global increase in electricity demand, along with climate change, dwindling fossil fuel reserves, and the difficulties of extracting fossil fuels, are major factors driving the gradual transition to renewable energy sources. As worldwide energy needs continue to grow quickly, they are projected to multiply fivefold by 2100.²⁵⁹ Around 75% of the world's energy demand is met by fossil fuels, which contribute significantly to greenhouse gas (GHG) emissions.²⁶⁰ As the global energy shortage worsens—driven by rapid urbanization, shrinking fossil fuel reserves and the urgent need to replace carbon-intensive, non-renewable resources with safe, zero-carbon alternatives—there is growing emphasis on prioritizing sustainable energy sources.²⁶¹ Using wind, solar, hydropower, and other renewable energy sources can significantly reduce the release of hazardous pollutants and greenhouse gases into the atmosphere, helping to lower our reliance on fossil fuels.²⁶²

Bangladesh has long had the ambition for renewable energy, but for nearly twenty years, progress in implementation and production has been slow. The country's first renewable energy policy in 2008 aimed to overhaul the grid, yet seventeen years later, renewables account for barely 5% of installed capacity. Sadly, the 5% target was missed by 2015, and the 10% goal by 2020. Now, with the Renewable Energy Policy 2025 setting a new target of 20% by 2030, the question is whether we will achieve it this time. It's possible, but it requires a solid strategy, planning, commitment, and dedication. The numbers suggest skepticism: early this year, Bangladesh's renewable capacity was around 1690 MW out of a total generation capacity exceeding 28000 MW. To meet the 2030 goal, the Institute for Energy Economics and Financial Analysis (IEEFA) estimates the country must add approximately 760 MW of renewable capacity annually, reaching about 5850 MW by then. Bangladesh has never approached this pace before. At current rates, we are likely to fall slightly short again. Solar energy dominates this transition, contributing roughly 80% of renewable generation, with the aging Kaptai hydropower plant and a still-developing wind sector accounting for the remainder. This concentration isn't

necessarily a flaw, as Bangladesh's solar potential exceeds 50000 MW- enough, in theory, to meet 80% of the projected energy demand in 2041. The resource is available; the real constraints are land availability, financing, grid capacity, and a tariff system that still subtly favors fossil fuels.²⁶³

Consider the government's flagship rooftop solar program launched last year (in 2025), which aimed to add 3000 MW of new capacity by December — a goal that proved overly ambitious. Judged reasonably, it was highly unrealistic, given Bangladesh had installed only 245 MW of rooftop solar from 2008 to mid-2025. Achieving 3000 MW in six months would have required more than a twelvefold increase in installation rates across rooftops, government offices, hospitals, and schools, whose combined sanctioned electrical load did not even initially support this capacity. The program was well-intentioned but failed to account for the actual infrastructure capacity. This disconnect between announcement and engineering feasibility has become a recurring pattern in Bangladesh's energy sector. However, there are signs of a genuine policy shift beyond rhetoric: the FY27 budget waived import duties, regulatory fees, and advance taxes on solar panels, inverters, and related components until 2031, and extended tariff relief to battery storage systems — marking the first serious effort to dismantle a tax structure that previously made clean energy imports more expensive than fossil fuels. Additionally, a new policy allows private firms to sell renewable energy directly to consumers, addressing the slow pace of electrification by state utilities. Industry voices are also gaining momentum; at a Dhaka press briefing this May, energy experts and civil society leaders urged the government to further streamline investor services and reduce duties, aiming for a 10000 MW solar capacity target by 2030.²⁶⁴

However, supply-side incentives are effective only if demand responds, but Bangladesh's tariff policy undermines this. Solar power now costs about Tk 8 to Tk 9 per unit, making it genuinely competitive. Yet, retail electricity tariffs remain artificially low, offering little financial motivation for consumers and factories to switch. A country cannot subsidize fossil-fuel grid electricity while expecting households and industries to switch to solar based on cost alone. Until this inconsistency is addressed, tax waivers on panels and inverters will benefit importers' profits more than encourage actual adoption.²⁶⁵ The urgency is concrete. This year, Bangladesh faces a severe energy crisis: gas shortages alone caused a nearly 3900 MW generation gap in just one month, further worsened by 1668 MW lost due to plant shutdowns and maintenance. Gas plants make up 43% of installed capacity, while coal accounts for 27%, highlighting the country's reliance on fossil fuels. This dependence exposes Bangladesh to risks whenever global energy prices soar or regional conflicts disrupt supply chains, as current tensions in West Asia have already shown.²⁶⁶ In fact, renewable energy isn't just an environmental luxury; it's the most straightforward way to achieve energy security and stable prices because sunlight and wind, unlike LNG and coal, aren't dependent on cargo shipments affected by geopolitics.

Land scarcity is an urgent constraint that requires more innovative policy solutions than currently provided. Densely populated delta countries, like Bangladesh, lack the extensive space needed for utility-scale solar projects. Industry experts suggest alternatives such as floating solar panels and the use of riverine char lands—the seasonally exposed sandbars along Bangladesh's rivers — to address this challenge.²⁶⁷ These are practical adaptations that a land-constrained, river-rich country should be actively testing at scale rather than just debating at conferences.²⁶⁸ What the sector currently needs most is to strengthen institutional capacity, not just to set new headline targets. The Sustainable and Renewable Energy Development Authority (SREDA), responsible for managing this transition, has consistently faced staffing and resource shortages, making it ill-equipped to handle the coordination demands of a 20% renewable energy target by 2030. This encompasses land allocation, grid connection, tariff setting, and attracting investors, all happening simultaneously. Ambitious policies without a strong, empowered implementation agency have previously led Bangladesh to miss two targets in a row. The new goals—20% renewable energy by 2030 or 30% by 2041—are appropriately ambitious given the high costs of fossil fuel imports. However, the real challenge lies in rationalizing tariffs to ensure solar's cost advantage benefits consumers, enabling SREDA to operate at the pace required by the policy, and investing in grid and land-use innovations necessary for a dense, low-lying country. We are currently at a standstill, where success or failure over the next four years will be decided. Bangladesh doesn't need more ambitious promises but needs to actually fulfill existing commitments. For the first time in nearly twenty years, we have the potential to do so.²⁶⁹ Solar power is frequently discussed as a policy goal in Bangladesh, especially given the current global energy uncertainty and price fluctuations. The country's energy security hinges on how swiftly renewable projects, mainly solar, are realized. Developing approximately 5000 MWp of solar capacity could require over Tk 35,000 crore in investment for generation alone, excluding land and infrastructure, making bankability and investor confidence crucial. In Bangladesh, 1 MWp of solar can produce about 1.4 million kWh annually, underscoring its potential to boost the national grid. Despite long-term energy plans and policy promises, solar deployment remains limited—mostly due to incomplete implementation frameworks. Many projects were awarded without confirmed land access, grid connection, or demonstrated financial and technical readiness from developers. Consequently, many face delays in reaching financial closure or starting construction. Solar costs depend on technology and financing conditions, land issues, infrastructure, and project risks. While concessional financing exists, scaling its deployment is challenging. Lower costs require reducing project risks via bankable PPAs, secure payments, and credible pipelines.

Institutions like the Infrastructure Development Company (IDC) can contribute through blended finance and credit enhancement, especially if scaled and tailored to utility-scale projects. Mitigating foreign exchange risk can attract international capital. Moving toward competitive solar tenders is a crucial step, as they enable transparent price discovery, but only when projects are truly ready. Poorly structured tenders may lead to aggressive bids that become unviable, causing delays or cancellations. Procurement frameworks should verify that winning bidders have credible projects, secure sites, and delivery capacity. Past project challenges often stem from insufficient readiness at award. Successful projects require key fundamentals from the start: secure land rights, dispute-free sites, and preliminary grid approval. Financial strength should be backed by credible commitments from experienced institutions, with bid bonds and guarantees to deter speculation. After awarding, clear timelines must govern each phase: power purchase agreements (PPAs) and implementation agreements within three months; financial closure within six months; and construction within 12–18 months, depending on size and conditions. Penalties, including performance guarantee encashment, should apply to delays. Without disciplined timelines, projects risk prolonged development that never progresses to construction. Enforcing such schedules ensures smooth transition from award to operation.

Land and grid access remain key obstacles to expanding solar in Bangladesh. Utility-scale solar needs large areas, roughly 2200 to 2300 acres for every 1000 MWp of capacity. In a densely populated nation, locating suitable sites is challenging. The ‘solar park’ model offers a practical solution: the government prepares land and infrastructure—such as roads, drainage, and substations—and leases plots to private developers. This method tackles land and grid issues early, reducing risks, lowering costs, and speeding up development. These models can be financed without initial public funding, as infrastructure costs are recovered via land leases, developer fees, or public–private partnerships. Without a coordinated solar park framework, transmission remains a major hurdle—developers must build lines to the nearest substation at their own expense, often over long distances and through complex rights-of-way, with lines connecting to the national grid only after project completion, which can increase costs and cause delays. Targeted fiscal incentives can encourage early solar investments. Rooftop solar offers a rapid expansion route: about 6,000 square meters of roof space can generate roughly 1 MWp. Large factory rooftops are ideal for distributed solar, and tools like net metering and third-party PPAs make deployment possible without upfront costs.²⁷⁰

Bangladesh's ambitious renewable energy goals aim for 20% of electricity from renewables by 2030 and 30% by 2040, as outlined in the Renewable Energy Policy 2025. The country plans to significantly increase the share of renewables in its energy mix by 2050. The main hurdle is effective implementation, especially since previous deadlines were missed. The new policy should clearly define responsibilities, ensure transparent procurement, maintain stable tariffs, facilitate access to finance, and include regular progress assessments. Green finance will be vital, requiring approximately \$933–980 million annually until 2030, with higher amounts afterward. Domestic banks need to broaden renewable financing options, supported by instruments such as green bonds, climate funds, concessional loans, blended finance, and public-private partnerships, to lower capital costs. Projects must also be transparent and bankable to attract investors. Technological advancements, such as rooftop and floating solar, smart grids, and offshore wind, will influence the pace of the transition. Regional electricity trade can enhance energy security by integrating renewables with regional resources such as hydropower. Prioritizing these goals clearly is essential.²⁷¹

- Prioritizing rooftop solar expansion, particularly on government buildings, industrial sites, and large commercial facilities, enhances renewable energy generation while reducing the land used for agriculture.
- Encouraging solar-powered irrigation where it is economically viable and technically feasible can reduce diesel consumption and improve the long-term sustainability of energy use in farming.
- Bangladesh must upgrade its transmission and distribution systems. Without investing in the grid, the increase in renewable energy could cause avoidable reliability problems.
- The country should create a stable and predictable environment for investment. Investors require transparent details on land policies, tariffs, power purchase agreements, taxation, import duties, and grid connection procedures.
- Energy storage and digital grid management should be integral to renewable energy planning rather than afterthoughts.
- Renewable energy should be integrated into a broader national strategy encompassing energy efficiency, sustainable agriculture, industrial competitiveness, and climate resilience.

Proposed Framework towards Employing Solar Energy System: A Sample Case

Introduction. Aligned with SDG goal no. 7, the country aims for 20% renewable energy by 2030 and 30% by 2040. Data from the Institute for Energy Economics, available literature and financial analysis show that rooftop solar power began in 2008, reached 36 MW by 2018, and added approximately 209 MW from 2018 to June 2025. These figures partly confirm experts' concerns and doubts. To advance, we could implement rooftop solar projects on government and public buildings to generate at least 2,000 MW within a year, with each organization installing panels on its rooftop. Challenges include: a) changing traditional mindsets, navigating

bureaucracy, and tender processes; b) the current budget system limiting progress; c) grid infrastructure needing upgrades to support solar projects, which is challenging to execute quickly; d) ongoing system maintenance is difficult due to lack of funds and expertise; e) the energy division has not yet devised a clear plan to achieve the 2000 MW installation target.

Implementing a 2000 MW solar energy project within the given timeframe is feasible. This rooftop solar proposal considers the social fabric of our community, the social complexities we face daily, and our national moral character. It aligns with social business principles in power generation and requires government support for broader societal and economic benefits. To execute such a large project, additional funds must be allocated from the development budget's lump sum grant for the fiscal year. If the government allocates a significant portion of the development budget or reallocates funds from other projects, the successful realization of this project becomes possible.

Implementation Framework of the Proposed Project. Each government office, installation, or premises should initiate small-scale rooftop solar energy projects. These projects will be carried out by the organization heads or HOPE, which must prepare tender specifications, oversee the tender process, select bidders, and manage project implementation. If materials and equipment are sourced locally, it may take at least six months to gather resources and complete the project. For imported materials, the process can take longer than a year, depending on market availability. The traditional tendering and procurement process can delay project completion. Additionally, many offices lack the expert personnel needed to operate, monitor, and maintain solar systems, which requires HOPE to hire specialists or contract maintenance services, thereby increasing costs. Historically, technical projects have often suffered from poor quality, breakdowns, high maintenance costs, and limited lifespans, potentially becoming financial burdens for the government. To prevent this, adopting a sustainable and eco-friendly approach is essential. Projects should be executed with minimal oversight, limited quality assurance, and within a set timeframe to meet government policies. Operational and maintenance responsibilities will rest with the entrepreneurs, who view it as a social business. Nonetheless, a thorough financial and feasibility study must precede any implementation.

Given the limitations on implementing numerous small-scale projects of similar nature within a limited timeframe through traditional processes, an alternative model aligned with social business principles was developed. This model involves engaging a large number of young entrepreneurs in partnership with the government to execute these projects. Many educated, tech-savvy young entrepreneurs will participate in the solar energy sector, with each government office, facility, or organization partnering with one entrepreneur. These entrepreneurs will generate solar power, perform regular maintenance, and sell energy to their respective clients at a predetermined rate. This large-scale involvement of young entrepreneurs will bring positive societal change: they will develop business skills and potentially progress to higher levels of entrepreneurship, while the government benefits from increased employment and youth engagement. Society as a whole will benefit from this initiative, a social business designed to benefit a significant portion of society under active government guidance. The government will actively support this solar energy enterprise throughout all stages. The following outlines the step-by-step implementation of this social business model.

- The government's energy division should require all government agencies, offices, educational institutions, autonomous bodies, and other organizations funded by public funds to assess their potential for rooftop or ground-mounted solar energy. Following these evaluations, the energy division needs to conduct expert audits to verify the feasibility of installing solar power plants and assess the capacity of each proposed installation.
- Then, drawing on the proposal and information provided by the energy division, the division must determine the total requirement, taking grid capacity into account. The energy division should prioritize and select projects to meet the immediate goal of establishing 2000MW of solar energy, aligned with the proposed framework's strategy.
- Next, choose the type of solar panel and related equipment by prioritizing the best-value products from the local or international market. Record the price of each item and establish a framework contract with suppliers from either national or international sources.
- Then determine the cost of each project based on the energy division's audit report, separating costs for equipment, workmanship, installation, and commissioning.
- The government should conduct a two-week training program for aspiring entrepreneurs who are willing to start a business, have limited funds, and are open to taking on bank loans. These potential entrepreneurs will form the backbone of the projects. Each will take responsibility for one or several projects assigned by various government offices, organizations, or installations. The selection of investors or entrepreneurs may be made through the HOPE of each entity via a bidding process or a transparent central mechanism.
- Based on the cost estimates, the government should provide a soft loan (such as an SME loan with minimal or zero interest) to selected entrepreneurs or investors. This loan will cover the solar panels and related equipment for electricity generation. Costs associated with installation, commissioning, and workmanship

will not be included in the loan and must be covered by the entrepreneurs. No cash or checks will be given directly to investors or entrepreneurs; instead, the government will pay suppliers of materials and equipment, domestically or internationally.

- Each HOPE must sign a fixed-rate power purchase agreement with its respective supplier, acting as an entrepreneur. This agreement may be a term contract with provisions for periodic rate revisions. Each HOPE will ensure that the energy generated from these solar plants is given priority for consumption over other sources.

A cost comparison has been conducted to clarify why engaging in solar energy projects benefits each entrepreneur. An in-depth study is necessary to determine how this renewable energy method can effectively support government policy goals and ensure a return on investment. Table 1 below presents the initial costs of setting up a 100 kW solar plant on a rooftop or in an open space, based on various studies, prior research, and secondary data cited in the literature review. The electricity cost for government offices was primarily calculated using average peak-hour electricity prices across different locations, as well as the costs paid by the government for electricity purchased from multiple solar plants. Considering these factors and the literature, a cost-benefit analysis of a 100 KW solar power plant is provided in Table 3.

Elements	On-grid solar system	Hybrid solar system
Cost	60,00,000/00	80,00,000/00
Energy output per day	430-480 kWh	430-480 kWh
Energy output per month	14,400 Kwh	14,400 Kwh
Area required	600 Sq Meter	600 Sq Meter
Sale @ Tk15 per Kwh	1,72,000/00 (20% Less)	2,16,000/00
Monthly repayment (10-year repayment calculation with no interest)	50,000/00	66,666/00
Monthly earnings	1,22,000/00	1,49,334
Yearly earnings	14,64,000/00	17,92,008/00
First 10 years earnings	1,46,40,000/00	1,79,20,080/00
Next 20 years earnings	4,12,80,000/00	5,18,40,000/00
Total earnings less expenditure in 20 years	5,59,20,000/00	6,97,60,080/00

Table 3: An approximate cost-benefit analysis of a 100 KW solar power plant

This model makes several assumptions in the cost-benefit analysis. It assumes that all solar energy equipment will be procured in bulk by the government without import duties, significantly reducing costs. Additionally, the project is envisioned as a social business, likely involving a large group of young, energetic, educated entrepreneurs. They will receive interest-free financing for the solar panels and related equipment, to be repaid over 8 to 10 years. Furthermore, although power purchase agreements made by each HOPE are typically renegotiated every two to three years, this is not reflected in the current calculations. Consequently, revenue is expected to increase over time, encouraging more entrepreneurs to participate due to the potential for higher earnings.

The government's investment in developing rooftop solar energy is guaranteed to return. Although the initial outlay requires significant government expenditure, the investment will be recouped over time. Since both the loan facility and bill payment revenues are managed through the same bank and branch, the risk of a non-performing loan is minimized. While questions may arise about potential negative returns over 10 years when considering net present value, this loan funds a project aligned with our government's key goals—reducing net carbon emissions. Additionally, the government would likely invest much more in addressing the environmental impacts of carbon emissions. Therefore, it can be confidently stated that this investment guarantees a 100% return and offers substantial environmental and health benefits.

Challenges and Benefits. This new approach to government procurement in the development sector introduces a different model in which local development partners are involved, rather than relying solely on traditional funding from the government development budget. Conventional procurement and maintenance methods often lack transparency and accountability, leading to malpractice, waste, and inefficiency. This innovative approach aims to address these issues while offering several benefits over the traditional system. The following outlines some of these advantages. Additionally, a new framework for procurement, investment, and maintenance has been proposed that incorporates a social business model.

Traditional procurement systems used by each HOPE have inherent issues with transparency, accountability, efficiency, market evaluation, and cost estimation. The cost of similar solar plants varies across different tenders issued by each HOPE. In contrast, this new approach involves issuing a single tender for all solar equipment—such as panels, inverters, batteries, charge controllers, switchboards, and cables—by SREDA/Energy Division. These items for rooftop solar plants of various capacities will be listed in bulk under a term contract. Equipment

can be sourced domestically or internationally based on efficiency considerations, ensuring quality, standardization, bulk discounts, easier maintenance, and sustainability. This approach is expected to substantially reduce procurement costs. Traditionally, each HOPE also incurs maintenance costs and hires personnel for routine upkeep, often contracting with external organizations for high-value equipment, thereby increasing overall expenses. Due to corruption, inefficiencies, and skill shortages, maintenance costs across government entities are notably high, with significant government funds allocated for this purpose.

This new method of setting up a solar plant and generating electricity incurs no maintenance costs. The entrepreneur or vendor designated by HOPE will handle regular cleaning and upkeep. They understand that maintaining high standards is essential for optimal output and increased revenue. Unlike many government projects, which often face issues such as a lack of transparency, accountability, and resource waste—partly because government employees tend to prioritize rules and procedures over efficiency and quality—this approach minimizes these problems. The vendor-vendee relationship relies on a single large contract at the higher level and a simple electric meter at the lower level, making the processes clear and understandable. This structure reduces opportunities for corruption and waste in establishing solar plants and signing power purchase agreements with SME entrepreneurs.

Today, social businesses are rapidly evolving and guided by strong moral values. The key challenge was to develop a model that aligns with government regulations while creating employment opportunities that benefit society. Given the high unemployment among educated youth, this innovative social business approach offers hope. Young entrepreneurs can start ventures with minimal investment, potentially earning significant long-term returns through dedication and hard work. This new strategy encourages young entrepreneurs to participate in business activities. In this model, entrepreneurs need minimal capital, with the remaining amount (around Taka 80 to 90 lacs) provided as interest-free loans by the government, which may be transferred to nationalized banks. These funds could support climate-friendly social businesses aimed at reducing Bangladesh's carbon footprint. The loan would fund solar plants, with the generated energy consumed by the business, thereby generating revenue. This revenue would be used to repay the loan, with monthly installments deducted by the bank. Surplus funds are then released to the entrepreneur. This solar plant social enterprise can foster local entrepreneurship and potentially expand into other sectors.

Energy Reality Assessment and Way Forward

India established the Ministry of New and Renewable Energy in 2006, dedicating an institutional framework to renewable energy. The country intensified its efforts in 2014, when solar power capacity was only 2.82 GW. Since then, capacity doubled almost annually, reaching 55 GW in 2022 and 66 GW in 2023. (1 GW equals 1,000 MW.) To encourage rooftop solar, India launched a program on February 13, 2024, offering subsidies of 30,000 to 78,000 rupees for installing solar panels of 1 to 3 kilowatts or more. Another initiative helped install over 100,000 solar-powered irrigation pumps. The government also facilitated affordable bank loans covering up to 70% of solar project costs for capacities up to two megawatts. Consequently, solar growth accelerated. By March 2025, India's total solar capacity reached 150.26 GW, with 44 GW added in that year alone. Meanwhile, Vietnam's solar capacity grew from just 86 MW in 2018 to over 19,000 MW by 2025, including more than 9,000 MW from rooftop systems. Similarly, Pakistan has emerged as a recent solar success story. As electricity prices increased, households and businesses increasingly adopted rooftop solar. The government supported this shift through tax exemptions on imported solar equipment and policies allowing surplus electricity to be sold back to the grid. Grid-connected rooftop solar capacity now exceeds 6,000 MW. However, many sources suggest the actual rooftop solar capacity is several times higher, as much of it is used privately and remains off-grid. This has led to a decline in grid demand, causing authorities to continue paying capacity charges to idle power plants. Analysts attribute this disarray in the power sector to Pakistan's lack of planning.

For decades, Bangladesh has correctly identified itself as one of the most vulnerable countries to climate change. Rising sea levels, intensifying cyclones, salinity intrusion, and flooding are tangible issues, not just forecasted scenarios. The global community largely agrees that Bangladesh deserves climate finance and international support, and this remains valid. However, a troubling question is emerging domestically: can Bangladesh continue to portray itself primarily as a climate victim while heavily relying on imported fossil fuels that leave it vulnerable to economic and geopolitical shocks? Recent energy crises have brought this debate to the forefront. Global disruptions—such as the war in Ukraine and ongoing instability in the Middle East—highlight the vulnerability of fuel-import-dependent economies. Bangladesh's energy system, heavily reliant on natural gas, coal imports, and purchased electricity, could suddenly face rising costs, foreign currency strain, and shortages. Load shedding has returned, industrial confidence has waned, and public finances are burdened by energy subsidies. It is clear now that Bangladesh's energy challenge extends beyond environmental concerns.²⁷² It is nearly a strategic concern. Energy security, safety, economic sovereignty, and national progress have become interconnected.²⁷³

Until recently, Bangladesh's renewable energy policy advanced slowly. Solar targets were limited, implementation varied, and fossil-fuel generation grew rapidly to meet rising demand. The reasoning was straightforward: rapid industrialization needed dependable baseload power, and fossil fuels seemed the quickest

answer. Yet, the global energy situation has transformed. Imported fuel is no longer reliably inexpensive. Fluctuations in exchange rates impact electricity costs directly. Any external crisis—such as shipping delays or regional conflicts—now has immediate repercussions for factories, households, and government finances. As a result, renewable energy is now being seen not just as a climate initiative but also as a means of economic security. Since 2024, the key change has been conceptual rather than technological: policymakers increasingly view solar energy, regional hydropower trading, and energy efficiency as strategies to reduce dependence on international fuel markets.

Rooftop solar panels on factories, commercial buildings, and public institutions are becoming increasingly popular because Bangladesh lacks sufficient land for large-scale renewable energy parks. Urban density, once considered a challenge, could be an advantage if millions of rooftops are converted into small power stations. However, this shift won't be easy. Bangladesh has invested heavily in traditional power plants under long-term contracts, and many must keep operating to avoid penalties. The grid infrastructure needs upgrading before it can handle significant renewable energy inputs. Financing remains a challenge, with private investment hinging on stable regulations. Additionally, energy transitions are political issues; electricity prices directly impact voters, and industrial competitiveness relies on a reliable supply. Governments must navigate reforms carefully to maintain social stability. Therefore, Bangladesh is unlikely to stop using fossil fuels suddenly. Natural gas and nuclear power will continue to be key energy sources for years to come. A gradual diversification of energy sources is a more realistic approach than an abrupt change.

The current government in Bangladesh has a strategic opportunity to reshape its climate story. Instead of remaining a country waiting to be compensated for damages endured elsewhere, Bangladesh can position itself as a nation proactive in reducing vulnerabilities through local innovation and resilience-building efforts. This change is significant on the global stage, as international supply chains are increasingly favoring low-carbon production. Export sectors like garments and pharmaceuticals will increasingly need to meet sustainability standards set by European and North American markets. Additionally, cleaner electricity is becoming as much an economic advantage as an environmental benefit. There is also a generational aspect: Bangladesh's young workforce will operate within an energy system developed today. Investing in renewable energy, enhancing efficiency, and fostering regional power cooperation can chart a path toward greater energy independence.

The debate should not be about development versus climate responsibility. Instead, the key choice is between dependence and resilience. Bangladesh cannot influence global emissions or geopolitical conflicts, but it can manage its economic exposure to these issues. A practical energy transition—using renewables, nuclear power for stability, smarter grids, and reducing fuel imports—would enhance economic security and strengthen Bangladesh's moral stance in international climate talks. Bangladesh's leadership in adaptation has already gained global respect. Leading in energy transformation could define its future role. The next decade will show if Bangladesh remains a victim of climate change or becomes a model for strategic adaptation by vulnerable nations. Solar power offers prosperity, reliable energy, and decarbonization potential. As a low-lying, climate-vulnerable country, Bangladesh cannot delay this transition. It will lessen climate impacts and create a more resilient grid. Large solar projects can supply clean power to densely populated areas, while mini-grids can energize remote, off-grid regions. With supportive solar policies, Bangladesh can boost domestic renewable energy development.

I have installed a 6-kilowatt rooftop solar system with net metering at my building in Jolshira Bason, Dhaka, which successfully meets my energy needs and supports the national grid. The system cost Tk 350,000, and I save about Taka 4000 on my electricity bill each month. Rising electricity prices and frequent summer load shedding are motivating more households to adopt rooftop solar. According to ACI Motors' solar division, a 5-kW rooftop system costs around Tk 300,000, with prices likely to decrease further if import duty exemptions are fully implemented, a crucial step. The government has prioritized renewable energy, especially solar power, aiming to generate 10,000 MW of electricity from renewable sources over the next five years. Currently, solar equipment faces import duties and taxes of 30 to 50%. However, in this year's budget, the government eliminated import duties, regulatory duties, supplementary duties, and advance taxes on key solar equipment, which could reduce project costs by more than 25%. Industry stakeholders note that certain conditions might still limit the widespread adoption of rooftop solar.

Recommendation on Future Research

To advance solar energy development in Bangladesh, further research is essential to effectively integrate solar systems. Emphasis should be placed on developing strategies and policies for implementation, installation, distribution, and maintenance. An academic and industrial approach is necessary to lower costs, streamline processes, and ensure proper funding. Additionally, understanding the integration of solar technology is crucial for sustainable growth.²⁷⁴ Pragmatic and sustainable solutions are needed to address challenges related to expanding net metering, subsidizing low-income households, and developing renewable energy setups in urban and rural areas to foster market growth, innovation, and modernization. Initiatives are required to tackle current and future technical issues. Investments in grid infrastructure, energy storage, and smart grid technologies are essential to support high levels of solar PV penetration and overcome intermittency issues. Significant progress

has been made in developing battery storage technologies for off-grid hybrid microgrids, enhancing their effectiveness, usefulness, and sustainability across various rural communities. It is important to prioritize the development of hybrid systems that integrate renewable energy sources to ensure dependable, cost-effective, and user-friendly solutions for the future.²⁷⁵

We should establish a range of solutions to lower the capital costs of solar installations. This could include specialized green finance, microcredit, public-private partnerships, and social business models. These approaches are especially vital for rural and small-scale clients, who currently lack adequate support from the existing financial system.²⁷⁶ We determined that extending the tested business models from SHS programs to other solar sub-segments offers a promising opportunity to replicate the system.²⁷⁷ The subject of social acceptance and community needs should be addressed through sensitization programs, capacity building, and project design approaches that may involve local stakeholders, including individuals.²⁷⁸ However, environmental sustainability needs to be addressed seriously in future studies. The government and industry need to collaborate to develop solar PV waste management and recycling processes, as well as related infrastructure and technology, to mitigate potential environmental impacts.^{279, 280} Bangladesh needs to develop a stable, suitable, user-friendly, eco-friendly, sustainable, and robust strategy and framework for solar energy implementation, installation, and financial and technical solutions, aiming for a better future. Future research could focus on several aspects. New solar technologies in Bangladesh should be evaluated both technically and economically to inform investment decisions.²⁸¹ Bangladesh is at a crossroads, shifting from reactive to adaptive energy management. The country requires viable and intelligent energy systems that combine digital and smart solutions with solar sustainable energy planning and implementation.²⁸²

In the future, we need to conduct research to develop original, effective, and scalable solar-based energy control systems for off-grid nodes, which will help ensure energy availability in remote areas of Bangladesh.²⁸³ Social assessment of the potential for solar energy to reduce poverty and promote women's empowerment in poor, rural areas.^{284, 285} There is a need to create an innovative grid integration strategy that combines solar, energy storage, demand response, and distributed generation to operate the grid effectively.^{286, 287} It is necessary to assess performance at specific intervals and suggest improvements to adapt to changes in the market and technology.^{288, 289} There is an opportunity to integrate research that offers multi-sectoral benefits and addresses issues related to solar irrigation systems, which could improve agricultural activities.^{290, 291} Significant research exists on green energy and environmental sustainability. Currently, solar implementation is advancing rapidly, but in Bangladesh, awareness about recycling technologies, circular economy principles, and PV solar panel end-of-life (EOL) management remains limited. While the country recognizes the abundance and potential of solar energy, the integration of digitalization and artificial intelligence into the system is still underexplored.²⁹² To enhance system flexibility, resilience, and effectiveness, extensive research is required to assess the feasibility of AI-powered tools such as forecasting, demand-side management, predictive maintenance, and strategy and policy optimization and implementation. Additionally, solar energy is leveraged to foster inclusive development by providing socioeconomic benefits, including improved rural electrification, income opportunities, and climate change mitigation.^{293, 294} In Bangladesh, long-term resilience goals regarding technical challenges such as grid integration, energy storage, and environmental concerns like waste management and solar panel recycling are essential to consider, making related studies crucial. Localized and need-based innovations in solar energy technology, installation, implementation, maintenance, and recycling will facilitate and improve the success of solar energy development in Bangladesh.

Conclusion

The current climate crisis is largely the result of more than a century of industrialization in high-emitting countries. Many developed nations built their economies through the extensive use of coal, oil, gas, and industrial processes that generated massive greenhouse gas emissions. Developing countries like Bangladesh are now bearing the consequences through environmental damage, economic losses, and human suffering. This creates a strong ethical responsibility for high-emitting nations to support vulnerable countries in adapting to climate change and recovering from its impacts. One of the key outcomes of recent United Nations climate negotiations has been the establishment of the Loss and Damage Fund. This fund is intended to support countries like Bangladesh in addressing climate-related losses and damages. Such support can help communities recover, invest in adaptation measures, support climate migrants, and strengthen resilience. Compensation for climate-related losses should not be viewed as charity. It is a matter of accountability and global responsibility. Today we witnessed firsthand how climate change is affecting people's lives far beyond environmental degradation. It is undermining livelihoods, disrupting children's education, affecting public health, and weakening overall social protection systems. Despite their limited resources and reliance on traditional knowledge and coping mechanisms, vulnerable communities continue to fight for survival and adaptation. However, the scale and intensity of the climate crisis are increasingly exceeding their individual capacity to respond. This is why institutional support, international cooperation, and sustained climate financing are no longer optional—they are essential. Climate change is not merely an environmental crisis; it is one of the defining justice issues of our time. The farmer who loses his crops, the family displaced by riverbank erosion,

and the child facing an uncertain future are not responsible for creating this crisis. Yet they are paying its highest price. Countries like Bangladesh have repeatedly demonstrated remarkable resilience, innovation, and determination in the face of adversity. However, the scale and complexity of the climate crisis have now reached a point where no country, government, or community can address it alone. The time has come to move beyond commitments and towards meaningful action. Climate justice will only be achieved when responsibility, resources, and opportunities are shared more fairly among nations and communities. One day, history will ask us a simple but profound question: during the climate crisis, did we merely talk about the problem, or did we have the courage to take the right decisions for future generations?

The enormous energy produced by the fusion of hydrogen nuclei at tremendously high temperatures inside the sun and which is the main source of solar energy. As a result, the sun delivers huge energy to solar system including earth, that all living being including humans require. Solar power is very user-friendly and important for social, economic, and environmental concern and it benefits to develop rural electrification, improved public health, reduced environmental pollutions and give sustainable energy solution. Considering growing energy demand and vulnerability to climate change of Bangladesh, renewable energy in general and solar energy in particular is emphasized and very significant for enhancing energy security, safety and reducing greenhouse gas emissions along with ongoing economic development and national progress. There is an urgent need with integrated approach to combining technological innovation, helpful and articulate policy frameworks, tax-reduction motivation with financial incentives and active stakeholder participation to accelerate solar energy arrangement, giving special emphasis on dense urban environment and climatic constraints of the nation. For Bangladesh policies such as tax holidays, reduced or zero import duties on solar modules, inverters, etc. and key balance-of-system components and accelerated depreciation for renewable energy assets can significantly lower capital costs of solar energy installations. Because much solar equipment is imported, such measures can materially improve project economics and support more competitive tariffs. Solar expansion can also stimulate domestic industrial development and job creation. Growing deployment creates opportunities for local manufacturing and engineering firms to participate in the renewable energy supply chain, particularly in mounting structures, electrical systems and installation services. Over time, solar module assembly could also emerge as a viable domestic industry if deployment scales sufficiently. As solar capacity grows, complementary technologies such as battery storage will help manage intermittency and support grid stability. Bangladesh has both the demand and the opportunity to scale solar power rapidly. Now the challenge is just implementation. With the right implementation framework and strategy execution in place. Bangladesh can transform solar ambition into delivered capacity and strengthening energy security, enabling domestic industry and high-skilled job creation and driving long-term economic growth.

There are some gaps between the design and execution of strategy and policy, which may be assisted by empirical calculations of net metering, subsidy programs, or overall renewable energy targets. Again, decentralized solar projects and national energy plans can be better match with scenario or situation-based policy modelling. Such initiative can encourage general people and new entrepreneurs. Innovative financing strategies, such as mixed finance, pay-as-you-go models, green bonds, or carbon-linked incentives need to be examined in future study to determine how well those are effective tools for lower entry barriers for low-income individuals, SMEs, small trades and new entrepreneurs. Technically, high-penetration grid integration is an important area need to consider for study, research and improvement particularly when it comes to intermittence, voltage stability, and frequency management under growing solar participation. Effective and viable research on innovative modeling of smart grids, hybrid renewable systems, and large-scale energy storage adaptable for Bangladesh's grid limitations is essential. Additionally, for rural and poor people (like slum-area) electrification options, comparative research and motivational little training may be evaluated for all possibility among solar, biomass, wind, hybrid renewable, along with grid-interactive micro-grids in various geographic and socioeconomic circumstances can be useful and beneficial. Transforming Bangladesh's solar potential into a resilient, inclusive, and sustainable energy transition requires a robust and meticulous strategy. There need to be combined study in future on technology, engineering, finance, policy, management, and social sciences to integrated all possibility toward an interdisciplinary and systems-oriented approach for sustainable and effective solution of optimum utilization of renewable (mainly solar) energy.

Considering all the possibilities, ways of power generation, suitability and sustainability, Bangladesh should look forward on solar power as future of power generation. For a poor country like Bangladesh, it is really necessary to concentrate on solar power due to huge availability of resources and cost effectiveness rather than other ways of power generations which are also hazardous for environment. With the progress of development, demand of power is increasing. To meet up this demand solar power must be considered as a main source. With application of new technologies power generation can be possible with low rate and more easily. Proper use of solar power resources can be assured easily. System-level optimization, local innovation, social motivation and long-term sustainability need to be focused of future solar energy research and implementation in Bangladesh. However, long-term resilience goals towards such technical issues as grid integration, energy storage, and environmental issues, such as waste management, recycling EOL solar panel, are supposed to be taken into

account. For renewable energy, the government's policy can easily provide a strong base. However, more coordination, support systems, practicable policy framework and new funding facilities are paramount to achieve the magnificence of renewable energy success in Bangladesh. Application of solar power in the fields discussed in this article shows that people will not have to depend upon the national grid only, but they can also use solar power for various purposes to improve their lifestyle. On the other hand, solar energy is very useful to promote comprehensive development through socioeconomic benefits, along with better rural electrification, income generation, employment generation and mitigation of climate change. Bangladesh has enough potential to appear as role model to developing country for using renewable energy particularly solar power to fulfill its demand of electricity and people aspiration.

National geographical limitations of Bangladesh are often cited as a major obstacle to renewable-energy development. Land scarcity is certainly a serious constraint, but it should not be confused with an absence of renewable resources. The country has substantial opportunities in solar energy, rooftop generation, agricultural applications, wind, biomass, biogas and emerging technologies. Solar energy is clearly the leading renewable resource. Bangladesh receives substantial solar radiation throughout the year and the country has already demonstrated its ability to deploy solar technologies at scale. More than six million solar home systems have been installed, particularly in rural and off-grid areas. However, the major opportunity is rooftop solar. Bangladesh has millions of square meters of rooftops on factories, commercial buildings, educational institutions, hospitals and government offices. The ready-made garment sector alone provides an enormous opportunity for industrial rooftop solar. The National Rooftop Solar Programme has also given additional policy momentum to this approach. Rooftop generation does not require large quantities of agricultural land. Electricity can be generated close to the point of consumption, reducing pressure on the transmission network and lowering electricity costs for consumers. Again, another promising area is solar irrigation. Bangladesh has a large number of irrigation pumps, many of which depend on diesel or grid electricity. Solar-powered irrigation can reduce farmers' exposure to fuel-price fluctuations while providing a cleaner and potentially more economical source of energy.

Additionally, wind energy deserves greater attention, particularly in coastal areas and offshore locations. Bangladesh's long coastline and seasonal wind regimes provide opportunities for carefully selected wind projects. However, detailed site-specific resource assessment, modern technology and proper grid planning are essential before large-scale investment. Bangladesh cannot afford to regard renewable energy as a peripheral component of its energy system. Continued dependence on imported fossil fuels leaves the economy vulnerable to international price shocks, foreign exchange pressures and climate risks. Renewable energy offers an opportunity to diversify the energy mix, reduce import dependence and build a more resilient economy. The country's constraints are real, but they are not insurmountable. Land scarcity can be addressed through rooftops, floating solar, agro-voltaic and careful land-use planning. Grid limitations can be overcome through transmission investment, storage, digitalization and regional connectivity. Financial barriers can be reduced through green finance, appropriate incentives and transparent investment policies. The real challenge is therefore not whether Bangladesh possesses renewable energy potential. It is whether the country can convert that potential into reliable, affordable and scalable energy through disciplined policy implementation. A successful renewable energy transition would do more than reduce carbon emissions. It would strengthen energy security, conserve foreign exchange, support agriculture and industry, create new investment opportunities and enhance Bangladesh's capacity to withstand future economic and climate shocks. The time has come to move from renewable energy ambition to renewable energy implementation.

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