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Review Research

From Shadows to Sunrise: The Impact of Solar Power Plants on Enhancing Bangladesh's Economy

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ABSTRACT

Bangladesh has had a substantial evolution in its energy sector, mostly propelled by the emergence of solar energy as a catalyst for economic development and stability. The government has deliberately utilized solar energy solutions to address ongoing power shortages, reduce dependence on fossil fuels, and enhance electricity availability for isolated and rural regions, capitalizing on ample sunlight. The transition to solar energy has markedly enhanced energy security, generated new job possibilities, and stimulated technical innovation, accompanied by considerable investments in renewable energy infrastructure. The extensive deployment of solar facilities has significantly improved industrial productivity and agricultural efficiency, bolstering economic resilience across several sectors. Moreover, solar energy projects have enabled small enterprises, expedited rural electrification efforts, and significantly diminished carbon emissions, establishing Bangladesh as a model for renewable energy implementation in underdeveloped countries. Even though Bangladesh has made a lot of progress, it still faces big problems. These include high initial investment costs, technical issues, and regulatory gaps that make it hard to use solar energy on a large scale. This review paper analyzes the transformational economic effects of solar energy in Bangladesh, highlighting its essential contribution to sustainable development, poverty reduction, and long-term energy autonomy. This assessment highlights the necessity for supporting government policies, financial incentives, and ongoing technology breakthroughs to enhance the growth and effectiveness of Bangladesh's solar energy initiatives by meticulously examining current difficulties and potential prospects.

1. Introduction

Bangladesh, a South Asian country with 148,460 square kilometers (57,320 square miles), has a population of 162 million, rendering it the 8th most densely populated nation globally **(Central Intelligence Agency, 2020; Sunny et al., 2020a)**. Notwithstanding constrained natural resources

and excessive dependence on fossil fuels, Bangladesh has achieved significant economic development, with its Gross Domestic Product (GDP) increasing at an average rate of 6.5% over the previous decade **(Bangladesh Bank, 2019; Kuddus et al., 2021)**. By 2015, the nation achieved middle-income classification, and in 2019, GDP growth accelerated to 8.15% **(Islam et al., 2018a; Bangladesh Bank, 2019).** According to the World Bank, Bangladesh accounted for 0.58% of the world economy, with a total GDP of 302.57 billion US dollars in 2019 **(islam et al., 2018b; Kuddus et al., 2020; World Bank, 2020).** This swift economic growth has exacerbated the country's energy dilemma, since increasing electricity consumption exerts significant strain on its power sector. Presently, per capita energy consumption is 344 kilograms of oil equivalent (kg), indicating a 22% rise from 2013 to 2019 **(Hydrocarbon Unit, 2019)**. Notwithstanding the increasing demand, Bangladesh continues to rely heavily on fossil fuels, resulting in escalating import expenses, energy vulnerability, and ecological deterioration **(Islam et al., 2018c; Hydrocarbon Unit, 2019; Sunny et al., 2020b).** This reliance may impede future economic advancement without a sustainable energy solution.

In this context, solar energy has emerged as a revolutionary force that can reshape Bangladesh's economic landscape. The country possesses significant potential for solar power generation because to its year-round ample sunshine **(Sunny et al., 2018; Hydrocarbon Unit, 2019).** Solar plants are crucial in alleviating energy shortages, decreasing power expenses, enhancing industrial productivity, and generating new job possibilities. Utilizing solar infrastructure, Bangladesh may evolve from an energy-deficient country to a self-sufficient economy, guaranteeing long-term stability and sustainable progress **(Moorthy, Patwa, & Gupta, 2019)**. This research examines the role of solar plants in Bangladesh's economic transition, focusing on their impact on energy security, industrial growth, employment generation, and overall economic resilience. As Bangladesh transitions from energy issues to the dawn of renewable wealth, solar plants serve as a symbol of sustainable growth and economic development.

Bangladesh's present energy framework significantly depends on a variety of commercial energy sources, including as natural gas, coal, imported oil, liquefied petroleum gas (LPG), imported liquefied natural gas (LNG), imported electricity, and hydroelectric power. Biomass accounts for approximately 25% of primary energy, with the remaining 75% provided from commercial sources. Natural gas constitutes roughly 51% of Bangladesh's commercial energy, while imported LNG accounts for an additional 13% **(Sunny et al., 2019; Murshed & Alam, 2021**). Bangladesh imported approximately 9.56 million metric tons of crude and refined petroleum products during the 2021-22 fiscal year, with imported oil being a significant element **(Hydrocarbon Unit, 2019)**. In addition to natural gas and oil, coal is an essential fuel source, particularly in brick production and thermal power generation **(SEREDA, 2020).**

Bangladesh has further diversified its energy strategy by integrating solar home systems (SHS) for cooking and off-grid power, creating roughly 0.69 MW, and biomass gasification systems

producing around 0.4 MW **(Hydrocarbon Unit, 2019)**. The country's energy consumption is expected to attain around 57.20 million metric tons of oil equivalent (Mtoe), bolstered by an annual growth rate in energy demand of roughly 6%. Per capita energy consumption averages around 346 kg of oil equivalent, resulting in a per capita electricity generation of 608.76 kWh **(BPDB, 2019).** Notably, universal access to electricity has reached 100%.

Notwithstanding these advancements, Bangladesh's energy measures are significantly inferior to those of neighbouring South Asian nations. Natural gas is the predominant source in the commercial energy sector, comprising a significant 44.11% share, with oil at 24.1%, LNG at 13%, and LPG at 4%**.** Domestic coal use is limited to 0.31%, whereas imported coal constitutes 3.88% Renewable energy sources, such as hydroelectricity, solar, and wind, jointly account for 0.53% **(SEREDA, 2020).** Biomass constitutes around 27% of total energy consumption, with an energy value of 57.20 Mtoe. In the current context, Bangladesh has significant potential for the advancement of renewable energy sources, especially solar and wind energy. Recent measures, such as the use of solar-powered irrigation pumps, have exemplified the nation's commitment to diminishing dependence on traditional diesel and electrical sources, illustrating a successful approach to alleviating environmental and economic burdens **(Hydrocarbon Unit, 2019).** Consequently, Bangladesh's incremental yet consistent adoption of solar energy represents a vital shift towards attaining a balanced, sustainable, and resilient energy future.

2. Research Methodology

This review study utilized a meticulous and methodical approach aimed at thoroughly examining the impact of solar energy on the economic growth of Bangladesh. Finding, collecting, and putting together in a way that made sense peer-reviewed journal articles, institutional reports, technical papers, policy documents, and conference proceedings that were about solar energy use and how it affected the economy and society in Bangladesh were part of the study method.

2.1 Acquisition and Examination

The principal search terms employed in literature retrieval included combinations such as "solar energy in Bangladesh," "economic impact of renewable energy," "solar home systems Bangladesh," "solar energy policy and initiatives," "renewable energy barriers," "solar energy infrastructure," "solar energy and environmental impacts," and "solar energy potential." The preliminary database search produced several hundred documents. After conducting a preliminary evaluation for relevance using abstracts and keywords, we selected over 70 pertinent sources for a comprehensive study. To extract theme insights in specific domains, we thoroughly examined, evaluated, and synthesized the collected material.

2.2 Data Interpretation and Analysis

A thematic analysis was utilized to maintain academic rigor and reduce potential biases,

information triangulation from several independent sources was routinely conducted. All data obtained from diverse sources were cross-validated for consistency, dependability, and precision.

Present Solar Energy Applications: Photovoltaic (PV) and concentrated solar power (CSP) technologies, rooftop solar installations, floating solar systems, solar mini-grids, solar irrigation pumps, and hybrid solar-diesel systems.

Socio-Economic and Environmental Effects: Economic advantages, job development, enhancements in rural electrification, cost reduction effects, carbon emission reduction, and educational and recreational benefits.

Obstacles & Difficulties: Technical limits, financial constraints, legislative deficiencies, infrastructure shortcomings, and market-related obstacles affecting the widespread use of solar energy.

Government Initiatives and Policy Interventions: These are the programs and policies that organizations like IDCOL, SREDA, BREB, and BPDB have put in place to help build more solar energy infrastructure.

Comparative and International Perspectives: Evaluating Bangladesh's renewable energy adoption in relation to global leaders to discern possibilities and exemplary practices for future advancement.

3. Results and Discussion

This comprehensive literature analysis illustrates the effects of microcredit on social company growth, highlighting both beneficial impacts and significant obstacles. Microcredit has been crucial in advancing financial inclusion, fostering social enterprise development, generating employment, empowering women, enhancing financial literacy, and promoting digital financial services. Nonetheless, problems like as excessive indebtedness, difficulties in loan repayment, and regulatory deficiencies continue to exist. This section rigorously assesses these findings, synthesizing empirical evidence with theoretical frameworks and examining their implications for forthcoming microcredit schemes.

3.1 Practical Applications of Solar Energy in Bangladesh:

Solar energy may be captured via two principal methods: photovoltaic (PV) systems and solar thermal power. At now, photovoltaic technology prevails in the solar energy sector in Bangladesh. The nation administers one of the globe's most comprehensive domestic solar energy initiatives, bolstered by cooperative endeavours among the government, foreign development organizations, and the corporate sector. These collaborations seek to provide economical solar-powered electricity, especially to remote areas lacking access to conventional grid systems. By 2020, small-

scale solar home systems (SHS) supplied power to more than 4 million houses, helping almost 20 million people, which is nearly one-eighth of Bangladesh's population **(Islam et al., 2016; Hutt, 2020)**. The strategic roadmap created by the Sustainable and Renewable Energy Development Authority (SREDA) demonstrates significant expansion in many solar energy sectors from 2017 to 2020. Solar parks escalated from 3MW to 700MW, solar home systems augmented from 205MW to 252MW, and mini/micro/nano solar grids proliferated from 2.69MW to 7MW. The solar irrigation industry had significant growth, increasing from 14MW to 46MW, while rooftop solar initiatives, including net metering, escalated remarkably from 30MW to 650MW. Furthermore, solar-powered drinking water systems increased from 1.6MW to 6MW, solar-powered telecom towers expanded from 8MW to 15MW, and solar street lighting rose from 2.3MW to 5MW. Solar energy capacity had a significant rise from 266.59 MW in 2017 to 1681 MW in 2020 **(Trading Economics, 2020; SREDA, 2020).**

Since 2016, an innovative and quickly evolving use has been the installation of floating solar panels on aquatic surfaces, recognized worldwide for enhanced efficiency and diminished land utilization needs. Bangladesh, possessing extensive water resources almost 150,000 hectares of lakes presents considerable potential for floating solar power generation. Exploiting up to one-third of these lake regions can yield around 15,000 MW of energy. Bangladesh could also make better use of an extra 25,000 MW of solar energy by designating about 10% of shallow water bodies like lakes, rivers, and ponds as aquatic sanctuaries **(Alam, 2020)**. Despite the widespread use of photovoltaic technology, there is still much unmet potential for Concentrated Solar Power (CSP) technology. As acknowledged in Bangladesh's Renewable Energy Policy of 2009, Concentrated Solar Power (CSP) is progressively attaining cost-competitiveness relative to photovoltaic systems. The cost-effectiveness of CSP establishes it as a viable alternative for large-scale solar power generation to adequately meet Bangladesh's current and future energy requirements **(Adenle, 2020; Noor & Muneer, 2010).** Recent updates from SREDA indicate 36 projects with a combined capacity of 2,110.56 MW. Noteworthy among these is a 50 MW solar facility in Gauripur, Mymensingh District, in addition to two substantial solar projects with a total capacity of 200 MW now under development in Sundarganj, Gaibandha District, and Teknaf Upazila, Cox’s Bazar District **(Khasru & Rafee, 2021; Setyawati, 2020).).** These measures emphasize the government's dedication and reveal significant development prospects in Bangladesh's solar energy industry, therefore reinforcing the country's path toward sustainable and autonomous energy management.

3.2 Impacts of Solar Energy

3.2.1 Economic Impact

The use of solar energy in Bangladesh encompasses not only individual families but also yields significant economic advantages, especially in rural areas. Solar Home Systems (SHS) have substantially advanced the economic development of rural areas by decreasing home energy costs,

creating employment opportunities, and facilitating small enterprises **(Khandker, Samad, Ali, et al., 2014)** assert that solar energy augments household income and investment, thus improving overall financial well-being. A principal economic advantage of solar energy is the significant decrease in energy expenses. Historically, rural households depended on costly kerosene for illumination; however, solar energy eradicates these ongoing fuel expenditures, enabling them to redirect resources towards education, healthcare, and business investments **(Burke et al., 2019).** The expansion of the solar sector has generated substantial job prospects, especially in the installation and upkeep of solar panels and cultivating a proficient workforce in rural areas. Solar energy has significantly improved entrepreneurial endeavours. Small enterprises, including grocery stores and tailoring establishments, have profited from prolonged operating hours facilitated by dependable solar illumination, leading to enhanced sales and augmented revenue. Solar-powered irrigation systems in agriculture have diminished farmers' dependence on diesel pumps, therefore reducing expenses and improving production. Solar-powered cold storage facilities have facilitated the preservation of perishable items, enhancing market access and profitability for farmers **(Khandker et al., 2014b)**. Solar energy has significantly transformed the healthcare and education industries. Rural health clinics now possess a reliable power source for medical equipment and vaccine storage, markedly enhancing healthcare accessibility **(Khandker et al., 2014)**. Likewise, solar-powered illumination has enhanced children's education by facilitating nocturnal study, resulting in increased school attendance rates and improved academic performance **(Khandker, Samad, Sadeque, 2014).** Solar energy facilitates financial inclusion by powering mobile banking and digital transactions; therefore, it allows rural communities to access credit and savings options. Moreover, solar energy enhances economic resilience during natural catastrophes by supplying backup power for critical services, hence diminishing recovery expenses. Nonetheless, despite these benefits, obstacles including elevated initial installation expenses and battery disposal issues remain (Khan, 2019). Mitigating these challenges with subsidies and technical innovations can amplify the economic benefits of solar energy. We expect Bangladesh's solar projects to advance, fostering long-term financial stability, entrepreneurship, and comprehensive economic growth. Solar energy is a vital catalyst for economic advancement in rural regions by lowering energy expenses, generating job possibilities, and fostering company development **(Khandker et al., 2014).**

3.2.2 Impact of Solar Energy on the Environment

Solar energy substantially enhances environmental conditions by decreasing fuel usage **(Lu et al., 2020; Khandker et al., 2014)** report that families utilizing solar systems decreased kerosene usage by almost two litters per month relative to non-adopters. Additionally, using solar power for an extra year cuts kerosene use by an extra 0.71 litters per month. This makes the air quality inside much better and lowers the health risks associated with smoke and pollutants. The widespread use of solar energy improves energy security, especially in rural and off-grid areas with restricted access to conventional electricity. From 2003 to 2018, solar projects by the World Bank in Bangladesh mitigated over 9.6 million tons of greenhouse gas emissions and circumvented the use

of nearly 4.4 billion gallons of kerosene **(Cabraal et al., 2021)**. These numbers highlight the essential function of solar energy in alleviating climate change by significantly decreasing carbon footprints. Furthermore, the extensive use of solar technology fosters sustainable economic development by generating job opportunities in the solar sector, encompassing production, installation, and maintenance services. Nonetheless, despite these environmental and economic advantages, substantial ecological issues persist concerning solar energy. The manufacturing of solar panels and batteries entails hazardous chemicals that, if inappropriately discarded, can damage the environment **(Khan, 2019; United Nations, 2015**). Inadequate recycling and waste management techniques for abandoned solar panels may lead to electronic waste, creating significant concerns regarding soil and water pollution. To mitigate the long-term environmental impact of solar power, it is essential to develop sustainable waste disposal methods and enhance solar technology through the utilization of eco-friendly materials and improved recycling techniques **(Dumitrescu et al., 2021; Khan, 2019).**

3.2.3 Solar Energy and Child Education

The introduction of solar energy markedly enhances children's educational performance in Bangladesh by prolonging study possibilities during the night **(Samad et al., 2013).** Improved lighting conditions enable students to study after sunset, especially aiding rural regions with insufficient or inconsistent grid energy. Extended study hours result in enhanced academic achievement and elevated school enrolment rates, promoting superior educational results **(Khandker, Samad, Sadeque, 2014)**. Solar-powered illumination decreases reliance on kerosene lamps, which release detrimental smoke that impacts interior air quality. Inadequate illumination and indoor air pollution adversely affect students' focus, efficiency, and well-being, leading to problems such as eye strain and respiratory disorders. The availability of solar-powered illumination enhances safety and health in study environments, hence improving learning circumstances and academic achievement **(Samad et al., 2013).** Moreover, solar energy improves instructional infrastructure in remote schools. Numerous rural schools encounter electrical deficits, constraining their capacity to employ contemporary educational resources or provide nighttime instruction. Solar systems mitigate these issues by delivering reliable electricity for schools, facilitating sophisticated pedagogical techniques, and fostering a more stimulating educational atmosphere. Financial savings from decreased kerosene use can be allocated to educational resources, such as books and supplies, which enhance school enrolment and retention, especially among low-income families. Consequently, solar energy plays a crucial role in alleviating poverty by enhancing access to excellent education and broadening future prospects for children in Bangladesh **(World Bank, 2021; Khandker et al., 2014).**

3.2.4 Solar and Recreational Outcomes

Solar energy markedly improves recreational and leisure activities in rural villages of Bangladesh. Dependable access to power via solar systems directly facilitates the operation of vital entertainment and communication equipment, such as televisions, radios, and mobile phone

charging stations **(Jacobson, 2007)**. The extensive use of solar energy technology significantly enhances living standards by introducing new recreational options, alleviating the monotony of everyday life, and facilitating needed relaxation and enjoyment **(Rahman & Ahmad, 2013).** Television, powered by solar energy, has become an essential medium for information distribution, education, and entertainment, offering rural communities crucial news, instructional material, and cultural programming. Before the implementation of solar solutions, insufficient grid connectivity significantly constrained access to television in several distant regions. Solar-powered systems have successfully addressed this disparity by providing rural populations with cost-effective and sustainable energy sources, hence enhancing their connectedness to national and global events. Improved television accessibility has broadened the consciousness and perspective of these communities, ensuring they remain informed about current events and worldwide advancements. Likewise, solar-powered radios remain essential communication devices in isolated areas with restricted internet connectivity. Solar-powered radios offer uninterrupted access to essential information, such as meteorological predictions, agricultural updates, and health advisories. This is especially advantageous for farmers and rural labourers, who rely on prompt and precise information to enhance their agricultural output and general welfare **(Mahmud et al., 2021).** Additionally, radio broadcasts provide entertainment via music, plays, storytelling, and cultural material, therefore conserving local traditions and enhancing social cohesion and community relationships among rural communities. The utilization of solar energy for mobile phone charging markedly enhances rural connection, improving communication, financial transactions, and access to emergency services. This enhanced connectedness cultivates robust social networks, facilitates economic possibilities, and strengthens overall community resilience. So, solar energy solutions not only make leisure activities better, but they also help rural communities grow socially and economically by bridging the digital divide and encouraging growth for everyone **(Rahman & Ahmad, 2013).**

3.3 Government Initiatives for Solar Energy

The government of Bangladesh supports renewable energy projects to attain energy security through both renewable sources (solar, wind, hydro, biomass) and conventional sources (oil, gas, coal). The government's renewable energy initiatives seek to achieve policy goals of ensuring residents have safe, dependable, and cheap energy access **(Masud et al., 2020)**. To achieve these goals, entities like Infrastructure Development Company Limited (IDCOL) and Bangladesh Power Development Board (BPDB) have methodically executed renewable energy initiatives and advocated for energy efficiency **(Majid, 2020; BPDB, 2019; IDCOL, n.d.).** The subsequent sections outline the initiatives of BPDB and IDCOL to promote solar energy adoption.

3.3.1 Solar Home Systems (SHS)

A substantial segment of Bangladesh's populace inhabits rural and isolated regions, frequently marked by restricted or absent access to traditional power networks. In response to this difficulty, the government of Bangladesh, via the Infrastructure Development Company Limited (IDCOL),

launched the Solar Home Systems (SHS) initiative in 2003 to address fundamental electrical requirements in these underserved areas **(IDCOL, n.d.).** Solar home systems gained rapid popularity owing to their cost-efficiency, straightforward installation, and capacity to provide instant advantages to rural homes **(Islam et al., 2014).** As of 2018, IDCOL has built almost 6.8 million solar home systems (SHS) throughout Bangladesh, yielding a total power-generating capacity of roughly 220 MW, therefore substantially furthering the government's objective of attaining universal electricity access by 2021 **(Masud et al., 2020).** The extensive use of SHS has had significant socioeconomic advantages beyond simple energy supply. This program significantly diminished the nation's dependence on kerosene for illumination, conserving around 1.14 million tons of kerosene, equating to nearly USD 410 million in economic savings **(IDCOL, n.d.)**. The decrease in kerosene use has not only decreased family energy costs but has also markedly enhanced indoor air quality, therefore mitigating health concerns linked to extended exposure to kerosene vapors **(Khandker et al., 2014a)**. The comprehensive SHS program has significantly invigorated local economies by generating some 75,000 direct and indirect job possibilities, especially in system installation, maintenance, and related technical services **(IDCOL, n.d.).** Participation in the private sector has been essential in expanding the SHS program, with significant donations from entities like Grameen Shakti. These alliances have improved program outreach and efficacy, guaranteeing that millions of rural families have access to dependable and sustainable energy solutions. In addition, the SHS project has indirectly led to improvements in education by letting students' study for longer periods of time and by providing a steady supply of electricity to medical facilities in rural areas **(Samad et al., 2013; Khandker et al., 2014).** These projects collectively illustrate Bangladesh's strategic dedication to using solar energy to promote rural development, economic empowerment, environmental conservation, and improved quality of life for millions of its rural residents.

3.3.2 Rooftop Solar Projects

In Bangladesh, land scarcity presents considerable obstacles for extensive solar installations, necessitating around 3.5 to 4 acres of land for each megawatt of solar power producing capacity **(Solangi et al, 2021; IDCOL, n.d.).** Thus, the government favors rooftop solar initiatives as a viable approach to maximize urban space and facilitate efficient energy generation without encroaching on essential agricultural land. The Infrastructure Development Company Limited (IDCOL) has actively facilitated rooftop solar installations by providing requisite financial support, required technical help, and rigorous performance monitoring. As of July 2019, IDCOL had successfully financed eleven rooftop solar projects, four of which were operational, together providing an installed capacity of roughly 3.07 MW. IDCOL projected further development, planning to fund and build a total rooftop solar capacity of around 300 MW by 2022 **(IDCOL, n.d.).** At the same time, the Bangladesh Power Development Board (BPDB) carried out extra solar projects that included both grid-connected and off-grid systems. This greatly increased the country's renewable energy capabilities **(BPDB, 2019; Sunny et al., 2017).**

3.3.3 Solar Mini Grid Projects

Solar mini-grids have emerged as essential elements in Bangladesh's goal to efficiently electrify distant and off-grid villages. These solar mini-grids often vary in size from a few kilowatts to 10 MW, providing energy directly to rural residences and commercial entities. The implementation of mini-grids facilitates the efficient use and distribution of excess energy, optimizing the overall efficacy of local energy management. IDCOL implemented 26 solar mini-grid installations with a total capacity of 5 MW, benefiting almost 16,000 rural homes **(IDCOL, n.d.).** International funding groups like the World Bank, the Japan International Cooperation Agency (JICA), the United States Agency for International Development (USAID), and the Asian Development Bank (ADB) have all made important contributions to these mini-grid projects. This shows that the world is working together to make renewable energy more accessible in Bangladesh **(IDCOL, n.d.).**

3.3.4 Solar Irrigation

The solar irrigation effort tackles essential energy consumption challenges in the agriculture industry, predominantly reliant on diesel-powered irrigation pumps. Bangladesh utilizes around 1.61 million irrigation pumps, using annually about 900 million liters of fuel and nearly 700 megawatt-hours of energy. Diesel pumps account for almost 83% of the overall energy usage **(Sunny et al., 2020; Baky et al., 2017)**. Solar-powered irrigation offers a sustainable and economically beneficial option. IDCOL's strategic goal seeks to build 50,000 solar irrigation pumps by 2025, significantly diminishing reliance on fossil fuels in agriculture. As of October 2019, IDCOL has effectively built 1,630 solar irrigation pumps, totaling around 32 MW in capacity, with 1,323 pumps now functioning **(IDCOL, n.d.)**. This deliberate transition to solar irrigation significantly impacts operational costs for farmers, boosts agricultural output, and promotes environmental sustainability by decreasing carbon emissions.

3.3.5 Solar-Disel Hybrid Solutions

The telecommunications sector in Bangladesh has likewise profited from the introduction of renewable energy, especially via solar-diesel hybrid systems. Traditionally, Base Transceiver Stations (BTS) for telecommunications that are located far away have relied heavily on diesel generators, which required regular maintenance, fuel transfers, and other logistical issues. Using solar-diesel hybrid systems is a beneficial way to deal with these problems because they use solar energy as their main source of power and diesel generators as backup sources. IDCOL has played a crucial role in this shift by offering financial assistance for 138 solar-diesel hybrid power plants specifically designed for telecom infrastructure **(IDCOL, n.d.).** This program has markedly enhanced operational dependability, reduced maintenance requirements, and promoted ecologically sustainable and economically viable telecommunications services in remote areas.

3.3.6 Research and Development (R&D) Initiatives

Additionally, Bangladesh prioritizes research and development (R&D) in renewable energy technologies, markedly improving innovation capability and facilitating sustainable long-term energy transitions. IDCOL, acknowledging the significance of technical progress, funded thirteen

innovative renewable energy research and development activities with a $1 million grant from the World Bank **(IDCOL, n.d.).** The varied projects include a hybrid compact cold storage system made by United International University (UIU), solar photovoltaic-powered boats, an advanced monitoring system for solar irrigation, and DC nano-grid solutions designed for use in homes and businesses. In this research and development effort, other groundbreaking projects include solar-powered electric rickshaw vans made by BRAC University, thermal energy storage using Phase Changing Materials (PCM) made by Dhaka University of Engineering & Technology (DUET), and advanced battery charging stations for small electric vehicles made by Solar E Technology. Also, the Bangladesh Atomic Energy Commission (BAEC) is working hard to create dye-sensitized solar cells (DSSCs) using materials from Bangladesh **(IDCOL, n.d.).** Through mini-grid implementations, solar irrigation, hybrid telecom energy solutions, and large-scale research and development efforts, these comprehensive and focused activities show that Bangladesh is serious about advancing renewable energy development. These strategic projects together highlight Bangladesh's commitment to attaining comprehensive sustainable development goals, strengthening national energy resilience, advancing technical innovation, and promoting long-term economic and environmental sustainability.

3.4 Prospect of Solar Energy in Bangladesh:

Bangladesh's future energy strategy encompasses a thorough assessment of local energy resources, geographical location, and diplomatic connections with adjacent nations. When thinking about the best mix of energy sources, it's clear that solar power needs to be added to the national grid because it's sustainable and cheap **(EIA, 2020).** The Levelized Cost of Energy (LCOE) for solar energy generation has significantly reduced, making solar energy more economically attractive compared to conventional energy sources like coal and natural gas **(EIA, 2020).** The substantial decrease in solar panel costs has enabled broader and more cost-effective deployment of solar energy nationwide. Bangladesh has pledged to significant projects to greatly augment renewable energy capacity, including extensive solar parks, floating solar systems, and comprehensive rooftop solar initiatives. Floating solar initiatives in Bangladesh utilize the abundant water bodies, optimizing land usage while enhancing renewable energy generation capacity **(Alam, 2020).** Rooftop solar arrays optimize metropolitan areas, enhancing energy production without encroaching on scarce agricultural and residential land. To make the switch to renewable energy work, Bangladesh needs to change its current energy laws to include helpful tools like the Feed-in Tariff (FIT) system, which gives solar energy producers long-term investments and financial incentives. Offering subsidies and economic incentives can enhance private sector participation and expedite the construction of large-scale solar power projects. Policy interventions are essential for attaining national renewable energy objectives and promoting sustainable economic development and environmental preservation **(Masud et al., 2020).**

Moreover, progress in energy storage technology and smart grid systems is crucial for improving the incorporation of intermittent solar energy into the national electrical grid. Smart grid

architecture can effectively regulate energy distribution, reduce waste, and provide consistent and dependable power supply, particularly from renewable sources. Adding advanced energy storage systems like batteries and pumped hydro storage will help manage the intermittent nature of solar power, making sure there is a steady flow of energy **(IDCOL, n.d.).** Although hydropower is essential to Bangladesh's renewable energy policy, emphasizing solar energy development provides significant advantages by diminishing the nation's reliance on imported electricity. Bangladesh presently imports around 660 MW of energy from India via the Bheramara-Baharampur interconnection and is in discussions to import an additional 500 MW of hydropower from Myanmar **(Schaefer, 2017; Power Cell, n.d.).** Concentrating on local solar power capabilities may substantially improve energy security, mitigate geopolitical concerns linked to energy imports, and foster national energy independence. In the end, Bangladesh's strategic focus on and proactive progress toward solar energy infrastructure set the country up for a sustainable, resilient, and economically independent future. Improving laws, encouraging new technologies, and making it easier for the government and businesses to work together would make solar energy even more important, which would help Bangladesh reach its long-term sustainable development goals **(Masud et al., 2020**; **IDCOL, n.d.).**

4. Conclusion and Recommendation

This review paper comprehensively examines the transformational impact of solar energy on economic enhancement and energy sustainability in Bangladesh. Bangladesh has a lot of potential to greatly improve its solar energy capabilities by taking advantage of favourable Global Horizontal Irradiance (GHI) levels and making smart investments. Renewable energy use has grown a lot thanks to government programs and help from groups like the Bangladesh Rural Electrification Board (BREB), the Sustainable and Renewable Energy Development Authority (SREDA), and the Infrastructure Development Company Limited (IDCOL). This is especially true in rural and off-grid areas. These advancements highlight Bangladesh's strategic potential to emerge as a significant participant in the global renewable energy market. Some major problems still exist, even though there has been a lot of progress. These include problems with grid connectivity, limited funds, inadequate infrastructure, and differences in technical ability. To solve these problems, we need to work together on a plan that includes changing policies, finding better ways to pay for things, and coming up with new ways for the government and businesses to work together. The government needs to improve the rules and regulations that are already in place by putting in place full Feed-in Tariff (FIT) procedures and specific subsidies to encourage private investment, new ideas, and more widespread use of solar technology. From a worldwide comparative standpoint, the experiences of prominent solar energy providers indicate substantial prospects for Bangladesh. Adopting innovations in energy storage, smart grid technologies, floating solar installations, and rooftop solar projects is crucial for optimizing solar energy consumption. Moreover, targeted research and development (R&D) efforts that tackle local issues and improve technology advancements in renewable energy sectors are essential for ongoing

improvement. Future research should focus on assessing the socio-economic effects of extensive solar implementation, enhancing hybrid renewable systems, and tackling environmental issues associated with solar panel lifetime management. Therefore, despite significant accomplishments, Bangladesh needs to implement progressive policies and strategic planning to surmount current obstacles and fully harness its renewable energy potential. Bangladesh may be able to move toward a sustainable and energy-secure future if it deals with the problems that have been identified through effective policies, focused research and development, international partnerships, and involving all stakeholders. These proactive actions would enhance economic resilience and substantially aid global climate mitigation efforts and sustainable development objectives.

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Author Contribution
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A statement of conflicting interests
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