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A Review on Current Renewable Energy Development Prospects and Challenges in Bangladesh

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Abstract: This review examines the function of renewable energy to highlight its significance in Bangladesh's power generation mix. The report highlights the importance of solar, hydro, wind, biomass, biogas, geothermal, and nuclear energy in the system. Graphs, charts, and maps clearly show the significant capacity and wide distribution of renewable power plants, underscoring the pressing need for additional development and integration of renewable energy in Bangladesh. The study highlights investment requirements, low-cost production, and greenhouse gas emission mitigation and discusses opportunities and obstacles to growing renewable energy. The main barriers to rural electrification include limited acreage for project implementation, financial constraints, and limits in grid infrastructure. The analysis underscores the significance of technological innovation, international cooperation, green financing, and policy reforms in propelling the sector. Lastly, it provides solutions for these challenges, such as adopting climate-resilient systems, updating infrastructure, and advancing sustainability. With 230 MW, hydropower is second after solar energy, with 459 MW. The results emphasize the necessity of a comprehensive, cooperative approach to fully utilize Bangladesh's renewable energy potential and assist its sustainable energy transition.

Keywords: *Renewable energy, Electricity generation, Prospects, Challenges, Bangladesh*

Introduction: Bangladesh's population is currently estimated at 174.7 million [1] and will reach 189 million by 2041 [2]. Bangladesh aspires to be a prosperous nation by 2041, and as its population grows, so will its economy. The expanding population offers prospects and obstacles to advancing the economy. A larger workforce can boost economic growth and productivity but also strain the infrastructure, social services, and available resources, necessitating careful planning to ensure sustainable development. Hence, this calendar year is significant for the nation's future [3]. Bangladesh must prioritize industries to become a high-income or established nation. It also needs reliable and continuous electricity generation [4].

On the other hand, the requirement for electricity is expected to rise from 20,129 MW in 2024 to 82,292 MW in 2041 [4,5]. Bangladesh must become profitable in producing electricity to fulfill the world's growing need for power and become an economically developed country. Bangladesh's current energy mix as of August 2024: Coal (20.45 %), Natural Gas (43.35 %), Furnace Oil (21.18 %), Diesel (2.25 %), Renewable Energy (2.39 %), Power Import (9.56 %), Hydro (0.83) [6]. Table 1 presents the installation and dated capacity of the BPDB (Bangladesh Power Development Board) Power plant and major fuel contribution in Bangladesh as of August 2024 [6].

Table 1: Installed power generation capacity as of August 2024 for BPDB [6] .

Fuel Type	Capacity (Unit)	Total (%)
Coal	5683.00 MW	20.45 %
Natural Gas	12048.00 MW	43.35 %
Furnace Oil	5885.00 MW	21.18 %
Disel	626.00 MW	2.25 %
Renewable Energy	663.00 MW	2.39 %
Power Import	2656.00 MW	9.56 %
Hydro	230.00 MW	0.83 %
Total	**27791 MW**	**100 %**

Bangladesh's natural gas supplies will run out by 2028; they currently account for most of the nation's energy mix. Until then, it will be impossible to find any additional gas deposits [7]. Bangladesh's government depends on importing diesel, LNG, and LPG to run its power plants because the country lacks those resources. Therefore, there needs to be more than just imported fuel to be justified as a means of achieving electrical power independence. Bangladesh imports coal from Mozambique, Indonesia, Australia, and India for its power plants. Even though the coal deposits there are of exceptionally high quality and will run out by 2050, it is

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preferable to use them rather than imported coal [8]. The primary obstacle to building various nuclear energy facilities in Bangladesh's tiny, highly populated territory is the need for remote locations outside settlements. Even though a 2400-MW (2*1200) plant is already built in Ruppur, Bangladesh, using assistance from Russia, this supply of electricity would not be enough to meet the requirement in 2041. Hence, the lack of suitable locations makes the idea of building more nuclear power plants in Bangladesh intolerable [9]. Figure 1 shows Bangladesh's installed power production capacity and highlights the nation's energy mix, which includes both conventional and renewable sources.

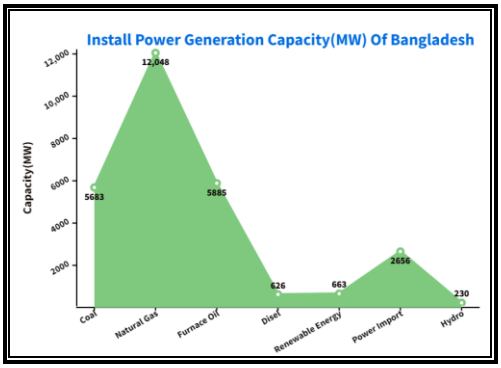

Fig. 1: Install Power Generation Capacity (MW) of Bangladesh.

This review's distinguishing feature is its thorough examination of Bangladesh's renewable energy environment. It highlights current developments in energy efficiency and the pressing need for sector changes. This study provides new insights into the country's progress and problems in creating a greener energy future by concentrating on the interaction between growth rates, environmental sustainability, and renewable resource optimization. It also emphasizes the significance of these reforms.

Methodology: As an undertaking of comprehensive studies, vital information has been collected from scholarly journals, yearly reports, or official websites. Selecting appropriate buzzwords is a critical task while creating reviews on any subject. 250 scholarly works are located using the chosen parameters. The primary requirement for carrying out a comprehensive study is a well-thought-out strategy. The three main sections of the research approach are the initial planning, assessment, and outcome phases, as shown in Figure. The following sections that follow provide further details on them. The process for conducting the review job is shown in the illustration. Fig. 2 illustrates the comprehensive review methodology, encompassing source identification, screening, and data analysis to synthesize insights for the research.

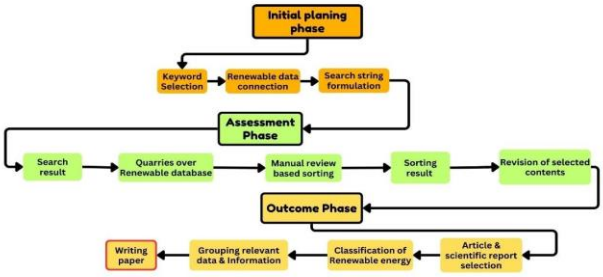

Fig. 2: Review Methodology.

Initial planning phase: The initial planning phase marks the start of the comprehensive study procedure. This phase involves developing the research objectives. Next, an inquiry was conducted using a set of key phrases selected according to the main aims to accomplish the goal. The main sources used to look up research publications include those from Taylor & Francis, Elsevier, Springer, Sage, IEEE, and MDPI. Publications from the government discussing power and renewable energy are also considered. Statistics on energy from other power-related web pages are additionally studied.

Assessment phase: During the assessment phase, yearly reports, review articles, and scientific papers were among the materials thoroughly examined using research-specific questions and targeted buzzwords. Every source was thoroughly inspected using pre-established criteria to ensure adherence to the research objectives. A systematic screening procedure ensured that only reliable and pertinent sources were kept for additional research. To preserve the integrity and narrow focus of the research, any materials that went off course or interfered with the study's objectives were carefully removed.

Outcome phase: In this stage, data is gathered from the selected research sites. The information is separated into several key parts. After that, relevant data and insights are gathered, and finally, the piece is written utilizing this methodical approach.

Current Status of Operational Renewable Energy Initiatives in Bangladesh:

Hydropower: Bangladesh is well-positioned to capitalize on the potential of power from water, utilizing its water resources for both modest and significant projects, thanks to its aquatic landscape [10]. The natural smoothness and environmental friendliness of hydropower make it a key component in the nation's pursuit of renewable electricity. Concluding testimonials of worldwide accomplishments and China's reduction of greenhouse gas emissions by 100 million tons through hydropower [11]. The focus of Bangladesh on hydroelectricity is consistent with the World Bank's support for this low-emission source of energy [12]. Since water is a limitless asset, the revolutionary potential of hydropower goes beyond its current strength, as demonstrated by the fact that about 20% of global energy comes from this source [13]. Hydroelectric power adaptability provides a range of simple power solutions, from micro to large-scale capacity [14]. Tiny-scale plants generating 1–30 MW and micro-hydropower plants providing up to 100 kW are just two examples of how this environment-friendly system may easily be integrated within water supply networks and tiny river flows, improving both the economy and the surroundings. Table 2 highlights the contribution of various hydropower plants to the national grid, emphasizing their role in diversifying renewable energy sources. Hydropower is an incredibly effective renewable energy source for the changing energy environment of Bangladesh since it functions not only as an electrical source but also as a multipurpose green technology that can satisfy many energies demands of both businesses and particular residences [15].

Table 2: Various hydropower plants contribute to the grid, diversifying renewable energy distribution.

Types of Hydropower plant	Capacity of Hydropower plant	Data
Pico Hydropower Plant	Under 5 KW	[16]
Micro Hydropower Plant	Up to 100KW	[17]
Mini Hydropower Plant	100KW-1MW	[19]
Small Hydropower Plant	1MW-15MW	[18]
Medium Hydropower Plant	15MW-100MW	[19]
Large Hydropower Plant	>100MW	[20]

Bangladesh mostly has flat terrain, except for a few valleys in the north and southeast part of the country, which limits its hydropower potential [21]. The rivers Karnafuli, Shangu, and Matamuhuri have multiple branches and numerous falls with potential for establishing micro-hydroelectric power plants, particularly in the mountains of the southeast. To provide electricity to a Buddhist temple and approximately 140 nearby families in the village population the first privately funded micro hydropower unit featuring a 10 KW capacity has been installed in Bandarban. This installation has brought electricity to the community and reduced their dependence on fossil fuels, significantly reducing carbon emissions. In 2005, the BPDB established a 50 kW micro-hydro plant in Barkal, Rangamati, and a 50 kW–70 kW Mohamaya Hydro Power-cum-Irrigation Project in Mirersorai, Chittagong, which have similarly benefited the local communities [6]. In Bangladesh, the average installed hydropower capacity was 228.33 MW between 2000 and 2011. That said, there was a 10 MW decrease in 2011 and 2012, as the Bangladesh Power Development Board (BPDB) has indicated its intentions to increase the Kaptai Hydroelectric plant's productivity to 330 MW by 2030. Bangladesh targets its huge hydro-energy reserves, estimated at 1,100 TWh/year [22]. Other possible sites for 79 MW hydropower plant construction are the Sangu and Matamuhury rivers, which are 6 km downstream of the current Karnafuli Hydropower Project [23, 24].

Solar Energy: Among all renewable energy sources, solar power is the cleanest, greenest, and most environmentally healthy. It can also greatly improve the country's power situation. The sun represents the source of all energy, from fertilization to the production of photovoltaic power, thanks to all-powerful makers. The sun generates sufficient power per second for the entire season's worth of requirements on Earth's crust [25]. It is predicted that the solar system will discharge about 450 EJ worth of power equivalent to 7500 times more powerful than the world currently consumes [26]. Solar photovoltaics (PV) is considered a standard choice in the electricity industry. More and more nations are installing photovoltaic panels to produce more than 20% of their total electricity [27]. Figure 3 illustrates the diversity of solar energy practices in Bangladesh. A variety of systems, including solar parks, roofing photovoltaic farms, solar irrigate systems, mini- and nano-grid solar layouts, rooftop solar power areas, sunpowered telecom base transceivers, solar residence systems, and solar led lamps, are used to harness solar energy in Bangladesh [28].

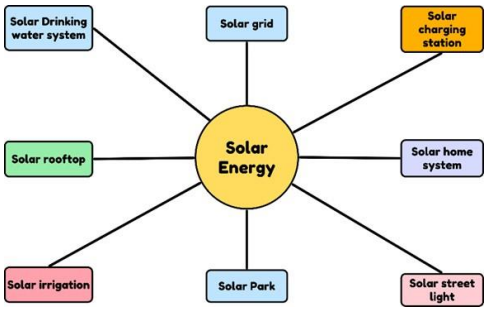

Fig. 3: Diversity of solar energy practice in Bangladesh.

Bangladesh is now generating 459 MW of electricity from Solar energy [7]. Geographically Bangladesh is between $20^0 34'$ and $26^0 38'$ North latitudes, making it a semitropical land [29]. Bangladesh's daily average solar radiation is between 4-5 kWh/m^2 and Around 1900 kWh/m^2 /annum [87]. Throughout the year, it receives an abundance of sunlight, thus consistently promoting the generation of an enormous quantity of power via solar energy. The nation obtains moderately intense yearly sunlight, ranging from 4 to 6.5 kWh/m^2/day [30]. Figure 4 displays the nation's prospective solar power split geographically.

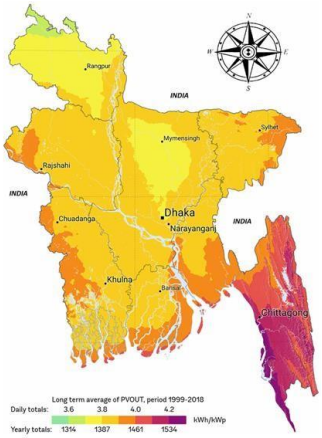

Fig. 4: Geographical distribution of photovoltaic power potential [31].

Wind energy: The basic power requirements of Bangladesh are rising with its development and growing population [1]. Historically wind power has been utilized for various tasks, such as powering windmills, circulating water, watering plants, and moving boats. However, to run wind turbines and use the kinetic energy of the wind to produce power, a specific velocity of the wind is required. Bangladesh benefits from continental weather that brings forth the monsoon and typhoon periods, as well as copious precipitation and sporadic gusts of wind [1]. Using the geographic data, government agencies, and a few collaborators conducted a wind resource assessment campaign to create specialized scientific viability studies. Bangladesh's consequent wind resource map is shown in the illustration [32, 33]. Only nine of the twenty meteorological locations that were included in the measurement period from June 2014 to December 2017 covered each of the four major geographic zones of the country [32]. To produce 60 MW of power from the wind, 22 turbines were constructed, one of which has a capability of 3 MW [34]. The following table lists the plants from the ongoing projects that will have substantially contributed by June 2023 [35, 36]. In addition, other groups are currently examining whether small-scale wind farms with offshore and onshore arrangements are feasible in the southern region of Bangladesh [37, 38]. Bangladesh has a location with average wind speeds (m/s) at 20 meters above the ground [88]. Figure 5 shows the geographical distribution of wind power potential.

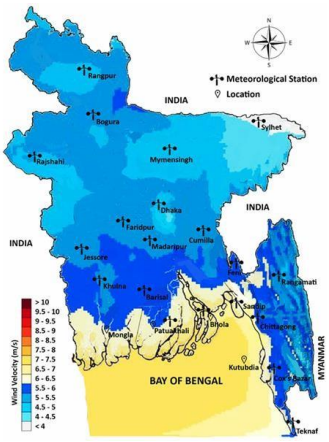

Fig. 5: Geographical distribution of wind power potential [41,42].

Biomass: Waste materials that are reusable and come from animals and plants are called biomass [44]. To Put it differently, biomass refers to any organic material found in the environment, whether from plants or animals, that is immediately utilized as fuel or driftwood or converted into various forms before being burned. It includes a wide range of biological materials, including biomass and aquatic fauna, such as wood, fallen shrubs, limbs, crops, botanical leftovers, livestock manure, grain hulls, and other aquatic creatures [45]. Figure 6 illustrates the available biomass sources in Bangladesh. In Bangladesh, the primary biomass fuels utilized by the agrarian and economically deprived are livestock vomit (mostly cow dung), crop scraps (primarily rice grain), and woodland fuel (largely fallen tree limbs and lumber bits). LP (Liquefied petroleum) gas (available in pipes or cylinders) is utilized for heating and cooking by both high-class and slum dwellers. More than 94% of Bangladeshi tribal residents utilize conventional solid biomass cooking methods, which are ineffective and generate harmful oxides of carbon and particulate matter due to incomplete combustion, the main culprit of respiratory illnesses [46]. Most of the victims are women and children to suffer from chronic bronchitis or emphysema due to their increased exposure to domestic smoke [47]. At the moment, Bangladesh uses biomass to generate 0.40 MW of electricity [48].

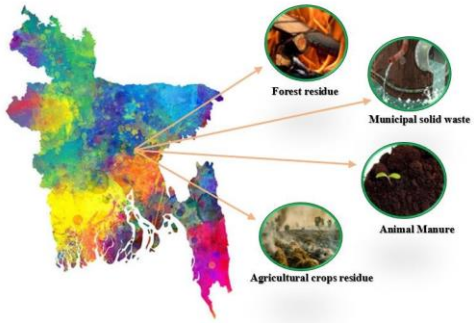

Fig. 6: Available biomass sources in Bangladesh.

Biogas: Biogas is a mixture of gases that mainly consists of CH_4 (40–70%) plus CO_2 (30–60%), containing tiny quantities of NH_3 and CO as well as H_2O condensate (1%–5%) plus N_2 (0%–5%) [49-52].

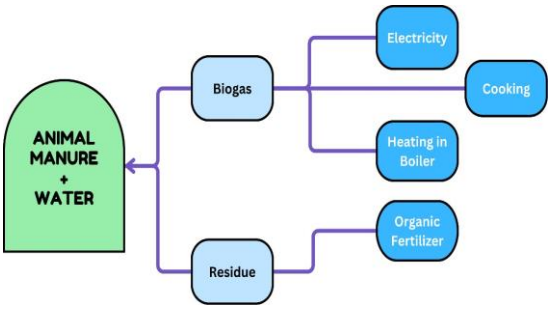

Fig. 7: An outline of biogas generation and its uses.

Plant material, animal excrement (particularly cow manure), and garbage (both municipal and agricultural) can all be used to make this. Consequently, biogas facilities generate gas and, as Figure 7 illustrates, aquatic food and fertilizers. Burners and biomass cook burners are becoming increasingly common in several poor nations. REN21 in Rwanda reports that the government has donated roughly 30,000 biomass-powered cook burners [53]. It is estimated that as of the end of 2020, Bangladesh had installed 140,500 biogas plants, of which about 1500 are industrial and the remaining are residential units [54,55]. At the moment, Bangladesh uses biogas to generate 0.69 MW of electricity [56].

Geothermal: The possible locations for geothermal power within Bangladesh are spread throughout several departments. Aesthetically promising areas are, for instance, Habiganj, Titas, Shabajpur, Bangora, Singra, and Saldanadi [57]. With a temperature gradient ranging from 20.8° to 48.7°C/km, the northwest of the country, in particular, exhibits tremendous promise beneath several kilometers of earth [58]. Though still in its early stages, the Ministry of Power, Energy, and Mineral Resources approved its first geothermal project. Investor Anglo MGH is building it in Thakurgaon. At the moment, it can only hold 200 MW [59]. As a result, it has yet to add electricity for the nation [60].

Nuclear: Another nonrenewable energy source is generally thought to be nuclear energy. While nuclear energy is a sustainable energy source in and of itself, the materials utilized in nuclear power plants are not [89]. Construction of Bangladesh's first nuclear reactor, the Rooppur Nuclear Power Station, began in November 2017, marking the beginning of the country's path toward nuclear plant ownership. By 2024, the reactor, known as Rooppur 1, is expected to be operating [61]. With a production capacity of 2400 MW, this important energy source may meet 15% of the country's energy needs. Situated on the Padma River in the Pabna district, 160 kilometers west of Dhaka, the power facility is easily accessible and secure [62].

Future Prospects and Challenges of Renewable Energy in Bangladesh:

Prospects and challenges of solar energy in Bangladesh: Fossil fuels such as natural gas, coal, and petroleum [63], constitute about 75% of global energy production [64] and significantly contribute to greenhouse gas emissions [65]. These fossil fuels are becoming increasingly scarce and costly, with estimates suggesting they could be depleted within a few decades [66]. In contrast, Bangladesh is making substantial progress in renewable energy, particularly solar power [67]. The country has implemented the world's largest Solar Home System (SHS) program, installing 5 million SHSs, which has created over 100,000 jobs and benefited more than 30 million people [68,69]. The geographical position of Bangladesh, receiving an average daily solar radiation of 4-5 kWh/m², makes it highly suitable for solar energy [70]. The state-owned IDCOL has installed 3 million SHSs, providing clean energy to over 13 million rural inhabitants. The Vision 2021 mega electricity project aims to further expand solar energy, with Bangladesh noted as the fastest-growing nation in SHS adoption [71]. Research indicates significant potential for industrial rooftop solar installations, identifying over 6,000 industrial sites that could contribute 7.4 GW of solar power, generating 11 TWh annually and meeting more than 6% of the country's current electricity consumption [72]. This approach could save around 13,000 acres of land for agricultural and other uses, addressing land scarcity issues. Overall, the focus of Bangladesh on solar energy demonstrates a scalable and feasible solution to its energy needs, reducing reliance on depleting fossil fuels and promoting sustainable development. Utilizing solar energy is fraught with difficulties, such as high initial prices, upkeep problems, and a shortage of replacement parts. Some households need help to afford the high upfront expenses of mini-grids and solar residential systems. Maintenance is also a significant issue due to limited knowledge and resources for upkeep. Additionally, the scarcity of spare parts complicates repairs when systems break down. Establishing large-sized commercial solar plants is particularly difficult in Bangladesh due to the scarcity of open land in the overpopulated country. As a result, the government concentrates on installing solar panels in open areas, usually on the rooftops of homes and businesses [29,73].

Prospects and challenges of Biofuel/Biomass/Biogas in Bangladesh: As an agricultural nation, Bangladesh possesses enormous potential to produce biogas from animal waste, including cattle, goats, sheep, and buffaloes, and use it for bioenergy production. As the estimated 263 million chicken population continues to grow [74], the recovery rates for animal waste and poultry droppings are considered to be 60% and 50%, respectively [75]. From 24.48 million cattle and buffaloes, approximately 186,000 tons of dung are available daily [10], which can produce around 2.5 billion m³ of biogas per day, equivalent to 2.56 million tons of coal or 1.28 million tons of kerosene [10]. Additionally, considerable amounts of biogas can be generated from other biomass resources like waste and poultry droppings. Bangladesh has over 350 potential oil-bearing crops for biodiesel production, including J. curcas, sunflower, sesame, castor, cottonseed, and groundnut oils [60]. Biomass energy, encompassing bioproducts, bio-energy, and bio-power, holds immense potential due to abundant resources and the need for sustainable solutions [76]. It can lessen dependency on imported fossil fuels, improve energy security, and meet the energy needs of rural areas. Government support through renewable energy policies and incentives, along with technological advancements in cookstoves and biogas plants, can improve efficiency and reduce pollution [77]. Environmental benefits include lower greenhouse gas emissions, while social benefits include job creation in rural areas. Addressing challenges like resource collection, sustainability, and technology adoption is crucial. Learning from successful projects can provide valuable insights, making biomass energy a promising opportunity for Bangladesh's energy security and sustainable development.

Prospects and challenges of Wind Energy in Bangladesh: The coastal areas of Bangladesh, particularly regions like Chittagong, Hatia, Swandip, Kutubdia, and Saint Martin, have high wind energy potential [78]. The Asian Development Bank estimates that Bangladesh could generate 2000 MW of wind power [79]. The Bangladesh Meteorological Department identifies Chittagong as the most promising site for wind energy harnessing. The nation is perfect for wind energy projects since it boasts the longest coastline belt in the world, 724 kilometers along the Bay of Bengal. The Bangladesh Power Development Board (BPDB) has identified 22 sites for onshore wind power generation and has planned several wind generation plants, including a

50-200 MW plant in Anawara, Chittagong, and a 15 MW plant in Muhuri Dam, Feni [80]. Table 3 illustrates the wind plant projects in Bangladesh. Despite the significant prospects, challenges such as high initial costs, the need for reliable wind assessments, grid integration issues, and infrastructure development must be addressed [81]. Government policy support, investment in research, and international cooperation are essential for overcoming these challenges and effectively harnessing wind energy to contribute to Bangladesh's sustainable and secure energy future. By 2030, Bangladesh intends to generate 5000 MW of power through wind supplies, which will include both onshore and offshore farm establishments [39]. Subsequently, it is dependent on encouraging wind speed data encompassing more than 7700 square miles of land area provided by an American agency. At nine different places in six districts: Natore (Lalpur), Chattogram (Sitakunda, Chandpur, and Parki Beach), Mymensingh (Gouripur), Habigonj (Madhupur), Khulna (Dacop), Cox's Bazar (Inani Beach), and Rangpur (Badarganj), the agency investigated an accessible wind resource. Based on initial studies conducted there, the average wind velocity at elevations above 60–80 meters are 5-7 m/s, which is sufficient to run a tiny wind turbine [40].

Table 3: Wind plant projects in Bangladesh [36,46]

Location	Capacity	Status
Bagerhat	50 MWp	Under planning
Chuadanga	50 MWp	Under planning
Sonagazi, Feni	30 MWp	Under planning
Mongla Upazila, Bagerhat	55 MWp	Under planning
Maheshkhali Upazila, Cox’s Bazar	100 MWp	Under planning
Anowara, Chattogram	100 MWp	Under planning
Chandpur Sadar, Chandpur	50 MWp	Under planning
Payra, Patuakhali	50 MWp	Under planning
Cox’s Bazar Sadar Upazila, Cox’s Bazar	50 MWp	Under planning
Inani, Cox’s Bazar	50 MWp	Under planning
Parki Beach, Chattogram	2 MWp	Under planning
Kalapara Upazila, Patuakhali	10 MWp	Under planning

Figure 8 illustrates the underpinnings of wind energy. In total, wind power plants are being planned in 11 places. The highest capabilities are Maheshkhali Upazilla, Cox's Bazar, with a capacity of 100 MWp, and Anowara, Chattogram, with a capacity of 100 MWp.

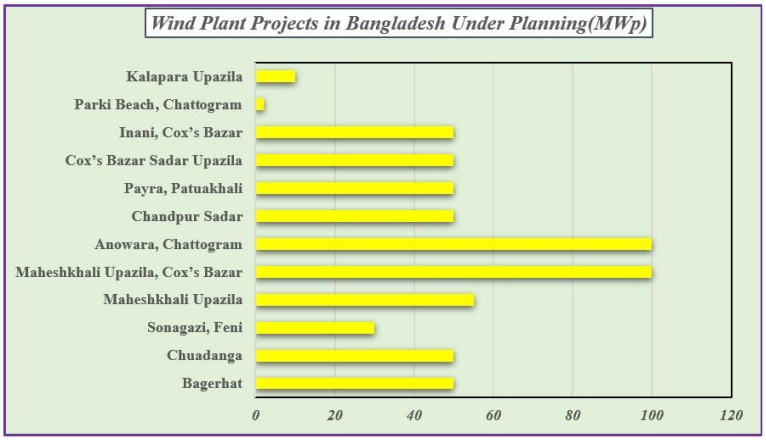

Fig. 8. Wind Plant Projects in Bangladesh Under Planning (MWp).

Prospects and challenges of Hydro energy in Bangladesh: Hydroelectricity, a natural renewable power source, utilizes water flow to rotate turbine propellers, converting water head into kinetic energy [50]. Bangladesh's hydroelectricity production is relatively low compared to global rates, with a total production of 879.0 MTOE at the end of 2014, reflecting a 2.0% increase but still below the 10-year average of 3.3% [21]. Efforts to explore small hydropower potential have identified 19 possible installation sites through studies by BPDB and BWDB, and 12 additional sites were found by Chinese experts, with Mahamaya Chara noted as a prime location. Additionally, 10 major hydro potential rivers in the Northeast have an annual generation

capacity of about 1410 GWh [10]. Despite these prospects, challenges such as high initial infrastructure costs, environmental impacts, community displacement, and seasonal water flow variability need to be addressed [82]. Government policies, technological investment, and community engagement are crucial to effectively harness hydro energy, enhancing Bangladesh's energy mix with a sustainable and renewable source.

Prospects and challenges of Geothermal energy in Bangladesh: Geothermal energy, derived from the Earth's core heat, represents a renewable and clean energy source. In Bangladesh, the geothermal gradient ranges from 19.8 to 48.7°C/km, with temperatures of 110-153°C at depths of 304 kilometers. Key geothermal hotspots include Rangpur Saddle, Madhupur Clay, Kuchma and Bogra, and Thakurgaon warm water region. The government plans to establish a 200 MW geothermal power plant in Thakurgaon with Anglo MGH [83]. The northern regions show significant potential for geothermal energy, which can help meet increasing electricity demands in both urban and rural areas, contributing to energy diversification and reducing fossil fuel reliance. Despite its promise, challenges such as high initial exploration costs, limited technological expertise, and environmental impacts need to be addressed. Investment in research, international collaboration, and capacity building are essential to harnessing geothermal energy effectively, promoting a sustainable energy future for Bangladesh.

Prospects and challenges of nuclear energy in Bangladesh: Bangladesh can benefit greatly from atomic energy as it seeks to diversify its energy sources and guarantee long-term energy security. With Russian assistance, the Rooppur Nuclear Power Plant is now being built and will produce 2,400 MW of electricity, demonstrating nuclear energy's capacity to deliver a large-scale, reliable power source [62]. This shift can minimize reliance on fossil fuels and cut greenhouse gas emissions by meeting the expanding electrical demands of the urban and industrial sectors, which will stimulate economic growth [84]. The requirement for strong regulatory frameworks to guarantee the safety and efficient treatment of radioactive waste, as well as significant initial capital expenditure and lengthy building times, are obstacles [85,86]. Furthermore, the successful execution of nuclear projects depends on the growth of a competent staff and public acceptance.

Strategic Solutions for Renewable Energy Challenges: Figure 9 illustrates the following usual topics to cover in a research paper on how Bangladesh may enhance renewable energy development and solve related obstacles:

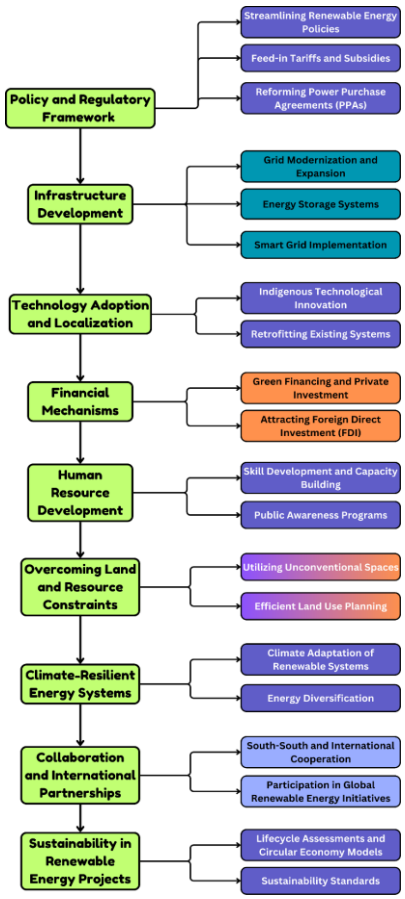

Fig. 9. Strategic Solutions for Renewable Energy Challenges.

The Bangladeshi government's efforts focus on the Sustainable Development Goals (SDGs), particularly SDG 7 (Affordable and Clean Energy). By 2025, 10% of its power generation mix will come from renewable sources. Reducing carbon emissions, guaranteeing energy security, increasing solar and wind power, and providing electricity to rural regions are all crucial strategies to meet SDG 13 (Climate Action).

Conclusion: This comprehensive review explores the current landscape of renewable energy development in Bangladesh, focusing on its prospects and challenges. The analysis reveals a promising trajectory marked by significant contributions to the national grid from various renewable sources.

i. **Renewable Energy Contribution:** Bangladesh's renewable energy capacity, primarily solar power, currently contributes 663 MW to the national grid and reflects a significant transition from fossil fuels to energy diversity. Moreover, with fewer sources of conventional energy, Bangladesh should look for alternatives. However, a 12.78% utilization of renewable energy is a good sign for a developing country. Besides Solar and hydropower, wind, biomass, and geothermal energy sources are also found to be promising for Bangladesh.

ii. **Solar and Hydro Leadership:** With 459 MW produced by solar energy and 230 MW produced by hydropower, solar energy is the most significant renewable energy source. There is the most potential for growth in these two areas in the nation's energy mix. In addition to that, a thorough feasibility study for expanding these options can make significant changes in the energy sector.

iii. **Greenhouse Gas Mitigation:** Reducing greenhouse gas emissions necessitates a shift to renewable energy, including significant investments in affordable technology to enable environmentally responsible and sustainable energy generation. Considering the example of China hydropower can be a potential alternative to fossil fuel in reducing greenhouse gas.

iv. **Challenges and Solutions:** Significant obstacles like grid upgrades, financial investment, and rural electrification must be overcome by legislative changes, technological advancements, and green financing to utilize renewable energy fully.

v. **Path Forward:** Bangladesh can ensure long-term energy security, resilience, and economic growth by accelerating renewable energy development, strengthening local technology competence, and boosting public-private collaborations.

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