An Overview of the Growth of Bangladesh's Renewable Energy Sector, Outlining Current Challenges and Future Prospects

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***Abstract*—The main objective of this review is to develop renewable energy (RE) sectors and overcome any obstacles regarding this in Bangladesh. Bangladesh has been facing energy crisis in all sectors in need of electricity. The techno-economical and policy making challenges are the main barrier of renewable energy sources installment in Bangladesh. But in recent years, Bangladesh has achieved notable progress in the development of its renewable energy industry. Bangladesh produces 723.26 MW of electricity from renewable sources, which include 67.61% solar, 31.80% hydro, and 0.58% wind, biogas, and biomass. Of these, 489 MW are produced by more than 6 million (63, 25, 278) installed solar cells. This assessment offers a thorough examination of the nation's present renewable energy situation, stressing both the fundamental difficulties and noteworthy successes. The research reviews the many renewable energy sources, such as hydropower, biomass, mechanical vibration, wind, and solar electricity, and assesses how much of each the country needs to use. Analyzing the legal and policy environment that governs renewable energy in Bangladesh, the research highlights the necessity of focused measures to remove current obstacles. It talks about how overcoming obstacles and promoting sustainable growth can be accomplished through international cooperation and financial assistance. The research also looks at the socioeconomic effects of renewable energy programs, considering how they may affect employment and electrification in rural areas. The analysis provides an outlook on the prospects of the renewable energy sector in Bangladesh. Emerging technologies, possible market trends, and innovative prospects are covered. To assist stakeholders, investors, and legislators in navigating the shift to a more resilient and sustainable energy future, recommendations are offered. With an emphasis on highlighting successes and outlining challenges, this research provides a thorough analysis of Bangladesh's renewable energy industry. Bangladesh may establish itself as a regional leader in the adoption of renewable energy sources and support international efforts to mitigate climate change by recognizing the obstacles of the present and laying out a plan for future development. This research will help to the researchers and policymakers for making more renewable energy in Bangladesh without facing any difficulties.**

***Keywords*—Renewable Energy, Solar, Wind, Biomass, Hydropower, Challenges, Development of Renewable Energy**

I. INTRODUCTION

Bangladesh is a heavily populated, quickly developing nation that is at a crossroads with sustainability and energy security. The necessity of diversifying the country's energy mix and lowering its reliance on conventional sources has become increasingly apparent in recent years. Natural gas, oil, diesel, and coal accounted for more than 99% of the nation's energy mix in 2021 [1]. Around 67% of the energy in the nation is produced by natural gas, making up most of the energy share. Roughly 26% of Bangladesh's natural gas being imported at the same time [2]. Bangladesh was able to achieve its electrification targets despite its dependence on fossil fuels, mostly through resource utilization. It does, however, also highlight the drawbacks of fossil fuels. In order to shed light on the accomplishments made, the current challenges, and the bright future ahead, this review will examine the development trajectory of Bangladesh's renewable energy sector. Bangladesh's economic expansion, urbanization, and growing industrial activity have all contributed to a spike in the country's energy consumption. The nation is in the process of utilizing renewable energy resources in order to meet this growing demand while reducing its impact on the environment [3]. Having gratitude The renewable energy sector in Bangladesh is significant for a number of reasons, including strategic, economic, social, and environmental factors. By lowering dependency on imported fossil fuels, diversifying the energy mix by adding renewable sources improves energy security. Like many other nations, Bangladesh is confronted with environmental issues such as air pollution and climate change. Making the switch to renewable energy helps address climate change concerns, lessen greenhouse gas emissions, and mitigate environmental effects. Achieving a sustainable, resilient, and inclusive energy future depends on comprehending and advancing Bangladesh's renewable energy sector. It supports the nation's economic, social, and environmental well-being, improves energy security, and is consistent with the objectives of global sustainability. The need to reduce carbon emissions and achieve energy self-sufficiency and resilience against fluctuations in global energy prices are the driving forces behind this change. Beyond national boundaries, the wider effects of renewable energy for Bangladesh have a multifaceted impact on the international community. Bangladesh's sustainable development is aided by renewable energy, which raises living standards, supports economic growth, and provides clean, inexpensive energy. Off-grid

renewable energy solutions are essential for expanding energy access to underserved and remote communities, enhancing their quality of life, and advancing social justice.

With an annual per capita availability of 279 KW-hr, only 59.60% of the population in Bangladesh has access to electricity [4]. Bangladesh comprises about 87,319 villages, the majority of which are not linked to the country's electrical grid. Bangladesh confronts a number of challenges in the production of electricity, including a lack of natural gas, outdated, unreliable power facilities, population growth, etc. In Bangladesh, the production of electricity can be severely impacted by the absence of natural gas or by the outdated infrastructure used to generate it. This can result in a number of issues and limitations, such as the country's power sector being dependent on natural gas, experiencing power generation shortages, having outdated infrastructure, and facing environmental consequences. Bangladesh may need to take into account a multifaceted strategy to address these issues, one that involves building new infrastructure, diversifying the energy mix, investing in efficient and modern power generation technologies, and putting policies in place that support the development of sustainable energy. It is around 63% dependent on natural gas. Numerous issues arise from this over-reliance. Power output will be hindered by a decline in natural gas generation or a scarcity of natural gas supply [5]. Over 20-year-old power plants generate 23% of the nation's electricity. With a 500 MW generation capacity at launch, BPDB was not very powerful. At the conclusion of FY 2021–2022, the nation's installed capacity has grown to 22,482 MW (or 25,700 MW when captive and off-grid renewable energy is included). This is a 50-year service milestone [6]. Table 1 shows the current Power Sector Details in Bangladesh.

Table 1. Power sector details in bangladesh

Unit Type	Capacity (Unit) MW	Total (%)
Coal	250.00	2.39 %
Gas	6719.00	64.33 %
HFO	1963	18.79 %
HSD	783.00	7.5 %
Hydro	230.00	2.2 %
Imported	500.00	4.79 %
Total	10445.00	100 %

This thorough analysis will examine the major stages of Bangladesh's renewable energy sector development, closely examining the laws, programs, and innovations in technology that have influenced the sector's course. The analysis will also look at the current situation, explaining the obstacles preventing the industry from reaching its full potential. In addition, the review will look ahead, providing perspectives and tactical routes that can help Bangladesh move toward a more resilient and sustainable energy future. The nation of Bangladesh is facing two challenges: meeting its growing energy demand and addressing environmental issues [7]. Despite these obstacles, the country has made significant progress toward a sustainable energy future. The nation has worked hard to diversify its energy sources in recent years, with a particular emphasis on renewables. Through a historical analysis, this review explores the complex environment of Bangladesh's renewable energy sector. Examining both successes and setbacks, the study spans the early policy frameworks and innovative projects to the current situation. Regulatory complexity and technological limitations are just two of the many obstacles that the industry currently faces that prevent it from realizing its full potential [8]. In spite of these obstacles, the review aims to identify the hidden opportunities and calculated courses of action that could lead to Bangladesh having a more resilient and sustainable energy future. This review seeks to provide important insights that can guide policy decisions, encourage technological advancements, and direct Bangladesh's renewable energy sector toward greater success and sustainability by critically analyzing the past, closely examining the present, and imagining the future.

The investigation of the renewable energy sector becomes crucial given Bangladesh's exceptional economic growth and growing energy requirements. The country faces the challenge of striking a balance between environmental sustainability and economic development in the context of highly populated urban centers and expanding industries. By presenting a narrative that spans the early efforts to harness renewable sources to the present issues that the sector faces, the review seeks to provide a comprehensive understanding of how Bangladesh has traversed this complex terrain. Bangladesh is in a critical position to shape its energy future as the world struggles with the effects of climate change and the movement toward sustainable practices picks up steam globally [9]. The challenges of today, in terms of technology integration or policy implementation, are important points of reflection and strategic realignment. The prospects also highlight the country's potential to become a regional leader in sustainable energy practices. In addition to closely examining Bangladesh's renewable energy sector's history, this review sets the stage for a future in which renewable energy is essential to building a more resilient, inclusive, and sustainable country [10].

II. METHODOLOGY

To improve energy security, diversify its energy mix, and lessen its impact on the environment, Bangladesh has been making progress in utilizing renewable energy sources. Rural households now have access to solar home systems thanks to Bangladesh's successful implementation of one of the biggest off-grid solar programs in the world. In coastal regions with favorable wind conditions, Bangladesh is actively investigating the potential of wind energy. The potential of flowing water for the generation of electricity is being tapped into by developing small-scale run-of-the-river hydropower projects, particularly in hilly areas. To hasten the adoption of renewable energy, the government of Bangladesh has been aggressively pushing laws and programs in partnership with donors and international organizations. An organized and methodical approach was used in the process of performing a thorough analysis of Bangladesh's renewable energy sources shown in Fig. 1. [11]. This methodology describes the goals, parameters, and selection criteria for relevant sources and was sparked by the creation of an extensive literature review protocol. A thorough search strategy is developed using pertinent keywords and Boolean operators after the databases, which include government and academic repositories, have been selected. The inclusion criteria have been meticulously crafted to guarantee that the chosen studies

are in direct alignment with the temporal scope, the focus on Bangladesh, and renewable energy [12]. The information gathered is kept accurate and relevant by the use of exclusion criteria.

Fig. 1. Renewable energy in bangladesh context

The methodical extraction of relevant information from chosen studies, such as specifics about projects, policies, difficulties encountered, and opportunities for the future in Bangladesh's renewable energy industry, is referred to as data collection. A thematic analysis is used to synthesize data and identify common themes related to development, obstacles, and prospects. Quality assessment criteria are applied to evaluate the credibility and rigor of each selected study. One useful tool for identifying differences and patterns in the literature is a comparative analysis, when appropriate. Renewable energy in Bangladesh context has been shown in Fig. 1. A comparative analysis has been added here. All through the process, ethical considerations are taken into account, including correct citation and avoiding plagiarism.

The development, challenges, and prospects of Bangladesh's renewable energy sector are reviewed using a methodical approach to data collection, analysis, and synthesis [13]. Because creating a protocol that specifies the goals, parameters, and standards for choosing content. Defining important words, inclusion/exclusion standards, and the review's time range. Gathered information from government archives, business reports, and academic databases to identify pertinent databases for a literature search in this review. It has been used a combination of keywords, Boolean operators, and controlled vocabulary pertinent to the review's topic to create a thorough search strategy. Design the plan to include as much literature as possible about the prospects, challenges, and growth of Bangladesh's renewable energy industry [14]. Established the standards for which studies will be included, such as relevance to Bangladesh, an emphasis on renewable energy, and coverage of challenges, opportunities, and aspects of development. Indicate which kinds of publications journal articles, reports, and conference papers will be featured.

Data from a few chosen studies like google scholar that have been gathered and organized. Gathered pertinent data about projects, regulations, difficulties, and prospects for renewable energy in Bangladesh [15]. Included a methodology section, a bibliography, and a summary of the main conclusions in an organized fashion. used a thematic analysis to combine all of the information gathered. found recurring themes regarding the challenges encountered, opportunities for growth, and state of the renewable energy sector in Bangladesh. Sort the results into important categories so that the story makes sense. When appropriate, compare various studies to identify patterns, trends, or agreement in the literature about the growth, difficulties, and prospects of Bangladesh's renewable energy industry [16]. By employing this methodology, the review hopes to present a thorough, coherent, and fact-based examination of Bangladesh's renewable energy market, providing valuable perspectives on its growth, present obstacles, and potential futures. The paper is organized in the following ways.

- The introductory part of this review has been discussed in section I.
- Review structure has been explained in section II.
- Section III discussed the renewable energy scenario in Bangladesh.
- In section IV, calculation of total power for renewable energy has been discussed.
- Discussion and conclusion have been explained in section V & IV.

III. Renewable Energy Scenerio in Bangladesh

Bangladesh has made notable progress in the installation of solar-powered homes. Millions of SHS had been installed by early 2022, giving rural households access to electricity [17]. Large-scale solar power plants have also been developed in the nation, adding to the national grid. For example, significant additional solar capacity has been added through projects like the 200 MW Teknaf Solar Park [18]. Despite not being as popular as solar energy, wind energy has been tested in pilot programs and feasibility studies. Wind energy's share of all renewable energy sources was still quite small as of 2022. Onshore systems accounted for 93% of the 900 GW of built wind capacity in 2022, with offshore wind farms accounting for the remaining 7%. Since offshore wind is still in its infancy and only has capacity in 20 nations, onshore wind is a more mature technology, having been implemented in 115 countries worldwide [19]. The Chinese company Power Construction Corporation, POWERCHINA Chengdu, constructed the wind farm in Cox's Bazar. It is the first large-scale centralized wind power facility in the nation, with a total nominal power of 66 MW [20].

Although there have been feasibility studies and pilot projects, wind energy has not been as widely adopted as solar. Wind energy's share of the overall renewable energy mix was comparatively small as of 2022. Bangladesh's topography makes large-scale hydropower projects less feasible. Installed hydro capacity in Bangladesh is 230 MW. Hydro generation per year is 982 GWh. Technically feasible hydro generation potential per year is 1,500 GWh. Hydropower has made up a comparatively small portion of the total renewable energy portfolio [21]. Bangladesh's topography makes it less suitable for large-scale hydropower projects. Hydropower has made up a small portion of the portfolio of renewable energy sources overall. Six 48 MW units make up the single big hydro project in Bangladesh, called Kaptai Karnafuli [22]. For these three products, ANDRITZ is the original equipment manufacturer. ANDRITZ was chosen as the winner of a tough international bid procedure, and the business is currently renovating and modernizing units #1 and #2. By the end of 2020, the project should be fully operational. ANDRITZ has also opened an office in the nation's capital, Dhaka, to improve market accessibility and

customer service. More than fifteen ANDRITZ Hydro turbo generating units, with ratings ranging from thirty to forty-five MVA, were shipped to Bangladesh. With the company's main regional base in India's neighbor, aftersales services are made available for these machines. Energy generation using biomass and biogas has been decentralized. Particularly in rural areas, biogases plants help meet the needs for small-scale electricity and cooking [23]. To promote private investment in the renewable energy sector, the government has put the Renewable Energy Policy into effect. Goals for increasing the capacity of renewable energy are included in this policy. Incentives and subsidies of various kinds have been offered to encourage the installation of renewable energy systems, particularly off-grid [24].

Decentralized energy generation has made use of biomass and biogas. Biogas plants help with small-scale electricity needs and cooking, especially in rural areas. Bangladesh currently ranks eighth in the world for population density, with 73% of the country's energy coming from biomass. Cooking fuel is made from biomass resources found in rural areas, such as wood, cow dung, and agricultural waste. Merely 5% of individuals in rural areas use kerosene as fuel [25]. The Renewable Energy Policy was put into effect by the government to promote private investment in the industry [26]. There are goals for increasing the capacity of renewable energy in this policy. The installation of renewable energy systems has been encouraged by a number of financial incentives and subsidies, particularly in off-grid. The Renewable Energy Policy was put into effect by the government to promote private investment in the industry. There are goals for increasing the capacity of renewable energy in this policy. To encourage the installation of renewable energy systems, particularly in off-grid and rural areas, several financial incentives and subsidies have been offered [27]. The expansion of the renewable energy industry may be hampered by inconsistent or ambiguous laws and regulations. Barriers to renewable energy projects can include limited finance options and expensive upfront expenses. For large-scale renewable energy projects, like wind parks and solar farms, finding adequate land can be difficult [28]. For renewable energy projects, Bangladesh can be dependent on foreign technology, which could provide risks such as higher expenses and supply chain interruptions. Cyclones and flooding are examples of the weather disasters that can affect Bangladesh. Resilient designs are essential because these occurrences have the potential to affect the efficiency and dependability of renewable energy infrastructure.

Technological solutions are being employed to tackle ongoing challenges pertaining to grid integration, intermittent, and balancing the grid with renewable energy sources [29]. Renewable energy projects continue to face difficulties in financing and luring investment, but initiatives to secure funds and encourage public-private partnerships are being undertaken. In the upcoming years, Bangladesh hopes to greatly increase its capacity for renewable energy. A significant increase in solar and wind power capacities is one of the goals [30]. The future roadmap calls for investigating novel solutions like floating solar projects and further diversifying the mix of renewable energy sources [31]. Comparing the current solar power situation in Bangladesh with other global regions. Moreover, a detailed outline of artificial intelligence's potential to expedite solar energy enhancement is provided. Bangladesh has an abundance of solar resources at its disposal. The most ideal energy source to reduce this highly populated nation's high energy demand is solar power [32].

IV. Calculation of Total Power for RE

The individual power equations and total power equation for each renewable energy sources are given below [33]. With the solar panel's rated wattage, anyone can use this easy formula to calculate how much electricity the panel will generate: Watts of power times the number of hours in direct sunlight each day equals daily watt-hours. Energy production by week, month, and year can be easily calculated using this simple method [34].

Solar Power,

$$P_{solar} = (Area\ per\ sq-ft\ \times watts\ per\ sq-ft) \quad (1)$$

Wind Power,

$$P_{wind} = \left(\frac{1}{2}\right) \times \rho \times A \times V^{3} \quad (2)$$

Where,

A = Area perpendicular to the direction of flow (m^2)

V = Wind velocity (in ms^{-1})

ρ = Density of air which is about 1.2 Kgm^{-3}

Biogas generator power,

$$P_{biogas}(W) = \frac{50\%\ of\ 100\ Kg\ per\ day\ animal\ waste \times 1000}{2\ Kg\ animal\ waste\ per\ kWh\ \times 5\ \text{hours operation a day per year}} \quad (3)$$

Hydro Power,

$$P_{hydro}(W) = H \times Q \times g \times 1000 \quad (4)$$

Where,

H = Gross water head (in meter)

Q = Flow of water (in m3/sec)

g = Gravitational acceleration, i.e. 9.81 (in ms-2)

Therefore, total power:

$$PT\ (W) = P_{solar} + P_{wind} + P_{hydro} + P_{biogas} \quad (5)$$

V. Challenges Faced by Bangladesh's Renewable Energy Industry

Bangladesh encountered a number of challenges as it worked to grow and expand its renewable energy industry [35]. The renewable energy industry frequently demands large initial outlays. Access to finance and limited financial resources can impede the growth of renewable energy initiatives. Investors and developers may experience uncertainty due to inconsistent or unclear policies and regulations [36]. Investing in the renewable energy sector requires a stable and encouraging regulatory environment. Inadequate transmission and distribution networks, for example, or a lack of grid connectivity can make it difficult to integrate renewable energy sources into the electrical grid [37]. It can be difficult to find suitable land for renewable energy projects, like wind and solar farms. Conflicts over land and conflicting land uses could make things more difficult [38]. The implementation of renewable energy projects may be hampered by a lack of advanced technological know-how and accessibility. These issues can

be addressed with the aid of training initiatives and alliances with foreign organizations [39]. Certain renewable energy sources, like wind and solar, are sporadic, which can put the stability and dependability of the electricity grid at risk. To solve these problems, smart grid technologies and energy storage options are required [40]. Investor confidence can be impacted by political and economic uncertainty. Attracting long-term investments in the renewable energy sector requires both a robust economy and a stable political climate. It's critical to remember that the public, private, and other sectors of society must work together to address these challenges [41].

VI. DISCUSSION

The thorough analysis of Bangladesh's renewable energy industry captures a complex picture of the country's achievements, current issues, and promising future directions. The conversation starts off with a look at the sector's historical development, highlighting important legislative changes, ground-breaking projects, and innovations in technology. As the country's energy needs rise, it becomes clear that Bangladesh has made impressive strides toward diversifying its energy mix and utilizing renewable energy sources. But a complicated web of barriers exists now, ranging from the complexities of regulations to the real difficulties in incorporating renewable technologies into the current energy infrastructure. The review looks critically at these issues and recognizes that in order to guarantee the sector's sustainable growth, strategic solutions are required. In the face of these obstacles, the conversation shifts to the future, presenting a picture of a Bangladesh that uses cutting-edge technology, global partnerships, and changing energy regulations to maintain its position as the region's front-runner in the adoption of renewable energy. In addition to capturing the complexities of the industry's past and present, the conversation also lays the groundwork for a positive future by highlighting the revolutionary potential that renewable energy holds for Bangladesh's resilient and sustainable energy future.

The complex dance between lofty objectives and realistic challenges becomes evident when considering the current challenges facing Bangladesh's renewable energy sector. There are many obstacles that need to be strategically addressed, including bureaucratic roadblocks, regulatory complexity, and grid integration-related problems. Further adding to the sector's current complexity are the early stages of development of some renewable technologies and the requirement for large upfront investments. The socioeconomic aspects are also covered, recognizing the need to guarantee affordable and accessible energy for all societal groups. The necessity of an all-encompassing, inclusive approach to sustainable energy development is emphasized, and community engagement and awareness-building are highlighted as essential elements in tackling these issues. As we look to the future, Bangladesh's renewable energy sector has exciting opportunities. Because of its advantageous location, the country can explore a wide variety of renewable resources, each offering its own set of opportunities. The efficiency and dependability of using renewable energy sources could be completely transformed by the possible integration of cutting-edge technologies, such as sophisticated energy storage systems and smart grid solutions. International alliances and partnerships also create channels for the transfer of technology and knowledge, which enhances Bangladesh's renewable energy environment.

VII. CONCLUSION

In summary, this review weaves together a story of development, difficulties, and a bright future to capture the dynamic trajectory of Bangladesh's renewable energy sector. The industry's historical development highlights the country's resolve to embrace sustainability and diversify its energy sources. Nevertheless, the current environment reveals a patchwork of difficulties, requiring strategic and cooperative efforts, from the complexities of regulations to the realities of technology integration. Even so, the future looks bright despite these obstacles. Bangladesh is about to enter a revolutionary period in which the country can move toward a resilient and sustainable energy future through technology advancements, international partnerships, and changing policies. A convincing story of advancement is told by the possibilities for utilizing a variety of renewable resources and incorporating creative solutions. The imperative for the country is to engage communities in the sustainable energy journey, ensure affordability, and foster inclusivity as it navigates the complexities of its energy transition. Beyond national borders, the future vision sees Bangladesh as a leader in the adoption of renewable energy in the region and a proactive participant in the pursuit of global sustainability goals. This review functions as a call to action, highlighting the public, industry, and policymakers' shared accountability for directing Bangladesh's energy trajectory. The search for a cleaner, more sustainable energy paradigm becomes both a national goal and a global necessity as the country advances, conquering current challenges and seizing opportunities. Bangladesh can become a global leader in sustainable energy development by implementing a well-thought-out plan, coming up with creative solutions, and remaining steadfast in its commitment to the cause.

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