Renewable Energy Resources in Bangladesh: Prospects, Challenges and Policy Implications

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Abstract- Bangladesh earned lower middle-income country status in 2015 due to satisfactory level of (previous) continuous economic growth. Later the country entered into the United Nations' list of Least Developed Countries (LDC) in 2018 and is on track to achieve the middle-income country status by 2024. Key criteria for this achievement will be the nationwide rapid sustainable economic growth in coming years. Economic advancement of the country will be largely depended on its energy sector flourish, more explicitly on electricity generation. At present more than 90% of the electricity in Bangladesh is produced from fossil fuels (from imported and national reserve) such as diesel oil, furnace oil, natural gas, and coal. Irrational burning of these fossil fuels expedites the rapid depletion of national coal and natural gas reserve as well as put additional burden on national economy due to oil import, threatening continuous electricity supply for the future economic prosperity. At the same time deterioration of environmental quality as a whole is also associated with this fossil fuels usage. Thus, to ensure an unremitting supply of electricity in coming days, the country needs to have both sustainable and environment friendly energy sources and technologies. Hence, this article discusses the potentiality of various renewable energy resources (solar, hydro, biomass, and wind), their current contribution in country's energy sector, and relevant challenges for utilization. In addition, this paper includes the future government policies for renewable energy integration with the conventional energy generation for overall energy security attainment and economic development of Bangladesh.

Keywords: Renewable energy, Bangladesh, Hydro energy, Solar energy, Bioenergy, Wind energy.

1. Introduction

Fuels and power are the key elements for economic growth and socioeconomic development of a country. But it is unfortunate that this craved development is largely responsible for the environmental damage caused by the greenhouse gas CO_2 generated during fossil fuel consumption [1]. Therefore, more and more countries are adopting renewable energy technologies [2, 3]. Over one decade (2004 to 2014), the global renewable energy investment has experienced a fourfold increase, i.e. from USD $36 billion to $139 billion in developed economies, with the growth factor of this energy resource more than 14 [4, 5]. Since the liberation in 1971, Bangladesh has been undergoing rapid industrialization and technological development. With an exponential demand of energy, which is mostly dependent on the imported fuel, the country has been constantly suffering energy scarcity since then [6].

Although several petroleum mines have been discovered over the last few decades, the country is not self-dependent to withdraw and process them into finished products. Moreover, the reserve of primary energy resources of Bangladesh is inadequate, and the strategies of energy transmission and usages are not modernized compared to the world energy sector. In this circumstance, the renewable sources are considered as a potential and reliable option to mitigate the deficiency of energy demand. The Government of Bangladesh has set forth many policies and goals to achieve 10% of total electricity generation from renewable energy sources by 2020 and 20% by 2035 [7, 8]. However, the achievement was only 3% by 2020 and is far from fulfilling the energy demand and proper utilization of the renewable sources [9]. Siddique et al. identified multiple barriers including social, economic, technological, and regulatory aspects that impede the utilization of renewable energy resources [10].

The government has recently committed to safeguard the right to use a cost-effective electrification system throughout the country by 2021. Currently, only about half of the population has efficient access to electricity [11]. Moreover, the supply of electricity is inadequate and unreliable [12]. As of 2014, the per capita energy consumption in Bangladesh was 311 kWh; one of the world's lowest per capita energy use [13]. The energy use per capita by country is presented in Fig. 1 as reported by Dudley [14]. It has been suggested that the widespread use of renewable energy will contribute to achieving sustainable development goal (SDG 7), ensuring clean, affordable, and sustainable access to energy for all by 2030 [15].

Fig. 1. List of per capita energy use by several countries in 2018

The government of Bangladesh has adopted a comprehensive energy development strategy to discover both demand management and supply-side options for preserving energy and preventing any wasteful use [16, 17]. Recently, Global Climate Scope ranked Bangladesh in the 41st position from all observed markets in terms of attractiveness for renewable energy investments [18]. The future of renewable energy in Bangladesh seems very impressive which concurrently requires comprehensive reviews of the energy sector encompassing potential, challenges, and strategies for its successful integration to the country's existing energy sector. Therefore, the main objective of the present review is to critically scrutinize the recent past to current exploration of the renewable energy resources to represent the prospects, scopes, and challenges associated with this energy sector of Bangladesh. Most crucial policies and reform strategies for this are also reviewed in this study. Finally, several future policy implications, based on the findings of this review, are suggested to ensure a sustainable development of renewable energy sector in Bangladesh. The novelty of this review is that all type of existing renewable resources (in Bangladesh) is reviewed while most of the previous studies concentrated around the certain type of resources. While reviewing the resources, not only the corresponding potentialities are examined but also the associated challenges and required policies are identified. Authors of this study believe that without the dedicated framework, technological transition to the implementation level would not be possible. Therefore, a combined approach is suggested in this review for successful integration of technological evolution with their implementation to bring the sustainable contribution of renewable energy in country's whole energy sector.

2. Present energy scenario in Bangladesh

The power sectors in Bangladesh are highly dependent on the conventional fossil fuels including gas and coal. According to the Bangladesh Power Development Board (BPDB) report in February 2020, the installed capacity of power generation was 19,580 MW, where the major sources of fuels were gas and furnace oil (Table 1).

Table 1. Installed capacity of Bangladesh power development board (BPDB) power plants as of February 2020

Fuel type	Capacity (MW)	Total (%)
Coal	524.00	2.68
Gas	10628.00	54.28
HFO	5208.00	26.60
HSD	1795.00	9.17
Hydro	230.00	1.17
Imported	1160.00	5.92
Solar	35.00	0.18
Total	**19580**	**100**

HFO-heavy fuel oil; HSD-high speed diesel;
Source: BPDB (https://bpdb.gov.bd/)

According to Table 1, the renewable sources such as solar and hydro energy combined contributed 1.35%, which is insignificant compared to that of the gas and furnace oil. Moreover, the actual production capacity is lower than the installed capacity. Though the installed capacity is quite high, the actual production is incapable of meeting the daily demand. The daily prediction and actual data of power generation showed that the daily deficiency is nearly 37% (Table 2).

Table 2. Electricity generation, as of February 2020

Week	Forecasted (Weekly Average)		Actual (Weekly Average)		Shortage		Percentage Gap (%)	
	Day Peak (MW)	Eve Peak (MW)	Day Peak (MW)	Eve Peak (MW)	Day Peak (MW)	Eve Peak (MW)	Day Peak (MW)	Eve Peak (MW)
Week 1	11876.43	14451.86	7222.04	8874.14	4654.39	5577.71	38.90	38.61
Week 2	11684.00	14444.00	7634.89	9078.14	4049.11	5365.86	34.59	37.11
Week 3	11569.57	14274.29	7709.19	9089.14	3860.39	5185.14	33.38	36.33
Week 4	11681.38	14439.38	7696.09	9273.63	3985.29	5165.75	34.14	35.78
Average	**11702.84**	**14402.38**	**7565.55**	**9078.76**	**4137.29**	**5323.62**	**35.25**	**36.96**

Source: BPDB (https://bpdb.gov.bd/).

Among the South-Asian countries, the per capita energy consumption in Bangladesh was one of the lowest, even was lower than Nepal [19]. In 2018, the Gross Domestic Product (GDP) of Nepal was US$ 29 billion whereas that of Bangladesh was US$ 274 billion [20]. Despite having a better economic condition, Bangladesh's energy situation is worse than (Fig. 2) that of the most of its neighbouring countries. The gap between the demand and supply of the electricity in Bangladesh is very high and is forecasted to increase in the future as the fossil fuels deplete and the energy demand rises. Again, the burning of fossil fuels releases greenhouse gases, such as CO_2, NO_2 and SO_2 that are responsible for global warming. Therefore, the rising concern of the rapid depletion of fossil fuels and global warming are the governing factors behind the current trend of switching to renewable energy [21].

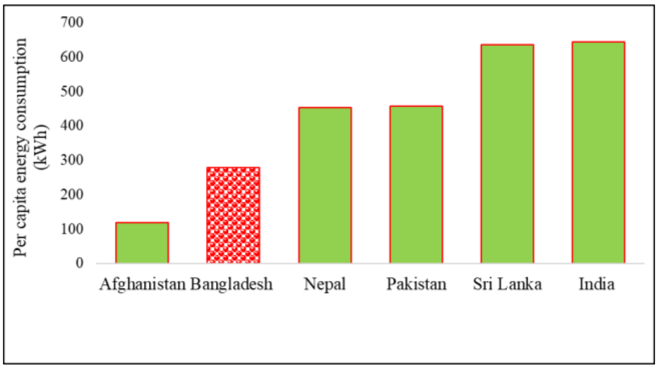

Fig. 2. An overview of per capita energy consumption in South-Asian countries

3. Renewable Energy in Bangladesh

Renewable energy, by definition, is produced from renewable resources. They are naturally replaced either through natural reproduction or other recurring processes such as biomass, sunlight, wind, rain, hydro, tides, waves, and geothermal heat. In Bangladesh, the communities tend to dependent on the renewable energy in areas where the conventional electricity supply is absent. Using biomass for cooking, solar power and wind for drying grain and fabrics etc. are the traditional ways of utilizing the renewable energy in Bangladesh. The current sharing of various kinds of renewable energy sources in Bangladeshis presented in Fig. 3.

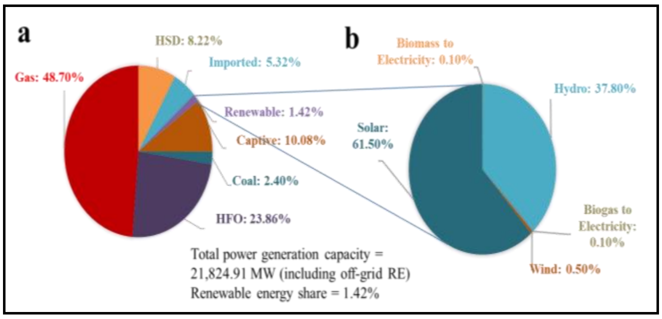

Fig. 3. a) Electricity generation from mixed sources and b) sharing of renewable sources according to Sustainable and Renewable Energy Development Authority (RE-renewable energy, HFO-heavy fuel oil, HSD-high speed diesel)

Although the contribution of renewable energy is very insignificant, Bangladesh has a prolonged history in this field, which began with the construction of the country's first hydro-electric power plant with three planned generator units on the Karnaphuli River in Kaptai, Chattogram in 1957. On October 1988, the addition of fourth and fifth units with a 50 MW Kaplan type turbine increased the total power generation up to 230 MW. In the mid-eighties, several private enterprises played a vital role in establishing the country's first Solar Home System (SHS) in Sylhet. In later years, the SHS program was greatly expanded by the Infrastructure Development Company Limited (IDCOL) which has been the largest renewable energy program in

Bangladesh since 1996. So far, about 5.8 million SHSs have been set up all over the country [9] and the number is growing because of the integrated programs adopted by the government through financial institution-IDCOL. The SHS is a huge and trusted system, and the rural homes are still coming under this system due to its apparent success.

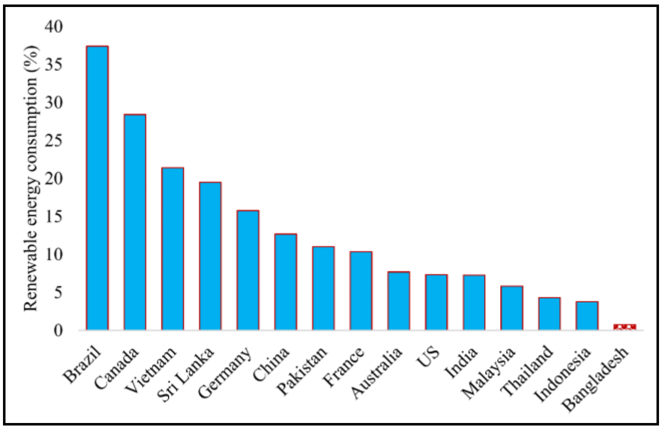

Fig. 4. Country-wise consumption of renewable energy sources in 2018

A couple of the major targets of switching to renewable energy are to supply electricity in the rural areas and reduce carbon emissions and government subsidies [22]. To decrease the dependency on fossil fuels, the global warming, and the risk of natural disasters, the government of Bangladesh enacted 'Sustainable and Renewable Energy Development Authority' (SREDA) Act-2012 to provide energy security by harnessing renewable energy and expanding its utilization. The broader goal of SREDA is to build an energy conscious nation through promoting sustainable energy and reducing carbon emission. With the Vision 2021 Bangladesh aims at achieving a renewable energy share of 10% by 2021 [23]. However, the current actual contribution is far behind the predicted value. According to SREDA, the contribution achieved was only 1.42% by 2015 (Fig. 3a) and 2.84% by 2019. Being a densely populated country, Bangladesh has huge biomass resources but its contribution to the renewable energy sector is insignificant (0.20%) whereas the major contributors are solar (61.50%) and hydro (37.80%) energy (Fig. 3b). As it can be seen from Fig. 4, the renewable energy consumption in Bangladesh was very low compared to that of the many other countries of the world [14, 24]. Therefore, intensive strategies and research are required to improve the current situation.

4. Hydro Energy

Among the various natural energy sources, the energy from water, termed as hydro power or hydroelectricity, is the most prominent due to its simplicity, reliability, and environmentally friendly operation. Being a riverine country with numerous canals and estuaries, Bangladesh holds a huge potential for the hydro power generation. Typically, a dam in a river is used to create a reservoir and control a waterfall which is guided through a penstock and pushes a turbine's blade causing the turbine to spin. The kinetic energy of the falling water converts into mechanical energy by the turbine that is connected to a generator through a rotating shaft. The shaft causes the generator to spin as the turbine spins and thereby converts the mechanical energy into the electric energy. Based on the power regeneration capacity, the hydropower plant can be categorized into several types such as large hydro (>100 MW), medium hydro (15-100 MW), small hydro (1-15 MW), mini hydro (>100 kW), micro-hydro (5 kW-100 kW), and pico-hydro (up to 5 kW) [25].

4.1. Potentiality of hydro energy

Kaptai hydroelectric power plant, owned by the BPDB, is the first and only large hydro power plant of Bangladesh which was established in the Basin of Karnafuli River in 1957. It was launched with two units with a capacity of 50 MW each and thereafter three more units were added by 1988, raising its total capacity to 230 MW. This is about 36.7% of the country's total installed renewable energy capacity and is still stuck at that value [26]. Till now, this is the only hydro power plant in Bangladesh and is the lowest among the South Asian countries as shown in Table 3 [27].

Table 3. Hydropower potential in the South Asian countries

Country	**Theoretical potential (MW)**	**Commercial potential (MW)**	**Current utilization (%)**
Bangladesh	755	755	30.4
Bhutan	30,000	24,000	5.3
India	184,700	84,004	28
Nepal	80,000	43,000	1.1
Pakistan	100,000	59,000	7.3
Afghanistan	23,000	23,000	1.9

In the fiscal year 2018-19, the electricity from this hydro power plant comprised only 1.21% of the total national installed capacity [28], whereas 19% of the global electricity comes from the hydro power [25]. A plan has been taken to increase the capacity of this plant to 230 MW. Moreover, the government has a plan to increase another 5 MW to national capacity from the hydro power source by 2021 [29]. Bangladesh has an estimated hydropower potential of 1897 MW, which includes 330 MW in Karnafuli river basin, 87 MW in Sangu river basin, 80 MW in Matamuhuri river basin [30]. Although there is a huge potential for hydro power, only a little has been exploited. A similar situation is observed in other Asian countries as depicted in Fig. 5. Among the continents, Asia has the highest potential for hydro power; however, this has been underutilized.

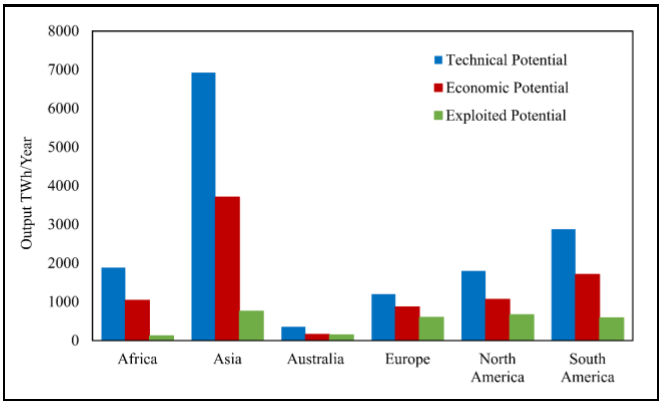

Fig. 5. Exploited hydro potential by different continents [31]

Installation of large hydro power requires a dam which may obstruct the natural flow of water and destroy the aquatic life forms. Therefore, the current trend is inclined to small scale hydro power generation - micro-hydro power - that can generate electricity 24/7 at constant rate. Bangladesh is a riverine country with approximately 700 rivers containing tributaries and distributaries that allow a total waterway length of around 24,140 km[32].Most of the water bodies of Bangladesh are situated within the floodplains of three mighty rivers: the Ganges, Brahmaputra, and Meghna, and their tributaries including the Dharla, Dudhkumar, Kushiyara, Surma, and Teesta. On average, 1121.6 km^3 of water cross over the borders of Bangladesh annually, of which 85% ensues between June and October. About 48% (537.2 km^3) is contributed by the Brahmaputra, 47% (525.0 km3) by the Ganges, 4% (48.4 km^3) by the Meghna/Barak, and nearly 1% (11 km^3) by other minor rivers [33, 34]. Moreover, Bangladesh is bestowed with huge rainfall during rainy season which ranges from 1500 mm/year in the west to 5000 mm/year in the northeast, as shown in Fig. 6 [35].

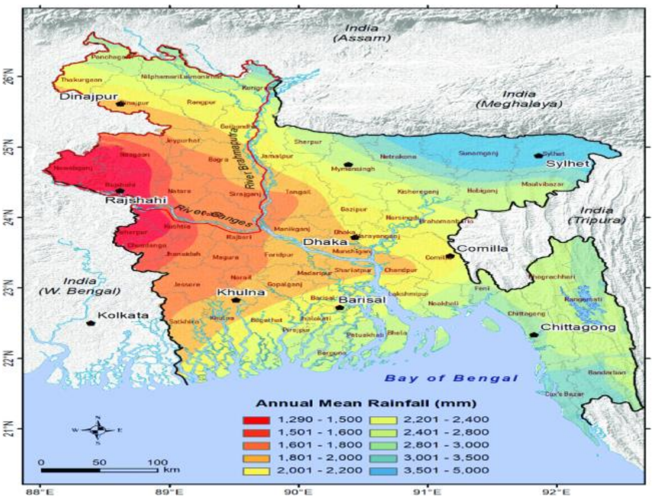

Fig. 6. Average rainfall in Bangladesh [35]

Since Bangladesh holds a huge promise for small and/or micro-hydro power generation, the potentiality of the hydro power has already been studied by several organizations. In a joint venture, Bangladesh Water Development Board (BWDB) and BPDB identified 19 possible locations for establishing a small hydro power plant in 1981 [36]. The district-wise estimated capacity for these potential sites ranged from 80 kW to 642 kW as summarized in Table 4. Later, in 1984, a Chinese consultancy team identified 12 potential sites for micro-hydro power plant and suggested only Mahamaya Chara, nearby Mirersharai, close to Dhaka-Chattogram highway as the most excellent location for such installation [37]. Accordingly, BWDB and BPDB jointly surveyed the area to develop an incorporated project for power generation, flood control, and irrigation. Based on their survey, a dam was planned to be constructed on Mahamaya Chara to (i) reserve monsoon run-off water from a drainage area of around 10.5 km^2; (ii) offer irrigation amenities from that reservoir at the rear of the dam and (iii) extract power by installing a mini hydro power plant at its base [38].

Table 4. District-wise potential for small hydro power plant identified by BPDB and BWDB [39]

District	Potential of electrical energy (kW)
Chattogram	132.00
Sylhet	642.00
Jamalpur	172.00
Dinajpur	171.00
Rangpur	80.00
Total	**1197**

In 1992, Northeast Regional Water Management Project assessed some designated rivers in the northeast region under the Flood Action Plan (FAP). The outcome of the assessment was promising since most of the rivers and sites appeared to have suitable flow to develop a run-off river hydroelectric plant. Classically, these types of plant are environmentally friendly as they utilize the power of natural flow of water. The study identified 10 major and medium perennial rivers which can provide enough flow to produce power throughout the year. Based on the average monthly discharges and a 5 m head (assumed), the hydro potential of these rivers was projected as 161 MW leading to an annual energy generation of about 1410 GWh [37]. However, there are rivers which showed seasonal variation in water flow, with very small flows during the dry season and high discharges during the monsoon. The proper plan would involve a diversion structure across the river channel, a diversion channel along the bridge, and a powerhouse at a suitable location that delivers adequate head. This very assessment by FAP reported such nine rivers with an estimated annual power output of 35 MW with an approximate annual energy generation of 307 GWh [37, 38].

After two decades, in 2004, Local Government Engineering Department (LGED) surveyed several areas in Chattogram to find possible locations for installing the micro-hydro power plants. The survey was performed under

Sustainable Rural Energy (SRE) project that estimated a power capacity of 135 kW in 7 locations, mostly in hilly region [30]. Bangladesh Council of Scientific and Industrial Research (BCSIR) also proposed two sites in Chattogram Hill Tracts (CHT), namely, Shailopropat in Bandarban and Madhobkundu in Moulvibazar, with capacities of 5 kW and 15 kW leading to an annual energy production of 43,800 kWh and 131,400 kWh, respectively [37]. Altogether, the aforementioned studies pointed out to the sites holding a potential for at least 1.409 MW micro-hydro power generations [36]. In 2009, Wazed and his colleagues [40] identified the Sapchari waterfall in Khagrachari district as a potential site for a micro-hydro power plant having a waterfall head of 10 m and power rating ranging from 0.525 kW to 3.458 kW. Since then to date, no feasibility study for establishing a small and/or micro-hydro plant has been done at government and private levels and is not reported in the literature either.

However, the country's first micro-hydro power plant with a power capacity of 10 kW was established at Bamerchara, Chattogram through the private initiatives [37]. In 2005, BPDB established a micro-hydro power plant of 50 kW at Barkalupazila of Rangamati district and another one called Mohamaya irrigation-cum-hydro power project of 50-70 kW is in construction at Mirershorai, Chattogram [41]. Since then, no noticeable steps toward installation of new micro-hydro power plant had been observed. The combination of topology and hydrology make the CHTs an excellent location for micro-hydro power generation which could supply power in surrounding rural areas. Apart from rivers and charas, the entrance of culvert and the sewage opening to canals and rivers might be potential sites, especially during the rainy season, for micro-hydro power installation.

4.2. Challenges of hydropower

Though the country holds huge possibilities for electricity generation from hydro power ranging from small scale to large scale, little efforts have been made in this sector in the last few decades. Due to very high capital cost and environmental concerns related to the construction of hydropower facility, the hydro power has received less attention from the government and non-government investors. In that case, the micro-hydro power could be a plausible solution, however, it has also been proved to be expensive and uneconomical in comparison between its excessive cost associated with the installation and maintenance of hydraulic turbine, electrical equipment, controller etc. and the low revenue from the power it produces [42, 43]. Moreover, unlike SHS, the hydro power requires a huge space for the installation and a long transmission line for the distribution. In hilly areas, the installation of the hydro plants can also arise safety issues, especially, during the heavy rainfall. But, the micro-hydro power plant can convert 60 to 90% of the hydro energy to hydroelectricity whereas the solar cell has efficiency between 10 to 12% [44]. Hence, realizing the high efficiency of hydro plant, the government should emphasize on hydro power generation its renewable energy policy. It should provide some economic and regulatory concessions in this sector so that foreign and local shareholders are encouraged to invest in the hydro energy businesses. Moreover, the blue battery energy storage concept can be introduced near the coastal areas. This concept involves the establishment of a huge reservoir below the sea level located close to the island which will function similar to a pumped hydro storage power plant [45, 46]. Another challenge is the lack of feasibility study on installing hydro power plant. Relevant and related research institutes should come forward to identify potential sites for hydro power installation, to study the ways for reducing civil work-related cost and to incorporate the cutting-edge technologies to replace the costly mechanical parts. The Government can encourage these activities because it will not only solve energy related problems but also the country's ever-increasing unemployment problem.

5. Solar energy

Solar energy is the most promising and abundant natural energy source around the world that can be exploited to produce Direct Current (DC). Solar photovoltaic (PV) technology is based on photovoltaic effect in which photons from sunlight strike the surface of a solar cell to knock out electrons from their orbit and thus establish a potential difference, that drives current through an external load. In a typical solar-PV system, solar PV modules or solar panels convert solar radiation into DC which finds its application in home appliances after being converted to Alternating Current (AC) by an inverter. The excess energy can be stored as DC in a battery and used when necessary upon conversion to AC [47]. Main applications of solar PV include SHS, solar roof-top system, solar cooking, solar powered irrigation pump, and solar charging station. Moreover, this technology has been successfully synchronized to nearby grid system by using a power conditioning sub-system which transforms DC current to AC [48]. Thus, the excess energy produced is stored in the grid system which can be used later as-needed basis. This system is widely known as 'net metering system' which eliminates the necessity of chemical battery as energy storage source responsible for lowering PV efficiency. Through this system, the consumers will also be able to sell any unused solar electricity to the government. Solar PV is increasingly gaining popularity due to its off-grid application, high modality, no requirement for additional resource, no moving parts, easy installation, no monthly payment, and low-maintenance [49, 50].

5.1. Potentiality of solar energy

According to Renewable Energy Policy 2008, Bangladesh has a ground plan to supply 10% of its total power production from the renewable energy sources by 2020 [51], mostly from the solar energy as it is a good recipient of Global Horizontal Irradiance (GHI) of 4.33-4.95 kWh/m^2 (Fig. 7), with 89.4% radiation within 4.40 to 4.80 kWh/m^2/day [52]. The GHI of different regions of Bangladesh along with the specific photovoltaic power output is shown in Table 5. With this GHI and specific photovoltaic power output, Bangladesh holds an enormous

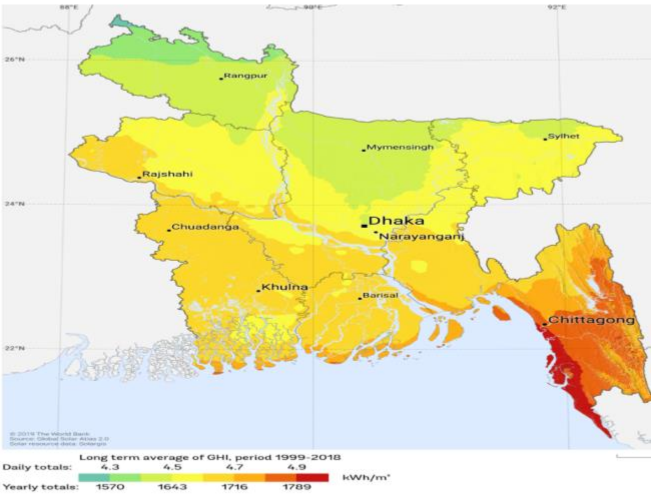

Fig. 7. Global horizontal irradiance on Bangladesh [53]

potential for the solar power generation since these values are comparable to and in some cases higher than those of the top ten solar energy producing countries, as reported in Table 6. However, Bangladesh has installed a total of 392.62 MW solar powers to date, which is 62.7% of the country's total renewable energy installation capacity [26].

Table 5. GHI and specific photovoltaic power output of different regions of Bangladesh [52]

Region	**Global horizontal radiation ($kWh/m^2/day$)**	**Specific photovoltaic power output (kWh/kWp/day)**
Dhaka	4.43-4.64	3.76-3.90
Sylhet	4.44-4.58	3.83-3.94
Rajshahi	4.48-4.68	3.80-3.94
Khulna	4.57-4.78	3.83-4.02
Barisal	4.60-4.81	3.85-4.07
Chattogram	4.57-4.97	3.87-4.25
Rangpur	4.28-4.53	3.63-3.85

By utilizing the enormous potential of solar energy, Bangladesh can address its ever-increasing energy demand and concomitantly contribute to the global pollution control movement. However, in succeeding the Government's vision to offer electricity for all by 2021, it is necessary to keep in mind that many of the rural areas are not accessible to grid power. Aiming to address this grid power limitation through alternative clean energy source, Bangladesh Rural Electrification Board (BREB) had initiated its Renewable Energy Program and till June 2019, it has generated about 17.61 MW electricity by installing different types of the solar plants [11]. Moreover, other government agencies, such as IDCOL, BPDB, and SREDA are contributing to the solar power generation on their own or by financing and monitoring private agencies. According to SREDA, the Bangladesh government has planned to produce 1150.74 MW from solar energy and as of 2018 it has generated 350.74 MW [29].

Table 6. Comparison of solar power generation potential of Bangladesh with that of top ten solar power producing countries [14, 52]

Country	**Global horizontal radiation ($kWh/m^2/day$)**	**Specific photovoltaic power output (kWh/kWp/day)**	**Cumulative installed photovoltaic power (MW)**
China	2.64-5.93	2.21-5.82	175032
Japan	2.94-4.27	2.65-4.07	55500
United states	2.34-5.97	2.32-5.47	51450
Germany	2.75-3.34	2.72-3.32	45932
Italy	2.92-4.93	2.67-4.54	20126
India	3.77-5.64	3.39-5.54	17873
United Kingdom	2.10-3.07	1.94-3.08	13108
Australia	3.77-6.37	3.60-5.32	9769
France	2.97-4.42	2.90-4.38	9483
South Korea	3.65-4.20	3.32-4.02	7862
Bangladesh	**4.33-4.95**	**3.68-4.23**	**392.62**

In 1993, BREB introduced SHS for the first time in Bangladesh through the project "Diffusion of Renewable Energy Technologies" sponsored by the French government. Since then up to June 2019, it has installed 53,762 SHSs nationwide with an electricity generation capacity of 9.76 MW [11]. The Bangladesh government has also taken a visionary attempt to distribute SHS free of cost to the rural people under its safety net program-KABIKHA/TR programs (Food for Work and Test Relief programs). IDCOL started its SHS program in 2003 and till now it has installed 4.5 million SHSs, as illustrated in Fig. 8, directly impacting 18 million rural off-grid people that brought the program a recognition of world's largest off-grid renewable energy program [54, 55].

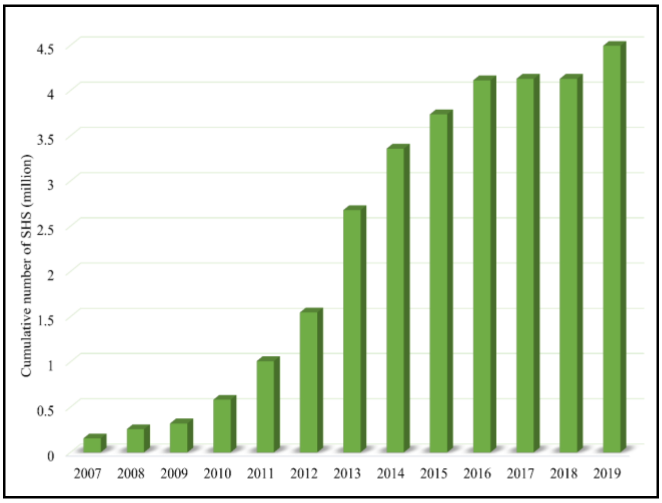

Fig. 8. Growth in installation of SHS by IDCOL (source: IDCOL)

This program, perhaps most interestingly, saved 3.6 million tons of kerosene which can be a pioneering step towards zero carbon foot print. Currently, IDCOL is funding 56 partner organizations under the SHS program to implement the government's vision to ensure the electricity for all. It has planned to fund 6 million SHSs by 2021 with an estimated power production capacity of 220 MW. In total, the number of total installed SHS by different agencies crossed 5.8 million as reported in Table 7.

Table 7. Total installed SHSs by different agencies [55]

Agency	Number of SHS	Capacity (MW)
BREB	53762	9.76
IDCOL	4494162	187.12
Deutsche GesellschaftfürInternationaleZusammenarbeit (*GIZ*)	400	0.2
Ministry of Disaster Management and Relief (MoDMR)	1294410	60.14
Total	**5842734**	**257.22**

Apart from providing clean energy, the solar energy technology plays a significant role in changing the socio-economic life of the general people. According to a survey conducted by Bangladesh Institute of Development Studies (BIDS), the SHS program run by IDCOL improved study hours of rural students, lessened respiratory diseases, decreased CO2 emission by reducing kerosene consumption, and created direct and indirect employment opportunities for about 75,000 people[54]. Due to SHS, the rural women can now watch TV and use mobile phone, which is helping them in socializing, learning different health issues, and getting innovative business ideas. They can now invest their leisure time for making handicrafts which is bringing them economic independence through entrepreneurship. In that context, SHS is fostering women's empowerment, a prerequisite for the sustainable socio-economic growth.

Installing solar panels on the roof space in the buildings in urban areas can be promising since a major constraint to harness the solar energy is the requirement of a vast area. Keeping this in mind, IDCOL has designed a special solar rooftop financial scheme for industries and commercial establishments to promote the clean energy as well as to reduce the electricity cost of the owners. Till July 2019, it has approved 11 projects among which 4 are already in operation with a production capacity of 3.07 MW, and planned to finance 300 MW by 2022[54]. Moreover, BREB has come up with the net metering system to augment the use of solar rooftop technology. Up to June 2019, BREB has installed 100 net metering systems with 6.762 MW generation capacities that produced 751,613 kWh energy and exported 184,951 kWh energy to grid. BREB also extended this system to different industries, such as SF Textile Ltd. (Narayanganj), Far East Industries Ltd. (Habiganj), Raising Industries Ltd. (Manikganj) with a combined power generation capacity of 3.870 MW. According to SREDA, the government has planned to achieve a minimum of 30 MW from solar roof-top systems by 2020. As a part of this mission, BREB has taken an action plan to establish on-grid rooftop solar panel at 76 Palli Bidyut Samity (PBS) headquarters and 75,407 educational institutions [11]. However, according to an assessment ran by IDCOL, the textile and spinning mills under Bangladesh Textile Mills Association (BTMA) have a total roof-top space of approximately 42 million sq. ft. which can act as a source of more than 400 MW, considering 0.1 million sq. ft. roof space required for generation of 1 MW solar power [56]. To date, 876 net metering rooftop solar systems with total capacity of 12.81 MW have been installed under different government agencies which include, but are not limited to, BPDB and BREB [57].

Grid-tied solar plant/solar park is an excellent option where there is plenty of empty space. Bangladesh carries a potential of 50,174 MW grid connected solar PV [30]. The government has targeted unproductive agricultural land and wasteland of railway for installing grid connected solar PV. From 2017 to 2019, BPDB approved several grid-connected solar plants, on its own and under Independent Power Producer (IPP) project, of approximately 1368 MW of which some have been completed and some are under construction [28, 58]. IDCOL also financed grid-tied solar projects at Sharishabari and Majhipara, Panchagar with a total production capacity of 11 MW [54]. Till now, 36 such solar parks have been financed with a cumulative installed capacity of 2110.56 MW of which some are operational and others are in either planning or implementation phase [59].

Solar mini-grid is an excellent solar technology for people who do not have the provision or ability to install SHS. It is greatly beneficial for areas where there is unlikelihood of having national grid connection in the distant future. In a solar mini grid system, the electricity is produced by several solar PV panels located in a central power station and the consumers can purchase electricity by means of a prepaid meter. According to SREDA, a total of 21 solar mini grid systems have been installed with a capacity of 4.538 MW and another 6 will be online very soon providing 1.118 MW [60]. Funded by Bangladesh Climate Change Trust Fund, BPDB has completed a 650 kW solar mini grid power project in Sullah, Sunamganj, which is believed to be the largest solar mini grid in south Asia [58]. These mini grids can deliver grid quality electricity to villagers, village markets, schools, and other small-scale institutions and thereby improve the life standard, economic condition, and education system of the rural people. Being encouraged from the success of previous projects, IDCOL has planned to invest in 50 solar mini-grid projects by 2025.

Solar irrigation can bring a new dimension to the agro-based economy of Bangladesh by providing an economic and environmentally friendly pumping system, supporting green agricultural economy. Having 18.64% of the country’s GDP depending on the agriculture and 64% people directly or indirectly associated with this profession, irrigation is a crucial part of crop production which is responsible for 43% of the production cost [61]. Additionally, diesel run pumps, conventionally used for irrigation system, are costly and harmful to the environment. Therefore, IDCOL started its first solar based irrigation project in 2009 and by October 2019, it has granted financial support for setting up 1,630 solar powered irrigation pumps of which 1,323 are in operation with ~ 32 MW capacities. It has an ambitious vision to install 50,000 solar irrigation pumps by 2025 [62]. Figure 9 presents the growth of solar irrigation pump installation by IDCOL and its future projection plan. BREB has also emerged in the PV based irrigation system by providing 40 pumps to rural farmers with a capacity of 239 kW. Solar based irrigation is highly beneficial as it reduces the government’s cost regarding fuel subsidy and fuel importing and diminishes carbon emission. Inspired from these benefits, the government has issued a plan to restore all the diesel run pumps with solar pumps which can conserve around 150 MW [62].

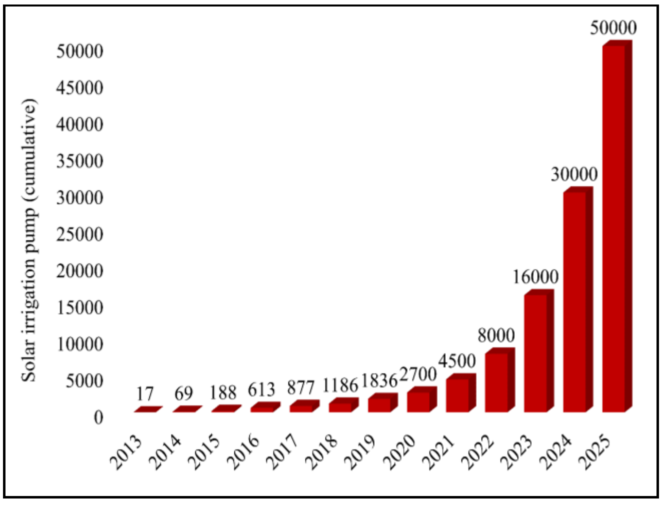

Fig. 9. Growth of installed solar irrigation pumps and future projection (source: IDCOL)

The government’s plan to utilize solar radiation in every possible way has led IDCOL, BREB, and SREDA to foster several other innovative uses of solar PV panel, such as solar battery charging station, solar powered telecom, Base Transceiver Station (BTS), solar powered drinking water distribution, solar cold storage, heater and cooker, and solar street lighting in the 8 city corporations. Auto rickshaw, easy bike etc., available in regional streets, are common three-wheelers that require a rechargeable battery to operate. The common practice of charging these batteries by connecting them to national grid electricity consumes huge energy. To save grid electricity, BREB already installed 14 solar charging stations having a capacity of 303 kW [11]. For ensuring uninterrupted wireless communication, a continuous electricity supply to telecom BTS is necessary which is quite challenging in some places including off-grid areas. IDCOL has provided a solar power solution for 138 telecom BTSs in some off-grid areas, an example that can be implemented in other telecom BTSs as well [54]. Apart from irrigation, the solar pump can be used to supply pure drinking water to salinity affected areas in Bangladesh. Moreover, the solar based water purification system, such as arsenic removal, desalination, and filtration are gaining popularity in coastal and northern regions. Currently, 120 solar based drinking water systems are operational in coastal areas, funded by the government [63]. Solar water heaters have been widely used in developing countries as an alternate to gas/electric heater to save energy. Recently, SREDA commenced experimental installation of solar heaters in the industrial and commercial sectors. The Bangladesh government is also planning to update the building code incorporating provision for the solar powered heater.

5.2. Challenges of solar energy

While there are immense prospects of the solar energy in Bangladesh, some challenges are worth considering for its widespread implementation. One of the main constraints is that its installation requires extensive infrastructure and equipment which are too costly to be funded solely by private organizations. The government has already taken some projects on its own and provided funding to several private organizations through IDCOL. However, the amount and scope of funding should be more widespread, and the terms and conditions should be flexible to allure different non-government organizations to conduct their business in the solar energy sector. Moreover, the government should attract more foreign investors and international donor organizations to invest in this sector. Another obstacle is that the installation of solar panels needs a large area. To compensate for this problem, the government has taken initiatives to install solar panels on uncultivated land, wasteland, rooftops of all types of establishments in the rural and urban areas, and SHSs in off-grid areas. The government is also working to update the building code including solar rooftop provision. The main challenge of solar rooftop and SHS is-consumers may be reluctant to buy these due to their high cost. The government should subsidize for the solar PV and allow small loan to the end users at minimum interest rates.

At present, most of the parts of solar panels are imported which adds to their high cost. If both government and non-government organizations come forward to produce solar cells locally, it will diminish the price of solar panels and create a huge employment opportunity. Moreover, the benefits of using solar energy in terms of both economic and environmental aspects should be disseminated and the awareness about solar PV should be created through seminars, campaigns, and advertisement. For example, IDCOL, BREB, and SREDA are actively implementing these dissemination and awareness programs that are increasing the acceptance of solar PV among the consumers. However, maintenance and troubleshooting of the installed solar PVs will be a major issue since there is a lack of technical experts in our country. This issue can well be taken care of by producing skilled people who will be able to grab this rapidly expanding job sector. A reduction in tax and tariff on raw materials of solar cell and subsidy on products that compete with solar cell and sanction of small loan on easy terms and conditions will encourage new entrepreneurs to produce solar cell locally, helping to alleviate the unemployment problem. In addition, finding alternate cheap raw materials could be a sustainable way to lower the price of solar cells. For this purpose, research and development regarding the solar energy should be emphasized in the research institutes with a guaranteed funding from both the government and non-government agencies. Bangladesh Energy and Power Research Council (BEPRC) have been established recently in this purpose by the government and this council has already started its activities. Additionally, the research personnel should come up with a central long-term storage solution so that the stored solar energy can be used during winter and rainy seasons when there is a little chance of getting solar radiation.

6. Bioenergy

Currently, 63% of the inhabitants of Bangladesh are dwelling in countryside and majority of them are directly or indirectly involved in agricultural activities, farming, and forestation (in some extent) [64]. These activities produce a large amount of agricultural, animal, and forest residue. Moreover, fertile agricultural lands of the country generate a large amount of agricultural residues after seasonal crops harvesting [65]. Additionally, young work force across the country is involved in systematic farming of different animals and forestation that generate a significant amount of animal and forest residues as byproduct. This agricultural, animal, and forest residue have been used in rural areas in a traditional and ineffective way - direct burning for cooking and heating purposes. In addition, city corporations and large municipalities produce a huge quantity of municipal solid waste (MSW) every day due to rapid economic growth of the country. At the same time, most of the city corporations have also developed systematic process for waste collection and utilization. Altogether, biomass (agricultural residue, animal residue, MSW, and forest residue) generated from both rural and urban areas can be processed for electricity and liquid biofuel cogeneration through different biochemical and thermochemical conversion processes. Figure 10 shows a summarized roadmap for bioenergy coproduction from locally available biomass of the country.

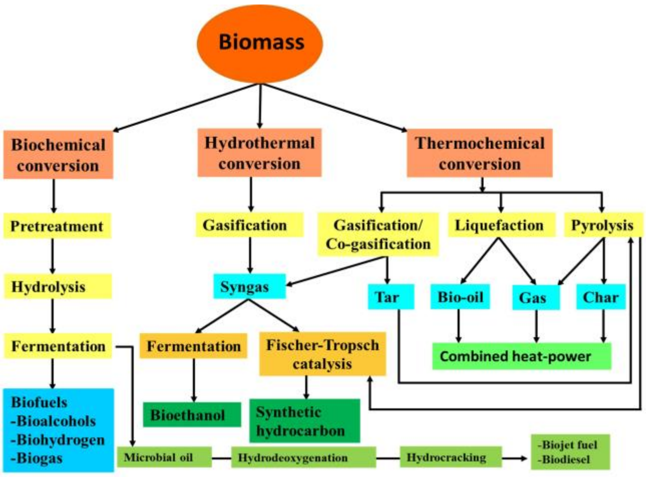

Fig. 10. Biomass conversion processes for different end products.

6.1. Biomass sources

Agricultural residue, animal residue, MSW, and forest residue are considered as the potential sources of biomass in Bangladesh. Different crop-fields are the major sources of agricultural residue since farmers generally collect the food or grain parts mostly. Residual parts remain as leftover in the field which is classified as field-residue rice straw, jute stalks, and sugarcane leaves are the example of such type of residue [66]. Other food crops, for example, maize and wheat and non-food crops– cotton –also contribute small amount in the field-residue [67]. Another type of agricultural residue, called as process-residue, is generated during the processing of food crops for food products generation [66]. For instance, bagasse is produced from sugarcane processing during sugar production while rice husk is produced from rice processing in rice mills. Bangladesh produced around 9,687 ktons of rice husk in 2017 – 18 whereas yearly bagasse production of the country was about 1055 ktons [68, 69]. Overall, a total recoverable agricultural residue was found approximately 100,096 ktons in 2017 – 2018 and Figure 11 shows the contribution from every single crop in that amount [68, 69].

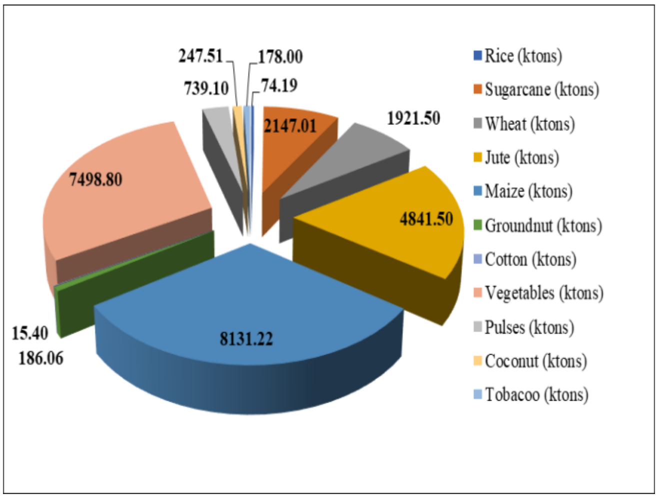

Fig. 11. Agricultural residue generation in 2017 – 2018 based on total about 100,096 ktons residue

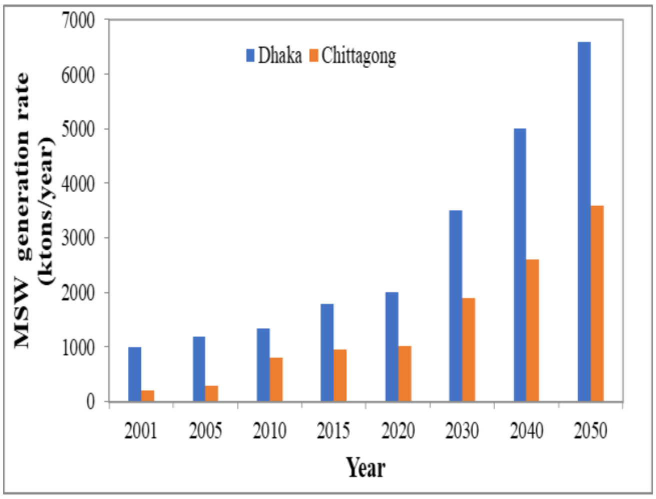

Fig. 12. MSW generation rate in Dhaka and Chittagong between 2001 and 2050

Utilization of animal residue provides two folds advantages: it minimizes the environmental pollution by removing fetid odor at first and, secondly, it offers huge potentiality to mitigate local energy demand. Several scientific studies [66, 70] and database maintained by Food and Agriculture Organization (FAO) [71] show that both the number of livestock and poultry farming has been increasing every year across the country. At present, it is estimated that approximately 55 and 338 million livestock and poultry farms respectively are operational across the country. Present waste generation from these sources (including human waste) at a rate of 93.00 million tons/year, total 56.80 million tons of recoverable animal residue was generated in the year of 2017 – 18. As anticipated, livestock animals (cattle, buffalo, sheep, and goat) combinedly produced the highest 45.11 million tons waste while the second largest animal residue – 6.17 million tons – collected from the poultry animals – chicken and duck. The remaining amount was generated from human waste.

MSW has become another potential source of bioenergy due to several reasons. Both the MSW generation rate and its systematic utilization have increased significantly over the last couple of decades [72]. Since 2004 and onward, Bangladesh has recorded around 50% increase in yearly MSW collection that reached to 61% in 2010 [73]. Figure 12 represents the yearly MSW generation rate for two major cities – Dhaka and Chittagong – of the country [74]. It clearly illustrates the gradual increase in waste generation rate from 2001 to 2020. The same study predicts 6600 and 3600 ktons of MSW generation respectively in Dhaka and Chittagong by 2050 [74]. However, all together more than 14.00 million tons MSW was generated across the country in 2017 – 18.

Bangladesh has 2.53 million hectares forest land as of 2016 which are accounted 17.5% of the country's overall area [75]. The Forest Department of Bangladesh controls 1.53 million hectares, while 0.73 and 0.27 million hectares are un-classified as state forests and village forests, respectively.

Table 8. Bangladesh government managed forest facilities [75]

Forest type	**Total area (Million hectors)**	**Area corresponding to country's area (%)**	**Location**
Natural Mangrove Forests	0.60	4.09	Khulna division
Mangrove Plantations	0.14	0.97	Coastal districts, such as, Noakhali, Barishal etc.
Hill Forests	0.67	4.65	Chittagong division
Sal Forests	0.12	0.83	Mymensingh and Dhaka Division
Total	**1.53**	**10.54**	

Forest department classified forests under their jurisdiction into several categories which is tabulated in Table 8 along with their area and location [76]. Wood fuel, forest residues (tree log, bark, leaves etc.), and process residues - saw dust, generated during veneer sheets, plywood, particle board, hard board, fiber board etc. production – have potential for being used as biomass [73]. Wood fuel is most widely used forest derived biomass mainly for cooking and heating both in rural and urban areas. FAO estimated augmented wood fuel use for Bangladesh since 1961; it was 16.51 million m^3 at that time whereas reached to 25.75 million m3 in 2018 [77]. Considering all sources, total quantity of biomass produced in Bangladesh was 213.81× 106 tons in 2012-2013 [70] whereas this amount increased to 224.80 million tons in 2017 – 2018 (Fig. 13).

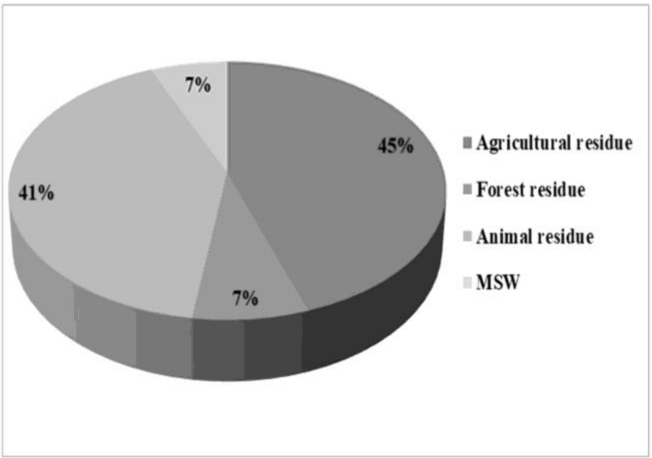

Fig. 13. Total biomass generation in Bangladesh (2017 – 2018), based on total generation of 224.80 million tons

6.2. Potentiality of Bioenergy

Biomass including agricultural residue, wood residue, animal residue, and MSW has a huge potential for energy production. Although some literature has reviewed the jute waste for higher bioenergy potential [78], Bangladesh is planning mostly to utilize sugarcane bagasse which is abundant in the North-western districts of the country. To use the bagasse, fourteen co-generation power plants have been established in that region with an overall electricity generation capacity of 37.6 MW [66]. All together these fourteen power plants will process 19.37 ktons bagasse per day to generate 48,570 MWh electricity when fully operational [66]. On the other hand, available rice husk has already been assessed for electricity generation capacity. Hil Baky et al. [66] estimated 29.05 and 41.45 MW electricity generation potential from gasification plant and steam turbine using rice husk, respectively. Bangladesh government sponsored two rice husk-based gasification power plants through IDCOL; one in Gazipur with 250 kW electricity generation capacity and another one in Thakurgaon with 400 kW capacity [79]. IDCOL has also plan to set up another 30-rice husk-based gasification power plants throughout the country since these plants produce valuable by products – precipitated silica, calcium carbonate, and activated carbon – along with the electricity generation. Rice husk can also be used to make biomass briquette which has already gained popularity for cooking among lower income people of the country. This biomass briquette can alone replace 4.8 million tons wood-fuel which will save 24.14 thousand hectare forest land from deforestation [80]. Unfortunately, despite of having potential for making 1 million tons biomass briquette per year from rice husk [81], Bangladesh is only making 19.88 thousand tons biomass briquette [66]. Apart from above mentioned biomass potential, animal manure and MSW are being utilized for biogas and biofuel production. In fact, IDCOL along with its partner organizations financed for 33,000 biogas plants setup across the country between 2006 and 2014. Biogas plants gained popularity among the local people for couple of reasons-it saves peoples' effort for fuel wood collection and provides bio-fertilizer. In addition, Pongamia pinnata (locally known as Karanja) [82] and Jatropha curcas (locally known as Jatropha) [83] have shown potentiality for biodiesel production due to their adaptability to the country's weather. So far only a private company named Nitol Motors Limited has come forward for producing biofuel from molasses.

Table 9. Comparative study of biomass recovery and energy potential between 2012–13 and 2017 – 18

Biomass source	**2017 – 18**		
	Recovered biomass in wet basis (million ton)	Recovered biomass in dry basis (million ton)	Energy potential (PJ)
Agricultural residue	45.17	38.90	618.37
Animal residue	56.80	35.67	475.31
Forest residue	16.94	13.91	204.50
MSW	10.32	5.67	105.35
Total	**129.23**	**94.15**	**1403.53**

Those are either the visible or under planning projects taken to utilize the biomass generated across the country, but Bangladesh has much higher potential for harnessing bioenergy. For example, in 2012 – 13 Bangladesh had 1344.99 PJ energy potential from possibly total 90.21 million tons recoverable dry biomass. However, the total generated biomass across the country was far higher, since recoverable dry biomass presented in Table 9 was calculated at several steps: firstly total generated biomass was counted on the basis of several national and international database [71, 77], then recoverable wet biomass was calculated by considering possible percentage of recovery for individual biomass source [84], after that moisture content was excluded to calculate the total recoverable dry biomass [70, 84]. This biomass generation was raised at 94.15 million tons in 2017 – 18 and it was available for harnessing 1403.53 PJ as bioenergy. At the same time total electricity generation potential was estimated 389.91 TWh. The source-based electricity generation potential of biomass is graphically shown in Fig. 14. In contrast to 389.91 TWh electricity generation potential solely from biomass sources, Bangladesh generated only 627.82 MW electricity from all renewable resources combined– solar, hydro, wind and biomass – in 2018 [85].

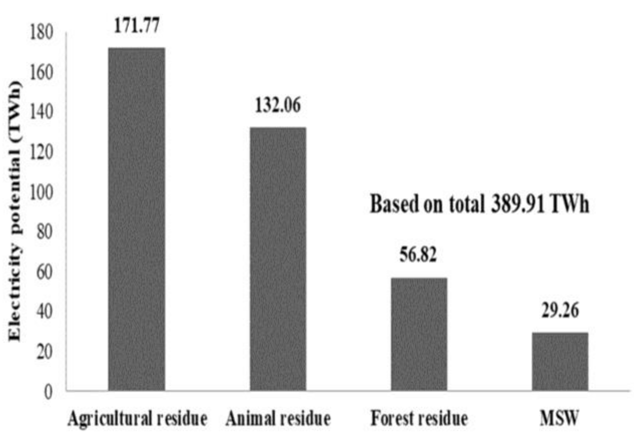

Fig. 14. Electricity generation potential of biomass 2017 – 18

6.3. Challenges of Bioenergy

The bioenergy potential is also accompanied with some challenges. First and foremost one is ensuring an uninterrupted supply of feedstock [86]. One of the most discussed biomass feedstocks is the agricultural residues. Production of this residue is largely dependent on the suitable climate; however, no one can ensure expected production for the next couple of decades due to rapid climate change across the globe. Additionally, rapid industrial growth is competing with the agricultural and farming activities in Bangladesh which will reduce the animal manure generation rate in the future. The second crucial challenge for bioenergy generation is ensuring homogeneous supply of biomass feedstock, at least this is very much true for MSW [86]. Conversion technologies have been developed based on the present composition of MSW, but it is totally uncertain that the same composition will prevail over the decades. For example, metals, once present in high percentage in MSW, have now been replaced by plastic materials. Subsequently, the plastic proportion has increased significantly in the MSW compared to metal percentage. Such type of in homogeneous nature of MSW will have to be handled in the future as well. However, a side industry- pre-treatment processes -for MSW based bioenergy plants can be developed alongside, although this will raise the bioenergy cost. Another challenge is that biomass based energy promotion culture can enhance the food versus energy debate [86]. Already due to the rapid utilization of forest residue, countries like Bangladesh have faced serious deforestation and severe ecological imbalance. Another serious challenge is the utilization of biomass conversion processes itself [87]. Thermochemical conversion processes, for example, direct combustion, pyrolysis, gasification etc., produce greenhouse gases, SO_X and NO_X whereas biochemical processes have not shown productivity for the longer periods.

7. Wind Energy

Wind is generated due to uneven heat distribution across the globe. Wind turbines are aerodynamically designed in such a way that transforms kinetic energy of the wind into the highest possible mechanical energy. This mechanical energy runs the interconnected generator that produces electricity. Source of wind energy in Bangladesh is south – western monsoon wind, generated in the Indian Ocean. This monsoon wind passes over the large water body of the ocean and subsequently enters the Bangladesh coast. V – shaped Bangladesh coast further speeds up the wind which can be utilized to rotate wind turbines [88].

7.1. Wind energy potential

Bangladesh Centre for Advanced Studies (BCAS) in association with LGED, Department of Foreign and International Development (DFID), and Energy Technology and Services Unit (ETSU), UK monitored wind speed at seven coastal sites for one year period (1996-97) [37, 88]. They determined the wind speed at 25 m height at the following coastal sites: Cox's Bazar; Char Fassion; Kutubdia; Kuakata; Noakhali; Patenga; and Teknaf. In addition, wind speed was assessed at a height of 10 m only at Char Fassion. Study findings summarized in Fig. 15 shows the maximum average annual wind speed of 4.52 m/s at Kuakata whereas the minimum (2.94 m/s) was recorded at Teknaf. Furthermore, the lowest monthly average wind speed was recorded from November to February.Inthe same year, July – September period had the highest monthly average wind speed. Another finding of that study was that the south – western coast of the country has relatively lower wind speed compared to south – east coast [66]. Nevertheless, the single most important finding of that study was that Bangladesh coast has an average annual wind speed of 2.94 – 4.52 m/s at 25 m height (due to much lower wind speed at 10 m height, data is excluded from Fig. 15). This average annual wind speed is lower than the threshold value (7 m/s) [30] for a large scale commercial wind turbine project which resulted into no mentionable large commercial wind turbine project in the country before 2017. Only 2 small scaled wind turbine plants were set up with 1 MW and 900 kW electricity generation capacity prior 2017 [89].

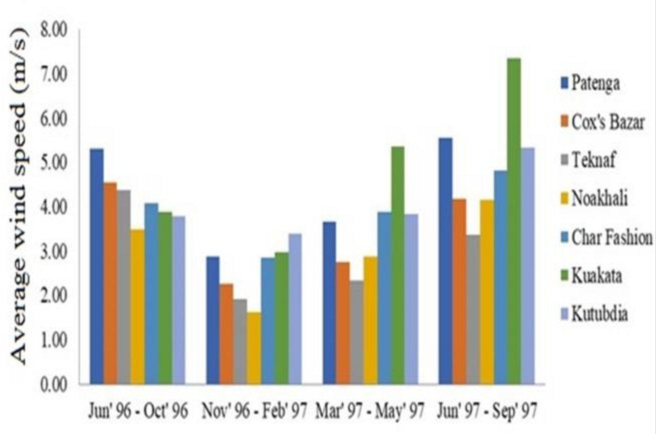

Fig. 15. Average monthly wind speed at 25 m height from seven stations in Bangladesh

However, a recent study performed by the National Renewable Energy Laboratory (NREL) of the United States Department of Energy has shown promising wind speed value in Bangladesh [90]. NREL installed nine meteorological stations – shown in Fig. 16 – to measure wind speed at five different heights under the NREL's Bangladesh Wind Mapping Project. They monitored wind speed between 12:00 AM UTC on 1 Jun 2014 and 23:00 PM UTC on 29 Dec 2017 and the average wind speed is tabulated in Table 10 at different heights.

Table 10. Average wind speed between Jun 2014 and Dec 2017 in Bangladesh [90]

Height (m)	**Average Wind Speed (m/s)**								
	Rangpur	**Mymensingh**	**Sylhet**	**Rajshahi**	**Chandpur**	**Mongla**	**Sitakunda**	**Parki Beach**	**Inani Beach**
30.00	3.36	3.10	3.13	3.44	3.97	3.87	4.27	4.47	4.39
80.00	4.32	4.20	4.03	4.29	5.08	4.93	5.48	5.53	5.45
100.00	4.53	4.44	4.18	4.50	5.39	5.30	5.82	5.80	5.72
120.00	4.71	4.59	4.38	4.69	5.60	5.50	5.98	6.11	5.94
160.00	5.03	4.85	4.82	5.01	5.86	5.97	6.32	6.25	6.32

It is seen that some areas - Rangpur, Mymensingh, Sylhet/Mirzapur, and Rajshahi - do not show potential wind speed even at the higher heights; almost all those areas have very lower wind speed than the threshold value. However, coastal regions such as Chandpur, Mongla, Sitakunda, Parkay, and Inani sea beach have comparatively higher wind speed than previously mentioned regions. From 80 m to greater heights, all the coastal regions have higher wind speed with an average of 5.0 - 6.3 m/s speed. The study concluded that Bangladesh has potential wind speed for electricity generation at sufficiently greater heights along the coastal regions. Furthermore, it is estimated that Bangladesh has potential for generating more than 2000 MW wind-based electricity [88].

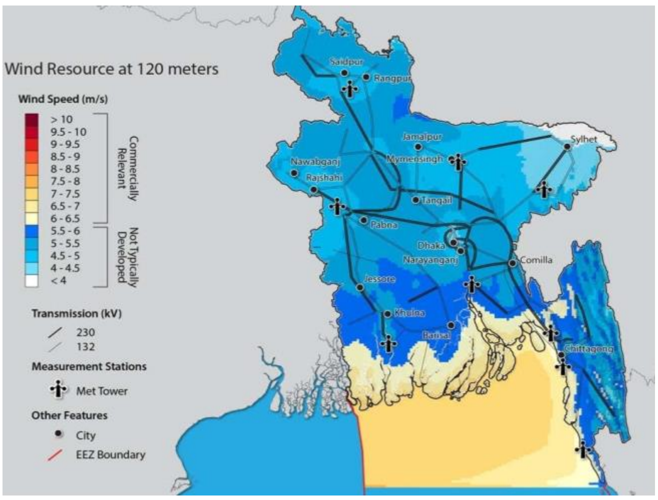

Fig. 16. 2017's wind mapping project of Bangladesh along with meteorological stations position and transmission lines [90, 91]

7.2. Present scenario and future of wind power generation

National Database for Renewable Energy shows that Bangladesh has only two completed wind power plants under BPBD up to 2020. One in Sonagazi, Feni with 900 kW capacity, which was installed in 2006. Another one is Wind Battery Hybrid Power Plant in Kutubdia, Cox's Bazar with 1,000 kW capacity, which was commissioned in 2008 [89]. Later, both the power plants went off grid due to frequent natural disasters, consequently, measures were taken for maintenance work to back them on grid within 2015, but no update has been posted yet after completion of scheduled maintenance work [66, 89]. Moreover, different government organizations such as Bangladesh Army, BCSIR, Institute of Fuel Research and Development etc. and some non-government organizations namely Grameen Shakti, BRAC etc. had been working mainly in the coastal areas of the country for wind turbines installation, however, their combined effort accounted only about 20 kW electricity generation [66]. Nevertheless, due to the availability of new and feasible wind speed data in 2017, Bangladesh government has undertaken several large wind power plant projects. Among them the largest wind power project with a 60 MW capacity started in 2017 in Chakaria, Cox's Bazar. In 2019, installation of another 2 MW power plant started in the bank of Jamuna River, Sirajganj [89]. Additionally, planning has been finalized for 10 MW power plant installations in Kalapara, Patuakhali which is scheduled to start up in 2022 [89]. A feasibility study was conducted in 2019 to survey the potentiality of a wind farm in Matarbari, Cox's Bazar under supervision of Coal Power Generation Company Bangladesh Limited (CPGCBL)[89]. Despite of tremendous efforts, Bangladesh has harnessed 2 MW electricity out of 2,000 MW energy potential from wind in 2020. However, an electricity generation potential of about 75 MW is estimated to be produced from this renewable source once the scheduled projects will be completed [89].

7.3. Constraints of wind energy

Bangladesh has constraints for wind energy generation at different levels. Firstly, proper policies, rules, and regulatory frameworks were totally absent for wind energy generation; although in 2002, Bangladesh government finalized its renewable energy generation policies [92]. Previously, due to lack of proper policies, no effective communication between public and private organizations was established to generate wind energy. Then reliable ground level wind data were unavailable at technical level, only a survey from 1996–97 concluded that Bangladesh has relatively lower wind speed for electricity generation [66]. But a recent survey carried out by NREL concluded that Bangladesh has sufficiently higher wind speed at greater heights along its coastal areas for electricity generation [90]. Additionally, the wind turbines produce noise similar to the small jet planes which makes nearby locals uncomfortable to live within several meters radius of the wind mills [93]. Unpredictable natural calamities such as storms, cyclones etc., also hinder the development of wind energy generation. Industries for wind turbine manufacturing, installation and maintenance have not been established locally which results in large cost on wind turbines import [93]. At commercial level, due to unreliable nature of the wind energy–at least from the perspective of Bangladesh–no financial institutions have extended their support or incentives for the wind energy whereas other energies such as solar and bioenergy received substantial financial incentives from both public and private organizations and even from international donors. Lack of such financial support is another obstacle for wind energy. Finally, the wind energy has not gained popularity among general people like bioenergy due to the lack of sufficient publicity and promotion while this type of energy has the highest potential for electricity generation without emitting any kind of greenhouse gases including SOx and NOx. Moreover, deployment of hybrid energy system involving wind energy with solar energy can be an effective way of popularizing wind energy. Use of this technology in roads and highways lights will be an impressive method of decreasing energy consumption [94].

8. Current and Future Strategies of Government

8.1. Adopted policies

The government is providing various incentives to the implementers and investors of the renewable energy project. Financing activities have been expanded through the public financial institutions such as IDCOL, Private Commercial Banks, and Bangladesh Bank. In addition, the government of Bangladesh provided incentives on various renewable energy commodities such as solar panels and solar panel manufacturing components, charge controllers, inverters, light emitting diode lights, solar powered lamps, and wind power plants. Taking inspiration from the success stories of the SHS, several government programs like solar rooftop, solar park, solar boating, solar irrigation, solar mini/micro grid have been launched in Bangladesh. Currently, solar energy is considered highly promising among the various renewable energy sources along with some limited use of bioenergy.

In 2014, the National Centre for Atmospheric Research (NCAR) undertook a project with NREL in cooperation with Government of Bangladesh (GOB) and financed by United States Agency for International Development to assess and measure the wind resources in Bangladesh. This is guaranteed by the GOB that about 10% of its national electricity generation will be achievable from the renewable sources by 2021. However, no utility-scale wind farms exist in Bangladesh to date. The NCAR's dataset was utilized by the NERL research team as the reference for their wind resource estimation. The potential for wind speed was studied here under nine meteorological stations. Average air speed data has been analysed and published in the NREL website which now can be used for harnessing the wind energy in Bangladesh. Recently, a biomass resource mapping survey was undertaken from the Sustainable Renewable Energy Power Generation (SREPGen) Project funded by

United Nations Development Program. After this survey, a clear concept on the biomass energy potential will be accessible in the country.

8.2. Scaling up strategy of Renewable Energy Program

Based on the data (from 1990 to 2018) reported by International Energy Agency [95] , it has been forecasted (using Microsoft Excel with 95% confidence interval) that the energy production, consumption, and deficiency will continue to rise with time as demonstrated in Fig. 17. In 2040, the total energy production will be 218 PJ, whereas the total energy consumption will be 281 PJ, with a shortfall of 63 PJ. However, the energy deficit is expected to be even greater, given the dwindling resources of fossil fuel sources. Therefore, harnessing energy from renewable sources is imperative to meet the increasing energy demand. To that end, Bangladesh has intended to expand its renewable energy capacity to 4,000 MW by 2030 [73]. To realize, in part, this ambitious plan of the country, the World Bank's Board of Executive Directors authorized funding for a project worth of 156 million U.S. dollars under Scaling Up Renewable Energy Program (SREP) in March 1, 2019 [96]. The project is likely to increase up to 310 MW in renewable energy production capability in Bangladesh and to organize up to US$ 212 million from private sector involvement to meet the growing demand for electricity in the country. The project intends to improve the invested capacity of renewable resources through piloting and enlarging investments in the key market segments. It would be helpful to reduce emissions by 377,000 tons of CO_2 equivalent a year by means of avoiding burning of fossil fuels: a promise of better access to cleaner electricity and environment. The project will also support IDCOL with advancement of the Renewable Energy Financing Facility and offer resources to build up market size and to create a pipeline of the renewable energy projects.

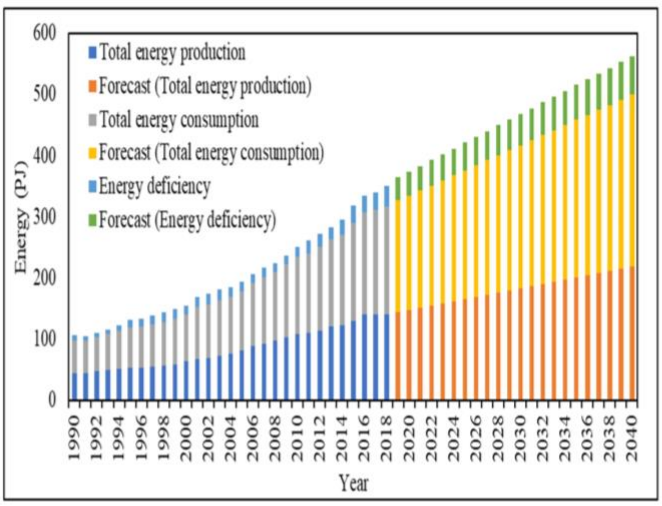

Fig. 17. The total energy production, consumption, and deficiency in Bangladesh from 1990 to 2018 and their projection up to 2040

Intended to demonstrate the economic, environment, and social feasibility of low carbon development pathways in the energy sector of low income countries, SREP was projected in February 2008 and made operational in December 2009 [97]. SREP is funded by the Strategic Climate Fund that is one of the two funds within the Climate Investment Funds agenda and is administered by the World Bank which is also a trustee of this fund [98]. The SREP was founded to scale up the utilization of renewable energy solutions and to develop the renewable energy markets in the poorest countries of the world. Later in June 2014, Bangladesh was nominated as one of the latest pilot countries to take part in the SREP program. In 2015, World Bank Group and Asian Development Bank mutually launched a mission to introduce SREP to different key stockholders of Bangladesh including SREDA and IDCOL and to evaluate required technological support and funds for fostering an investment plan within a comprehensive timeline. Thus, SREP Bangladesh was published at the end of 2015 to outline possible investment and development plan in renewable energy sector of the country [99].

This is expected that the proper implementation of the investment plan of SREP Bangladesh will be revolutionary to launch a prospering drive toward the incorporation of renewable energy production into the grid, and a continuous development of the off-grid electrification programs in the country. SREP Bangladesh can arrange for policy support and technical guideline to develop the national renewable energy strategies. This could also underwrite the risks and additional capital costs related to renewable energy investments and other instruments to lower the risk to the investors. Furthermore, SREP Bangladesh should expand its aims to i) promote revolutionary change to reduce carbon pathways by using the potential of renewable energy; ii) highlight environmental, economic, and social co-benefits of renewable energy programs; iii) scale up private sector investments to obtain SREP objectives; vi) empower combined funding from various sources to facilitate scaling-up of renewable energy packages; v) accelerate information sharing and exchange of international knowledge and experiences.

8.3. Recommendations for future development

The policy and practice of producing renewable energy in Bangladesh is not very long and the first renewable energy strategy was finalized in 2002 [92]. The renewable energy policy reflects mitigating the gap of energy demand of Bangladesh by exploiting a huge quantity of renewable resources. To make the renewable energy technologies sustainable and to contribute to the national energy sector significantly, the following suggestions are proposed:

- Inclusion of academicians and researchers in national policy body
- Establishment of National Laboratory for Renewable Energy Research (NLRER)

- Modern software based (e.g. Long range Energy Alternative Planning system-LEAP)modelling of energy system should be done to estimate the rate of future energy consumption and the future potentials for the energy in the country
- Provide subsidy for energy production rather than energy importation
- Preferential tax treatments for renewable energy sector, such as tax credits, tax rebates, reduced tax rates
- Inclusion of chapter/course on energy uses in all levels of education
- Emphasis on establishment of micro-hydro power plant
- Providing non-arable land with minimum cost or free of cost to the investor for solar power plants
- Offering bank loans with flexible terms and conditions
- Supporting low-cost insurances to ensure the economic security to the investor
- Tax-free capital can be offered in an Enterprise Investment Scheme for biogas plants
- Tax-free dividends should be provided
- Duty free importation of tools and machineries related to renewable energy plant as they are costly
- Consideration of renewable energy sector as sustainable solution of unemployment problem
- Execution of smart grids, which has the potential for reducing fossil fuel consumption significantly and thereby lowering the burden on renewable energy resources [100]
- Media support to popularize the renewable energy technologies

9. Conclusion

Bangladesh possesses very high potentiality to generate renewable energy from various sources including solar, biomass, hydro, and wind. Although the country initiated few strategies to improve the renewable energy sector, it could not achieve the goal due to lack of involvement of all stakeholders such as energy experts, researchers, investors, producers, suppliers, policy makers, politicians, environmentalists etc. Most of the previous renewable energy strategies (policies) were prejudiced toward energy production only, but it should be interconnected to associated socio-economic and environmental factors for sustainable energy generation. Existing policies are required to be refined while new policies should be made to achieve the integrated benefits of these factors. Incorporation of socio-territorial factors to recompense the use of heat or other by-products of renewable energy technologies can diversify their uses beyond the electricity generation only. Energy subsidization strategy must be improved emphasizing additional components such as, but not limited to, renewable energy technology education and training for household and commercial beneficiaries, financial supports and favours for technology management and maintenance, etc. A synergistic effort in all types of renewable sources (hydro, solar, bioenergy, and wind) can significantly contribute to the national energy demand in Bangladesh.

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