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Development of renewable energy sector in Bangladesh: Current status and future potentials

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ABSTRACT

Bangladesh is a hugely populated country in South Asia. The country produces its electricity mainly from natural gas followed by liquid fuels. Although the installed electricity generation capacity of the country has been increased to 12,261 MW, there is scarcity of electricity in the hot summer season which is a barrier to industrial development as well as socio-economic development. Combustion of fossil fuels releases greenhouse gases (GHGs) into the atmosphere which causes global warming. Bangladesh can be badly affected by greenhouse effect and global warming. These problems can be mitigated by incorporating renewable energy sources (e.g., solar, wind, hydro, biomass, etc.) to the country's electricity generation. Renewable energy resources are considered as clean and can serve the electricity demand in the remote areas where grid connection is not possible. The potential of solar energy and biomass is enormous in Bangladesh and people have already started to harness energy from these sources. The government and the policy makers should come forward to encourage the people of rural areas as well as urban areas to use renewable based electricity. The government of Bangladesh has set up a plan to generate 5% of the country's total electricity from renewable sources within 2015 and 10% within 2020. However, within 2015 the country has been able to generate only 3.5% of the total electricity from renewable sources. This paper presents a thorough review of the current status and future potentials of renewable energy sector in Bangladesh. In this paper the updated information is provided for the overall renewable energy sector of the country.

1. Introduction

Global warming and the greenhouse effect are the main reasons to investigate and incorporate clean fuel technologies and new energy sources around the globe [1–3]. These environmental issues and also the rapid depletion of fossil fuels encouraged the countries and different organizations to attain highly efficient and green power plants [4,5]. Technological advancement helps in achieving some means of harvesting energy from the renewable sources and to use them as the source of new, clean and sustainable energy to meet the world's demand [6–10]. Renewable energy resources are regenerative and do not deplete over time. Renewable energy ensures improved energy security of the countries all over the world and reduces carbon emissions.

From 1981–2014, CO_2 (carbon-di-oxide) emission has been increased from 19 billion tons to 34.7 billion tons and is expected to further increase by 85% within 2030 [11–13]. CO_2 emission has been increased with the increased use of fossil fuels. In the last few decades fossil fuel consumption has seen remarkable growth. The primary energy consumption has been increased from 8146 Mtoe (million tons of oil equivalent) in 1991 to 12,928 Mtoe in 2014 [14]. Moreover, it is estimated that 90% of the primary energy consumption will be supplied by fossil fuel until 2020 [11]. Recently, fossil fuel supplies 85.77% of the primary energy consumption of the world and 55% of this amount is used in the transportation sector [14,15]. Transportation sector is the main consumer of oil and other petroleum products. The use of oil is increased from 3137.6 million tons in 1991 to 4211.1 million tons in 2014 [14,16]. Coal and natural gas are mainly used in power sector and are also depleting alarmingly. This concerning scenario resulted from rapidly diminishing resources is highlighted by International Energy Agency which forecasted the exhaustion of fossil fuel in about 100 years [17]. According to British Petroleum statistical review of the world energy report 2015, the range of exhaustion is estimated to be 53–110 years [14] (see Table 1).

However, shifting to renewable energy will help to fulfill the dual goal of mitigating the greenhouse gas emission and also finding a way to alternate energy source other than fossil fuels. At present renewable energy share is 17% of the world's energy supply and this share is

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Table 1
Global reserves and availability of major fossil energy resources.
Source: Ref. [14]

Category item	Oil	Natural gas	Coal
Total reserve (end of 2014)	1700.1 billion barrels	187.1 trillion cubic meters	891,531 million tonnes
Production in 2014	32.277 billion barrels	3460.6 billion cubic meters	3933.5 million tonnes of oil equivalent
Remaining years for exhaustion of fossil fuel	52.5	54.1	110

Table 2
World renewable energy production and use by type.
Source: Ref. [5]

	2010	2020	2035
Electricity generation (TWh)	**4206**	**6299**	**11,342**
Bioenergy	331	696	1487
Hydro	3431	4513	5677
Wind	342	1272	2681
Geothermal	68	131	315
Solar PV	32	332	846
Concentrating solar power	2	50	278
Marine	1	5	57
Share of total generation	**20%**	**25%**	**31%**
Heat production (Mtoe)	**337**	**447**	**604**
Industry	207	263	324
Buildings and agriculture	131	184	280
Share of total production	**10%**	**12%**	**14%**
Biofuel production (mboe/d)	**1.3**	**2.4**	**4.5**
Road transport	1.3	2.4	4.4
Aviation	–	–	0.1
Share of biofuels in total transport	**2%**	**4%**	**6%**

estimated to be increased by 60% within 2070 [18]. The renewable energy market has grown sharply in the last 5–6 years. Global investment in harvesting renewable energy has been increased in recent times [19]. Investment on renewable energy is increased by 17% in 2014 over the previous year and reached at least USD 301 billion [20]. Newer technologies have opened up more opportunities, reduced cost and increased confidence. Hence, it is expected that global electricity from renewable sources will grow 2.7 times between 2010 and 2030 as shown in Table 2. At the same time interval biofuel consumption is projected to increase by more than three times from 1.3 million barrels oil equivalent per day to 4.5 million barrels oil equivalent per day and most of these biofuels will be used in the transportation sector. Electricity generation will have the most share of renewable energy compared to heat production or road transport.

Bangladesh is blessed with several renewable energy sources which could be utilized to meet the increasing power crisis. Biomass is the major potential source of renewable energy in this country and can be used for power generation. Due to suitable geographical location solar energy is also a bigger source of renewable energy in Bangladesh which is becoming popular across the country mainly through the supply of off-grid electricity to the hilly, coastal and rural areas. Although wind and hydro potential is not too high, the government and some private organizations are trying to establish small scale plants to utilize these energy sources.

There have been few studies that conduct the techno-economic assessments of different renewable energy sources in Bangladesh [21–25]. A recent study by Hossain et al. [26] investigated the marketing strategy for solar energy business. The paper outlines the problems related to this type of business in Bangladesh. Halder [27] studied the economic viability of three different capacity (20 W_p, 30 W_p and 42 W_p) solar home systems at two randomly selected villages in Bangladesh. A study by Khan and Matin [28] presented a review of different biogas digester technologies used in Bangladesh. They found that the quality and quantity of biogas can be improved by controlling the parameters (e.g., temperature, pH, agitation, etc.). On the other hand, Hossen et al. [29] presented an assessment of biomass for power generation and chemical production in Bangladesh. Some of the researches conducted earlier worked on particular locations to investigate renewable energy potential for energy generation. There are some studies that reviewed the status of specific types of renewable energy resources but there is limited information on the overall scenario and future potential of renewable sources in Bangladesh. Moreover, some of the numbers presented in the earlier studies are outdated. The detailed information of various renewable energy resources and their utilization needs to be compiled to understand the entire picture of the renewable energy sector. The overall objective of this paper is to provide an up-to-date review of the status of renewable energy sector of Bangladesh. Journal articles, conference proceedings, web materials, books, government and non-government reports, and communication with renewable energy experts of various organizations were used as data collection sources. The specific objectives of the paper are:

- to review and discuss the overall energy scenario of Bangladesh;
- to review the status of renewable energy sources and extent of their availability in Bangladesh;
- to review the development of renewable energy sector in the course of time; and
- to review and discuss the future target of renewable energy development.

2. Economy and energy context of Bangladesh

Bangladesh is a south Asian country between 20°34″ to 26°38″ north latitude and 88°01″ to 92°41″ east longitude with a population density of 1222/km^2. The geographical map of Bangladesh is presented in Fig. 1. The country has a total land area of 147,570 km^2 [30]. Per capita income of Bangladesh is US$ 1314 [31]. The country secured an economic growth rate of 6.2% over the last decade which is well above the global economic growth [32]. Being unaffected by the global fickleness, the growth of economy of Bangladesh maintained its stability and secured a growth of 6.5% of GDP (Gross Domestic Product) in 2015 [32]. This was possible because of higher growth of the industrial sector as well as the service sector. Bangladesh also shifted up from low income country to lower middle income country. The growth of export sector was lower in 2015 (3.3%) compared to the preceding year (12.1%). This was because of the slow growth of export of the garments sector of this country, which is the second largest garments exporter in the world after China. Agriculture, industry and the service sector contributes 17.2%, 28.9% and 53.9% of the country's economy, respectively [33]. Because of the rapid reduction of agricultural land, the contribution of agricultural sector in GDP is decreasing. On the other hand due to urbanization and rapid progress of business and commerce the share of service and industry sector is increasing.

It is assumed that 0.23% of GDP growth can be obtained by each 1% increase in the per capita energy consumption [34]. Even if the energy consumption has been increased by 4.5% from 1990 to 2012 which is close to the highest percent increase among other Asian countries, per capita energy consumption for Bangladesh is still very low [35]. Figs. 2 and 3 show the per capita energy consumption and energy use growth rate in different Asian countries, respectively. When the per capita energy consumption of China, India, Pakistan and Sri Lanka are 2143 kgoe (kilograms of oil equivalent), 624 kgoe, 524 kgoe and 554 kgoe, respectively, Bangladesh has only 214 kgoe (see Fig. 2) which is even among the lowest around the world [35]. Per capita electricity consumption also shows the necessity for expansion of the energy supply in Bangladesh. Per capita electricity consumption in Bangladesh is only 279 kWh, which is very far behind USA (12,954 kWh/capita) or

Fig. 1. Geographical map of Bangladesh.
Source: Ref. [37]

the other developed countries [36].

The breakdown of the source wise electricity generation of the world and Bangladesh are shown in Figs. 4 and 5, respectively. Although some countries are achieving maximum of the electricity from renewable sources these days, as the Fig. 4 indicates still only 16.8% of the world's electricity is coming from renewable source (hydro). The electricity generation from the other renewable sources are very less. In Bangladesh, renewable sources have a very little share in the total electricity generation. Only 423 MW out of a total 12,261 MW is coming from the renewable sources [38]. Except hydro-electric and solar energy, electricity generation from other renewable sources is even more negligible [39]. In Bangladesh the main source of electricity is natural gas. Natural gas contributes almost 63% of the total installed capacity and 72% of the actual electricity generation as of 2014 [40].

Other than electricity, natural gas is used as the major energy source of some other sectors of Bangladesh. It constitutes 75% of the primary commercial energy supply. Of the total natural gas consumption, 41% is used by power plants, 17% by industry, 16% by captive power sector, 12% by domestic sector, 8% by fertilizer sector and the rest 6% by the transport (CNG) sector [40]. Dependency on natural gas is even increasing day by day. It has been increased by 300% from 1992 to 2012 [39]. Oil is another major source of energy. For oil, Bangladesh mainly depends on refined and unrefined petroleum fuels. These are

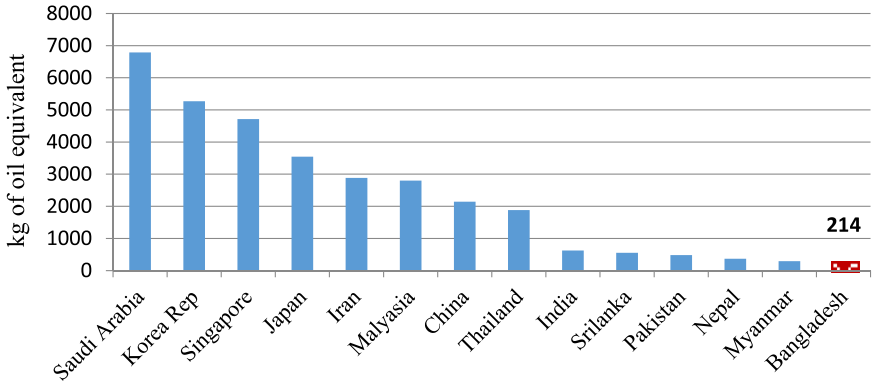

Fig. 2. Per capita energy use in different Asian countries.
Source: Ref. [35]

mainly used in transportation sector and agriculture sector. 45% of the total oil is consumed by the transportation sector and 21% for irrigation. Rest is used in power sector (19%) and domestic sector (9%) [42].

To reduce the dependency on fossil fuels alternative sources of energy should be implemented. Renewable sources will reduce the threat to the small reserve of gas and coal as well as will help in reducing the greenhouse gas emission.

3. Renewable energy in Bangladesh

Renewable energy sources are sustainable and clean and can reproduce without depletion in the course of time. They can support the effect of continuous reduction of fossil fuels and tackle the impact that fossil fuels have on the environment. Although the greenhouse gas emission is not a primary concern for a low economy country like Bangladesh, incorporation of renewable energy is obvious because of rapidly reducing natural resources. Bangladesh has few renewable energy potentials among which solar and biomass are the most promising sources. Among the others, hydropower has limited potential due to flat surface and low available head [43]. Due to insufficient data availability, the assessment of wind power generation is difficult [44]. Table 3 shows the current status of installed renewable energy capacity from different sources in Bangladesh [38].

This 423 MW of electricity from renewable sources is only 3.5% of the total installed capacity of this country. Table 4 shows the number of installed renewable technology measures [38]. Target to achieve 5% of the electricity from renewable sources within 2015 by Bangladesh Policy of Renewable Energy (BPRE) couldn't be achieved. The share of renewable energy is only 3.5% as of 2015. However, the government is working for the next target of 10% of the electricity generation from renewable sources by 2020 [44].

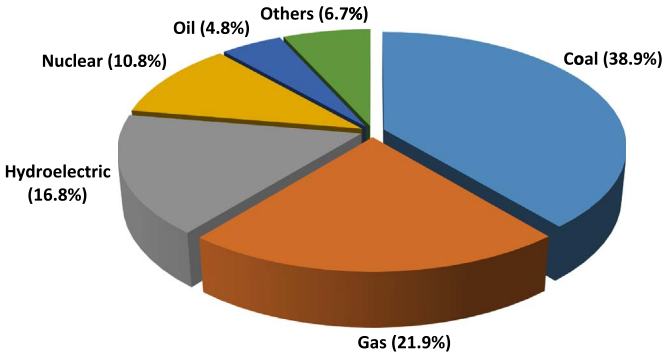

Fig. 4. Breakdown of world electricity capacity (by type of source).
Source: Ref. [41]

3.1. Solar energy

Solar energy is the most abundant and promising renewable energy resource with higher potential to gain energy than any other sources [45]. It can be used in two ways known as thermal route and photovoltaic route. In thermal route the heat from solar energy is used for various purposes like heating, water purification, power generation, etc. On the other hand in photovoltaic route the light in solar energy is converted into electricity, which can be used in lighting, pumping and power supply in rural areas where grid electricity is not reachable [46]. Solar photovoltaic (PV) has become center of attention to the oil companies and solar product manufacturers considering its high potential and they are investing heavily in this sector in recent days [12]. This is reflected in Table 5 where it can be seen that in 2014 alone the addition in the global power capacity from solar PV was 40 GW which led to the total of almost 177 GW. Although this is only 0.9% of the world's total power capacity, its share is increasing rapidly in the recent years.

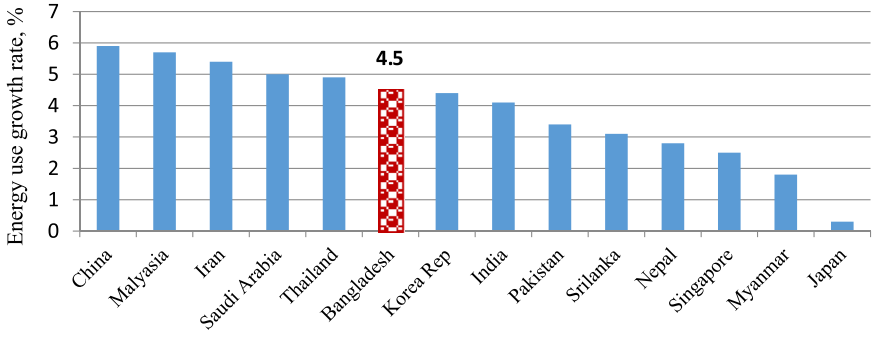

Fig. 3. Energy use growth rate in different Asian countries (from 1990 to 2012).
Source: Ref. [35]

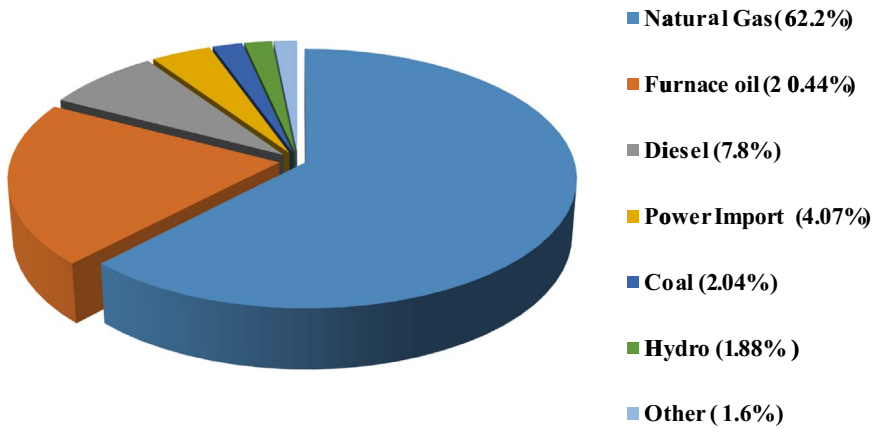

Fig. 5. Breakdown of electricity capacity of Bangladesh (by type of source).
Source: Ref. [40]

Table 3
Installed renewable energy technologies in Bangladesh.
Source: Ref. [38]

Technology	Off-grid (MW)	On-grid (MW)	Total (MW)
Biogas to electricity	5	–	**5**
Biomass to electricity	1	–	**1**
Hydro	–	230	**230**
Solar PV	184	1	**185**
Wind	1	0.9	**1.9**
Total	**191**	**232**	**423**

Table 4
Measures of renewable technology installed in Bangladesh.
Source: Ref. [38]

Type	Number
Solar home system	3.6 million
Solar irrigation pump	366
Solar water heater	–
Solar drinking water system	140
Biogas plant	38,000
Improved cook stove	20,00,000
Improved rice parboiling system	68
Total	**5.63 million**

Table 5
Distribution of installed world renewable energy technologies in the top five countries.
Source: Ref. [20]

Technology	World (GW)		Top countries (GW)				
	Total	Added in 2014	China	USA	Germany	Japan	India
Bio power	93	5	10	16.1	8.8	4.7	5
Geothermal power	12.8	0.6	~0	3.5	~0	0.5	0
Hydro power	1055	37	280	79	5.6	22	45
Ocean power	0.5	~0	~0	~0	0	0	0
Solar PV	177	40	28	18	38	23	3.2
Concentrating Solar thermal power	4.4	0.9	~0	1.6	0	0	0.2
Wind power	370	51	115	66	39	2.8	22
Total renewable power capacity	**1712**	**134**	**433**	**185**	**92**	**54**	**76**

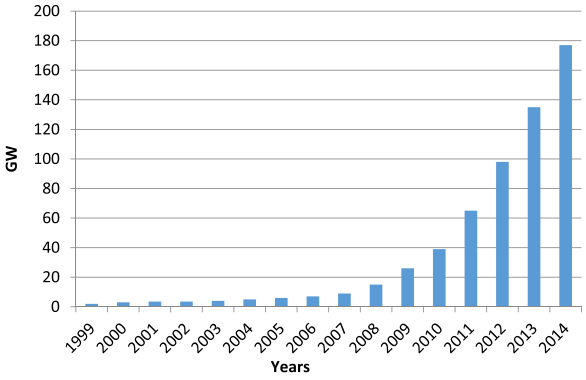

Fig. 6. Installed PV worldwide (till 2014).
Source: Ref. [47]

Fig. 6 shows that almost 60% of the world solar PV capacity was installed from 2012 to 2014. In 2014 five countries added more than 1 GW of solar PV to their grid, which led to a total of twenty countries now with a capacity of at least 1 GW from solar PV. Asia topped all other markets by adding 60% of the global addition. China generated 200% more electricity in 2014 compared to the previous year because of newly added solar PV in their grid [48].

However, because of geographic position, Bangladesh has a great potential of utilizing solar irradiation. Bangladesh receives an average of 4–6.5 kWh/m^2 of solar radiation daily. This can produce a total of 1018×10^{18} J of energy [49]. About 0.11% of this energy can meet the primary energy consumption of this country [49]. Table 6 shows the average monthly solar radiation in different cities of Bangladesh.

Table 6
Average monthly solar insolation (kWh/m^2/day) at different cities in Bangladesh.
Source: Ref. [50]

Month	Rajshahi	Jessore	Bogra	Dhaka	Barisal	Sylhet
January	3.96	4.25	4.01	4.03	4.17	4.00
February	4.47	4.85	4.69	4.78	4.81	4.63
March	5.88	4.50	5.68	5.33	5.30	5.20
April	6.52	6.23	5.87	5.71	5.94	5.24
May	6.17	6.09	6.02	5.71	5.75	5.37
June	5.25	5.12	5.26	4.80	4.39	4.53
July	4.79	4.81	4.34	4.41	4.20	4.14
August	5.16	4.93	4.84	4.82	4.42	4.56
September	4.96	4.57	4.67	4.41	4.48	4.07
October	4.88	4.68	4.65	4.61	4.71	4.61
November	4.42	4.24	4.35	4.27	4.35	4.32
December	3.82	3.97	3.87	3.92	3.95	3.85
Average	**5.00**	**4.85**	**4.85**	**4.73**	**4.71**	**4.54**

Maximum solar radiation can be found from March – April and minimum in December – January (see Table 6). Rajshahi district gets the highest solar radiation with huge opportunity to harness solar energy.

The annual average direct natural insolation of 1900 kWh/m^2 in Rajshahi is found to be sufficient to utilize concentrating solar power technology [51]. This technology could generate a total of 100 MW of electricity if in a 2 m^2 area the annual average radiation is 2000 kWh/m^2 [52].

Although concentrating solar power is in nascent stage, other technologies are expanding quite rapidly in Bangladesh. Among them solar home system (SHS) is the most successful one. There are 3.6 million solar home systems of a total capacity of almost 150 MW has been installed around the country [38]. Infrastructure Development Company Limited (IDCOL) is the leading organization in this sector and it has started to work with SHS since 2003 with a view to providing sustainable energy to the electricity deprived rural people. It is working on a target to install 6 million solar home systems with an estimated capacity of 220 MW by the year 2017 [53]. Under this project almost 65,000 SHSs are now being installed every month resulting 58% annual increase every year. About 180,000 tons of kerosene with an estimated value of USD 225 million will be replaced by this project [53]. On the other hand, grid connected solar systems are incorporated in several areas of the country which is adding new dimension in the solar energy utilization. The system provides grid quality electricity to the households, offices and small industrial enterprises. Several projects are being taken by IDCOL and Bangladesh Power Development Board (BPDB) to accomplish several mini grid projects. Seven solar mini grid plants have been installed by IDCOL at different locations of Bangladesh and several projects are under construction (see Table 7). Moreover, 3 MW_p and 8 MW_p of grid connected solar power plants are under construction by BPDB at Jamalpur and Rangamati, respectively. Usually a mini grid can supply electricity to 250–300 households and a market place consisting 80–100 shops. Table 7 represents the approved mini grid projects financed by IDCOL.

Roof-tops of the commercial and residential buildings can be utilized by installing solar PV to meet their electricity demand and to supply the surplus electricity to the grid. Installing PV systems in the residential buildings to meet a fraction of the load is a prior condition for getting electricity connection. The targeted capacity from solar roof-top project is 30 MW. As of 2014, a total of 10 MW_p solar roof-top PV systems were installed. The roof-top solar PV systems are already installed in the Bangladesh Bank head office and WAPDA (Water and Power Development Authority) buildings [38]. Non-agricultural lands owned by the government are being used for Solar Park project to produce clean electricity. The electricity will be fed into the national grid of Bangladesh on commercial basis. The expected capacity addition from this project is 135 MW. The government has already identified eight sites for solar park project [38].

Solar water heating can also reduce the dependency on fossil fuels. In the urban areas industrial and commercial sectors use hot water that is produced by natural gas or electric heaters. Hence, inclusion of solar water heaters is a priority of the government to replace gas and electric heaters.

Solar irrigation is another trending technology in Bangladesh utilizing solar radiation. This is of utmost importance since the country has a huge amount of almost 1.61 million irrigation pumps out of which 1.34 million (about 83%) is running by diesel and 0.27 million (about 16%) is by electricity. These pumps are consuming 700 MW of electricity and 900 million liters of diesel every year. 1550 irrigation pumps are planned to be energized by solar power by 2017 where 38 of them are already running. IDCOL has approved a total of about 7 MW capacity solar PV project to run irrigation pumps across the country [53]. Drinking water from solar powered pumps can provide quality water to the rural people. 112 solar powered drinking water pumps have already been installed in the coastal areas of Bangladesh [38].

Hybrid renewable energy sources are getting popular in Bangladesh. The hybrid renewable energy systems can provide reliable electricity to the remote off-grid locations. There is an ongoing project to produce 7.5 MW power in Hatiya Island of Noakhali using solar-wind-diesel hybrid system [40]. A study conducted by Nandi and Ghosh suggests a wind-PV-battery hybrid system can be used as a potential technology in the remote areas of the country.

Solar charging can be an effective alternative to the conventional fossil fuels in the transport sector as well [54]. So to achieve the targeted 10% electricity from renewable sources the government and other organizations should utilize the solar energy to its full potential.

Table 7
Approved mini grid projects financed by IDCOL.
Source: Ref. [53]

Project location	Capacity (kW_p)	Project status
Enam Nahar, Sandwip, Chittagong	100	Operational
Kutubdia, Cox's Bazar	100	
Bagha, Rajshahi	141	
Paratoli, Raipura, Narshingdi	141	
Narayanpur, Nageshwari, Kurigram	158	
Godagari, Rajshahi	149	
Monpura, Bhola	177	
Nooner Tek, Sonargao, Narayangonj	168	Under construction
Rupsha Char, Sadar, Sirajganj	130	
Chilmari, Daulatpur, Kushtia	188	
Munmiar Char, Islampur, Jamalpur	162	
Baghutia char, Doulatpur, Manikganj	228	
Nijhum island, Hatiya, Noakhali	200	
North Channel Union, Sadar, Faridpur	162	
Char Kajal, Patuakhali	100	
Char Biswas, Patuakhali	100	
Ghaschapru, Belkuchi, Sirajganj	218.4	
Poschim Shalipur, Char Bhadrashan, Faridpur	156	

3.2. Wind energy

Exploitation of wind energy largely depends upon the wind resource since the available wind energy changes by the cube of the wind speed. This leads to the necessity of selection of a suitable site for an economically viable wind energy farm using properly designed wind turbines. Depending upon the power generation capacity wind turbines are classified as micro (50 W to 2 kW), small (2 kW to 40 kW), medium (40 kW to 1 MW) and large turbines (more than 1 MW) [55,56].

World's total installed wind energy capacity is 432,419 MW at the end of 2015 where China has the largest share of almost 33.6% (see Fig. 7). Cumulative installed wind capacity from 2000 to 2015 is shown in Fig. 8. Wind energy growth is driven by competitive pricing, enhanced energy security and price stability. In 2015 a total of almost 63 GW (see Fig. 9) of wind capacity has been installed worldwide out of which 48.4% in China, 13.6% in USA and 9.5% in Germany [57]. For eighth years in a row Asia topped the regional wind energy market with China in the leadership position. Germany's record installation set Europe an increasingly concentrated market. After a dismissal in 2013 US market recovered in 2014 and looks strong for another two years similar to Canada.

In Bangladesh the wind speed is not satisfactory for large scale wind parks. When more than 7 m/s of wind speed is necessary for large scale grid connected wind energy, a study conducted by Bangladesh Center for Advanced Studies (BCAS) between 1996 and 1997 has found that Bangladesh has only 2.94–4.54 m/s of average annual wind speed at a height of 25 m measured at seven different spots which are Patanga, Teknaf, Cox's Bazar, Noakhali, Char Fassion, Kutubdia and Kuakata (see Table 8). Among them the maximum 4.52 m/s was observed at Kuakata and the minimum 2.94 m/s was observed at Teknaf. It is also observed that wind speed in the south-eastern part of the country is

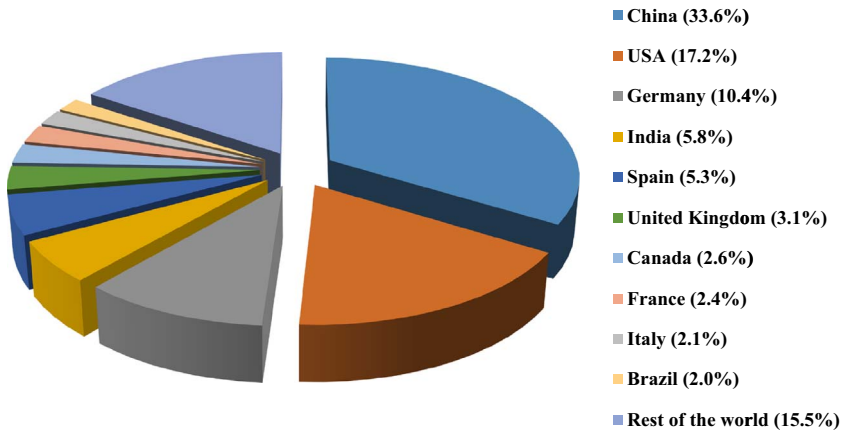

Fig. 7. Shares of top 10 countries in cumulative wind capacities (till December 2015).
Source: Ref. [57]

higher than south-western part. Also between coastal areas and inlands, coastal areas have higher wind speed. Wind speed is found to be relatively higher from April – August and from September – March its low.

Due to lack of ground data, less wind velocity and uncertain weather condition, Bangladesh has only two completed wind energy projects at Feni and Kutubdia districts. Out of them at Sonagazi, Feni Bangladesh Power Development Board (BPDB) has implemented four grid connected wind power plants each of 225 kW capacity and at Kutubdia a wind battery hybrid power plant has been installed with fifty wind turbines each of 20 kW of capacity [40]. But due to natural calamities such as cyclone and other technical problems these plants have not been running lately. Recently, these plants are under reconstruction, repair and maintenance stage and soon they will be fully functional. Measures have been taken to install wind plant of 15 MW capacity in the coastal areas of Bangladesh including Muhuri Dam Area of Feni, Mognamaghat of Cox'sbazar, Parky Beach of Anwara in Chittagong, Kepupara of Borguna and Kuakata of Patuakhali. A 7.5 MW of wind- solar- diesel/ heavy fuel oil hybrid plant is under construction at Hatia Island, Noakhali [40]. BPDB has a plan to implement 50–200 MW wind power project at Parky Beach area, Anawara in Chittagong [40]. Table 9 represents the wind turbines that are installed by different government and non-government organizations. To bring the large segment of people under electrification who are out of reach of electricity because of unreachable grid connection and lack of natural resources, renewables like wind energy should be used in an effective way with other type of renewable energy technologies like solar photovoltaics [58,59]. More research and development should be done in this sector to extract as much energy as possible from wind.

3.3. Hydro energy

When water streams flow down from a higher level to a lower level, the potential energy of water is converted into kinetic energy which is used in water turbines to produce electrical energy. Although hydro energy is not a completely clean source of energy, it has two main advantages compared to other natural sources like coal, oil, uranium and natural gas, etc. First, the cost of supply and secondly emission of greenhouse gases both are lower compared to those other sources [61]. Yet, the greenhouse gas emissions are being analyzed by few institutions. Because of the lack of standardized methodology for gathering data and also because of nonlinear greenhouse emission nature, values analyzed by different institutions have discrepancies. However, Dos Santos et al. [62] found that only if the generation of hydroelectricity is less than 0.1 W per m^2 of reservoir area then the greenhouse gas emission is higher compared to a conventional power plant generating same amount of electricity. They have concluded that the damage caused by hydroelectricity is lower compared to other thermal sources; hence this is a reliable solution in mitigating the GHG emission in the power sector.

Only six countries contain almost 59% of the total hydroelectric capacity of the world (see Table 10). According to 2015 report of Renewable Energy Policy Network, world's total installed capacity was 1055 GW as of 2014. 37 GW was added in the world's capacity in 2014 where a significant amount is added by China (22 GW) leading to a year-end amount of 282 GW. Other top countries Brazil, Canada, India and Russia also added substantial amount in the country's total. Due to drought United States could not add any amount in 2014 and many other countries suffered from decline in energy generation. Table 10

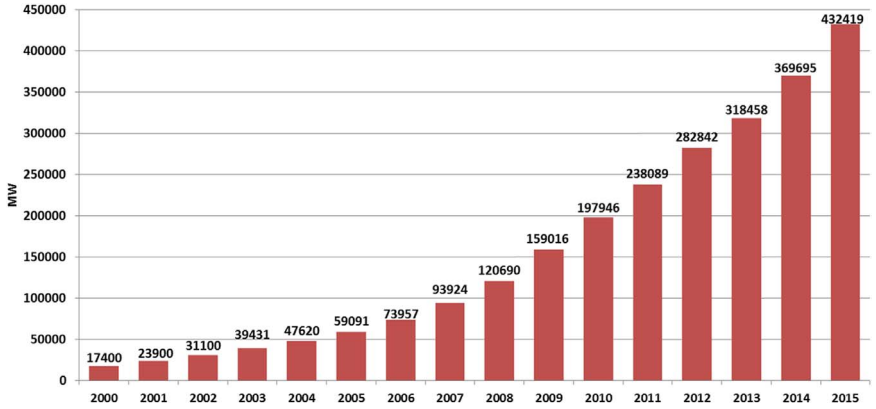

Fig. 8. Global cumulative installed wind capacity (2000–2015).
Source: Ref. [57]

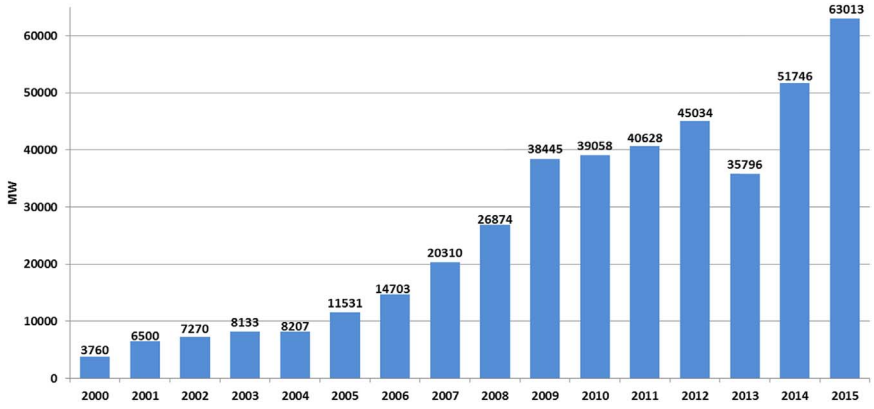

Fig. 9. Global annual installed wind capacity (2000–2015).
Source: Ref. [57]

shows the hydropower capacity of top six countries.

Despite of having numerous rivers Bangladesh has limited potential of hydro energy because of lack of suitable head and flow of water. Almost 90% of the rivers originate from neighboring countries India and Myanmar. Until 2005 Bangladesh had only one hydroelectric plant known as Kaptai Hydroelectric Power Plant located at the basin of Karnafuli river of total capacity 230 MW consisting of two 40 MW and three 50 MW Kaplan turbines. Bangladesh Power Development Board (BPDB) is considering addition of another 100 MW of capacity in this power plant to be run mainly in the rainy season when excess water spills out [40]. In 2005 another micro hydro power plant of capacity 50 kW has been installed in Barkal Upazila of Rangamati district [40]. Two other sites with major potential of hydro energy are in the Sangu and Matamuhuri river basin with 87 MW and 80 MW of potential capacity, respectively. Brahmaputra river basin has a potential to generate 1400 MW [49]. Some other potential sites across the country, which were discovered as suitable site for micro hydro power plant by BPDB and Bangladesh Water Development Board (BWDB), are shown in the Table 11. Sustainable rural energy (SRE) project discovered some locations suitable for micro hydro plants in 2004 in Chittagong areas. The total capacity of hydro power was estimated to be 135.5 MW. Table 12 represents the potential of micro hydro power sites explored by SRE. A Chinese expert team has identified twelve sites suitable for micro hydro power plant; among them the best one was found at Mahamaya Chara, near Mirersharai from where electricity production is possible throughout the year except April and May (see Table 13). Based on this, BPDB is currently installing a 50–70 MW irrigation-cum-hydro power plant in that location [40].

3.4. Biomass

Biomass energy is renewable and sustainable and is derived from a wide range of materials covering from firewood to agricultural crops, animal waste to municipal waste, etc. Biomass can be directly burned to produce heat energy, it can also be converted to other types of bioenergy (e.g., biofuel) through different biochemical and thermo-chemical processes such as anaerobic digestion, combustion, gasification, etc. (see Fig. 10). These converted bioenergy can be stored and transported.

The share of bioenergy in the global primary energy consumption is 10% as of 2014 and it is estimated that by 2050 world's primary energy consumption from biomass sources will be 15–50% [20,46]. Solid biomass is the main contributor in both global heat and electricity generation from biomass sources. Share of different types of biomass in heat and electricity generation is shown in Table 14.

Common biomass sources in Bangladesh are agricultural residue, wood residue, animal waste and municipal waste, etc. Agricultural resides are mainly collected from crops such as rice, wheat, sugarcane, maize and vegetables, etc. These residues can be directly collected from the land and some are collected after the processing of the crop for

Table 8
Monthly average wind speed (m/s) from seven station in Bangladesh.
Source: Ref. [50]

Month	Patenga[a]	Cox's Bazar[a]	Teknaf[a]	Noakhali[a]	Char Fassion[b,c]	Kuakata[a]	Kutubdia[a]
Jun '96	8.75	–	–	–	–	–	–
Jul '96	5.87	5.42	5.77	–	–	–	–
Aug '96	5.32	5.33	4.90	4.70	4.60, 5.20	5.70	–
Sep '96	3.36	3.69	3.46	2.94	2.80, 3.34	3.77	3.58
Oct '96	3.20	3.74	3.30	2.83	3.07, 3.70	2.18	3.98
Nov '96	2.61	2.93	2.29	1.91	–	1.98	3.23
Dec '96	2.97	1.78	1.44	1.35	2.38, 3.09	3.35	3.38
Jan '97	3.25	2.33	1.99	1.31	2.19, 2.80	3.18	3.67
Feb '97	2.66	1.99	1.90	1.90	2.02, 2.69	3.37	3.29
Mar '97	3.13	2.42	2.26	2.38	3.09, 3.54	4.85	3.53
Apr '97	2.88	1.84	1.65	2.25	2.28, 3.29	4.93	3.11
May '97	4.96	3.97	3.09	3.99	3.71, 4.81	6.28	4.89
Jun '97	5.83	4.64	3.26	5.00	4.42, 5.76	7.31	5.90
Jul '97	5.67	4.80	4.33	4.92	3.94, 5.22	7.34	6.17
Aug '97	5.13	4.31	4.03	3.85	4.01, 5.17	–	5.34
Sep '97	–	2.96	1.83	2.77	2.20, 3.08	–	3.94
Annual average	**3.95**	**3.34**	**2.94**	**2.96**	**3.21, 4.07**	**4.52**	**4.21**

[a] Wind speed was measured at 25 m height.
[b] Wind speed was measured at 10 m height.
[c] Wind speed was measured at 25 m height.

Table 9
Wind turbine installations by different government and non-government organizations.
Source: Ref. [60]

Organization	Location	Type	Installed capacity (kW)
Grameen Shakti	Grameen offices in the coastal region	3 Hybrid	4.5
	Cyclone shelter in the coastal region	Hybrid	7.5
BRAC	Coastal region	Stand-alone	0.9
	Coastal region	Hybrid	4.32
Bangladesh Army	Chittagong hill tracts	Stand-alone	0.4
IFRD	Teknaf	Stand-alone	1.1
	Meghnaghat	Stand-alone	0.6
LGED	Kuakata	Wind-PV hybrid	0.4
Total			**19.72**

Table 10
Hydropower global capacity and addition in 2014 in top six countries.
Source: Ref. [20]

Top countries by total capacity	Total at the end of 2014 GW	Added in 2014 GW
China	280	22
Brazil	89	3.3
United States	79	0.0
Canada	77	1.7
Russia	48	1.1
India	45	1.2
Top countries by addition		
China	280	22
Brazil	79	3.3
Canada	77	1.7
Turkey	24	1.4
India	45	1.2
Russia	48	1.1
World total	**1055**	**37**

Table 11
Potential small hydro power sites identified by BPDB and BWDB.
Source: Ref. [63]

Sl. No.	District	River/Stream	Potentiality of electrical energy (kW)
1	Chittagong	Faiz Lake	4
2	Chittagong	Choto Kumira	15
3	Chittagong	Hinguli Chara	12
4	Chittagong hill tracts	Sealock	81
5	Chittagong	Lungichara	10
6	Chittagong	Budichara	10
7	Sylhet	Nikhan Chara	26
8	Sylhet	MadhabChara	78
9	Sylhet	Banga Pani Gung	616
10	Jamalpur	Bhugai Kangsa	60 kW for 10 months 48 kW for 2 months
11	Jamalpur	Marisi	35 kW for 10 months 20 kW for 2 months
12	Dinajpur	Badul	24
13	Dinajpur	Chawai	32
14	Dinajpur	Talma	24
15	Dinajpur	Pathraj	32
16	Dinajpur	Tangon	48
17	Dinajpur	Punar haba	11
18	Rangpur	Bari khora	32
19	Rangpur	Ful kumar	48

Table 12
The potential of micro hydro power sites explored by SRE.
Source: Ref. [49]

Location	Expected power production (kW)
Nunchari Tholipara, Khagrachari	3
Chang-oo-Para, Bandarban	30
Bangchari, Bandarban	25
Liragaon, Bandarban	20
Kamalchar, Rangamati	20
Thang Khrue, Rangamati	30
Monjaipara, Bandarban	7.5
Total	**135.5**

Table 13
Average monthly flow and head at Mahamaya Chara.
Source: Ref. [50]

Month	Flow (m^3/s)	Head (m)
Jan	5.8	11.4
Feb	4.9	9.9
March	5.4	8.1
April	5.1	5.3
May	2.2	4.3
June	2.0	7.8
July	2.0	10.8
August	2.0	13.3
September	2.0	14.0
October	2.1	14.0
November	2.9	13.7
December	3.8	13.0

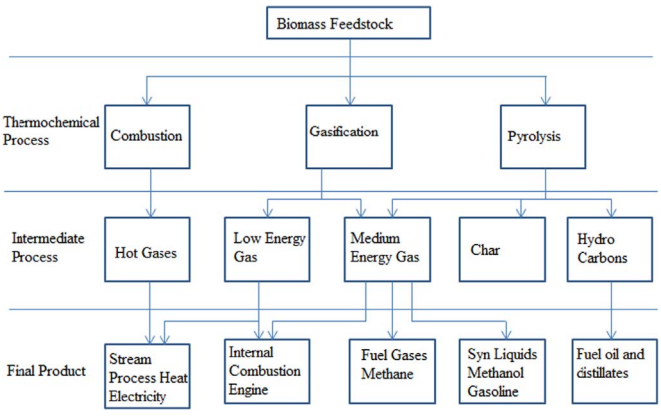

Fig. 10. Bio-power conversion processes for different end products.
Source: Ref. [5]

making of other food or products; known as field residue and process residue respectively [64–66]. In Bangladesh crop residues in the rural areas are mainly used for cooking purpose. 46% of the total bioenergy comes from rice husk, rice straw, sugarcane bagasse and jute sticks [67]. Rice is the major user of agricultural land in Bangladesh. Almost 76% of the agricultural lands are used for rice production and a total recoverable residue from this sector is found to be 58,503 ktons in fiscal year 2010–2011 (see Table 15). Wasted rice from restaurants can also be used for biogas production. In Bangladesh one project produced biogas with 69% methane using only wasted rice [68]. Sugarcane

Table 14
Share of biomass sources in global heat and electricity generation.
Source: Ref. [20]

Types of biomass	Heat generation	Electricity generation
Solid biomass	80%	75%
MSW (Municipal solid waste)	15%	15%
Biogas	4%	7%
Biofuel	1%	1%

bagasse and tops are good source of bioenergy. Recoverable sugarcane residue in FY (fiscal year) 2010–2011 was 2702 ktons (kilo-tons). Among the other agricultural crops jute has the higher potential in biomass production.

Use of animal manure reduces the bad odors from the environment and also works as a good source of energy. Cattle, goat, sheep and buffaloes are the main sources of animal manure. The amount of livestock and poultry are increasing with time and is estimated to be 50 and 263 million, respectively. Considering a manure generation rate 2.86 kg dry matter/cattle/day, 2.52 kg dry matter/buffalo/day, 0.55 kg dry matter/goat/day, 0.33 kg/sheep/day and 0.02 kg/poultry/day total recoverable residue are shown in Table 16.

Municipal solid waste and forest residues are also good sources of biomass energy. Also considering all other sources it is estimated that the total produced and recoverable biomass in Bangladesh are 182 and 108 million tons/year, respectively [70–73].

Agricultural residue, wood residue, animal waste and municipal waste can be used for generating electricity. In the years 2012–2013, biomass resources had a potential of generating 373.71 TWh power from 45.91 million tons of coal equivalent of biomass [74]. Table 17 represents the total biomass potential in Bangladesh for power generation in fiscal year 2012–2013.

There are around one hundred thousand rice mills all over the country [75]. Rice husk is a by-product of paddy processing that can be used to produce heat for the boilers to produce electricity. In 2011, the amount of rice husk produced was about 9.0 million tonnes [76]. Islam and Ahiduzaman [75] identified four potential zones - Dinajpur, Naogaon, Bogra and Ishawrdi (Pabna) for rice husk collection from the rice mills. The annual paddy processing capacity and amount of surplus husk were found to be 3.62 million tonnes and 455,356 tonnes, respectively [75]. Using rice husk the potential electricity generation capacities were estimated to be 41.45 MW and 29.05 MW in steam turbine plant and gasification plant, respectively [75]. Two rice husk gasification power plants (250 kW and 400 kW) financed by IDCOL [53] are already in operation.

Biogas and bio-fuels are the two main forms of energy derived from biomass sources. Biogas plants have seen to become popular in the rural areas of Bangladesh these days. Both animal manure and municipal solid wastes are good source of biogas. IDCOL has been working on biogas in Bangladesh since 2006 and till April 2014 along with its partner organizations IDCOL has installed a total of 33,000

Table 16
Generation and recoverable rates of animal products in Bangladesh.
Source: Ref. [69]

Residues	Generation ratio (kg dry matter/ capita/day)	Waste generation (ktons/year)	Waste recovery (ktons/ year)	Waste recovery percentage (%)
Animal waste				
Cattle	2.86	23,978.38	14,387.03	60
Buffalo	2.52	1195.74	717.44	59.99
Goat	0.55	4496.8	2698.08	60
Sheep	0.33	345.69	207.41	59.99
Subtotal		30,016.61	18,009.96	59.99
Poultry droppings	0.02	1917.12	958.56	50
Total		31,933.73	18,968.52	59.40

Table 17
Total biomass potential in Bangladesh.
Source: Ref. [74]

Source of biomass	Biomass generation (million tons)	Coal equivalent (million tons)	Electricity generation (TWh)
Agricultural residues	94.10	19.88	161.80
Forest residues	17.44	7.19	58.53
Livestock residues	88.89	15.58	126.81
MSW	13.38	3.26	26.57
Total	**213.81**	**45.91**	**373.71**

Table 15
Generation of recoverable rates of agricultural products in Bangladesh in fiscal year 2010–2011.
Source: Ref. [69]

Crops	Residues		Generation ratio (ktons/capita/day)	Residue generation (ktons/year)	Residue recovery (ktons/year)
	Field residue	Process residue			
Rice	Straw	–	1695	56852.17	19,898.26
	–	Husk	0.321	10,766.70	10,766.70
	–	Bran	0.83	27,839.11	27,839.11
Sugarcane	Tops	–	0.3	1401.40	490.50
	–	Bagasse	0.29	1354.70	1354.70
Wheat	Straw	–	1.75	1701.15	595.40
Jute	Stalks	–	3	25,157.52	8805.132
Maize	Stalks	–	2	2036.56	712.80
	–	Cobs	0.273	278	278
	–	Husks	0.2	203.65	203.65
Groundnut	Straw	–	2.3	123.43	43.20
	–	Husks	0.477	25.60	25.60
Cotton	–	Stalks	2.755	39.89	39.89
Vegetables	Residues	–	0.4	1224.73	428.65
Pulses	Residues	–	1.9	441.04	441.04
Coconut	–	Shells	0.12	39.11	39.11
	–	Husks	0.41	133.64	133.64
	Subtotal	–	–	88,938	31,427.62
	–	Subtotal	–	40,680.4	10,680.04
	Total	–	–	129,618.4	72,107.66

Table 18
Cogeneration plant capacity is sugar mills.
Source: Ref. [82]

Name of the mill	Annual operation (days)	Installed capacity (tons/day crushed)	Plant capacity (MW)	Electricity generation (MWh)
Panchagar	150	1016	2	2967
Thakurgan	148	1524	3	3878
Setabganj	114	1250	4	3838
Shyampur	138	1016	2	2897
Rangpur	131	1321	2.6	3879
Jaypurhat	136	2032	2.5	3586
Rajshahi	162	2000	3.5	5519
Natore	167	1500	4	5972
North Bengal	166	1500	2	4159
Kushtia	130	1524	3	3104
Carew	175	1150	3	3446
Mobarakganj	156	1500	2	1888
Faridpur	160	1016	2	299
Zeal Bangla	155	1016	2	3138
Total		**19,365**	**37.6**	**48,570**

biogas plants all over the country utilizing animal manure mainly [53]. This biogas is mainly used for cooking purpose. Hence, 80 million tons of firewood have been saved which costs almost USD 2 million. The fertilizers obtained from these plants replaced 28,000 tons of chemical fertilizer worth of USD 20 million. IDCOL is working on a plan to install 100,000 more biogas plants by 2018 [53]. On the other hand, production of biofuel is at the nascent stage in Bangladesh. Nitol motors, Bangladesh is working on producing biofuel from ethanol molasses [77]. However, Pongamia pinnata and Jatropha curcas can be used for production of biofuel since these are relatively cheap and has promising potential to be used for the production of biodiesel in the climate of Bangladesh [78,79]. Biofuels will be a good alternative for the fuels in transportation sector reducing greenhouse gas emission and also the price. Biomass briquette is a solid fuel produced from rice husk and used for cooking purpose in the rural areas of the country. Although the country has a potential to produce about 1 million tons of briquette [80], the yearly production is about 19,881 tonnes [81]. Sugarcane bagasse is a good source of power generation in Bangladesh as the country has many sugar mills. Fourteen cogeneration power plants are already installed in the sugar mills that can generate 48,570 kWh electricity [69]. Table 18 represents the electricity generation capacity in fourteen cogeneration plants using sugarcane bagasse as fuel.

3.5. Geothermal energy

Geothermal energy market is growing substantially. According to 2014 Annual U.S. & Global Geothermal Power Production Report, the installed capacity of geothermal power is 12,000 MW. United states is the largest producer of geothermal power with a capacity of 3.44 GW, followed by Philippines with 1.9 GW and Indonesia with 1.33 GW [83]. The geothermal power capacities of top eight countries are depicted in Fig. 11.

As there are few thermal gradient sites (see Table 19) in Bangladesh, geothermal energy can be used to generate electricity. But it requires in depth knowledge for the assessment of geothermal energy. The government and private sector should come forward to evaluate the potential of geothermal energy so that this resource can be utilized properly.

4. Future target for renewable energy development

Considering 30% of the total population who are yet to be taken under electrification facility and also the gradually increasing energy

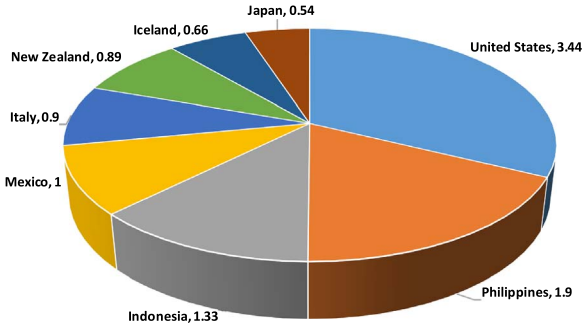

Fig. 11. Electric power capacity (GW) from geothermal energy of top eight countries.
Source: Ref. [83]

Table 19
Geothermal gradients at different locations in Bangladesh.
Source: Ref. [84]

Location	Depth (km)	Gradient (K/km)
Hazipur	3.816	30.9
Bakhrabad	12.837	25.0
Titas	13.758	30.1
Habigonj	13.509	31.6
Rashidpur	13.861	26.8
Biani Bazar	14.107	28.7
Kailas Tila	14.139	27.8
Sylhet	12.377	31.1
Chhatak	12.133	33.8
Semutang	14.088	30.3
Begamganj	13.656	31.7

demand, government has set a master plan to achieve 38,700 MW by 2030 [40]. This plan outlined reduced dependence on natural gas and increased use of coal and renewable energy. Current share of renewable energy is only 3.5%. The roadmap of production of electricity from renewable sources until 2021 is shown in Table 20. As part of this plan the government of Bangladesh is working on different renewable energy projects. For the national grid the government has initiated a 500 MW solar power development program [85]. This program will include construction of solar powered irrigation pump replacing diesel irrigation pump, construction of solar parks, solar mini grid power systems in remote villages, roof top solar power solution for commercial, industrial and residential buildings and electrification of health centers, educational institutions, E-centers at union level, religious institutions and railway stations. Out of this 500 MW, 340 MW will be used for commercial purpose and 160 MW will be used for social services. Sector wise distribution of 500 MW solar power is shown in Table 21.

It is estimated that completion of this 500 MW solar program will require 2.76 billion USD, out of which 2.23 billion USD is expected to come from development partners and the remaining will be arranged from the government and private sources [85].

With a view to generating 1370 MW of electricity from wind energy within 2021 Bangladesh government is assessing the availability of wind flow at several places of Bangladesh. Wind velocities at nine such places including the offshore areas of Bangladesh are being observed under “The Wind Resource Mapping Project” for the last couple of years to find out the potential of wind energy. Table 22 shows the latest update of wind data collection at various locations in Bangladesh. Based on the availability of wind velocity observed from the wind mapping project wind turbines will be installed commercially in the selected regions.

To be noted, wind speed data for one year at Mohuri Region of Feni and Mognamaghat of Chittagong have been collected under the wind mapping project and the government has already taken steps to build wind power plants of 30 MW and 60 MW at these two places,

Table 20
Renewable energy target (MW).
Source: Ref. [38]

Technology	2015	2016	2017	2018	2019	2020	2021	Total
Solar	222	253	421.75	237	195	203	208	**1739.8**
Wind	0	20	250	350	350	200	200	**1370**
Biomass	1	16	6	6	6	6	6	**47**
Biogas	1	1	1	1	1	1	1	**7**
Hydro		2	2	–	–	–	–	**4**
Total	**224**	**292**	**680.75**	**594**	**552**	**410**	**415**	**3167.8**

Table 21
Share of commercial and social projects.
Source: Ref. [85]

Sl. No.	Category	Types of project		Capacity (MW)
1.	Commercial solar power projects	Solar irrigation		150
2.		Solar mini grid		25
3.		Solar park		135
4.		Solar roof top	Residential and commercial	10
			Industrial	20
5.	Social solar power projects	Electrification of health centers, educational institutions, etc.		160
Total				**500**

Table 22
Locations under "The Wind Resource Mapping Project".

Sl. No.	Location	Tower height (m)	Latest update (till August 2016)
1.	Lalpur, Natore	80	24 months data collected
2.	Jafrabad, Chandpur	60	24 months data collected
3.	Inani Beach, Cox's Bazar	40–200	12 months data collected
4.	Sitakundu, Chittagong	80	20 months data collected
5.	Parki Beach, Chittagong	80	20 months data collected
6.	Badarganj, Rangpur	40–200	12 months data collected
7.	Gouripur, Mymensing	80	12 months data collected
8.	Madhupur Tea Garden, Habiganj	80	10 months data collected
9.	Dakope, Khulna	80	10 months data collected

respectively.

Recently SREPGen project, assisted by UNDP, undertook a biomass resource study in Bangladesh. We will have an idea on the potential of biomass in the country after the result of this study is published. On the other hand with the estimated total urban population of 78.44 million by 2025, the total municipal solid waste (MSW) generation is expected to reach 47,000 tons per day from 23,688 tons per day in 2014. Using landfill gas recovery process the electricity generated from MSW can be as much as 186,408 kWh/day [38]. Recently, the government has set initiatives to form a company to maintain the utilization of MSW of Dhaka and adjoining cities. SREDA is also piloting a project to setup a plant in Keraniganj Upazilla. There are no plans for geothermal power production right now because of low thermal gradient in Bangladesh.

The promotion and development of renewable energy will require the collaborative work of public and private sectors. Several public and private organizations are funding for the development of renewable energy sector. Hence it is expected that the energy scarcity will soon be mitigated with the completion of the projects that have been taken in action by different organizations.

5. Conclusions

Natural gas, refined petroleum products and coal are the main sources of energy supply in Bangladesh. Natural gas contributes a major portion of the total power generation followed by refined petroleum products (e.g., furnace oil and diesel). With the current reserve and the rate of consumption natural gas is expected to be dried out within the next 10–12 years [49,86]. Hence the diversification of source for power generation is required. Being a lower middle income country incorporation of renewable energy in the main energy supply will take time and strong initiatives. However, Bangladesh is now producing 3.5% of the total power generation from renewable sources. Solar home systems and biogas plants are getting popular among the people of the rural areas. IDCOL has already installed 3.6 million SHSs around the country of a total capacity of 150 MW [53]. A number of solar mini grid projects, roof-top solar PV systems, solar parks and solar irrigation systems are under construction by BPDB. To achieve the targeted 1739.75 MW from solar within 2021 the government of Bangladesh has already initiated large scale solar power development program. Wind mapping project is initiated to collect data for finding possible locations to install wind power plants of total 1370 MW. Although several river basin for example: Sangu, Matamuhuri, Brahmaputra, etc. have potential for hydroelectricity, no major hydro power plant installation is recently initiated. IDCOL and several other organizations such as LGED, Grameen Shakti, and some public and private organizations are working on the promotion and distribution of the renewable energy technologies in Bangladesh. More effort needs to be given in research, development and introduction of varying renewable energy technologies in the country in order to achieve the targeted renewable energy fraction in the electricity generation capacity. However, renewable energy is of great help in improving the energy growth and economy of the country and hopefully the share of renewables will increase in the near future and overcome the difficulties created by conventional resources on the environment.

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