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A Prospective Assessment of Biomass Energy Resources: Potential, Technologies and Challenges in Bangladesh

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Olden energy system only operated well when energy fuel was inexpensive and lavishly accessible, but absolutely does not produce affluence if the energy fuel becomes costly and scare. Bangladesh is passing by a cross road in its effort to struggle the present energy crisis and future energy need. Bangladesh has struggled in finding new energy sources for a long time. The extensive dependence on limited coal and gas has put the country under tremendous pressure. It is projected that with the rapid increase in population and industrialization the demand of energy will be doubled in 2050. Geologically it is impossible to connect by the grid line to the rivers, canals, island based off-grid area. Renewable resources has opened new door with ample opportunities for those off-grid areas by generating grid quality electricity. For thousands of years biomass has been overwhelming as associate degree energy supply by men. To ensure the optimal utilization there is the need to assess the existing biomass potential, technologies and challenges. The assessment is conducted by analyzing the accessible data from diverse consistent sources through the procedure of exact qualitative and quantitative to authenticate the results. This assessment evaluates the biomass energy potentiality which includes agricultural residues, forestry residues, animal dung, solid waste

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from municipalities, and the consumption pattern of biomass, practicing technologies, and challenges in Bangladesh. The assessed entire quantity of biomass source offered for energy in Bangladesh in 2017-2018 is 94.16 (million tons) with yearly energy potentiality of 47 (million tons) of coal equal. In 2017-2018, the retrievable quantity of biomass is 94.16 (million tons) which has associate energy potentiality of 1378 (PJ) that is comparable to 383 (TWh) of electricity.

Keywords: Biomass, Electricity, Technologies, Challenges.

1. INTRODUCTION

Accession to energy is vital for the economic progress of a country. Advanced echelons of financial development, attached through rising population and suburbanization have caused in an exceedingly important rise in mandate for energy. The affiliation among usage of energy and monetary progress has been a focus of more attention like energy is deliberated to be one of the key driving forces of financial progression in all economics [1]. The affiliation among economic progress and energy consumption rely on the structure of the economy [2]. In a typical developing country each 1% growth of GDP leads to an increase of 1.4% mandate of electricity. More electricity consumption is prerequisite to make higher growth in GDP. [3] With the intention of assure sustainable financial progress, an adequate quantity of energy source must be make sure [3]. In 2017, world's total primary energy consumption was about 13511.2 million tons of oil equivalent and electricity generation was about 25551.3 TWh [4]. Energy Consumption and Electricity Generation by Fuel in 2017 is shown in Table 1 Biomass energy is that the leading renewable supplier to worldwide final energy mandate, and supplying more or less 13% of the entire. Amongst the 13%, nearly 8% is used for food preparation and heating purpose and rest of the 5% is used for contemporary practice such as heat demand in residential area (4%), manufacturing purpose (6%), electricity production (2%) and transportation necessities (3%) [5]. Renewable energy contribution in different countries is shown in Table: 2. Global biofuel generation rose about 2.5% compared to 2016, reaching 143 billion litres (3.5 EJ) [5] According to Bangladesh Power Development Board the installed power generation capacity is 18454 MW, derated power generation capacity is 17911 MW out of which 444 MW is generated by coal-fired power plants, 9406 MW from gas power plants with 39.97% plant efficiency, 4490 MW from HFO with 39.89% plant efficiency, 2181 MW from HSD with 31.69% plant efficiency, 230 MW from hydro power stations, and 1160 MW are imported in 2019. [6,7] Present status of power sector in Bangladesh is shown in Table 3. According to SREDA, renewable energy contributes only 3.06% in total energy mix in the year of 2018, where only 0.40 MW off grid electricity from biomass and 0.58 MW off grid electricity from biogas was generated [8]. Power generation scenario in Bangladesh is shown in Table 4.

Table 1. Energy consumption and electricity generation by Fuel in 2017 [4]

Fuel	Primary energy consumption (millions of oil equivalent)	Electricity generation (TWh)
Oil	4621.9	883
Natural Gas	3156	5915.3
Coal	3731.5	9723.4
Nuclear Energy	596.4	2635.6
Hydro Electricity	918.6	4059.9

Table 2. Renewable energy contribution in different countries [5]

Country Name	Total renewable energy capacity(GW)	Bio power capacity(GW)	Per capita capacity (kilowatts per inhabitants)
China	334	14.9	0.2
United States	161	16.7	0.5
Germany	107	8	1.3
India	61	9.5	0.05
Japan	57	3.6	0.4
United Kingdom	38	6	0.6

Table 3. Present status of power sector in Bangladesh [6,7]

Fuel type	Installed capacity(MW)	Derated capacity(MW)	Plant efficiency (%)
Coal	524	444	-
Gas	9843	9406	39.97
HFO	4492	4490	39.89
HSD	2205	2181	31.69
Hydro	230	230	-
Imported	1160	1160	-
Total	18454	17911	-

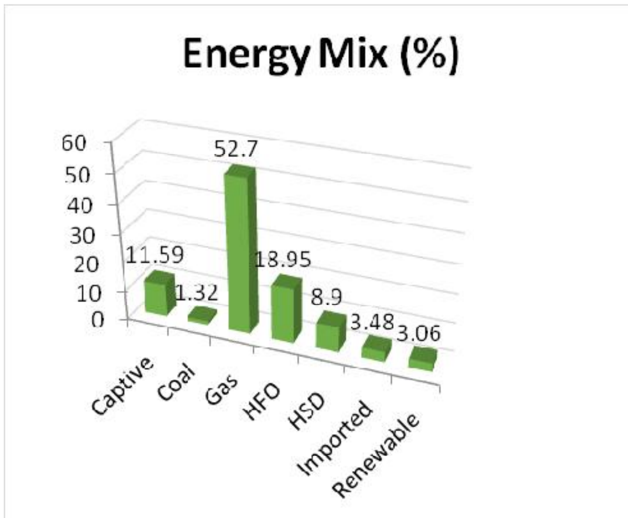

Fig. 1. Energy Mix (%) in 2018 in Bangladesh [8]

Table 4. Power Generation Scenario in 2018 [7,8,9]

Per capita generation (kWh)	Maximum demand (MW)	Maximum peak generation(MW)	Grid capacity electricity generation (%)	Load shedding (MkWh)	Electricity contribution to GDP growth (%)
464	14,014	10,958	58.4	32	0.17

According to SREDA, renewable energy adds only 3.06% in total energy mix in the year of 2018, where only 0.40 MW off grid electricity from biomass and 0.58 MW off grid electricity from biogas was produced [8]. Energy mix (%) in 2018 in Bangladesh is shown in Fig 1.

2. BIOMASS ENERGY

Biomass energy is one of the human's earliest sources of natural energy which is derived from plant and animal waste. Stored chemical energy in the plants and animals or in the wastes are converted into bio-energy. Chemical energy that stored in biomass comes from the sunlight, the process is known to be photosynthesis [10].The bio energy is reversal of photosynthesis, when the energy is released during burning of biomass, carbon is reoxidised to CO_2 to replace that which was absorbed while the plant is growing. In nature, all bioenergy decomposes to its elementary molecules with the release of heat, utilizing this energy recycles the carbon and doesn't add CO_2 to the atmosphere contrary to fossil petroleum. Usage of low emission fuels like biomass fuel is the one way of implementing the principles of sustainable development. [11,12] When burning biomass CO_2 and other pollutants are released that has been absorbed during the photosynthesis process carried out by new plants [13-15]. Emission index of fossil petroleum is several times higher comparative to the emission index of biomass fuels [16,17].The process parameters and the type of biomass fuel both are related to the emission that are generated during the combustion of biomass fuel [18-20]. Low cost and widespread distribution makes biomass fuel more popular compared to other fuel [21]. To reduce global warming and avoid dangerous climate change carbon sequestration which includes long term storage of CO_2 or other forms of carbon [22,23].

3. BIOMASS POTENTIAL IN BANGLADESH

Biomass includes agrarian residue, forestry residue, animal dung and municipal solid waste (msw) which is preferred as ecological energy with many benefits such as enormous resource capacity, lower expense, minimal percentage of sulfur and ash content and the feature of sustainability while it has likewise several negative features like greater moisture, lesser thermal output, and distributed source. By combining appropriate amount of biomass potential, native environments, usage of existing machinery, choice of a suitable practical method, implementation of innovative systems, expansion of new energy transformation techniques, and economic viability of biological system biomass resources can utilize effectively and efficiently to mitigate the energy crisis in the rural areas as well as the country. In rural areas of Bangladesh most commonly used biomass resources are Fuel wood, twings, leaves, bark, roots, branches, wood processing residues, dung cake, dung stick, rice straw and rice husk. Utilization pattern of biomass in Bangladesh is shown in Table 5.

3.1 Energy Potential and Recovery of Agricultural Residue

In Bangladesh, different types of crops cultivate plentifully due to fertile land and fortunate weather conditions. About 17% of GDP comes from agrarian sector. In Bangladesh agronomy area of different crops rice, wheat, maize, pulse, sugarcane, jute, tea, vegetables is respectively 74.85%, 2.92%, 2.20%, 2.44%, 0.65%, 4.46%, 0.39%, 2.64% [24]. Agricultural crops production in Bangladesh (10^5 t) in different fiscal year is shown in Table 6.

The agricultural crops production effects the residue production. Crops production (10^5t) in different fiscal year is shown in Fig 2. Agricultural crops generate a huge quantities of residues. Residue production rate (RPR) is a fraction which indicates production of residues for a particular crop. Considering the residue recovery factor the amount of recovered residue was estimated in wet basis. Crop residues include field residues as well as process residues. After harvesting field residues generally

Table 5. Different consumption pattern of biomass

Main Source	Residuum	Application
Rice	Rice Straw	Animal feed, fuel, animal bedding, housing material
	Rice Husk	Fuel, poultry bedding, mud plastering
Wheat	Wheat straw	Fuel, housing material
Jute	Jute stick	Fuel, housing material
Groundnut	Groundnut straw	Fuel, animal feed
Mustard	Mustard plant	Fuel
Vegetable	Vegetable plants	Fuel, animal feeding
Pulse	Pulse straw	Fuel, animal feed
Sugarcane	Sugarcane leafs	Fuel, animal feed
	Sugarcane bagasse	Fuel
Maize	Maize husk	Fuel
	Maize leaf and straw	Fuel, animal feed
Forest	Leaves, twings, and branches	Fuel, fencing
	Wood	Furniture, fuel
	Wood residue	Fuel
Animal waste	Cow dung	Manure, fuel
	Poultry excreta	Manure
	Goat feces	Manure
	Buffalo dung	Manure, fuel
	Cattle bedding material	Compost
Solid Waste	Industrial waste	Recycling, fuel
	Kitchen waste	Manure, animal feed

left in the field, local climate and soil condition effects the percentage of field residues of a particular crop, local climate and soil condition effects the percentage of field residues of a particular crop. During crop processing, process residues are generated and procurable at a central processing [33-35]. Field residues have only 35% of recovery factor while process residues have 100% of recovery factor [36,34]. The calorific value of the husks varies with the crops variety [37]. The quantity of residues have been estimated by relating a residual factor from numerous studies for various agrarian crops [38-44]. Proximate and ultimate analysis of agricultural residues imply the percentage of different element like volatile solids, ash content, fixed carbon, hydrogen, nitrogen, oxygen, Sulphur, high heating value which allude the combustible properties of residues [45,46]. Proximate and ultimate analysis of agricultural residues is shown in Table 7. It was estimated that 1 kg of rice husk equivalents to 0.33 kg of fuel oil or 0.5 kg of coal [47] while one kWh of electricity can be generated by burning 1.86 kg of rice husk. [48] Energy potentiality from different agrarian residue in 2017-2018 is shown in Table 8.

In 2017-2018, it is assessed that entire volume of retrievable agrarian residues (wet) in Bangladesh was approximately 45.17 million tons which consists of 65.5% field residues as well as 34.5% process residues. Dry amount of crop residues are estimated by considering the moisture content of each crop. Net recoverable residue was about 38.94 million tons which consists of 65.7% field residue and 34.3% process residue. It is estimated that 618.37 PJ of energy can be recovered from agricultural residues which includes 406.67 PJ from field residue and 211.7 PJ from process residues.

Table 6. Annual agricultural crops production in Bangladesh (10^5 t) [24]

Crops	2015-2016	2016-2017	2017-2018
Rice	347.10	338.04	362.79
Wheat	13.48	13.11	10.98
Maize	24.45	30.26	32.88
Sugarcane	42.07	38.62	36.39
Jute	13.71	14.96	16.13
Pulse	3.77	3.87	3.89
Coconut	3.74	4.09	4.67
Groundnut	0.62	0.66	0.67
Vegetable	181.46	193.32	187.47
Cotton	0.059	0.056	0.056
Tea	0.64	0.82	0.78
Tobacco	0.88	0.91	0.89
Total	631.98	638.7	657.60

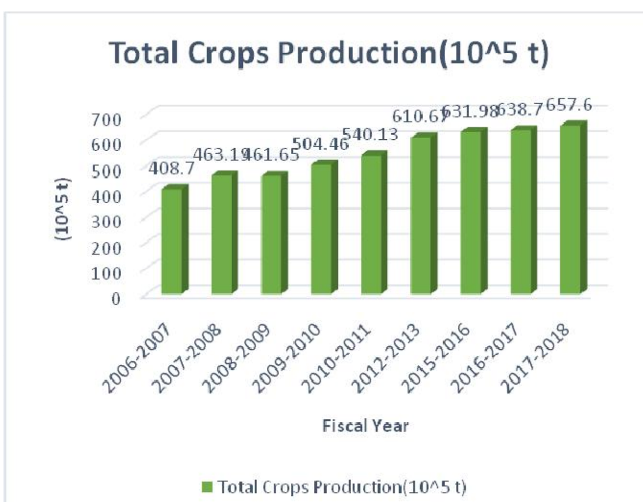

Fig. 2. Total crops production (10^5t) [25-32]

Table 7. Proximate and ultimate analysis of agricultural residues [45,46]

Volatile solids (%)	Ash (%)	Fixed carbon (%)	Carbon (%)	Hydrogen (%)	Nitrogen (%)	Oxygen (%)	Sulphur (%)	High heating value (MJ/kg)
61.2-76.05	0.47-20.49	14-24	38-50	6	0.19-1.78	30-43	0.05-0.38	14.66-20.58

Table 8-a. Energy potential of agricultural residue (Field Residues)

Crops	Total Crops Production in 2017-2018 Metric ton(10^3t)	Field Residues	Residue Production Ratio(RPR)	Residues generation (10^3t)	Residues recovery (10^3t)	Moisture%	Dry residues (10^3t)	Lower calorific value (GJ/ton)	Energy content (PJ)
Rice	36279	Rice Straw	1.695 [49]	61492.905	21522.52	12.7[49]	18789.16	16.30[49]	306.26
Wheat	1098	Wheat Straw	1.75 [50]	1921.5	672.53	7.5[51]	622.09	15.76[51]	9.8
Maize	3288	Maize Stalks	2 [50]	6576	2301.6	12[51]	2025.4	14.70[51]	29.8
Sugarcane	3639	Sugarcane leafs	0.3 [50]	1091.7	382.095	50[52]	191.048	15.81[50]	3.02
Jute	1613	Jute Stalks	3 [50]	4841.5	1694.5	9.5[51]	1533.52	16.91[51]	25.93
Pulse	389	Pulse Residues	1.9 [51]	739.1	258.685	20[51]	206.95	12.80[51]	2.65
Vegetable	18747	Vegetable Residues	0.4[51]	7498.8	2624.58	20[51]	2099.6	13[51]	27.3
Tobacco	89	Tobacco Stalks	2*	178	62.3	8.9[53]	56.76	17.70[53]	1
Cotton	5.624	Cotton Stalks	2.755 [50]	15.4	5.39	12[51]	4.74	16.40[51]	0.08
Groundnut	67	Groundnut Straw	2.3 [50]	154.1	53.935	12.1[52]	47.4	17.58[52]	0.83
Total	65214.6								**406.67**

**consider RPR is 2 for Tobacco*

Table 8-b. Energy potential of agricultural residue (Process Residues)

Process Residues	Residue Production Ratio(RPR)	Residues generation(10^3t)	Moisture %	Dry residues(10^3t)	Lower calorific value (GJ/ton)	Energy content(PJ)
Rice Husks	0.267[49]	9686.5	12.4[49]	8485.4	16.3[49]	138.31
Rice Bran	0.083[49]	3011.2	9[51]	2740.2	13.97[50]	38.28
Maize Cob	0.273[50]	897.624	15[51]	762.98	14.00[51]	10.7
Maize Husks	0.2[50]	657.6	11.1[52]	584.60	17.27[51]	10.09
Sugarcane Bagasse	0.29[50]	1055.31	49[49]	538.20	18.10[50]	9.74
Groundnut Husks	0.477[50]	31.96	8.2[52]	29.34	15.66[52]	0.46
Coconut Shells	0.12[50]	56.04	8[51]	51.6	18.53[50]	0.956
Coconut Husks	0.41[50]	191.47	11[51]	170.40	18.53[50]	3.157
Total						**211.7**

Total Energy Recovered= 406.67+211.7=618.37 PJ which equivalents to 171.8 TWh electricity

Table 9. Waste production rate in different season [69]

Major Sources	Waste generation rate in dry season (kg/unit/day)	Waste generation rate in wet season (kg/unit/day)	Waste generation rate in winter season (kg/capita/day)	Waste generation rate in rainy season (kg/capita/day)
Residential Solid Waste	1.38	2.05	0.28	0.37
Commercial Solid Waste	4.57	5.65	0.36	0.594
Institutional Solid Waste	8.50	11.90	0.145	0.2
Municipal Service Solid Waste	334	436	0.104	0.136
Industrial Waste	237	275	0.235	0.305
Medical Waste	30.50	35.50	0.53	0.66

Table 10. Proximate and Ultimate analysis of wastes. [73-75]

Volatile solids (%)	Ash residues (%)	Moisture content (%)	Bulk density (kg/m^3)	Gain size (mm)	pH	Carbon (%)	Hydrogen (%)	Oxygen (%)	Nitrogen (%)	Sulphur (%)
43-71	29-57	56-70	550-1125	2-220	7.7-8.7	43-50	6	36-45	0.2-3.5	0.01

Table 11. Generation and energy potential of MSW in Bangladesh

Region	Population (million)	Waste generation (kg/capita/day)	million ton/year	Waste recovery (million ton/year)	Moisture content (%)	Dry recovered waste million ton/year	Lower calorific value (GJ/ton)	Energy content (PJ)
Urban	50.42	0.45	8.3	5.8	45	3.16	14.0	44.24
Rural	117.65	0.15	6.44	4.51	45	2.48	14.0	34.72
	168.07[85]		**14.74**	**10.31**		**5.64**		**Total= 78.96**

3.2 Energy Potential and Recovery from MSW

Due to rapid urbanization and population growth, 522 urban centers which including 311 municipalities and 9 city corporation in Bangladesh generates a huge amount of municipal solid waste (MSW) daily which includes organic matter, paper, plastic, textile, wood, leather, rubber, metal, glass, industrial waste that creates an adverse effect on environment. It has been estimated that municipal solid waste generation rates in the major cities are 0.40-0.55 kg/capita/day in Dhaka city corporation (DCC), 0.30-0.45 kg/capita/day in Chittagong city corporation (CCC), 0.30-0.40 kg/capita/day in Khulna city corporation (KCC), 0.25-0.35 kg/capita/day in Rajshahi city corporation (RCC), 0.20-0.25 kg/capita/day in Barishal city corporation (BCC), 0.35-0.45 kg/capita/day in Sylhet city corporation (SCC) with the total waste collection rate of 35% in Bangladesh [54,55]. Around 8000 tons of solid waste is generating from six major city corporation among them 70% of waste is generating from Dhaka city which includes commercial (19.7%), residential (78.1%), industrial (1.2%), street sweeping (0.6%), and others (0.5%) in Bangladesh [54,56,57]. Around 45-55% of the total waste from DCC remain unmanaged and dumped in open space [58]. It was estimated that about 100 MW of electricity with 40% of plant efficiency can be generated from the MSW produced in Dhaka city. [59,60] Another study showed that around 76% of waste produced from residential area, 22% of waste produced from commercial area, and 1% produced from institutional [56,61]. The waste production rate was 0.49 (kg/capita/day), 0.5 (kg/capita/day), 0.5 (kg/capita/day) in the year of 1991, 2001, 2004 respectively [62,63]. Per capita waste generation (kg/day) from high socio economic, middle upper socio economic, middle socio economic, middle lower socio economic, low socio economic are 0.392(kg/day), 0.343 (kg/day), 0.312 (kg/day), 0.275 (kg/day), 0.222 (kg/day), 0.309 (kg/day), 0.070 (kg/day) respectively. Generation of different categories of waste from organic matter, paper, plastic, textiles and wood, leather and rubber, metal, glass, others are 5409 kg/day, 792 kg/day, 303 kg/day, 163 kg/day, 95 kg/day, 148 kg/day,58 kg/day, 722 kg/day respectively [56]. It has been estimated that different waste material have different recycling rate like plastic, paper, glass, and others have 83%, 65%, 52%, 95% respectively [64]. MSW consists of organic waste (67%) which contains high moisture about 62% and nonorganic waste (33%) contains low moisture content [54,65]. In urban and semi urban areas of developing countries exponential growth of MSW depends on Socio economic condition, standard of living, rate of urbanization, geographical condition, waste collection frequency and climate condition [66,67,68]. Waste generation rate in wet season was found to be greater compared to dry season as well as the generation rate was found 500 g per capita per day in wet season while the generation rate was found 340 g per capita per day in dry season [64]. Waste production rate in different season is shown in Table 9.

In rainy season the bulk of waste comprises extra weight than in the dry season due to presence of extra moisture in organic and perishable wastes [70,71]. Waste Generation in Different Season in different cities is shown in Fig. 3. Quantity and quality of the wastes are two significant parameter that determines the potentiality of energy retrieval from wastes. Quality of the wastes can be determined by analyzing proximate and ultimate analysis which describes the percentage of different elements contained by waste like volatile solids, ash residues, moisture content, bulk density, gain size, pH, carbon, hydrogen, oxygen, nitrogen, Sulphur, lower calorific value [72-75]. Proximate and Ultimate analysis of wastes is shown in Table 10. It has been showed that lower calorific value of MSW ranges from 2303 to 3559 KJ/kg is not suitable for combustion [64].

Without considering the subsequent environmental damage about 95% of MSW is dumped either in land, rivers, or even sea. [76] Landfilling is responsible for ground water contamination though it is cost effective [77]. By reducing the waste volume up to 90% thermal treatment may be the solution of solid waste disposal and can generate electricity. [78] In developed countries most common waste to energy practice is landfill methane capture via incineration or gasification of solid waste to mitigate GHG emission [79,80]. Landfill gas is one of the sustainable bio resources which consists of 50-55% of CH_4 and 40-45% of CO_2. It is estimated that about 60% of methane gas can be recovered by landfill gas collection system from municipal solid waste with 50% municipal solid waste collection efficiency [81-84]. Generation and energy potential of MSW in Bangladesh in 2017-2018 is shown in Table 11.

Total population of Bangladesh is about 168.07 million [85]. Considering 30% people lives in urban area and 70% people lives in rural area. Several research have found that the percentage of waste production in municipal and countryside area is 0.45 kg/capita/day [86] and 0.15 kg/capita/day [36] individually [36]. In 2017-2018, the assessed quantity was 10.31 million tons by considering 70% retrieval rate. By considering moisture percentage as 45% as well as lower calorific value as 14.0 GJ/ton individually entire energy potentiality in 2017-2018 was calculated approximately 78.96 PJ [36].

3.3 Energy potential and recovery from livestock

Bangladesh has a large number of livestock potential. Contribution of livestock in GDP was 1.54% and GDP growth rate of livestock was about 3.40% in 2017-2018. [87] Therefore total livestock is estimated about 561.07 million head in the fiscal year 2017-2018. Livestock in Bangladesh (million head) in different fiscal year is shown in Table 12. Manure generation from livestock depends on the size of body, type of feed and level of nutrition of the livestock. [88] Manure yield for cattle, buffalo, and goat was estimated as 5-10 kg/animal/day, 8-12 kg/animal/day, 0.25-0.50 kg/animal/day respectively. The feces generation was considered as 0.1 kg/poultry/day for chickens and ducks. Excreta generation was considered as 0.09 kg/human/day based on dry matter. [89] About 100%, 50% and 60% recovery rate has been considered for human excreta, poultry droppings and animal waste respectively. [36, 89, 90] The moisture content of animal waste and poultry droppings has been considered about 40% and 50% respectively. [88] Total energy potential from livestock is shown in Table 13.

Table 12. Livestock in Bangladesh (million head) [87]

Livestock species	2014-2015	2015-2016	2016-2017	2017-2018
Cattle	23.6	23.8	23.9	24.0
Buffalo	1.46	1.47	1.48	1.49
Sheep	3.27	3.3	3.4	3.5
Goat	25.6	25.7	25.9	26.1
Total Ruminant	53.97	54.4	54.7	55.1
Chicken	261.8	268.4	275.1	282.1
Duck	50.5	52.2	54.0	55.8
Total Poultry	312.3	320.6	329.2	337.9
Total Livestock	**366.27**	**374.9**	**383.9**	**393.1**

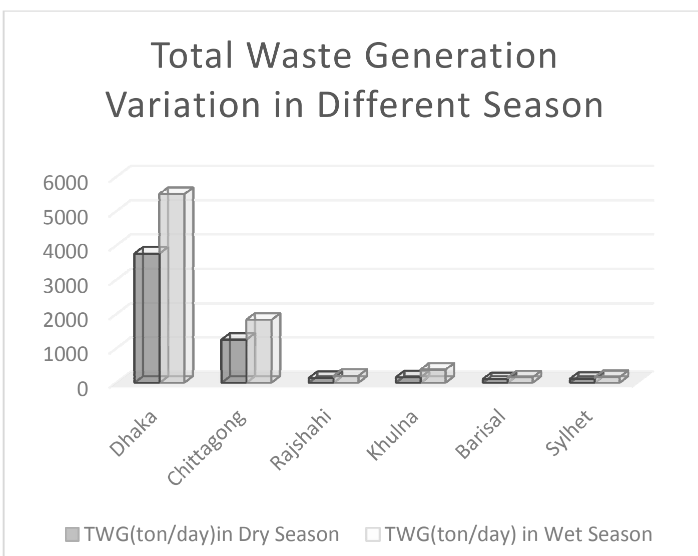

Fig. 3. Total Waste Generation in Different Season. [71]

Table 13. Energy potentiality from livestock

Livestock	Head (million)	Residues generation (tons/year)	Residues recovery (tons/year)	Moisture (%)	Dry residue recovery (tons/year)	Lower calorific value (GJ/ton)	Energy content (PJ)
Cattle	24	65700000					
Buffalo	1.49	5438500					
Sheep	3.5	479062.5					
Goat	26.1	3572437.5					
Total Ruminant	55.1	75190000	45114000	40	27068400	13.86 [91]	375.168
Chicken	282.1	10296650					
Duck	55.8	2036700					
Total Poultry	337.9	12333350	6166675	50	3083337.5	13.50 [90]	41.62
Human	168.07	5521099.5	5521099.5		5521099.5	10.60 [36]	58.52
Total	561.07	93044449.5	56801774.5		35672837		475.31

Table 14. Energy potentiality of forestry residue in Bangladesh

Wood Products	Quantity (1000m^3)	Quantity (million tons)	Moisture content (%)	Net amount (million tons)	Lower calorific Value (GJ/ton)	Energy content (PJ)
Wood Fuel	26256 [95]	14.96	20[49]	11.96	15[36]	179.4
Tree Residues		1.821[96]		1.821	12.52[96]	22.79
Wood Residues	284[95]	0.162	20[49]	0.129	18[36]	2.322
Total		**16.94**		**13.91**		**204.5**

In 2017-2018, total dry residues retrieval is assessed approximately 35.67 million tons that equal to 475.31 PJ which comprises 375.168 PJ, 41.62 PJ, 58.52 PJ from ruminant residue, poultry residue, and human residue respectively.

3.4 Energy Potential and Recovery from Forest Biomass

Forest biomass includes wood-fuel, tree residues which consists of twings, leaves, bark, roots, and wood processing residues consists saw dust, plywood dust, veneer log dust etc. Logging residues contain a high moisture content which consists of branches, leaves, lops, tops, damaged or unwanted stem wood. Recovery rate of forest residue depends on local condition. It has been estimated the retrieval rate of 66% with 34% being residues including of stamps, branches, leaves, and saw dust. Recovery rate of sawmill residues was estimated 50% with 38% solid waste and 12% saw dust. Recovery rate of plywood residue was estimated 50% with 45% solid wood residues and 5% sawdust. [92] Bangladesh has about 2.6 million hectors of forest land area which is almost 18% of total land area. Per capita fuel wood consumption and timber consumption rate is 0.0654 m^3 and 0.01076 m^3 respectively which are very low compared to other developing countries. [93] In 2005, it was estimated that the production of fuel wood was 27.66 million m^3 and per head wood fuel consumption proportion was 0.18 m^3. [94] In 2016, production of wood fuel including charcoal was about 26.256 million m^3 and production of wood residue was about 0.284 million m^3 [95]. In 2017-2018, total forest biomass was estimated about 16.94 million tons considering mass density of 0.57 t/m^3. In the fiscal year of 2017-2018, entire retrievable energy potentiality was assessed about 204.5 PJ by Considering 100% recovery rate of forest biomass [36], 20% moisture content of wood fuel, wood processing residues [49] and lower calorific value of each residues [36,96]. Energy potential of forest residue in Bangladesh in 2017-2018 is shown in Table 14. Energy potential of forest residue in Bangladesh in different year is shown in Table 15.

Burning of biomass releases a certain level of CO_2, CO, CH_4. Emission from biomass combustion varies from fuel to fuel and the technology that is practicing to burn the fuel [97]. Emission from Biofuel Combustion in ASIA (Tg pollutant/yr) is shown in Table 16. Emission released for biofuel burning in traditional cook stoves (gm pollutant/kg dry matter) is shown in Table 20.

Table 15. Energy potential of forest residue in Bangladesh in different year

Year	Energy content from wood fuel (PJ)	Energy content from tree residues (PJ)	Energy content from wood residues (PJ)	Total Energy Content (PJ)
2013	183.3[95]	22.79	2.322	208.41
2014	182.25[95]	22.79	2.322	207.36
2015	181.2[95]	22.79	2.322	206.31
2016	179.4[95]	22.79	2.322	204.5

Table 16. Emission from Biofuel Combustion in ASIA (Tg pollutant/yr) [97]

Sources	Biofuels (Tg DM)	CO_2	CO	CH_4	NOx*
Fuel Wood	753	1105	53	3.39	0.75
Crop Residues	465	554	40	2.14	0.33
Dung	123	124	7	0.33	0.30
Total	1341	1783	100	5.86	1.38

**Unit: Tg N/year for NOx*

Table 17. Assessment of biomass in Bangladesh in 2017-2018

Sources of biomass	Generation of biomass (million tons)	Dry biomass recovery (million tons)	Energy content (PJ)	Electricity generation (TWh)	Coal equivalent (million ton)	Gas equivalent (BCM)
Agricultural Residues	100.9	38.94	618.37	171.8	21.11	15.63
Forest Residue	16.94	13.91	204.5	56.82	6.98	5.16
Livestock Residues	93.04	35.67	475.31	132.06	16.23	12.01
MSW	14.74	5.64	78.96	22	2.7	2.0
Total	224.81	94.16	1378	383	47	35

Table 18. Assessment of biomass in some Asian Countries

Name of the country	Energy potentiality(PJ)	Generation of electricity(TWh)	Coal equivalent (million ton)	Gas equivalent (BCM)
Bangladesh	1378	383	47	35
India	8764.00[98]	2435.08	299.11	221.53
Sri lanka	141.80[99]	39.40	4.84	3.58
china	8899.80[100]	2472.81	303.75	224.96
Thailand	821.40[101]	228.23	28.03	20.76
Philippine	968.70[102]	269.15	33.06	24.49

Table 19. Biomass energy potential in Bangladesh in 2012-2013 and 2017-2018

Fiscal year	Energy potential(PJ)	Electricity Generation(TWh)	Coal equivalent (million ton)	Gas equivalent (BCM)
2017-2018	1378	383	47	35
2012-2013	1344.99[103]	373.77[103]	45.91[103]	34.01[103]

4. TECHNOLOGIES AND CHALLENGES RELATED TO BIOMASS IN BANGLADESH

Most common used technology to extract the biomass energy in rural areas is traditional cooking stove which releases extensive amount of gases such as CO, CO_2, CH_4 and other particulates [97]. Emission factors for different biofuel Combustion in simple cook stoves (gm pollutant/kg dry matter) is shown in Table 20. Technology practice in Bangladesh and related challenges are described in this section.

4.1 Biogas Plant

Biogas is a kind of natural gas which can be extracted from organic matter by the anaerobic digestion. By the chromatographic test it was found that biogas consists 40-70% of methane (CH_4), 30-60% of carbon dioxide (CO_2), 1.5% of supplementary gases by volume [104] and fluctuating quantities of water (H2O) with numerous trace gases like hydrogen sulphide (H_2S), nitrogen (N_2), and ammonia (NH_3), carbon monoxide (CO) [105]. It has been estimated that per kg of cattle dung, poultry droppings and human excreta can produce 40l, 70l, and 50l of biogas respectively. [106].Another study show that 0.037 m^3 of biogas can produce from 1 kg of cattle dung. [37] It has been estimated that 6 kWh of electrical energy is available in 1 m^3 of biogas which equals to 0.5 liter of diesel oil and 5.5 kg of fuel wood [106]. Yearly about 4.7t of carbon dioxide emissions can be saved by an average small-scale biogas. [107] Bangladesh has about 215000 poultry farms and 15000 cattle farms which produce a huge amount of manure daily and it has been assessed that approximately 2000 MW of electricity can be produced from these vast waste. There are three types of biogas plant use in Bangladesh fixed-dome, floating dome and bag type, among them fixed-dome biogas plant is most popular due to some advantage over floating dome and bag type biogas plant. Comparison between fixed dome And floating dome Plant is shown in Table 21 Different size of biogas plant with investment, amount of ingredients, burning hour in Bangladesh is shown in Table 22.

4.1.1 Ingredients

Several study and research had find out the explanations behind the poor performance of the biogas plant in Bangladesh. The reasons are: slow hydrolysis rate of complex organic matter, Technical problem, constructional problem, location selection failure, lack of proper knowledge to design a biogas plant, lack of social awareness, environmental failure. Study show that smaller biogas plant is more effective and efficient than larger biogas plant. [109] Maximum biogas production in different size of biogas plant is shown in Table 23. Organic recycling rate in Bangladesh is so poor comparative to other developed and developing country [110]. Financial viability of biogas plant has also an impact of biogas production. [111] Waste for biogas production can be categorize into two type like predigest and non-predigest. Predigest ingredients like animal manure and human excreta needs short time to generate biogas compared to non-predigest ingredients like water hyacinth, agricultural waste, and municipal solid waste. Poultry waste needs some refinement due to presence of sand, sawdust, and husk. It has been estimated that poultry waste contains a high amount of ammonia which leads to reduction of biogas production. C/N ratio is one of the leading factor in the process of anaerobic digestion, 20:30-1 is good for anaerobic digestion. It had been found that C/N ratio of cow dung is 24:1 while C/N ratio of poultry is 20:1. [112]

Table 20. Emission released for biofuel burning in traditional cook stoves (gm pollutant/kg dry matter) [97]

Sources	C%	CO_2	CO	CH_4	NOx*
Fuel wood	44.5-45.6	1520	69.2	5.06	1.19
Dung	33.4	1010	60	17	-
Crop Residues(Mix)	34.8-40.3	1130	86	4.6	0.70

**Units: gms N for NOx*

Table 21. Comparison between fixed dome and floating dome Plant [108]

Fixed-dome Plant	Floating dome plant
Low initial costs, maintenance cost.	Higher material costs, maintenance cost.
Long useful span life.	Shorter span life compare to fixed dome.
Fluctuating gas pressure.	Constant gas pressure.
Temperature doesn't changes inside the digester.	Sometime the temperature fluctuates.
The volume of stored gas is not directly visible.	The volume of stored gas is directly visible.

Table 22. Different size of biogas plant with investment, amount of ingredients, burning hour in Bangladesh [109]

Volume of plant(m^3)	Investment(Taka) approximately	Amount of ingredients(cow dung (kg) or no of chicken	No of stoves	Burning hour(Hour)
1.2	22000	30 kg or 200 chicken waste	1	3
1.6	26000	40 kg or 250 chicken waste	1	4
2	32000	50 kg or 300 chicken waste	1	5
2.4	36000	60 kg or 400 chicken waste	1	6
3.2	43000	80 kg or 500 chicken waste	1	8
4.8	52000	120 kg or 700 chicken waste	1	More than 10

4.1.2 Financial analysis of biogas plant

Economic viability of a biogas plant is most important to get the proper efficiency. The following terms are used to find out the economic viability of biogas plant. Financial viability of biogas plant increases with the size of plant size [111]. Financial analysis for different plant size is shown in Table 24.

4.1.3 Common Technical problem of biogas production in Bangladesh [111]

- Problems with gas burner.
- Slurry in pipeline.
- Clogging of pipeline with condensed water.
- Difficulties with main gas valves.
- Problems with mixture machine.
- Cracks with dome and digester.
- Broken turret.
- Crack in outlet walls.
- Problems with slurry flow because the plant was too deep.
- Incorrect levels of inlet, outlet, and hydraulic chamber.
- Gas leakages through pipeline and low gas production during winter months espacially in the months of november to february were the main problems.
- As Bangladesh is a riverine and flood affected country this is one of the challenging issue to select the proper location and introduces flood resistant biogas models. [112]

Table 23. Maximum biogas production in different size of biogas plant [109]

Biogas plant size (m^3)	Maximum production of biogas (m^3)	Production as % of plant size
1.6	1.3	81.25
2	1.46	73
2.4	1.63	67.92
3.2	2.11	65.94
4.8	2.6	54.17

4.1.4 Upgrading of biogas

Fuel that are used in vehicle, grid and industrial rich in energy density, contains marginal amount of CO_2, huge amount of hydrocarbons other than methane while biogas contains low energy density due to the presence of high levels of CO_2, H_2S, O_2, N_2, H_2O and particulates. [113]. These unwanted elements create the problem of corrosion and mechanical wear of the equipment in which biogas is used that's why natural gas is to be injected in the grid rather than using the biogas. To achieve that energy density to use in grid biogas need some special treatment which includes the separation of CO_2, H_2S, O_2, N_2, H_2O and increase the concentration of CH_4 content in biogas called upgrading of biogas. Different upgrading technology is used by different countries and upgraded biogas is used as vehicle and grid fuel in different countries. [113] In Bangladesh, biogas is mainly used for heating purpose like cooking but it has a higher potential to produce the electricity. Only methane has the heating value rest of the elements of biogas doesn't have any heating value. 1 m^3 of biogas has the heating value of 22.1 MJ/m^3 which equivalents to 0.7 m^3 of natural gas, 0.45 m^3 of propane gas while 1 kWh of electricity has the heating value of 3.6 MJ/kWh which equivalents to 0.2 m^3 of biogas, 0.1 m^3 of natural gas and 0.07 m^3 of propane gas. [114] In Bangladesh, some poultry and dairy farm are using the natural gas generator to produce electricity from biogas without any pretreatment of the biogas like H_2O, H_2S, CO_2 removing mechanism. It has been estimated that H_2S presence in biogas from poultry waste were found from 0.30 %(3000 ppm) to 0.8 %(8000ppm) where the tolerable limit of H_2S in natural gas were found 4 ppm. [114]The excess amount of H_2S combine with the H_2O of the biogas and forms sulphuric acids or sulphurous that causes the metal erosion and may lead to the failure of the system. Excess amount of CO_2 in biogas decreases the air fuel ratio of the engine which requires more biogas for the same thermal input of the system and limits the air flow in the engine reduces the maximum output of the engine. In Bangladesh H_2S and H_2O removal unit is rarely used to upgrade the biogas. [114].

4.2 Gasification Plant

During a gasification process synthesis gas (syngas) is produced from biomass in a gasifier under a measured quantity of air. Gasification process, gasifying element, and the feedstock composition has an effect over syngas composition. [115] Syngas can be utilized to produce power, heat, and electricity through internal ignition engine or in a cogeneration system. [37] By using thermochemical conversion process solid biomass fuel (wood, rice husk etc.) can be converted into a combustible gas called producer gas which consists of CO, H_2, CH_4, CO_2, and N_2. [37] The combustible producer gas is a low calorific value gas which is 5.4-5.7 MJ/m^3. [116]. This combustible producer gas either can be used in a diesel engine together with small fraction of diesel in a duel fuel mode [117-120] To get the optimum power output producer gas prerequisites to be accompanied by diesel. To get optimum output a 300 kW duel fuel generator should have the producer gas to diesel ratio is 70:30. [37] Existing fuel quality (size, moisture, as well as ash content), capacity range and gas quality condition are the key factor to select a suitable gasification technology [115]. It has been showed that small scale biomass gasification based power plant, downdraft gasifier is more suitable. [121,122] With little treatment down draft gasifier can be used directly in the internal combustion engine which produces very small amount of tar. Rice Husk Gasification Plant in Bangladesh is shown in Table 25.

Table 24-a. Financial analysis for plant (2 cum)

Plant Size(2 Cum)	Utilization factor	IRR	BCR	Financial viability
	85%	Above 15%		Financially viable
If investment is increased by 10%		IRR=7%	BCR<1	Not financially viable

Table 24-b. Financial analysis for plant (3 cum)

Plant Size(3 Cum)	Utilization factor	IRR	BCR	Financial viability
	70%	Above 11%		Financially viable
If investment is increased by 10%		IRR=5%	BCR<1	Not financially viable
If investment is increased by 10%	80%	IRR=16%	BCR>1	Financially viable

Table 24-c. Financial analysis for plant (4 cum)

Plant Size(4 Cum)	Utilization factor	IRR	BCR	Financial viability
	65%	Above 11%		Financially viable
If investment is increased by 10%		IRR=4%	BCR<1	Not financially viable
If investment is increased by 10%	70%	IRR=10%	BCR>1	Financially viable

Table 24-d. Financial analysis for plant (6 cum)

Plant Size(6 Cum)	Utilization factor	IRR	BCR	Financial viability
	65%			Financially viable
		IRR=12%	BCR<1	Not financially viable

Table 25. Rice Husk Gasification Plant in Bangladesh [123]

Plant Capacity (kw)	Location	Project cost (million BDT)	Organization
250	Kapasia, Gazipur	25.0	IDCOL
200	Dinajpur	-	LGED
400	Thakurgaon	64.25	IDCOL

Table 26. Briquetting machine in different region in Bangladesh

Greater District	No. of Machines	No.of Foreign Machine
Sylhet	248[132]	15
Khulna	174[35]	2
Chittagong	135	
Rajshahi	268	
Barishal	32	
Dhaka	47	
Total	**904**	**17**

Table 27. Some popular ICS practice in Bangladesh. [136]

ICS Type	Effective Fuel	Reasons of being popular
Grate-less portable single stove	Fuel Wood	Different types of fuel like leaves, agri-residues, twings, cow dung, wood can be used in ICS.
Grate-less fixed double stove with chimney	Fuel Wood	Reduction in smoke emission and less time to cook.
Portable single stove with filter plate	Fuel Wood	Can be shifted during rainy season.
Fixed single stove with filter plate	Fuel Wood	Different types of fuel like leaves, agri-residues, twings, cow dung, wood can be used in ICS.
Portable single stove with filter plate	Fuel Wood	No extra land to spare for cooking purpose.

4.3 Biomass Briquetting

It is a solid compact with compaction ratio alternated from 2.5:1 to 6:1 even more [124]. In the developing countries the most widely used densification process is screw extrusion system known as heated die screw press briquetting. The bulk density of raw material rice husk can be raised from 117.0 kg/m^3 to 825.4 kg/m^3 after densification. It was estimated that 0.942 million metric ton of rice husk briquette fuel can be produced from 1.0462 million metric ton of rice husk which equivalents to 0.493 million ton of coal [125].

Biomass briquetting has the following advantages: [126-130]

- Higher calorific value compared to traditional biomass.
- Comfort of carrying, storing and residual dumping.
- Provide identical form.
- Diminish inside air contamination.

Briquette made by BRRI with a efficiency of 20% from rice husk. The making cost of briquetting is BDT 1.75 per kg. [131] Though Bangladesh has enormous bio-residues that are enough to run more than 1800 briquetting machines, only 1000 heated-die type machines are operating [128]. Briquetting machine in different region in Bangladesh is shown in Table 26.

4.4 Improved Cooking Stoves (ICS)

Due to burning of biomass a substantial amount of GHG is released to the troposphere like CO_2, CH_4, and other gases. Carbon dioxide release (kg/kg fuel) from rice husk bituminous coal, and natural gas is 1.49, 2.46, and 1.93 respectively. [103] In traditional stoves due to incomplete combustion of biomass and large distance between the pot and the fuel bed, heat transfer to the cooking pot is very low and appreciable quantities of irritants, toxins, and carcinogens are released in the kitchen environment [133]. Annually approximately twenty lakh people die impulsively from illness provenance to internal air contagion, 44% deaths are due to pneumonia, 54% deaths are due to chronic obstruction pulmonary disease, and 2% deaths from lung cancer [134]. Most of the households used stored wood, wood branches, bamboo pieces, dried cow dung in rainy season and agricultural residues in winter or summer seasons [135]. Inefficient or traditional cook stoves contribute to deforestation and global climate change [133]. Improved cooking stoves can mitigate all the challenging issues of traditional cooking stoves. It provides the following advantages:

- Higher fuel proficiency [136].
- Saves 50-70% fuels compared to traditional stoves. [136]
- Saves cooking times 40-50%.
- Less blacking of the cooking utensils.
- Saves around 22 million tons of traditional fuel per year [133].
- Minimize the black carbon emission to the environment [133].

In Bangladesh a number of models of ICS was developed by Institute of Fuel Research and Development (IFRD). A different types of ICS have been designed and advanced which comprise of immobile and moveable type, metallic and clay, single and multiport, with chimney and without chimney, with grate and without grate etc. [136]. Some popular ICS practice in Bangladesh is shown in Table 27.

4.4.1 Challenges of ICS [136]

- Availability and cost of firewood.
- All fixed type of ICS would not be suitable for all areas and households.
- In case of watery fuel wood produces lot of smoke.
- Selection of suitable ICS depends on availability of fuels, energy savings, and reduction of smoke, cooking habits.

5. CHALLENGES OF BIO POWER IN BANGLADESH

Socio-economic contribution and availability of commercial energy has an impact on biomass consumption pattern. [137,138]. It has been showed that about 90% of carbon emission can be reduced from biomass fuel with compared to the fossil fuel [139]. Besides biomass energy ensures the economic viability and energy security by reducing the dependency on fossil fuel. To utilize this energy in a large scale there are also some challenges that are categorize below:

- 80% of biomass in countryside areas is consumed for domestic cooking rather than using it to generate electricity [140].
- Residues from forest are mostly used for cooking purpose.
- Dung cake as well as dung stick from animal manure are usually used for rural cooking.
- Power supply related specific legal framework is absent.
- In urban areas there is building restrictions based on height, aesthetics, noise or safety [141].
- Favorable transmission access to renewable energy producers may not be allowed by utilities or high prices for transmission access may be charged.
- Perceptions of more technical hazard than for conventional energy resources due to familiarity with new technologies [142].
- Specific land for growing biomass for electricity generation is impossible. Proper management of biomass resources is required to mitigate this problem.
- About 100,000 rice mills and 15 sugar mills are scattered all over the country which leads to inefficient use of residues from these mills. [143]
- In rural area, biomass plant should be set up where the biomass energy resources are available which will reduce the transportation cost, availability of manpower and ensure the energy security from being wasted.

- Complex arrangement of strategy and regulation for support a new technology. [143].
- The CO level in the flue gas was produced by burning rice husk with primitive boiler was found more than 10000 ppm that was more than that of industrial air standard 5000 ppm [144].
- In rural areas lack of cost effective infrastructure model for electricity providers with minimum impact on the existing infrastructure [145].
- Another challenges is creating of pellet in easy and cost effective way [145].
- Antiqued biomass conversion technology have used in Bangladesh which are less efficient and have high level of pollutant.
- The criterion for choosing the conversion technology should be at least 35% efficiency with minimum investment risk and maximum financial returns [146].

6. CONCLUSION

In rural areas in Bangladesh Biomass is considered as a main energy source. Effectual use of the energy resource can be used for the betterment of rural areas by providing electricity. It has been assessed that the entire yearly generation of biomass, and dry retrievable rates, in 2017-2018 were 224.81 and 94.16 million tons individually. Recoverable energy content has been estimated to 1378 PJ which equivalents to 383 TWh of electricity and 35.0 BCM of gas equivalent. Agricultural residues and livestock residues keep the subservient in dry biomass potential as 41.35% and 37.8% respectively. The huge measure of biomass can be utilized for decentralized power age in rustic zones however more than 80% of agricultural residues and livestock residues are used for cooking purpose in rural area. Lack of social awareness, lack of proper management of waste to energy, antiqued technology, technical failure, location selection failure, constructional failure and environmental issue, lack of knowledge about economic viability of new technology, complex policy and regulation are the remarkable barriers to utilize the biomass energy to electricity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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