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Research paper

Assessing the energy dynamics of Pakistan: Prospects of biomass energy

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ABSTRACT

The energy needs of Pakistan have increased many folds in recent years due to improved lifestyle, ever-increasing population, and economic development. Biomass energy has emerged as a promising renewable energy source and has an enormous potential to fulfill the energy requirements of the country. This paper aims to assess the current situation and future projections of electricity generation by using biomass energy resources. For this purpose, we critically reviewed extensive literature i.e., research papers, energy reports, official statistical data, relevant regulations, and government policies. Research findings reveal that the abundant biomass resources of the country include fuelwood, agricultural residues, animal dung, and municipal solid waste. 48% of the domestic energy needs are being fulfilled from fuelwood, while another 32% by crop and animal residues. 85 sugar industries of the country produce enough bagasse to generate 5800 GWh of electricity. Corn stalk, sugarcane trash, rice straw, wheat straw, and cotton stalks are the major crop residues having a production of 6.43, 8.94, 17.86, 35.6, and 50.6 Mt, respectively. The power generation potential from animal dung is 4800–5600 MW. Similarly, the electricity generation potential of municipal solid waste by thermochemical and biochemical conversion is 560 kWh/t and 220 kWh/t, respectively. As envisioned by the Pakistani government to enhance the share of renewables in the total energy mix of the country from 1.1% to 5% by 2030, biomass energy has high prospects to achieve this target.

1. Introduction

In terms of population, Pakistan is the 6th largest country of the world having 213 M population with an annual growth rate of 2%. Out of this, 37% live in urban areas, while a significant portion (63%) resides in rural regions (Pakistan Economic Survey, 2018-19). Pakistan is located between the latitudes 24^0 and 37^0 north and longitude 62^0 and 75^0 east (Irfan et al., 2019a). Energy demand has increased tremendously due to recent economic development and ever-increasing population. The country still relies on conventional thermal sources for electricity generation. However, these sources can no longer be relied on as primary energy choice due to high prices and adverse environmental impacts. The government of Pakistan is looking for cost-effective, clean and alternative energy sources to tackle the prevailing energy crises and keep track of the current economy. In 2018, renewable energy contributed 1.1% to the total energy mix of the country. However, the government plans to increase its share by 5% until 2030 (Iqbal et al., 2018).

Out of many renewable energy technologies, biomass energy is considered as a promising and true alternative energy option. Agriculture is the major profession of Pakistani people which not only offers employment opportunities to 38.5% of its population but also contributes 18.5% to the gross domestic product (GDP) of the country. In an agricultural country like Pakistan, biomass has massive potential for energy generation and can reduce the elevated power demand–supply gap (Javed et al., 2016).

Biomass has been the primary energy generation source since primitive times. The consumption of biomass energy dates to ancient times. Even in the modern age, biomass has been serving as the dominant fuel source for household purposes in many developing countries (Kumar et al., 2015). Current research is

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in progress to find more efficient ways of biomass energy consumption and numerous scientific experiments have been done in this regard to get maximum benefits from this energy source without damaging the environment. Biomass energy is of prime importance for energy-deficit developing countries due to less capital investment, minimum energy production cost, accessibility of its resources all over the year and stipulation of enormous employment opportunities. Owing to these facts, biomass energy has the maximum weight priority of 0.318 compared with other renewable technologies (Amer and Daim, 2011).

Sweden is the world leader in biomass energy generation. In terms of per capita GDP, Sweden is one of the most prosperous countries. The government of Sweden has a plan to increase the share of biomass energy up to 40% by 2020 (Johansson et al., 2004). Due to efficient government policies, the utilization of biomass energy mounted to 483 Petajoule (PJ) in the country, fulfilling 23% of the national electricity needs (Ericsson and Werner, 2016). Nepal, a South Asian country set an excellent example by installing 25 M domestic biogas plants under the Biogas Support Program with technical assistance provided by the Netherlands Development Organization and ranked 3rd in the world. This support program not only saves 1.8 M liters of kerosene oil, 0.5 Mt of fuelwood but also replace 446,700 t of chemical fertilizers annually (Kamaladi, 2014). Nepal is followed by Vietnam by having installed 12 M biogas plants (Surendra et al., 2011). It was reported that the potential of biomass energy in Vietnam is 1,450 MW, and it is generating 9,230 GWh of annual electricity in the country (Kolhe and Khot, 2015).

Rwanda, Tanzania, and Kenya have installed 12,600, 12,200 and 8500 biogas plants respectively and performed well in the African continent (Horváth et al., 2016). According to the International Energy Agency (IEA), China has a total installed biomass power capacity of 1800 MW (IEA, 2019). Meanwhile, India has the potential of 840 Mt of biomass/y (Joshi et al., 2013). At the end of 2016, India has installed 72,000 biogas plants throughout the country. The figure jumped to 4.46 M biogas plants by 2017, indicating a massive growth in this sector. The total renewable energy capacity has reached to 117,919 MW during 2019, out of which the share of biomass energy is 8.69% (IRENA, 2019).

Similarly, Sudan consumes 13.8 M m^3 of biomass every year (Omer, 2016). The share of biomass in the total energy consumption of Germany is 8% (Brosowski et al., 2016). Globally, biomass is fulfilling 4.1% of the energy requirements of the world (REN21, 2019).

There is a potential of 15 M biogas power plants in Pakistan (PCRET, 2010a). Sindh was the first province to install a biogas power plant in 1959. Later, 22 more such plants were installed by the Pakistan Council of Appropriate Technology (PCAT) in 1974. 1300 new biogas plants were commissioned to be installed under the Biogas Support Program (BSP) by 2000. Soon, this number increased to 12,000 (Zvinavashe et al., 2011).

National Institute of Silicon Technology (NIST) and Pakistan Council of Appropriate Technology (PCAT) were merged in 2001 to maximum deploy renewable energy in Pakistan. Later, the name was changed to the Pakistan Council of Renewable Energy Technologies (PCERET) (Amjid et al., 2011). The government of Pakistan established AEDB in 2003 to encourage, facilitate and promote renewable energy technologies in the country. According to the long-term plan of AEDB, 5% of the total energy demand of the country will be fulfilled from renewable energy sources by 2030 (AEDB, 2016). 14,500 biogas plants will be installed by the Rural Support Program Network (RSPN) until 2018. A New Zealand aided biogas power plant with a generation capacity of 30 MW is recently completed in Karachi (Sheikh, 2010).

2. Energy situation in Pakistan

The energy mix of Pakistan is mainly dependent on fossil fuels, and they will continue to be the major energy source (Irfan et al., 2019b). Fig. 1 compares the price trend of different fossil fuels for the year 2018–19 (OGRA, 2018), while Fig. 2 shows the prices of natural gas for the last six years (OGRA, 2014–2019). A comparison of the value and quantity of imported petroleum crude and their respective prices from 2015–2019 have been depicted in Fig. 3 (Pakistan Economic Survey, 2015-16, 2016-17, 2017-18, 2018-19). Oil and gas are generating 61% of Pakistan's electricity. These conventional sources not only costly but at the same time, threatening the environment. On the other hand, renewable energy's share in total energy generation is merely 1.1% (Pakistan Economic Survey, 2018-19).

Pakistan is confronting severe energy crises and it becomes more obvious during the summer season when the power outages prolonged in urban areas for 6–8 h and in rural areas for 12–16 h (Ghafoor and Munir, 2015). Less priority to renewable sources for energy generation, inefficient use of coal and hydro resources and lack of awareness are the main reasons for energy crises (Mirza et al., 2007, 2009; Butt et al., 2013). Per capita electricity consumption has increased from 500 kWh to 960 kWh during 2012–2018 in the country. Due to an increase in per capita electricity consumption, there is a massive shortage of electricity in the country. In the past, the power demand–supply gap has increased tremendously and reached a historic peak of 6,620 MW during 2012 (NEPRA, 2017). Fig. 4 shows the power demand–supply situation of Pakistan from the period of 2012–18 (Irfan et al., 2019a).

Pakistan Board of Investment reported that the total installed capacity of electricity generation is 25,374 MW. However, actual generation ranges from 20,000–24,000 MW and peak electricity demand reach 23,000–25,000 MW (Tajwar, 2011). Projections of electricity demand and supply from a period of 2010–2030 have been shown in Fig. 5. It is evident from Fig. 5 that energy demand is continuously increasing with an annual growth rate of 5%–7%. The green curve represents the projection of electricity supply if energy projects under the China–Pakistan Economic Corridor (CPEC) program complete on time (Iqbal et al., 2018).

Compressed Natural Gas (CNG), an alternative to diesel and petrol is also in deficit. There is a shortfall of 220 M cubic feet in Khyber Pakhtunkhwa (KPK) and Punjab provinces/d. Federal Petroleum Ministry revealed that the gas shortage has increased to 38% of the total demand in the country (Dost, 2016). Out of 3400 CNG stations, 1600 stations have been shut down due to excessive gas shortage. In 2012, 3.4 M CNG supported vehicles were compromised, as the government announced to supply gas to power plants and fertilizer industries on a priority basis (Santana, 2012).

The immense power demand–supply gap has led the government of Pakistan to import costly oil. A substantial national budget has been allocated for this purpose which not only worsened the financial condition of the country but also forced the National Electric and Power Authority (NEPRA) to increase electricity prices. All sectors have been affected severely, especially Pakistan's premier textile industry. It has been reported that 50%–60% of the textile industry has shifted to China and Bangladesh (Khan, 2013).

2.1. Energy mix

The electricity installed capacity (in GW/h) from different sources has been shown in Table 1 from the period of 2008–2018 (Pakistan Economic Survey, 2018-19). As evident from the table, thermal energy is the primary electricity generation source of the

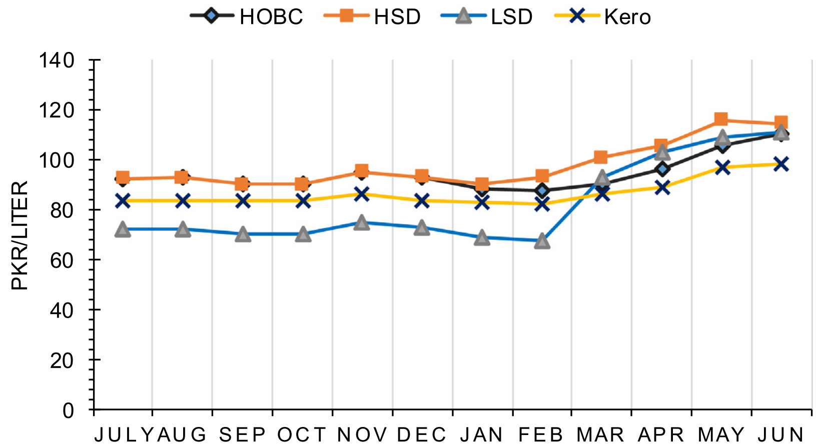

Fig. 1. Comparison of the price trend of different petroleum products for the year 2018–19 (OGRA, 2018). **Notes: HOBC:** High octane blending component, **HSD**: High-speed diesel, **LSD:** Light speed diesel, **Kero:** Kerosene oil.

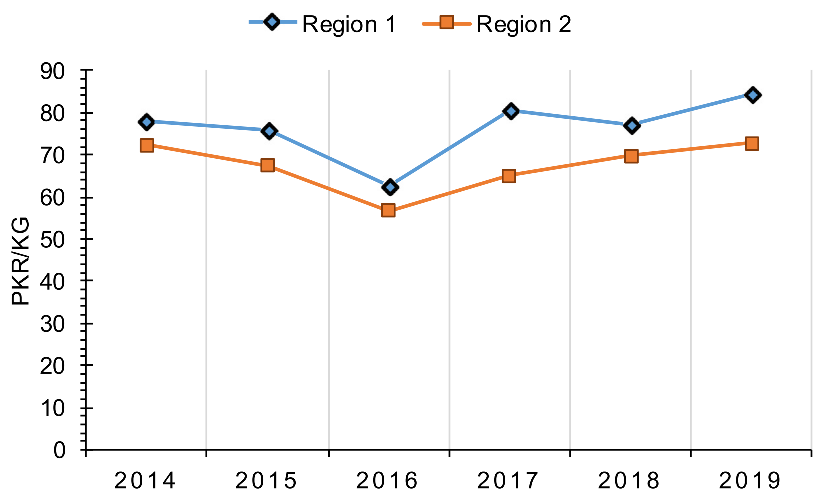

Fig. 2. Prices of natural gas from 2014–2019 (OGRA, 2014, 2015, 2016, 2017, 2018, 2019). Region 1 consists of Baluchistan, Khyber Pakhtunkhwa, and Potohar (Rawalpindi, Islamabad, and Gujarkhan). Region 2 consists of Punjab and Sindh.

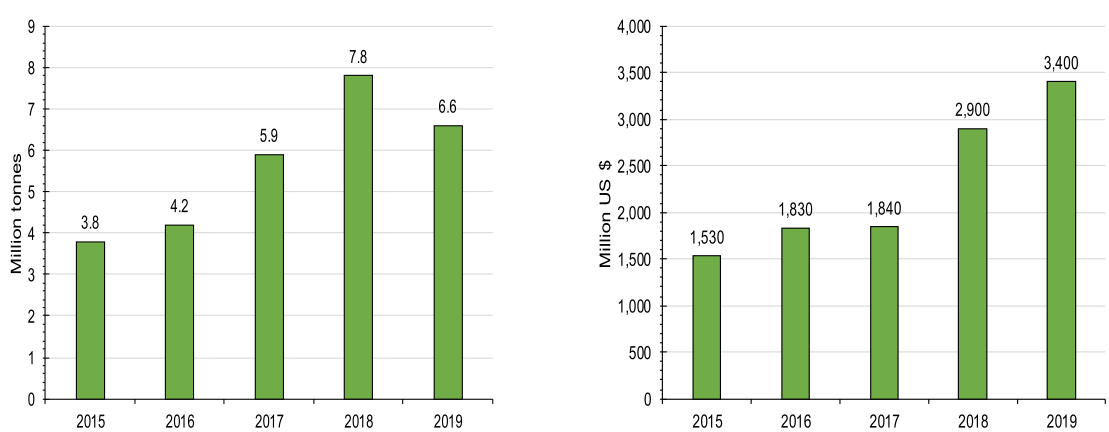

Fig. 3. Value and quantity comparison of the imported petroleum crude from 2015–2019 (Pakistan Economic Survey, 2015-16, 2016-17, 2017-18, 2018-19).

country, while the share of renewables in the total energy mix is negligible. The import of expensive oil has even deteriorated the fragile economic condition of the country (Tajwar, 2011; Aziz and Abdulaziz, 2010). Therefore, the government of Pakistan has started giving priority to renewable energy sources (Irfan et al., 2019c). In the long run, the Pakistani government has the plan to uplift renewable energy's share to 30% until 2030 (WWEA, 2019). Fig. 6 illustrates the thermal energy generation by fuel from the period of 2011–2017 (NEPRA, 2017).

2.2. Electricity consumption situation

Fig. 7 shows sector-wise electricity consumption from 2012–2018. It is depicted in Fig. 7 that there is an increasing energy

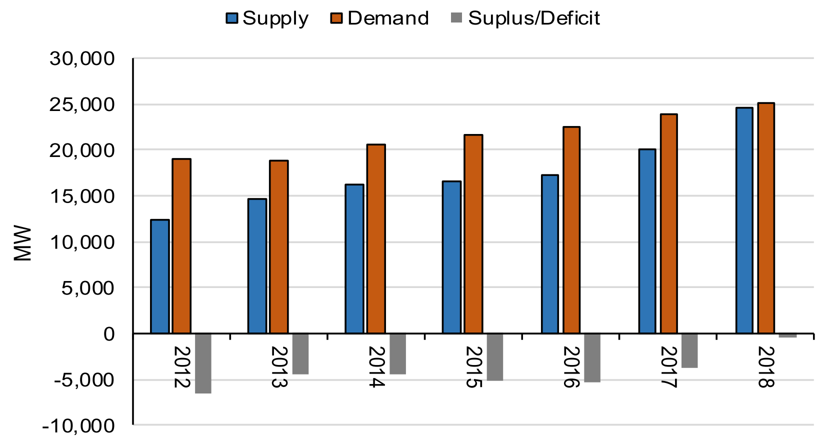

Fig. 4. Trend of power demand–supply in Pakistan from 2012–18 (Irfan et al., 2019a).

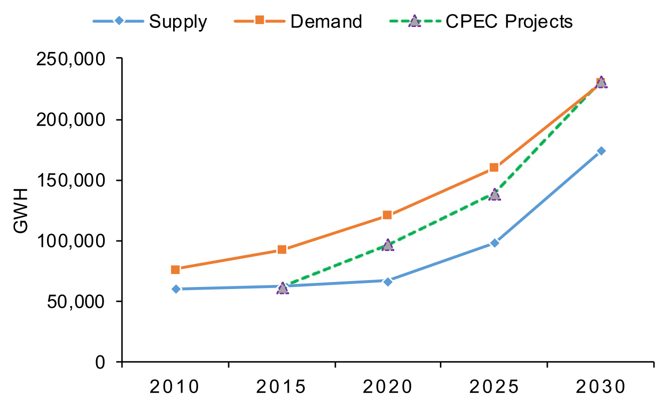

Fig. 5. Projected demand–supply situation in Pakistan from 2010–2030 (Iqbal et al., 2018).

consumption trend in all sectors of life. Electricity consumption increased from 76,789 GWh in 2012 to 106,927 GWh in 2018. At the same time, air quality has deteriorated due to overdependence on thermal energy. Thermal power plants, industrial units and the increasing number of vehicles are responsible for air pollution in Pakistan (Pakistan Economic Survey, 2018-19). According to World Health Organization (WHO), the intensity of suspended particulate matter was seven times higher than the recommended value in the four big cities of the country and this is increasing continuously (ADB, 2008).

3. Research source information

In this study, the data for analysis purpose has taken from different sources, including Pakistan Economic Survey, Pakistan Council of Renewable Energy Technologies (PCRET), Federal Bureau of Statistics, National Electric Power Regulatory Authority (NEPRA), Water and Power Development Authority (WAPDA), World Bank, Alternative Energy and Development Board (AEDB), Oil and Gas Regularity Authority (OGRA), International Renewable Energy Agency (IRENA), Renewables REN21, Food and Agriculture Organization of the United Nations, published articles, research journals, books and some online data.

4. Biomass potential in Pakistan

Biomass is considered as an environmentally friendly and safe electricity generation source (Irfan et al., 2019d). Different resources of biomass, including crop residues and animal dung, have the propensity to generate bioenergy with fewer emissions of greenhouse gases. The total installed capacity of biomass energy has reached 130 GW globally (REN21, 2019). As 63% of the Pakistani population resides in rural areas, the highest share of biomass consumption is occupied by the household sector i.e., 76% (Pakistan Economic Survey, 2018-19). Animal waste, forest residues, agricultural residues, and municipal solid waste are the potential biomass resources that are being used for energy generation in Pakistan. Collectively, all these resources generate 230 billion t of biomass every year (Iqbal et al., 2018). Animal and agricultural waste resources have the potential of 652 M kg manure, 230,000 t agricultural residues and 60,000 t solid waste per day (Uddin et al., 2016; Khan and Latif, 2010). With efficient biochemical and thermochemical ways, these biomass resources can be modified into valuable products. Biomass is regarded as highly suitable for energy generation due to its important fuel product properties (Kamran, 2018).

Compared with fossil fuels, carbon and other emissions released from biomass resources are generally low in quantity (Ramachandra et al., 2004), but not always and depends on several factors such as type of biomass resources, how the fuel is produced and transported to target areas (Deborah et al., 2015). For instance, emissions produced during the generation of electricity by using Short Rotation Coppice (SRC) chips are 35 to 85% less than a combined cycle gas turbine power station, whereas 35% more by utilizing straw in some cases. Similarly, emissions savings could reduce between 15%–50% by transporting biomass fuels over long distances (Bates et al., 2009). Formerly, it was believed that all biomass energy is carbon neutral if it based on sustainable yield. However, in recent debates, researchers have revealed that a large amount of carbon is released during the burning of biomass which is reabsorbed by plants in their later

Table 1
Electricity installed capacity from different sources (Pakistan Economic Survey, 2018-19).

Fiscal year	Thermal	Hydroelectric	Nuclear	Imported	Renewable	Total generation
2008–09	62,214	27,784	1,618	227	–	91,843
2009–10	64,371	28,093	2,894	249	–	95,607
2010–11	59,153	31,811	3,420	269	–	94,653
2011–12	61,308	28,517	5,265	274	–	95,364
2012–13	61,711	29,857	4,553	375	–	96,496
2013–14	66,707	31,873	5,090	419	–	104,089
2014–15	58,635	32,563	4,996	443	803	96,997
2015–16	61,448	34,272	3,854	463	1,549	101,123
2016–17	66,468	31,786	5,868	496	2,937	107,059
2017–18	79,849	28,239	8,720	556	3,907	120,715

Notes: All values are in GW/h.

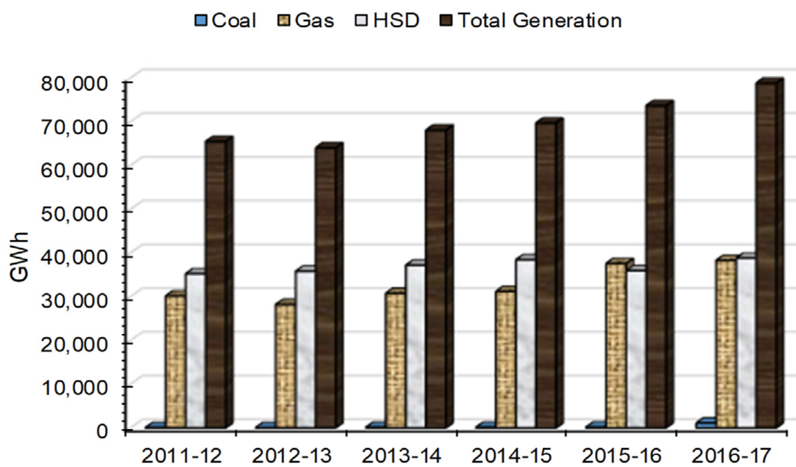

Fig. 6. Thermal electricity generation by fuel from 2011–2017 (NEPRA, 2017).

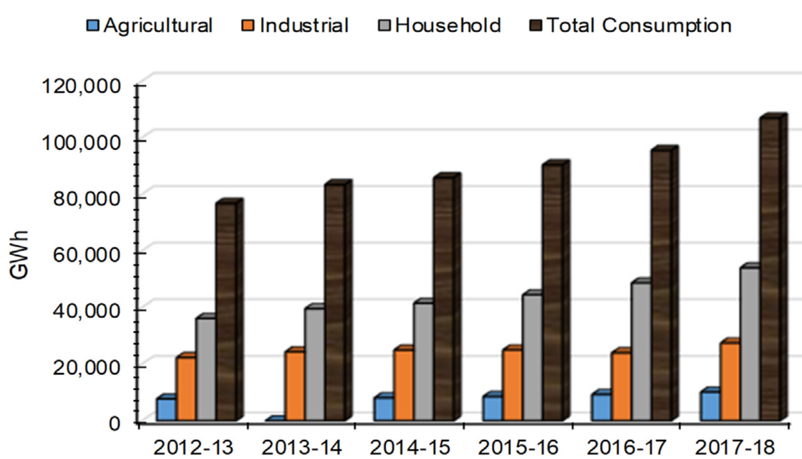

Fig. 7. Sector-wise electricity consumption from 2012–2018 (Pakistan Economic Survey, 2018-19).

growth. The amount of time plants needed to absorb carbon more than it would have been emitted by fossil fuels is termed as carbon payback. Plants continue carbon sequestration after payback and produce carbon dividend. Therefore, biomass energy has an edge over fossil fuels in this regard. (Timmons et al., 2016). Major carbon emissions released during harvesting, production, and energy conversion processes of biomass resources (account for more than 90%), while transport processes cause minor emissions (Rafael et al., 2015). In another study, it was revealed that on a lifecycle basis, coal-fired power plants have the maximum greenhouse gas (GHG) emission intensities among different electricity generation sources, whereas biomass energy has significantly lower emissions (WNA, 2011). Fig. 8 compares the GHG emissions from fossil fuels (coal, gas) and different biomass resources. It is evident from the figure that emissions released from coal and gas are considerably high than biomass resources, making biomass a preferred and environment-friendly energy choice.

Air pollution is a major problem which is caused by the toxic gases emitted during the inefficient use of thermal power plants and biomass systems. This is in turn, cause several diseases in humans including tuberculosis, abnormal births, lung cancer, and pneumonia. With the introduction of efficient biomass systems, the consequences of air pollution have been eradicated to a great extent in Pakistan. However, there are no such means for fossil fuel-based energy generation in the country. Currently, several kinds of energy devices for utilizing biomass exist, which are based on the direct combustion process to obtain useful energy.

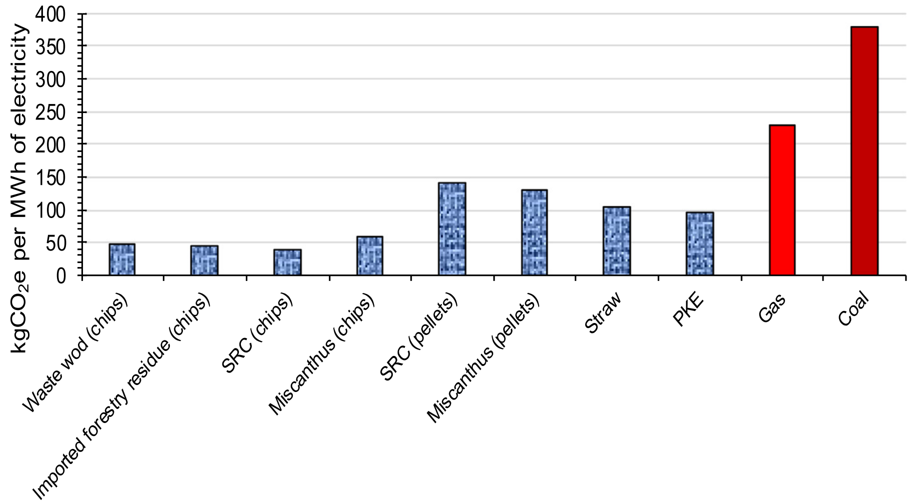

Fig. 8. Comparison of GHG emissions from fossil fuels and biomass resources (Bates et al., 2009). **Notes: SRC:** Short rotation coppice, **PKE:** Palm kernel expeller. Blue bars are the different biomass resources, while light and dark red bars are fossil fuels.

Table 2
Pakistan's forest and wooded land area from 2000–2019 (FAO, 2019).

Category	Area (hectares)			
	2000	2010	2015	2019
Forest	1746	1716	1701	1689
Other wooded lands	20	20	20	20
Other land	614	664	679	691
Total land area	2400	2400	2400	2400

In the industrial sector, these devices have been utilized in sugar mill boilers and brick kilns to avoid harmful emissions and save the environment (Butt et al., 2013).

Feedstocks contain energy which can be used for a variety of applications including electricity and heat. GHG emissions from feedstock generation and transportation differ considerably i.e., from about 10 $kgCO_2e$ per MWh for municipal solid waste to 100 $kgCO_2e$ per MWh for pellets produced from SRC chips. The major reasons for higher emissions include long transport distance, drying of fuel chips before palletization, and utilization of nitrogenous fertilizers (Bates et al., 2009). GHG emissions related to the generation, processing, and transportation of different feedstocks reduce significantly by adopting good practices. Good practices are the attempts where the efficient processing of the feedstocks is utilized. Fig. 9 depicts the GHG savings from biomass feedstocks by using good practices.

5. Potential of energy generation from major biomass resources

5.1. Fuelwood

Pakistan has a total landmass of 79,610, 000 hectares (ha), but the forest area only consists of 1,686,000 ha (Mongabay, 2011). Crop residues and animal waste fulfill 35% of the total area (Shah et al., 2007). During the summer season, when there is an acute shortage of electricity, fuelwood becomes the only way of fulfilling the energy needs of domestic users. Table 2 shows the wooded and forest area of the country from 2000–2019 (FAO, 2019).

Pakistan has a negligible forest area. The country stands at 112th position regarding forest area in the world (FBS, 2015). Forests only cover 5% of the total landmass of the country. Natural forests and coniferous make up 55% of this forest area (Nazir and Ahmad, 2018). In 2019, it was reported that the growth rate of forests is 8.76% which is 2.2% less compared with 2018 (Pakistan Economic Survey, 2018–19). Per capita forest area is only 0.04 ha. Due to the massive increase in population, the area is further reducing at a rapid pace (Nazir, 2015). Fuelwood consumption was 0.21 m^3/capita during 2015. Fig. 10 depicts the projection of wood consumption. This projection has been based on per capita fuelwood consumption. The consumption will increase further as 71% householders use wood for cooking, 16% use it for water heating and 10% use it for other purposes (FAO, 2019).

Fuelwood has several advantages over fossil fuels i.e., it is a cheap source of energy generation, could mitigate environmental pollution and has less amount of sulfur and other poisonous gases. Different woods have different chemical compositions. Therefore, their heating values vary considerably. However, tree branches, pellets, and softwoods are generally used for household purposes and their heating values are high compared with hardwoods. Green wood has a low heating value of 9.5 MJ/kg, as it has a moisture content of 52%, while the heating value of wood pallets is 19.8 MJ/kg (Iqbal et al., 2018). It has been estimated that 45,000 GWh can be added to the national grid/y if half of the total consumption is devoted to energy generation, which is 49% of the aggregate energy demand of 2018 (Pakistan Economic Survey, 2018-19). However, besides these advantages, fuelwood is considered a less preferred energy option, as the risk of deforestation creates environmental problems and a tough trade-off.

5.2. Crop residues

Another vital source of biomass is crop residues (Bhutto et al., 2011). Field residues and process residues make up crop residues. Table 3 shows the total electricity generation of crop residues, the production capacity of major crops/y and crop to residue ratio (Pakistan Economic Survey, 2018-19). The annual crop residue processing is 26 Mt which is enough to generate 18,74,786 TJ/y (World Bank, 2016a). Meanwhile, the annual production of crop harvesting residues is 115 Mt which has the potential to generate 524,580 GWh of electricity annually (World Bank, 2016b). Table 4 briefly analyzes the common crop residues being found in the country.

The chief cash crop of Pakistan is sugarcane. The crop produced 83 Mt during the fiscal year 2018–19. Fig. 11 shows the production of sugarcane form 2013–2019 (Pakistan Economic

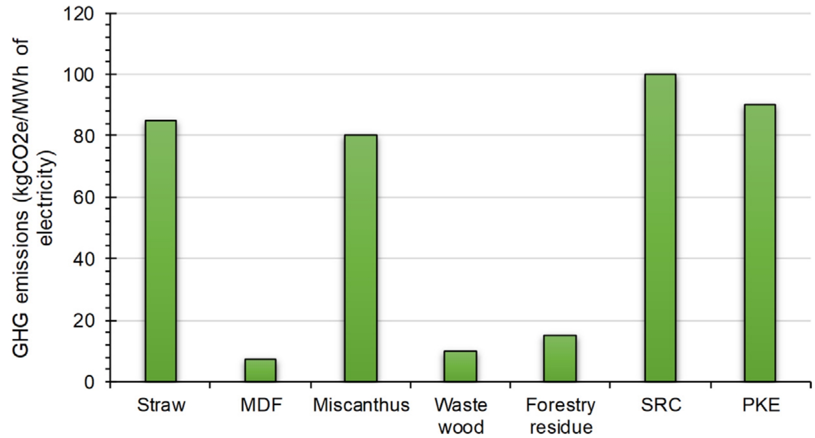

Fig. 9. GHG savings from feedstocks by adopting good practices (Bates et al., 2009). **Notes: MDP:** Medium density fiberboard.

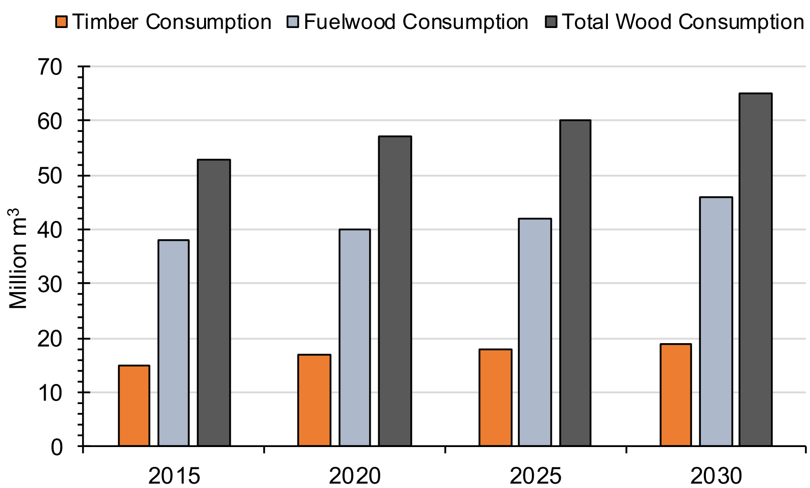

Fig. 10. Projected wood consumption in Pakistan (FAO, 2019).

Table 3
Annual Energy potential of total crop residues (Pakistan Economic Survey, 2018-19; World Bank, 2016a,b).

Crop type	Conversion technology	Crop to residue ratio/kg of crop	Annual potential of crop residue (1000 t)	Energy potential of crop residues	
				TJ/y	GWh^{th}/y
Barley	Gasification combustion pyrolysis	1.4	104	1,783	474
Rape seed	Extractions	0.6	110	1,860	496
Peanuts and walnuts	Transesterifications extraction	0.6	1,210	2,182	593
Sunflower	Transesterifications	0.6	231	3,751	1,127
Chilly	Gasification Pyrolysis	1.6	346	5,592	1,634
Millet	Pellet combustion	0.4	890	15,473	3,893
Corn	Gasification Pyrolysis	0.4	7,710	100,889	28,827
Sugarcane	Fermentation hydrolysis pyrolysis	0.4	2,845	246,500	69,285
Rice	Gasification Pyrolysis	0.3	21,195	255,773	71,851
Wheat	Gasification combustion pyrolysis	2.1	35,690	498,855	139,435
Cotton	Gasification combustion	2.3	50,512	742,128	206,965

Survey 2018–19). It is reported that 3.3 t of bagasse produced by the crushing of 10 t of sugarcane. Currently, there are 75 sugarcane crushing units operating in the country which produce millions of tonnes of bagasse. The potential of electricity generation from bagasse has been estimated to be 5800 GWh (Awan and Rashid, 2012). A precise estimation has revealed that the national grid can be supplied with 800 MW if bagasse utilized effectively in the sugar industry (AEDB, 2016).

Brown coal has high calorific value as compared to bagasse. The calorific value of bagasse with 5% ash is in the range of 1950–2000 kcal/kg (Ministry of Water and Power, 2008). Research shows that 17,900,000 t of bagasse were produced from 8 sugar mills during 2009 in Pakistan. It was calculated that 1,400 MWh electricity could be produced from such an amount of bagasse (Khan, 2010).

Alternative Energy Development Board (AEDB) reported that high cogeneration potential exists in 25 sugar mills of the country and these mills could supply 2900 GWh of electricity to the national grid annually (AEDB, 2016). Table 5 summarized the electricity generation potential of these sugar mills. Overall, Pakistan can produce 1900 MW from all 85 sugar mills by utilizing 18 Mt bagasse/yr (World Bank, 2016b).

In 2016, AEDB given letters of intent to 12 sugar mills which generated 387 MW of electricity at the end of 2018 (Hussain, 2017). In the first phase, 6 sugar mills have generated 213 MW electricity (Table 6), while during the second phase, an additional

Table 4
Proximate analysis of different crop residues in the country (Masiá et al., 2007; Channiwala and Parikh, 2002).

Biomass fuel	Ash (wt. %)	High heating value (MJ/kg)	Volatile matter (wt. %)	Fixed carbon (wt. %)
Rice husk	22.35	15.70	62.92	17.10
Cotton straw	8.76	18.79	74.26	20.95
Wheat straw	7.10	18.10	83.23	11.17
Hybrid poplar	3.80	20.13	85.892	13.50
Rice straw	21.49	15.96	66.8	14.10
Alfalfa stems	6.38	19.78	79.10	16.92
Cotton residue	7.72	17.10	73.90	21.60
Switch grass	10.25	19.17	77.70	15.45
Cotton stalk	18.30	16.94	63.10	20.13
Sugar cane bagasse	4.4	19.84	84.77	14.26

Notes: wt: Weight.

Table 5
Electricity generation potential of the largest sugar mills of Pakistan (World Bank, 2016b).

Sugar mill	Gross power capacity output (MW)	Electricity export (GWh/y)	Bagasse production (t/y)
Chaudhry Sugar Mills Limited	24	64	241,622
Kashmir Sugar Mills Limited	24	65	242,858
Shahtaj Sugar Mills Limited	24	76	246,215
Almoiz Sugar Mills Limited	28	79	249,010
Chashma Sugar Mills Limited Unit-1	28	81	253,517
Haseeb Waqas Sugar Mills Limited	29	84	257,711
Shakarganj Mills Limited-1, Jhang	29	88	250,336
Colony Sugar Mills Ltd.-1, Bahauddin	29	90	263,111
Faran Sugar Mills Limited	31	93	285,599
Habib Sugar Mills Limited	32	104	345,077
Mehran Sugar Mills Limited	33	106	3452,031
Ashraf Sugar Mills Limited	34	109	356,111
Layyah Sugar Mills Limited	34	111	356,974
JDW Sugar Mills Limited (Unit 2)	39	114	366,992
Tandlianwala Sugar Mills Ltd. (2)	39	118	387,298
RYK Sugar Mills Limited	39	121	389,430
Al Noor Sugar Mills Limited	43	123	398,089
Etihad Sugar Mills Limited	44	131	431,413
J.D.W Sugar Mills Limited	47	132	453,557
J.D.W Sugar Mills Ltd (Unit 3) - Ghotki	50	140	462,541
J.D.W Sugar Mills Ltd (Unit 4) -Dehrki	72	141	488,395
Kamalia Sugar Mills Limited	74	146	506,111
JDW Sugar Mills Limited	114	182	860,090
Hamza Sugar Mills Limited	134	301	1,138,598
Total	1,106	2,900	9,678,004

Table 6
Electricity generation from bagasse by cogeneration in the first phase (AEDB, 2016).

Sr. No	Sugar mill	Electricity generation (MW)	Province	Status
1	Hamza Sugar Mill	16	Punjab	Started
2	Alliance Sugar Mill	20	Sindh	Started
3	Safina Sugar Mill	21	Punjab	Started
4	Layyah Sugar Mill	42	Punjab	Started
5	Almoiz Industries	46	Punjab	Started
6	Etihad Power Generation	68	Punjab	Started

174 MW electricity was generated from the rest of the mills. Sindh and Punjab provinces have ample resources of rice straw and it is considered as the main crop residue. World Bank in collaboration with AEDB, assessed rice husk generation and estimated the energy production potential from 25 rice mills located in these provinces (Table 7). It was revealed that a cumulative potential of 500 GWh/y exists in these mills which could be supplied to the national grid (World Bank, 2016b).

5.3. Animal dung

At the national level, there is a power generation potential of 4800–5600 MW from animal dung (Zuberi et al., 2013). Currently, there are 202 M animals in the country. 20 M m^3 biogas could be generated daily by utilizing their waste (PCRET, 2010a). This enormous amount of biogas is enough to fulfill the cooking needs of 52 M people (PCRET, 2010b). Table 8 summarized the total animals and annual dung production from 2016–2019. Municipal, agricultural and animal waste could be utilized to install and operate pilot biogas plants easily (Abbas et al., 2017). AEDB with the cooperation of the World Bank conducted research and estimated the potential of biogas production and subsequent electricity generation from three largest dairy farms of the country (Table 9).

5.4. Municipal solid waste

Organic and inorganic wastes produced by human activities form Municipal Solid Waste (MSW) (Raheem et al., 2016a). The MSW potential of electricity generation from the thermochemical and biochemical conversion is 560 kWh/t and 220 kWh/t

Table 7
Production of Rice husk and electricity generation in the top 25 rice mills of the country (World Bank, 2016b).

Rice mill	Feedstock sourcing area (km^2/GWh)	Electricity export (GWh/y)	Rice husk production (t/y)
Husnain Rice Mill Ratodero	0.47	20	2511
Kashif Rice Mills	0.47	20	2201
Iqbal Rice Mills	0.46	20	2119
Aaqib Rice Mill Kamber	0.46	20	1710
Masha Allah rice Mill Ratodero	0.46 0	20	1710
Bismillah rice Mill Ratodero	0.46	20	1550
Madinah Rice Mill Miro khan	0.45	20	1310
Abdullah Rice Mill Miro khan	0.45	20	1310
Aziz Rice Mill Wagan	0.45	20	1,230
Ubaidullah Rice Mill Kamber	0.45	20	1230
Jawed Rice Mill Larkana	0.45	20	1230
Faiz Masan Rice Mill Nasir Abad	0.45	20	1230
Amin Ittefaq Rice Mills	0.45	20	1110
Bismillah Rice Mill Nasir Abad	0.45	20	972
Amanullah Rice Mill Larkana	0.45	20	912
Mughari Rice Mill chamber	0.45	20	810
Kashtkar Rice Mill Larkana	0.45	20	810
Tunio Rice Mill Mirokhan	0.45	20	810
Hamid Rice Mill Wagan	0.45	20	794
Dastagir Rice Mill Badah	0.45	20	790
Muzamil Rice Mill Miro khan	0.45	20	790
Memon Rice Mill Kamber	0.45	20	770
Abadghar Rice Mill Larkana	0.44	20	570
Al-Hameed Rice Mills	0.44	20	90

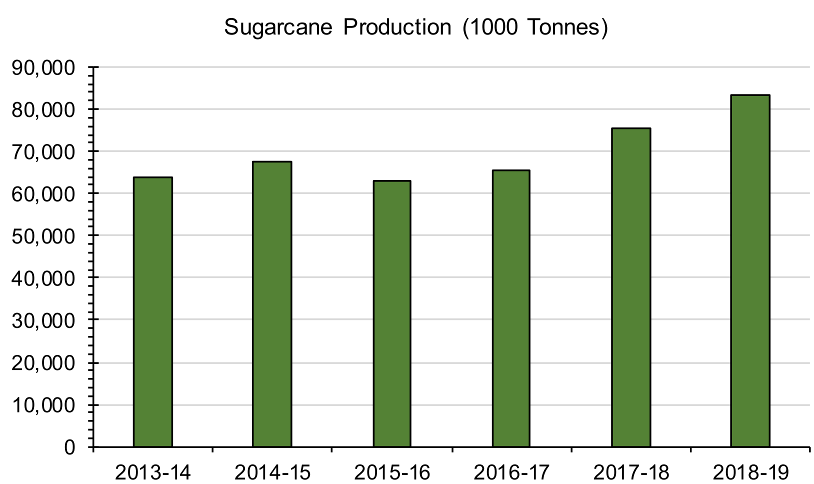

Fig. 11. Production of sugarcane in Pakistan form 2013–2019 (Pakistan Economic Survey 2018–19).

Table 8
Total animals and annual dung production in Pakistan from 2016–2019 (Pakistan economic survey 2018–19)..

Species	In millions		
	2016–17	2017–18	2018–19
Mules	0.2	0.2	0.2
Horses	0.4	0.4	0.4
Camels	1.1	1.1	1.1
Donkeys	5.2	5.3	5.4
Sheep	30.1	30.5	30.9
Buffalo	37.7	38.8	40
Cows	44.4	46.1	47.8
Goat	72.2	74.1	76.1
Dung produced	(1000 t) 1244	1282	1322

respectively (Korai et al., 2015). The annual MSW production capacity in Pakistan is 25.5 Mt with a 2.5% growth rate. It is expected that the volume of MSW will further increase in the future. Currently, no proper recycling process is being applied to the disposition of MSW (Khan et al., 2012). Handling enormous MSW is a challenging process that has increased public health issues recently. Table 10 shows the MSW collection efficiency and volume of major cities, while per capita and per time MSW generation rate has been reported in Table 11.

AEDB took a survey of 12 landfills and calculated that 28,000 t of MSW generated every day here with a net potential of 400 MW. By utilizing the MSW of these locations, the national grid can get a total of 2747 GWh electricity annually (World Bank, 2016a). A detailed analysis of these landfills with annual gross electricity output and electricity supplied to the national grid has been provided in Table 12.

6. Environmental and socio-economic benefits

6.1. Environmental benefits

Biogas convert industrial, livestock, agricultural and municipal wastes into energy. Therefore, it is one of the best technology options for electricity generation. To generate electricity by using all these wastes will not only reduce reliance on thermal resources but will also help to get rid of these wastes in an

Table 9
Biogas production and electricity generation from the three largest dairy farms (World Bank, 2016b).

Dairy farm	Daily manure collected (t)	Biogas production (m^3/y)	Gross electricity output (GWh/y)	Annual electricity export to the grid (GWh)
Sarsabz Dairy Farm Nestle	8	71,191	0.28	0.27
JK Dairies Pvt. Limited	29	351,510	0.95	1.9
Engro Dairy Farm Nara	63	758,637	2.8	2.8
Total	100	11,81,338	4.03	4.97

Table 10
MSW collection, efficiency and energy generation of major cities in Pakistan (Farooq and Kumar, 2013).

City	Waste collected (1000 t)	Efficiency (%)	Energy (M m^3)
Quetta	100	75	4
Gujranwala	128	52	5
Peshawar	149	67	7
Islamabad	225	91	22
Faisalabad	296	65	14
Rawalpindi	320	86	14
Multan	325	60	21
Hyderabad	374	72	21
Lahore	953	68	64
Karachi	1,378	53	72

Table 11
MSW generation/capita/d of Pakistan's major cities (FBS, 2015).

City	Waste generated (t/d)	Generation rate (kg/capita/d)
Sibi	57	1.38
Bannu	79	0.70
Hyderabad	314	0.32
Bahawalpur	405	0.60
Peshawar	792	0.73
Quetta	1,362	0.67
Faisalabad	1,860	0.60
Lahore	5,120	0.67
Karachi	12,142	0.50

environmentally friendly way. Additionally, deforestation will be reduced, as it substitutes fuelwood (Subedi et al., 2014). This will lead to less soil erosion and better watershed management. Meanwhile, during biogas generation, the slurry is also produced which is an excellent fertilizer (Wileman et al., 2012). Though CO_2 is also emitted during the production of biogas, it is utilized by plants for photosynthesis purposes. Therefore, compared with fossil fuels, biogas generation has lesser carbon impacts. The generation of biogas from anaerobic digestion produces minimum amounts of Nitrous Oxide (N_2O) and Methane (CH_4), making it an environmentally friendly energy choice (Seadi et al., 2008).

6.2. Socio-economic benefits

6.2.1. Inexpensive energy

The traditional and renewable energy resources have not thoroughly been explored in the country. Therefore, Pakistan import electricity to fulfill the gigantic energy needs. Electricity import is increasing continuously in the country. Fig. 12 depicts electricity imports from 2012–2017. Without the proper utilization of local renewable energy resources, the expensive electricity import bill will further increase. Pakistan is an agriculture country and it can effectively utilize local biomass resources to produce enough electricity, particularly for its energy deficit industry and agriculture. This electricity is not only cheap but also clean, compared with thermal power, which currently has a leading share in the total energy mix of the country (NEPRA, 2017).

According to PCRET, a biogas plant with a capacity of 10 m^3 can monthly save 128 kg of liquefied petroleum gas, 186 liters of kerosene oil and 1600 kg of wood (PCRET, 2010a).

6.2.2. Employment generation

Out of 62 M labor force, 3.79 M people are unemployed in Pakistan (Pakistan Economic Survey, 2018-19). Unemployed people (including male and female) have been reported in Table 13 from 2012–2018. Per 250 MW of electricity generation from biomass processes, offer 18,028 jobs (Chatzimouratidis and Pilavachi, 2008). Based on this scenario, 5,77,000 jobs will be created against 8000 MW potential of biomass energy from sugarcane and livestock and it will reduce unemployment by 18% in Pakistan (Zuberi et al., 2013).

7. Challenges of utilization

Though the Pakistani government has recently announced several programs for the quick deployment of biomass energy, still the sector is confronting with several challenges. Some of these challenges related to the site, region, and technology, while some are related to policy structure, financing mechanism, market situation, and regulatory framework. More specifically, these challenges are given as follows.

- *Lack of financing and high initial costs to set up a biomass power project:* Financial constraints and lending provisions to set up biomass energy projects especially at local level are on one hand hindering the smooth development of biomass industry and hamper the establishment of consumer service infrastructure on the other hand (Mirza et al., 2008).
- *Lack of training, awareness, and demonstration to farmers:* Residents especially rural people are unaware about the benefits of biomass energy. There are no demonstration projects at the community level and a lack of training which could educate farmers about the positive utilization of biomass energy (Javed et al., 2016).
- *Lack of government subsidies and incentives:* The interest of developers and local investors in biomass projects is insignificant due to the lack of incentives and government subsidy programs (Iqbal et al., 2018).
- *Lack of a centralized approach:* Previous organizational practices indicate that the organizations accountable for the implementation and development of renewable energy projects have mostly worked independently of each other. Organizations such as the Water and Power Development Authority (WAPDA) and the Ministry of Petroleum and Natural Resources (MPNR) are responsible for infrastructure development and energy supplies. However, limited attention was given to demand-side factors by these organizations. The benefits are not clear cut, basic processes, more detailed operations are not in place and there is a large room for error as the industry does not follow a centralized approach (Mirza et al., 2009).
- *Ineffective government policies:* The government policies are not well-defined and give more preference to conventional energy sources i.e., coal-fired power plants instead of the renewable energy sector. Besides, private participation is negligible due to complex procedures, delays in clearances and allotment of land for renewable energy projects (Raheem et al., 2016b).

Table 12
Projected electricity export to the national grid by utilizing MSW (World Bank, 2016b).

Waste management company	MSW dumped (t/d on wet basis)	Annual biogas production (M m^3)	Annual gross electricity output (GWh)	Annual electricity export to the Grid (GWh)
Ratta village (Sialkot WMC)	196	9.2	20.5	19.5
Tiba Badarshar (Bahawalpur WMC)	236	10	24.7	23.5
Eastern Pass (Quetta Municipality)	386	17.5	40.4	38.4
Sector 1–12 (Capital Development Authority)	710	31.8	84.5	70.8
Gondlanwala (Gujranwala WMC)	860	38.3	90.2	85.8
Ring Road (Water and sanitation services Peshawar)	860	38.3	90.2	85.8
Makkuana Site 1 (Faisalabad WMC)	1210	49.3	126.4	110.7
Lossar (Rawalpindi WMC)	1310	53.7	36.9	120.6
Mehmood Booti (Lahore WMC)	3610	164.4	377	359.7
Bhakkay Wala (Gujranwala WMC)	6103	273.9	630	608.6
Jam Chakro (Sindh Solid Waste Management Board)	6150	273.9	630	610.7
Gondpass (Sindh Solid Waste Management Board)	6230	273.9	630	612.6
Total	27,861	1234	2781	2747

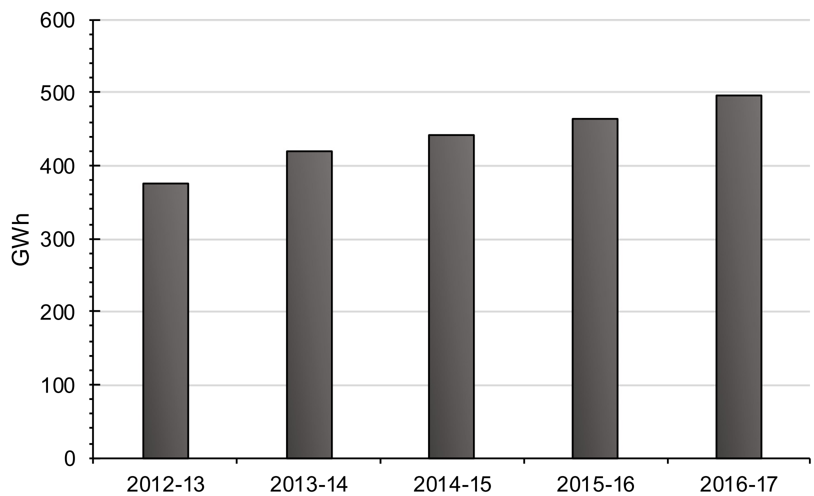

Fig. 12. Continuous import of electricity from 2012–2017 in Pakistan (NEPRA, 2017).

- *Lack of legal and regulatory framework:* The biomass industry in Pakistan lacks a comprehensive legal and regulatory framework. The lack of incorporation of biomass energy problems in the regulatory framework restricts technology penetration and further development of the sector (Irfan et al., 2019a).
- *Inadequate R&D activities:* R&D plays an important role in the sustainable development of any sector and industry. However, the country is lacking adequate R&D activities and currently, there is no renowned national institution for the R&D of the biomass industry in Pakistan. Therefore, technology is very costly and unaffordable for poor households (Naqvi et al., 2018).
- *Long payback time to investors:* Generally, investors prefer production choices that have comparatively low upfront costs, maximum efficiency and shorter payback periods. On the contrary, biomass energy development requires enormous investments with a long payback time, totally unattractive for developers. For instance, some biomass energy projects failed in Pakistan due to long payback periods (Saeed et al., 2015).
- *Undeveloped market/lack of commercial services:* The biomass industry does not have a developed market in Pakistan due to the lack of marketing infrastructure, after-sales service infrastructure, quality control measures, frequent fluctuations in price and unreliable biomass supply (Butt et al., 2013).

Table 13
Unemployed people in the country during 2012–2018 (Pakistan Economic Survey 2018–19).

Year	Unemployed	Male	Female
2012–13	3.73	2.49	1.24
2013–14	3.58	2.32	1.26
2014–15	3.62	2.31	1.31
2017–18	3.79	2.57	1.22

8. Discussion and policy recommendations

Recent industrial development, urbanization, and population growth led to severe environmental complications in Pakistan. Pakistan Environmental Protection Agency (PEPA), reported that the concentration of NO_2, CO_2, GHG, and other toxic substances has increased many folds in the country (Momete, 2011). Pakistan mainly relies on fossil fuels for energy generation purposes which are responsible for environmental degradation. The adoption of renewable energy is the only and permanent solution for sustainable development. Being renewable, biomass energy got attention recently. Though emissions also release during the regular functioning of biomass power plants, emissions can be reduced considerably by introducing good practices and efficient technologies, including proper landfill techniques and solid waste management (Panepinto et al., 2015).

Households in Pakistan are experiencing the problem of energy-security along with volatile and high electricity prices. Biomass energy has emerged to be a true alternative that not only assists local people in this regard but also strengthens the national economy. Biomass could offer all the key energy carriers i.e., gases, liquid fuels, and electricity for stationary and transport purposes. The local economy will be positively influenced by the construction of new biomass energy projects. Well-rewarding direct jobs will be created at the sites in all sectors including construction, transportation, operation and collection of biomass resources along with indirect jobs all over the country (Javed et al., 2016).

On the other hand, biomass energy has a significant social impact by concealing the deficit of costly electricity and endowing reliable solutions that are local, less expensive and environmentally friendly. The most important social benefit is the electrification of remote regions that are far away from the national grid and do not have electricity access (Amer and Daim, 2011). Farmers can enjoy an additional income source by harvesting crops which will later be utilized for biomass energy generation purposes, directly supporting the agriculture industry (Saghir et al., 2019).

The government of Pakistan issued letters of intent to establish a 12 MW biogas power plant in Jhang and a 9 MW power plant in Sindh to improve the economic and social conditions of the region. Keeping in view the social and economic benefits of biomass energy, the long-term plan of government is to install 5000 biogas units throughout the country (Zuberi et al., 2013).

Based on our research findings, the following policy recommendations have been suggested for the Pakistani government.

- *Establish financial mechanism:* As the initial costs to set up biomass projects are too high; the government should establish a proper financial mechanism, provide subsidies and monetary benefits to local developers for the quick penetration of biomass energy.
- *Launch environmental awareness and training programs:* Masses should be educated about the benefits associated with
biomass energy and make them aware of the harms related to fossil fuel-based electricity. This can be done by launching environmental awareness and training campaigns at the national level.
- *Reform policy structure:* Policy structure should be reformed by giving more preference to renewable energy technologies instead of conventional energy sources.
- *Improve R&D activities:* R&D is an essential value-adding part of the biomass industry's value chain. The country should improve intelligent and innovative and technologies to reduce operational costs and fulfill the existing needs of the biomass industry.
- *Encourage international cooperation:* International cooperation should be encouraged to transfer knowledge, technology, train local professionals and learn from each other's experiences.
- *Explore new markets, suppliers and modern technology:* There is a need to explore new markets, suppliers and modern biomass technology. This can be done by improving marketing and management skills.
- *Government's role:* The role of government is crucial in the value creation of the biomass industry. The development of the biomass industry is positively affected by tax incentives, supporting policies, and legislation. To increase the consumption of biomass-generated electricity, the government should provide recommendations on policy measures, make a legal and regulatory framework and aid grid connection. Above all, this is not possible to achieve without the government's proper support mechanism.

9. Conclusions

Pakistan is facing a power demand–supply gap of 3000 MW, which mounts to 5000 MW during the summer season when the demand for energy is at its maximum. This gap causes a 3%–6% loss to the national GDP. It is expected that the energy crises will become even worst, as the annual demand for energy is at its constant peak of 8%–10% due to massive population and economic development. Pakistan is mainly dependent on fossil fuels, which fulfill the 61% energy needs of the country, whereas the share of renewable energy is only 1.1%. Due to this alarming situation, the Pakistani government has decided to increase the share of renewable energy in the total energy mix up to 5% by 2030. Being an agricultural country, Pakistan possesses abundant biomass resources for electricity generation. This study aims to assess the current situation and future projections of electricity generation by using biomass energy resources. For this purpose, we critically reviewed extensive literature, such as research papers, energy reports, official statistical data, relevant regulations, and government policies. Research findings reveal that the abundant biomass resources of the country include fuelwood, municipal solid waste, agricultural residues, and animal dung. 48% of the domestic energy needs are met by fuelwood, whereas crop and animal residues collectively supply another 32%. Forests' growth has dwindled to 8.76% in Pakistan, as only 5% landmass of the country has been covered by forests, indicating a negligible supply of fuelwood. The country has 85 sugar mills which generate 4–12 Mt of bagasse. 5800 GWh of electricity could be generated with this amount of bagasse. If bagasse utilized in cogeneration, the national grid could be supplied with 800 MW. Corn stalk, sugarcane trash, rice straw, wheat straw, and cotton stalks are the main crop residues with a production of 6.43, 8.94, 17.86, 35.6, and 50.6 Mt, respectively. The annual processing residues of all these crops are 26.38 Mt with an energy generation potential of 790.36 TWh/annum. Animal dung is also an important source of energy generation. There are 202 M animals in the country. The estimated potential of energy production from animal dung is 4800–5600 MW. Besides, the daily amount of nitrogen-enriched biofertilizer produced by animal waste is 58.6 M kg. Similarly, the MSW potential for electricity generation by thermochemical and biochemical conversion is 560 kWh/t and 220 kWh/t, respectively. The country has the potential to run 15 M biogas power plants successfully. As envisaged by the Pakistani government, biomass energy could assist in realizing the target of increasing the renewable energy share in the total energy mix of the country from 1.1% to 5% by 2030.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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