Chapter 9
Sugarcane Biofuels and Bioenergy Production in Pakistan: Current Scenario, Potential, and Future Avenues

Muhammad Tahir Khan, Imtiaz Ahmed Khan, Shafquat Yasmeen, Ghulam Shah Nizamani, and Shahid Afghan

9.1 Introduction

Sugarcane, the largest crop commodity with respect to total production, is grown in more than 70 countries all over the world to meet the global sugar needs (FAOSTAT 2017). However, it is also one of the most suitable sources of bioenergy as it exhibits the highest number of the major characteristics for an energy crop. Sugarcane is among worlds' best photosynthesizers and sucrose producers. Moreover, it records the greatest output to input ratio for biofuel engenderment, making it one of the most efficient crops for the purpose (Khan 2018). Further, the automated harvest technology for sugarcane, no requisites of prime agricultural lands in certain countries, and the already established sugar industry make the crop one of the best fits for the product.

Sugarcane also addresses one of the major concerns against biofuel crops, i.e., food security, as it yields huge biomass supplying lignocellulosic materials—source of second-generation biofuels—which does not affect the food production (Khan et al. 2017b; Matsuoka et al. 2015). Presently, the ethanol production from sugarcane is mainly done from cane juice and molasses. Biomass and field leftovers can also be employed for obtaining cellulosic biofuels; however, the conversion of raw materials of the commodity into cellulosic biofuels is extremely intricate (Pereira et al. 2015). Once the second-generation approaches have been perfected, sugarcane can be excellently utilized for producing this class of biofuels, along with the traditional production of cane sugar and ethanol.

M. T. Khan · I. A. Khan (✉) · S. Yasmeen · G. S. Nizamani
Sugarcane Biotechnology Group, Nuclear Institute of Agriculture (NIA), Tandojam, Pakistan

S. Afghan
Sugarcane Research and Development Board (SRDB), Faisalabad, Pakistan

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Sugarcane bagasse can also find applications in electricity cogeneration, another form of bioenergy. Such energy would not only satisfy the requirements of the sugar mills, but surplus energy can be supplied to the national grids (Leal 2007). Even more, sugarcane sector can also provide biogas for domestic uses (Rabelo et al. 2011). It indicates that sugarcane plays vital role in providing energy to the major cane cultivating countries such as Brazil, India, China, Thailand, Pakistan, and many more.

Pakistan, being the fifth largest cane producer, can extensively employ sugarcane for meeting its fuel and energy requirements. The country spends huge foreign exchange for meeting oil needs of the country. Moreover, Pakistan is facing huge electricity shortfalls since many years. Thus, sugarcane can play important role in diversifying Pakistan's energy matrix, reducing oil imports, and adding bioelectricity to the national grid.

9.2 Sugarcane Crop Situation in Pakistan

Sugarcane is one of the most important cash crops of Pakistan. It is the largest crop of the country with respect to total production (Fig. 9.1) (FAOSTAT 2017). Sugarcane was farmed on area of 1.22 million ha (Mha) in the year 2017, while its total production was 73.40 million tons (MT). The sugarcane production has constantly increased in the country over time (Fig. 9.2). Pakistan ranks at fifth position in overall sugarcane cultivation in the world, following only Brazil, India, China, and Thailand (FAOSTAT 2017, Pakistan Bureau of Statistics [PBS] 2017).

According to Pakistan Economic Survey, the yield of sugarcane crop has increased from 55.98 t ha^{-1} in 2010, to 61.97 t ha^{-1} by 2017, whereas area as well as total production has also shown growth, generally, over the said period (Ministry of Finance [MoF] 2018). Sugarcane is being cultivated in all four provinces of the

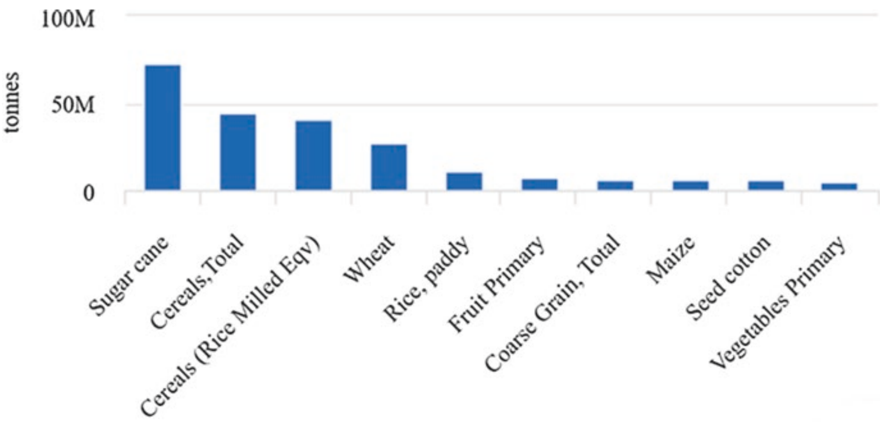

Fig. 9.1 Most produced commodities in Pakistan in 2017. (Source: FAOSTAT 2017)

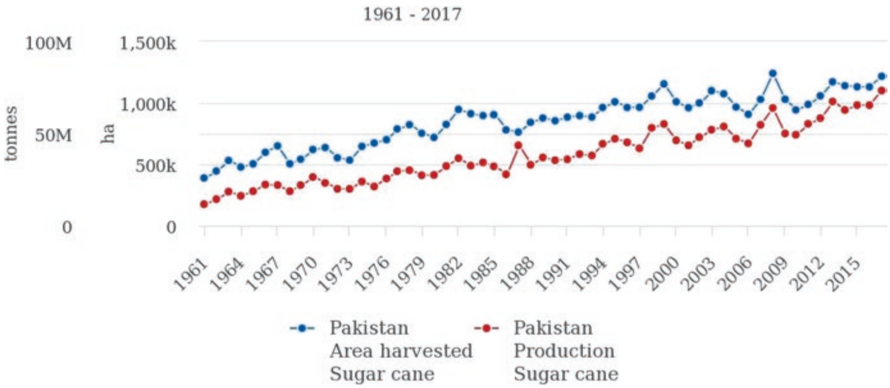

Fig. 9.2 Production and area of sugarcane cultivation in Pakistan from 1961 till 2017. (Source: FAOSTAT 2017)

country. Punjab, Sindh, and Khyber Pakhtunkhwa are growing the crop since independence, whereas its cultivation in Balochistan started in 1969. Punjab is the largest cane-producing province with total production of 49.61 MT, followed by Sindh, Khyber Pakhtunkhwa, and Balochistan. The Punjab province also leads in average sugarcane yield per hectare. Its yield is 63.78 t ha^{-1}, whereas Sindh, the second largest producer, harvests 63.05 t ha^{-1}. Khyber Pakhtunkhwa and Balochistan harvest 47.46 t and 45.14 t of sugarcane per hectare, respectively. The share of Punjab in sugarcane cultivation with respect to area under cultivation is 62%, while the other two major provinces, Sindh and Khyber Pakhtunkhwa, contribute for approximately 28% and 10% area, respectively (Punjab Agriculture Marketing Information Service 2017).

In recent years, the sugarcane production and area under cultivation have increased significantly. Improvements have also been observed in yield of the crop. However, the average sugar recovery has reduced from 10% to 9.87% over the last five cropping seasons. In the same period, however, total sugar production surged from 5.036 MT to 7.005 MT (Fig. 9.3) (Ministry of Finance 2018; Pakistan Sugar Mills Association [PSMA] 2018).

Sugarcane fulfils 99% sugar requirements of Pakistan, as sugar beet's cultivation is only marginal. Sugar industry is the second largest industry of Pakistan following only cotton sector. Pakistan is the greatest per capita sugar consumer of South Asia, surpassing the other three main sugarcane-growing countries in the region, i.e., India, China, and Thailand (Azam and Khan 2010). Sugarcane sector is also supporting production of various other products including alcohol, paper, and press mud. Moreover, raw material for confectioneries and chip board is also provided by the sugar mills. Additionally, its molasses is being exported for earning foreign exchange (Almazan et al. 1999). Contribution of the sugarcane sector toward total agricultural value addition is 3.1%, while its share in GDP of the country is 0.6% (MoF 2015).

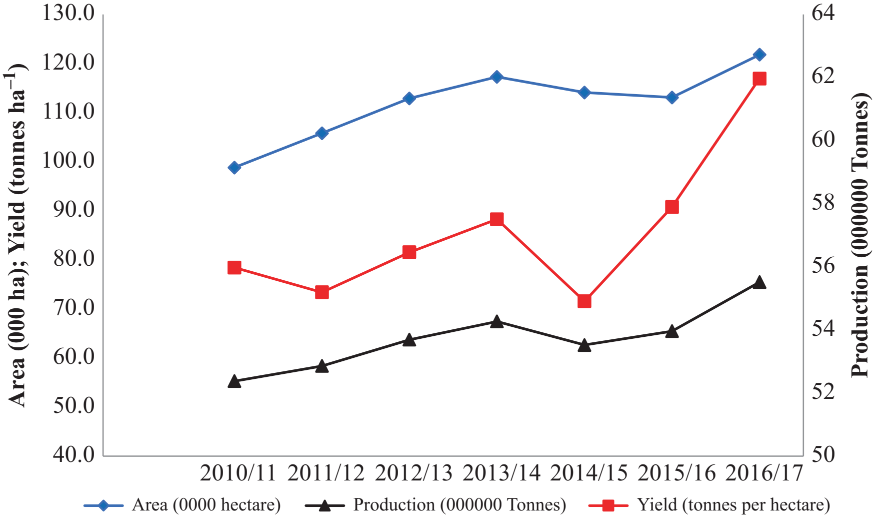

Fig. 9.3 Variations in total sugarcane production, area under cultivation, and per hectare yields of sugarcane in Pakistan since 2010 (Ministry of Finance 2018)

9.3 Sugar Industry of the Country

Sugar industry is a well-established industry in Pakistan. A total of 90 sugar mills are currently established in the country, out of which 45 are installed in Punjab, 38 in Sindh, and 07 in Khyber Pakhtunkhwa (PSMA 2017). Sugar mills in Pakistan, in season 2016–2017, crushed a total of 70.989 MT of sugarcane, manufacturing 7.005 MT of sugar (Table 9.1). The industry is currently producing surplus sugar and has potential to export the same. However, government policies discourage export of sugar as the country has suffered some severe sugar crisis in the past.

Industrial capacity of sugar mills is currently more than 70 million tons. Sugar industry of the country provides employment to 47,000 persons directly, and about a million overall. Mill-wise cane crushing, sugar production, recovery, and molasses engenderment data are presented in Table 9.2.

9.4 Energy Scenario of Pakistan

Pakistan does not have ample resources of energy to meet its needs (Table 9.3). Being a developing economy of more than 197 million people, the country has huge demands for petroleum as well as electricity. Petroleum requirements are fulfilled by imports from other nations, and thus, scarcity of oil resources creates one of the biggest burdens on country's import bills. Major traditional fuels used by automotive sector of Pakistan include petrol, diesel, liquefied petroleum gas (LPG), and compressed natural gas (CNG).

Table 9.1 Sugarcane crushing and sugar production in Pakistan (2010–2017)

Year	Mills	Cane crushed (tons)	Sugar produced (tons)
2010–2011	84	44,526,719	4,172,729
2011–2012	86	48,248,535	4,670,380
2012–2013	86	50,089,483	5,030,129
2013–2014	88	56,460,524	5,587,568
2014–2015	89	50,795,218	5,139,566
2015–2016	89	50,042,249	5,082,110
2016–2017	90	70,989,948	7,005,480

Source: PSMA (2017)

Table 9.2 Mill-wise sugar production in Pakistan during 2016–2017 season

Mill	Cane crushed (t)	Sugar production (t)	Recovery %	Molasses production (t)
		Punjab province		
Abdullah (Depalpur) Sugar Mills	276,714	25,250	9.12	12,452
Abdullah (Shahpur) Sugar Mills	Not operated			
Adam Sugar Mills	710,053	65,097	9.17	33,091
Ashraf Sugar Mills	1,529,531	151,585	9.91	78,628
Al-Moiz Sugar Mills – II	851,587	85,579	10.05	38,321
Baba Farid Sugar Mills	370,901	33,050	8.91	1669
Brothers Sugar Mills	Not operated			
Chanar Sugar Mills	630,374	58,035	9.21	31,800
Chaudhry Sugar Mills	522,958	52,070	9.96	23,533
SW Sugar Mills (Chishtian)	Not operated			
Colony Sugar Mills (Phalia)	Not operated			
Colony Sugar Mills (Punjab)	Not operated			
Etihad Sugar Mills	1,700,326	177,316	10.43	48,195
Fatima Sugar Mills	1,607,499	162,925	10.14	46,431
Darya Khan Sugar Mills (Fecto)	867,154	79,240	9.14	39,022
Hamza Sugar Mills	3,916,618	399,999	10.21	176,248
Haq Bahu Sugar Mills	322,568	29,676	9.2	14,516
Haseeb Waqas Sugar Mills	169,632	14,030	8.27	7,633
Huda (Fauji) Sugar Mills	495,605	47,350	9.55	22,302
Hunza Sugar Mills – I	1,068,352	96,295	9.01	48,076
Hunza Sugar Mills – II	852,231	79,914	9.38	38,350
Husein Sugar Mills	660,136	65,043	9.85	29,706
Indus Sugar Mills	1,449,023	146,699	10.12	55,250
Ittefaq Sugar Mills	426,707	41,830	9.80	19,202
Jauharabad Sugar Mills	546,857	53,972	9.87	15,990

(continued)

Table 9.2 (continued)

Mill	Cane crushed (t)	Sugar production (t)	Recovery %	Molasses production (t)
JDW Sugar Mills (United) – I	3,528,599	357,733	10.14	149,681
JDW Sugar Mills (United) – II	2,373,561	247,926	10.45	101,620
Two Star Sugar Mills	1,751,261	164,650	9.40	78,807
Kashmir Sugar Mills	664,661	61,931	9.32	29,710
Layyah Sugar Mills	1,831,557	176,520	9.64	82,420
Macca Sugar Mills	52,937	4450	8.41	2382
Madina Sugar Mills	1,205,955	115,416	9.57	54,268
Noon Sugar Mills	1,115,492	113,308	10.16	16,845
Popular Sugar Mills	668,764	66,159	9.89	30,094
Pattoki Sugar Mills	727,161	63,405	8.72	32,772
Ramzan Sugar Mills	982,208	93,709	9.54	44,199
Rasool Nawaz Sugar Mills	389,461	37,410	9.61	17,526
RYK Sugar Mills	1,728,228	168,116	9.73	77,770
Safina Sugar Mills	1,038,142	102,788	9.90	46,716
Shahtaj Sugar Mills	1,148,874	115,754	10.08	48,947
Shakarganj Sugar Mills – I	838,456	77,527	9.25	37,731
Shakarganj Sugar Mills –II	705,393	66,917	9.49	31,743
Sheikhoo Sugar Mills	2,340,612	222,539	9.51	105,328
Tandlianwala Sugar Mills – I	702,070	62,542	8.91	31,593
Tandlianwala Sugar Mills – II	1,375,104	130,474	9.49	61,883
Khyber Pakhtunkhwa				
AL-Moiz Sugar Mills	985,695	99,892	10.13	44,356
Chashma Sugar Mills – unit I	1,368,854	125,119	9.14	61,598
Chashma Sugar Mills – unit II	855,640	78,567	9.18	38,500
Khazana Sugar Mills	259,847	26,285	10.12	11,693
Premier Sugar Mills	268,864	25,047	9.94	12,030
Tandlianwala (Zamand) Sugar Mills	1,109,909	102,416	9.23	49,948
Bannu Sugar Mills	Not operated			
Sindh				
Al-Abbas Sugar Mills	659,154	70,848	10.69	30,277
Abdullah Shah Ghazi Sugar Mills	16,941	1200	7.08	762
Al-Noor Sugar Mills	1,315,682	127,798	9.71	56,560
Alliance Sugar Mills	1,151,138	112,466	9.77	57,256
Ansari Sugar Mills	245,803	41,304	9.69	19,467

(continued)

Table 9.2 (continued)

Mill	Cane crushed (t)	Sugar production (t)	Recovery %	Molasses production (t)
Army Welfare Sugar Mills	348,531	36,308	10.42	16,780
Bawany Sugar Mills	188,456	19,000	10.08	8730
Bandi Sugar Mills	709,987	68,800	9.69	29,985
Chamber Sugar Mills	316,100	31,525	9.97	14,280
Deharki Sugar Mills	1,950,674	205,041	10.51	79,152
Dewan Sugar Mills	507,088	52,000	10.26	24,260
Digri Sugar Mills	471,261	47,468	10.07	23,478
Faran Sugar Mills	993,390	106,319	10.76	44,309
Gulf Sugar Mills	1,204,370	125,165	10.40	54,197
JDW Sugar Mills – III	2,016,687	207,747	10.30	81,210
Habib Sugar Mills	865,530	86,316	9.97	42,067
Khairpur Sugar Mills	852,226	83,579	9.80	33,237
Khoski Sugar Mills	236,399	23,047	9.75	11,080
Kiran Sugar Mills	408,718	36,417	8.91	18,392
Larr Sugar Mills	190,574	18,816	9.87	8,495
Matiari Sugar Mills	500,203	51,657	10.33	22,205
Mehran Sugar Mills	1,056,198	116,780	11.06	47,865
Mirpurkhas Sugar Mills	738,378	78,897	10.69	34,860
Mirza Sugar Mills	134,593	12,655	9.40	6,745
Najma Sugar Mills	Not operated			
Naudero Sugar Mills	268,019	26,405	9.85	10,965
New Dadu Sugar Mills	351,906	32,609	9.27	14,769
Pangrio Sugar Mills	Not operated			
Ranipur Sugar Mills	338,174	30,645	9.06	14,877
Sakrand Sugar Mills	459,573	42,300	9.20	19,500
Sanghar Sugar Mills	625,237	63,380	10.20	30,300
Seri Sugar Mills	9,650	573	6.00	434
Shahmurad Sugar Mills	672,747	72,755	10.8	30,750
Sindabadgar Sugar Mills	593,037	61,670	10.41	28,781
Tharparkar Sugar Mills	334,171	32,521	10.15	17,921
Tando Muhammad Khan Sugar Mills	Not operated			
Sanghar Sugar Mills	537,606	54,690	10.17	24,192
Tando Allahyar Sugar Mills	549,616	55,568	10.11	24,311

Source: PSMA (2017)

The indigenous resources of the country only fulfil 18% of the total demand of petroleum products (Tariq et al. 2014). Oil demands of Pakistan have steadily increased over time. Transport sector, alone, accounts for more than 50% of the domestic petroleum consumption (Tariq et al. 2014). Within the last 5 years, petroleum consumption has escalated to 589 thousand barrels per day (B D^{-1}) starting from 442 B D^{-1}. Petroleum products share as much as approximately 40% toward overall energy consumption of the country (British Petroleum Company plc 2018).

Table 9.3 Primary energy consumption of Pakistan by fuel type (million tons oil equivalent)

Reserves		Production			Consumption						
Natural gas	Coal	Natural gas	Coal	Electricity	Natural gas	Oil	Coal	Nuclear energy	Hydroelectricity	Renewable energy	Total primary energy consumption
Trillion cubic meters	Million tons	Billion cubic meters	Million tons oil equivalent	Terawatt-hours	Billion cubic meters	Million tons oil equivalent	Million tons oil equivalent	Million tons oil equivalent	Million tons oil equivalent	Million tons oil equivalent	Million tons oil equivalent
0.4	3064	34.7	1.8	123.9	40.7	29.2	7.1	1.8	7.0	0.8	80.9

British Petroleum Company plc (2018)

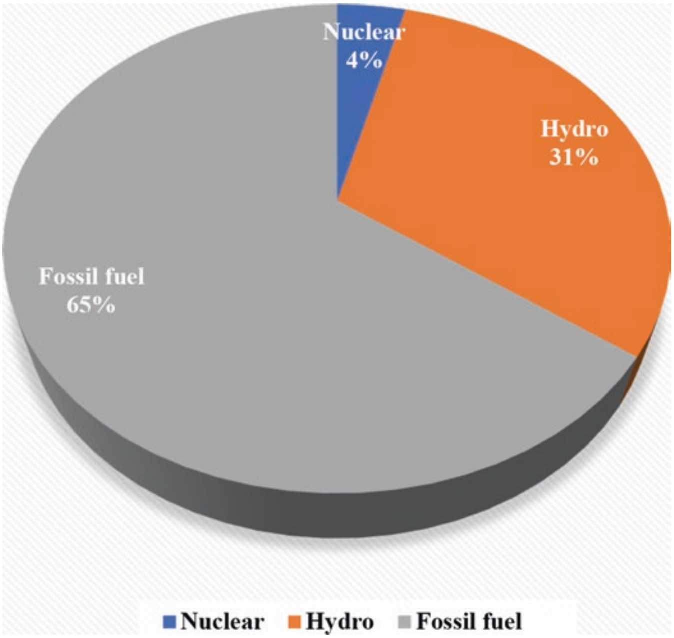

Fig. 9.4 Top three electricity sources of Pakistan. (Modified from Hussain et al. 2016)

Petroleum products are the greatest import of the country. Petroleum imports amplified by 30.5% year-on-year basis in 2017–2018. An import bill of $12.928 billion was recorded against $9.912 billion for the previous year. Regarding amounts spent on importing crude oil, a growth of 60.35% was observed as it costed the country ~$3.738 billion. However, keeping in view the imported quantity for the same, the growth was 28.72%, highlighting that the rise in import bills was more related to increase in international prices, depicting that Pakistan's economy is very much dependent on international oil prices (Arshad Hussain 2018).

Regarding electricity consumption of the country, Pakistan has a total installed capacity of 25,000 MW. Top three sources of electricity are fossil fuel, hydro, and nuclear (Fig. 9.4) (Hussain et al. 2016). Use of biomass, abundantly available in the country, has largely been underexploited. Supply and demand scenario of energy sector in Pakistan has remained extremely unbalanced for more than a decade. The country faced significant challenges in revamping its energy sector to fulfill the rising demands of power.

9.5 Sugarcane as a Fuel and Energy Source for Pakistan

Being one of the major cane producers of the world, Pakistan has a decent potential for producing cane-derived fuel and energy. Sugarcane is an excellent source of bioethanol as well as bioelectricity and can hence support energy needs of the country. Either first or second-generation ethanol can be obtained from sugarcane. The first-generation ethanol is produced from sucrose, cane juice, or molasses, whereas lignocellulosic biomass of the cane can be exploited for second-generation ethanol production. Ethanol, obtained from sugarcane, can be used as gasoline blend for consumption by vehicles (Khan et al. 2017a). Sugarcane bagasse, another byproduct in cane crushing, can be employed for electricity production (Khan 2018). Hence, molasses and bagasse are of great concern regarding cane energy production. Therefore, sugarcane can play important role toward petroleum fuels as well as power production (British Petroleum Company plc 2018).

9.5.1 Molasses Production in Pakistan

Molasses is the main source of ethanol in Pakistan. Ethanol can be utilized in fuel blending for economic and environmental reasons. Molasses production in Pakistan has gradually increased over time, attributed to rise in cane and sugar production and area under cane cultivation. Total molasses yield of Pakistan was 2.034 MT in 2011, which elevated to 3.077 MT in the year 2017 (PSMA 2017). Molasses and ethanol find applications in several domestic industries including pharma, food, cosmetics, and paper industry (Arifeen 2014).

Molasses is available in surplus amounts in Pakistan. The nation has been a major exporter of molasses to European Union (EU), Saudi Arabia, United Arab Emirates, and Afghanistan (Arifeen 2014). However, changes in import policies of EU have made molasses export to the region economically non-feasible. Consequently, Pakistan's export of molasses has greatly declined over time, in spite of increase in its production (Table 9.4). Pakistan recorded molasses export of 0.101 MT in 2017 as compared to 1.75 MT in 2000 (PSMA 2017).

Recognizing the advantages of employing molasses indigenously for various products rather than exporting it, Pakistan has imposed taxes on its export. As a result, domestic use of molasses in ethanol production has augmented in recent past. Ali et al. (2012) analyzed the ethanol production potential of Pakistan from molasses. Based on the ethanol recovery of around 240–270 l per ton of molasses, they projected that a total of two million tons of molasses (overall production at that time) could yield >0.6 MT of ethanol, which could be exported earning around $144 million. Pakistan's current molasses production is 3 MT, which can hence yield around 0.9 MT of ethanol as per their projection.

9.5.2 Bagasse Production

Bagasse is a leftover after juice and sugar extraction during sugarcane milling. It is residual dry fiber, which can be utilized for producing another form of bioenergy, i.e., bioelectricity. Bagasse is approximately fourth part of the cane, composed of

Table 9.4 Molasses production, exports, and export earnings of Pakistan (2010–2017)

Year	Production(Tons)				Exports (tons)	Value(million PKR)
	Punjab	Sindh	Khyber Pakhtunkhwa	Total		
2010–2011	1,249,324	643,651	141,580	2,034,457	86,437	892
2011–2012	1,445,830	624,956	153,583	2,224,369	55,608	577
2012–2013	1,422,807	663,305	166,639	2,252,751	225,221	2747
2013–2014	1,495,781	854,225	174,196	2,524,202	197,342	2510
2014–2015	1,281,767	781,665	183,702	2,247,137	83,229	1010
2015–2016	1,279,715	787,910	178,914	2,246,540	73,067	874
2016–2017	1,877,383	982,451	218,128	3,077,962	101,410	1217

Source: PSMA (2017)

50% cellulose, 25% hemicellulose, and 25% lignin (Rabelo et al. 2011). Sugar industry generally uses bagasse as a captive fuel for steam generation. Total calorific value of bagasse is around 2300 kcal kg^{-1} or 9731.984 kJ kg^{-1} (Arshad and Ahmed 2016; Sudhakar and Vijay 2013). High pressure boilers and special steam turbines are used by the sugar mills for electricity generation. By and large, one ton of bagasse produces 0.450 MWh of electricity (Arshad and Ahmed 2016).

Bagasse has huge potential for electricity generation. Bhattacharyya and Thang (2004) demonstrated that 3 kg of bagasse is needed for obtaining 1kWh of electricity through conventional technology. Moreover, Harijan et al. (2008) documented that 1 kWh electricity generation requires about 2 kg of bagasse. However, Purohit and Michaelowa (2007) illustrated that same amount of electricity can be produced only from 1.6 kg of bagasse.

Pakistan, a developing economy suffering from power crisis, is in urgent need of every possible route of adding power to the national grid. Electricity potential of bagasse in this regard is predicted to be around 1598–2894 GWh for the country (Arshad and Ahmed 2016). Sugar sector's potential for bagasse production and electricity generation from the same has been discussed in coming sections.

9.5.3 *Trash and Tops*

Sugarcane trash can also be utilized for energy production since it is a source of lignocellulosic materials (Pereira et al. 2015). Pakistan's sugarcane sector yields tons of trash every year which do not find appropriate applications. Cane trash and tops account for around 30% of the plant by weight, out of which 20% is shared by the tops. Although leaving trash in certain amounts is recommended for maintaining the land fertility, the quantity of trash available in fields is higher than what is required for this purpose. Hence, Pakistan can also employ the sugarcane leftovers for energy production (Aziz 2013). Keeping in view the current cane cultivation in

Table 9.5 Energy potential of cane trash available in Pakistan

Year	Cane production (MT)	Trash available[a] (MT)	Thermal energy available trash (GJ)	Power potential (GWH)
2015	62.652	6.265	41,976,840	11925.238
2016	65.482	6.548	43,872,940	12463.903
2017	75.482	7.548	50,572,940	14367.312

[a]Author's estimated values

Pakistan, the estimated available trash amounts to 7.548 MT. The projected thermal energy of this quantity of cane trash would be 50,572,940 GJ, which can offer a power potential of around 14,367 GWH per annum (Table 9.5).

9.6 Sugarcane Ethanol Production in Pakistan

Sugarcane is an excellent source of ethanol, which can be used as a transport fuel. Fuel ethanol is being produced in many of the cane-growing countries. Brazil, being a potential example in this regard, has extensively utilized sugarcane ethanol to fulfill its fuel demands. Ethanol can find applications as a stand-alone fuel or as a blend in gasoline in any ratio (Lisboa et al. 2011). For cane-producing countries like Pakistan, adoption of ethanol-blended fuel is a viable idea as it can help in decreasing the oil imports of the nation and provide environmental benefits.

Cane molasses is a cost-effective and abundantly available source of ethanol production. Industrial base for this feedstock already exists and is well-settled; however, the potential of molasses toward biofuel blending has remained untapped by now. Plentiful availability of molasses indicates that enhancing ethanol production in Pakistan will not affect the cultivation of other crops ensuring food security—the greatest concern against biofuels (Arifeen 2014).

Molasses' percentage from the crushed cane is around 4%, whereas the ethanol yields are up to 270 l per ton of molasses. Hence, as per current production of 3.08 MT of molasses, 770 million liters (ML) of ethanol can be produced (Arshad 2010; PSMA 2017). Pakistan is already producing surplus sugarcane, and the sugar industry of the country is continuously carrying-over the stocks of previous years (PSMA 2017). As of 2012, ~24.5 MT of sugarcane were available in excess after fulfilling the local demands of sugar. Subjecting this excess crop to ethanol for ethanol blending instead could yield up to 274 ML of ethanol. Considering the gasoline demand of 1435 MT for the same year, ethanol could substitute around 19.1% of annual gasoline consumption (Tariq et al. 2014).

Twenty-one distilleries are operating in the country having a capacity of two million tons of molasses processing, which can yield up to 400,000 tons of ethanol every year (Table 9.6). This amount is far higher than ethanol's current domestic applications, indicating that Pakistan does have surplus ethanol available for blending purposes (Ahmad et al. 2015; Arshad 2010). Arshad (2010) mentioned that

Table 9.6 List of distilleries and their installed capacities in Pakistan (2005–2006)

Name	Liters per day	Metric tons per year
Khazana Sugar Mills, Peshawar	23,000	4,600
Premier Sugar Mills & Distillery Co., Mardan	46,000	9200
Crystalline Chemical Industries (Pvt.) Ltd., Sargodha	100,000	20,000
CSK Distillers Ltd., Phalia	125,000	25,000
The Frontier Sugar Mills & Distillery Ltd., Takhat Bhai	14,000	2,800
Tandlianwala Sugar Mills Distillery, Faisalabad	125,000	25,000
Shakarganj-I – Jhang	160,000	32,000
Shakarganj-II – Jhang	100,000	20,000
Crescent Sugar Mills & Distillery Ltd., Faisalabad	22,000	4,400
Unicol, Mirpur Khas	100,000	20,000
United Ethanol, Sadiqabad	100,000	20,000
Haseeb Waqas Distillery, Nankana	125,000	25,000
Chishtia – Farooqia	100,000	20,000
Habib Sugar Mills Ltd. and Distillery, Nawab Shah	143,500	28,700
Al-Abbas Sugar Mills Distillery, Mirpur Khas	170,000	34,000
Matiari Distillery, Hyderabad	100,000	20,000
Dewan Distillery, Thatta	125,000	25,000
Shah Murad Distillery, Thatta	125,000	25,000
Murree Brewery, Rawalpindi	9000	1800
Pinnacle Distillery, Badin	125,000	25,000
Noon Sugar & Distillery, Bhalwal	80,000	16,000
Total	2,017,518	403,500

Modified from Khan et al. (2007)

Pakistan was producing 270,000 tons of ethanol per annum, in spite of its potential of around 400,000 tons year^{-1} in the mentioned year. Ahmad et al. (2015) reported the sum of ethanol demand of the country and exports to be around 80,200 tons, highlighting the possible availability of 318,000 tons of ethanol. Additionally, ethanol production in sugar mills also largely depends on the milling efficiency (fermentation, distillation, and dehydration processes). If milling efficiency of the sugar mills improves up to 47–48%, sugar industry may enhance ethanol production by 20–30% in Pakistan. On area basis, Eastwood (2011) suggested that 800 gallons of ethanol can be produced from one acre of sugarcane.

Ethanol can play three distinct roles in Pakistan. It can be used by domestic industries, can be exported abroad, and can be used for fuel blending. Pakistan's ethanol has majorly been exported, and its role in fuel blending has not been exploited well. Pakistan exports un-denatured ethyl alcohol and ethyl alcohol spirit (Table 9.7). The country has been the second largest exporter of ethanol to EU, following only Brazil. Moreover, Pakistani ethanol has also been exported to United

Table 9.7 Export of un-denatured ethanol

Year	Quantity (liter)	Value (PKR) (000)	Average price (PKR per liter)
2010–2011	168,509,200	9,506,883	56.00
2011–2012	215,814,894	14,234,428	65.96
2012–2013	142,065,426	835,649	61.49
2013–2014	492,476,805	32,168,695	65.21
2014–2015	421,881,994	25,749,257	61.00
2015–2016	396,940,741	22,929,248	58.00
2016–2017	358,483,301	29,330,083	82.00

Source: PSMA (2017)

Kingdom, China, and United States (Arifeen 2014). Tariq et al. (2014) analyzed the ethanol production capacity of Pakistan's sugar sector and projected that the country has potential to generate 274 ML of ethanol annually, without diverting the production of food products from cane crop.

Fuel grade ethanol needs to be ~99.8% pure. Molecular sieve technology can be employed for manufacturing fuel grade ethanol. In Pakistan, many of the sugar mills like Al-Abbas, Premier, Crescent, Habib, Colony, and Mehran have already installed their own distilleries. Moreover, eight distilleries have mounted the sieve technology for manufacturing fuel grade ethanol from the industrial alcohol (Khan et al. 2007). Unicol, a joint venture of three sugar mills, viz., Faran, Mehran, and Mirpur Khas sugar mills, has a capacity of producing 200,000 l of ethanol per day. This plant produces ethanol of up to 99.9% purity, apart from two other categories having >96%, and > 92% purity (Arifeen 2014).

Various ratios of ethanol can be implemented in Pakistan, keeping in view its production scenario. Tariq et al. (2014) designated E8 as the best possible blending rate for the country evaluating the ethanol production status of the country. The authors estimated that adopting this blend can reduce up to 0.5 MT of CO_2 emissions by the year 2030. However, it has been seen that startling rise in sugarcane production in recent years already surpassed their projection for ethanol engenderment and Pakistan's exports of ethanol rose up to 600 ML in 2017 (Fig. 9.5) (Agranet 2018). At current production rate, Pakistan has potential to attain up to 10% blending of ethanol.

Rise in ethanol production—if used for fuel blending—can help in saving huge foreign exchange by reducing country's petroleum import bills. Ethanol is a clean, low-carbon, and environmental-friendly fuel (Lisboa et al. 2011). Utilizing ethanol, or its blends in the energy sector, will not only benefit the country economically, but it will also contribute toward environmental commitments of the nation for reducing CO_2 emissions. Ethanol works as an oxygenate in fuel blends. It has 37% oxygen by weight which augments the octane rating of the fuel, leading to complete combustion and reduction in environmentally hazardous emissions (Tariq et al. 2014). Also, first-generation ethanol production from sugarcane is cost-competitive as the conventional technology used for the purpose does not require

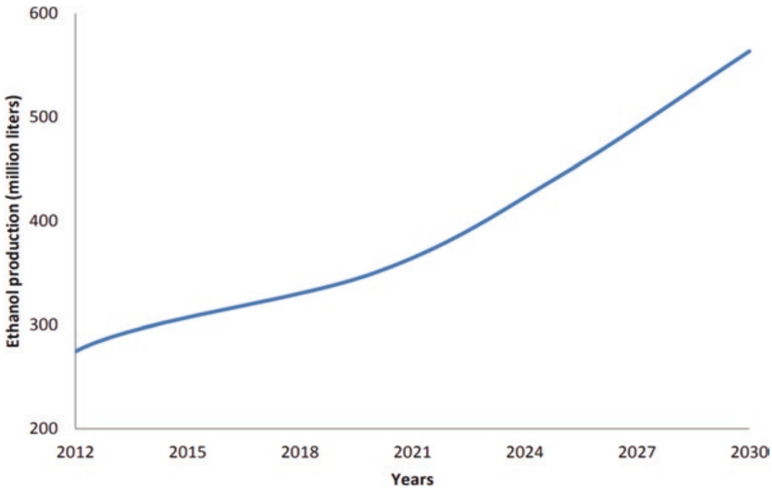

Fig. 9.5 Projection of ethanol production potential of Pakistan. (Source: Tariq et al. 2014)

expensive enzymatic pretreatments (Leal 2007). Furthermore, indigenous production of this fuel source will bring huge socioeconomic benefits to the local population by providing various direct and indirect jobs in cane production, sugar milling, and ethanol distillation.

For using ethanol in petroleum sector of the country, in 2006, Government of Pakistan directed the Pakistan State Oil (PSO) company to evaluate the performance of ethanol-blended fuel in selected cities. This was first attempt in the country for targeting biofuels adoption in future. After evaluation, PSO expanded its network of outlets providing E10 blends, and the marketing of blended fuel was also started in 2010. In order to promote adoption E10, economic incentives were also offered. However, till date, the venture did not progress majorly because of lack of coordination among involved stakeholders, improper planning and implementation, and no strict policies regarding blended fuels.

9.7 Sugarcane Bioenergy Production in Pakistan

Apart from being a source of ethanol-based biofuels, sugarcane sector can also provide bioelectricity. Cane bagasse, residual fiber collected after sugar extraction from sugarcane, can be employed for this purpose through cogeneration—the simultaneous production of heat and electricity (Naqvi et al. 2013; Kent 2010).

Sugarcane bagasse is widely employed for energy production in many countries such as Mauritius, Brazil, and India. Khoodaruth (2014) reported that sugarcane bagasse is contributing for 14% of electricity needs in Mauritius and its share is expected to increase up to 28% in recent future. Similarly, Ram and Banerjee (2003) illustrated that 3500 MW of electricity was being generated from sugarcane bagasse in India. Mbohwa (2003), and Mbohwa and Fukuda (2003) speculated that 210 MW can be obtained from bagasse cogeneration systems in Zimbabwe.

Bagasse has good potential for bioenergy production in Pakistan as country's power shortfalls, diminishing reserves of natural resources, environmental pollution, and economic disquiet have induced interests into renewable, sustainable, and environment-friendly sources of energy. Pakistan's total power generation capacity is 25,374 MW; 16,619 MW (65.50%) is shared by thermal sources, 7116 MW (28.04%) by hydroelectric, 787 MW (3.10%) by nuclear, and only 852 MW (3.36%) by renewable sources such as bagasse, wind, and solar (National Electric Power Regulatory Authority [NEPRA] 2016). The figures depict that bagasse has not been exploited to full capacity for energy production in the country.

Munir et al. (2004) reported that 11 kg of steam is needed to produce 1 kW of electricity and conservative boilers can generate 2.2 ton of steam from one ton of bagasse when 23 bars pressure is applied at 350 °C temperature. However, sophisticated modern pressure boilers can operate at 65 bar pressure with 510 °C temperature generating 2.40 tons of steam (Junqueira 2005). Hence, 1 kW of electricity can be cogenerated using only 5 kg of steam. A typical sugar mill processing 2000 tons of sugarcane has potential to generate 11 MW of electricity. Generally, requirements of such mills' own uses would be around 2 MW, and therefore, the rest (9 MW) can be sold to the grid. Hence, if this unexplored resource is utilized in Pakistan, up to 3000 MW of electrical energy can be added to the system through existing technology (PSMA 2016).

Interestingly, this 2000–3000 MWh of electricity by the sugar mills would be provided during the crushing season, which ranges from November to March every year. Pakistan suffers from extreme blackouts in same months because of reduction in hydropower production (PSMA 2016). Moreover, adopting the cogeneration technology at mills, 3613 MWh of electricity can be obtained. Electricity generation potential of Pakistani sugar mills through existing and cogeneration technology, as estimated by Arshad and Ahmed (2016), has been presented in Tables 9.8 and 9.9.

Shakarganj Mills Limited (SML) installed the first biogas-based electricity generation plant of the country in 2008. Faisalabad Electric Supply Company signed an agreement with the facility in the same year for inclusion into national grid. Pakistan was suffering from serious energy shortfall of 5000 MW in the said period, and such plant could contribute toward betterment of the situation by fulfilling the needs of 50,000 houses in the area where the mill is located. The plant uses Jenbacher gas engine which employs the extort from spent wash, collected during ethanol production from molasses, as feedstock. The capacity of the plant is 8.512 MW, and it has potential to cause 20,000 tons of certified emission reductions. Therefore, this project has been registered with United Nations Framework Convention on Climate Change (UNFCCC) by the Carbon Services Pakistan (DAWN 2008).

Table 9.8 Potential of electricity generation based on average cane crushed per day through existing technology

Year	No. of sugar mills	Sugarcane crushed (t)	Bagasse production (t)	Electricity production (MWh)	Electricity for mills' own needs (MWh)	Surplus electricity (MWh)
2008–2009	82	33,139,418	10,604,614	733	665	68
2009–2010	83	34,611,003	11,075,521	774	710	64
2010–2011	84	44,511,571	14,243,703	944	750	194
2011–2012	86	44,248,535	15,439,531	1023	800	223
2012–2013	86	50,089,483	16,028,635	1063	830	233
2013–2014	88	56,460,524	18,067,367	1369	840	529

Source: Arshad and Ahmed (2016)

Table 9.9 Potential of electricity generation based on average cane crushed per day through cogeneration technology

Year	No. of sugar Mills	Sugarcane crushed (t)	Bagasse production (t)	Electricity production (MWh)	Electricity for mills' own need (MWh)	Surplus electricity (MWh)
2008–2009	82	33,139,418	10,604,614	2121	665	1456
2009–2010	83	34,611,003	11,075,521	2215	710	1505
2010–2011	84	44,511,571	14,243,703	2849	750	2099
2011–2012	86	44,248,535	15,439,531	3088	800	2288
2012–2013	86	50,089,483	16,028,635	3206	830	2376
2013–2014	88	56,460,524	18,067,367	3613	840	2773

Source: Arshad and Ahmed (2016)

In February 2008, Al-Moiz industries situated at Dera Ismail Khan signed a conformity for electricity generation to supply up to 15 MW to national grid. The length of the agreement was 10 years, and the tariff was set at PKR 4.88 kWh^{-1}, together with bagasse fuel cost of PKR 3.62 kWh^{-1}. Later, Shakarganj Energy (Pvt.) Limited also initiated a bagasse-based isolated generation company having capacity of 31.50 MW. As of 2016, seven sugar units are exporting their excess electricity to the national grid in Pakistan, while four are in process.

Sugar mills are producing energy for their own use since 1990s. A renewable energy policy was launched by Pakistan in 2006. A list of bagasse-based power projects under said renewable policy is presented in Table 9.10, while Table 9.11 presented an overview of bagasse-based captive power producers. Most of the units are making use of Steam Turbine technology, as evident from the said tables. Energy production from cane is increasing in the country over time. A rise of 63 MW has been observed within a year (in 2015–2016). The overall input into National Transmission and Dispatch Company's system by the bagasse-based energy plants is 146 MW, summing their contribution to be 556 GWh (NEPRA 2016).

Table 9.10 Bagasse/Biomass power projects under renewable energy policy of 2006

S. No.	Name of Company and Location	Installed Capacity (MW)	Fuel Type	Technology
1	SSJD Bioenergy Limited, Mirpur Khas, Sindh	12.00	Bagasse	Bagasse
2	Lumen Energia (Pvt.) Limited, Jhang, Punjab	12.00	Biomass	ST[a]
3	Shakarganj Mills Limited-II, Jhang, Punjab	12.00	Bagasse +FO[b]	ST
4	Pak Ethanol (Pvt.) Limited, Tando Muhammad Khan, Sindh	9.132	Biogas	GT
5	JDW Sugar Mills Limited, Rahim Yar Khan, Punjab	26.35	Bagasse +Biomass	ST
6	JDW Sugar Mills Limited, Ghotki, Sindh	26.35	Bagasse +Biomass	ST
7	Chiniot Power Limited, Chiniot, Punjab	62.40	Bagasse	ST
8	RYK Mills Limited, Rahim Yar Khan, Punjab	30.00	Bagasse	ST
9	Hamza Sugar Mills Limited, Rahim Yar Khan, Punjab	15.00	Bagasse	ST
10	Alliance Sugar Mills (Pvt.) Limited, Ghotki, Sindh	30.00	Bagasse	ST
11	Ansari Powergen Company (Pvt.) Limited, Tando Muhammad Khan, Sindh	30.00	Bagasse	ST
12	TAY Powergen Company (Pvt.) Limited, Tando Allayar, Sindh	30.00	Bagasse	ST
13	Bandhi Powergen Company (Pvt.) Limited, Shaheed Benazirabad, Sindh	30.00	Bagasse	ST
14	Etihad Power Generation Limited, RYK, Punjab	74.40	Bagasse	ST
15	The Thal Industries Corporation Limited, Chiniot, Punjab	20.00	Bagasse	ST
16	The Thal Industries Corporation Limited, Layyah, Punjab	41.00	Bagasse	ST
17	Almoiz Industries Limited, Mianwali, Punjab	36.00	Bagasse	ST
	Total	496.63		

Source: NEPRA (2016)
[a]Steam Turbine
[b]Furnace Oil

9.8 National Policies

Pakistan's national policies, by now, have not focused much on adopting bioethanol or its blends. However, attempts have indeed been made to limited extent in the past.

In 2006, the Government of Pakistan initiated a pilot project by Alternate Energy Development Board (AEDB) for evaluating the use of E10 blend (10% ethanol +90% oil) in the country. The ethanol for the program was to be supplied by indig-

Table 9.11 Generation licensees: bagasse-based captive power producers

S. No.	Name of company and location	Installed capacity (MW)	Fuel type	Technology-wise capacity (MW)	
				Technology	Capacity
1	Shakarganj Sugar Mills Limited, Jhang, Punjab	8.512	Biogas	GT[a]	8.512
2	Almoiz Industries Limited, Dera Ismail Khan, Khyber Pakhtunkhwa	43.60	Bagasse + FO[b]	ST	43.60
3	Indus Sugar Mills Limited, Rajanpur, Punjab	11.00	Bagasse + FO	ST	11.00
4	Colony Mills Limited, Multan, Punjab	28.00	Bagasse + FO	ST	28.00
5	JDW Sugar Mills Limited, Rahim Yar Khan, Punjab	28.00	Bagasse + FO	ST	28.00
6	Brothers Sugar Mills Limited, Kasur, Punjab	13.00	Bagasse + FO	ST	13.00
7	Al-Noor Sugar Mills Limited, Shaheed Benazirabad, Sindh	36.80	Bagasse + FO	ST	36.80
8	RYK Mills Limited, Rahim Yar Khan, Punjab	18.00	Bagasse + FO	ST	18.00
9	Sheikhoo Sugar Mills Limited, Muzaffargarh, Punjab	18.00	Bagasse + FO	ST	12.00
10	Ashraf Sugar Mills Limited, Bahawalpur, Punjab	24.50	Bagasse + FO	ST	24.50
11	The Thal Industries Corporation Limited, Layyah, Punjab	30.70	Bagasse + FO	ST	30.70
12	Hamza Sugar Mills Limited, Rahim Yar Khan, Sindh	23.60	Bagasse + FO	ST	23.60
13	Eithad Sugar Mills Limited, Rahim Yar Khan, Punjab	22.00	Bagasse + FO	ST	22.00
14	Deharki Sugar Mills (Pvt.) Limited, Ghotki, Sindh	18.00	Bagasse + FO	ST	18.00
15	Tando Allayar Sugar Mills (Pvt.) Limited, Tano Allahyar, Sindh	12.00	Bagasse + FO	ST	12.00
16	Ittefaq Sugar Mills Limited, Pakpattan, Punjab	11.00	Bagasse + FO	ST	11.00
17	Digri Sugar Mills Limited, Mirpur Khan, Sindh	6.00	Bagasse + FO	ST	6.00
18	Fatima Sugar Mills Limited, Kot Addu, Punjab	120.00	Bagasse + FO	ST	120.00
19	Bandhi Sugar Mills (Pvt.) Limited, Shaheed Benazirabad, Sindh	12.00	Bagasse + FO	ST	12.00
20	Kamalia Sugar Mills Limited, Toba Tek Singh, Punjab	17.00	Bagasse + FO	ST	17.00
21	Ramzan Sugar Mills Limited, Chiniot, Punjab	12.00	Bagasse + FO	ST	12.00

(continued)

Table 9.11 (continued)

S. No.	Name of company and location	Installed capacity (MW)	Fuel type	Technology-wise capacity (MW)	
				Technology	Capacity
22	Noon Sugar Mills Limited, Sargodha, Punjab	14.80	Bagasse	ST	14.80
23	Fatima Energy Limited, Muzaffargarh, Punjab	120.00	Bagasse + Biomass	ST	120.00
24	Faran Sugar Mills Limited, Tando Muhammad Khan	13.00	Biomass + FO	ST	13.00
25	Chambar Sugar Mills (Pvt.) Limited, Tando Allahyar	5.00	Bagasse + FO	ST	5.00
26	Thal Industries Corporation Limited (for Safina Sugar Mills Limited – Plant I), Chiniot, Punjab	11.00	Bagasse	ST	11.00
27	Ranipur Sugar Mills (Pvt.) Limited, Khairpur, Sindh	25.50	Bagasse	ST	25.50
	Unicol Limited, Mirpur Khas, Sindh	6.60	Bagasse	ST	6.60
28	Alliance Sugar Mills (Pvt.) Limited, Ghotki, Sindh	13.50	Bagasse	ST	13.50
29	Habib Sugar Mills Limited, Benazirabad, Sindh	13.50	Bagasse	ST	13.50
30	Mehran Sugar Mills Limited, Tando Allahyar, Sindh	14.06	Bagasse	ST	14.06
31	Shahmurad Sugar Mills Limited, Thatta, Sindh	15.25	Bagasse	ST	15.25
32	Sanghar Sugar Mills Limited, Sanghar, Sindh	13.50	Bagasse	ST	13.50
33	Mirpurkhas Sugar Mills Limited, Mirpurkhas, Sindh	8.50	Bagasse	ST	8.50
34	Khairpur Sugar Mills Limited, Khairpur, Sindh	12.00	Bagasse + FO	ST	12.00
	Total	799.92			793.92

Source: NEPRA (2016)
[a]Gas Turbines
[b]Furnace Oil
[c]Steam Turbine

enous sources. Also, provincial governments were encouraged to enhance the blended fuel in the same year. The pilot project was launched in Islamabad by Pakistan State Oil (PSO), followed by opening of selected outlets in Karachi, and then Lahore. The program was conducted for half a year and 25 pre-identified vehicles using E10 blend were analyzed for performance (PSO 2006).

Pakistan Sugar Mills Association, in 2006, recommended that a 10% ethanol should be mandated through discussion with oil companies. They also suggested that substantial tax cuts should be offered for making operations for production of required quantities of ethanol possible, proposing the removal of GST as a major incentive in this regard. Later, in 2009, Economic Coordination Committee (ECC) permitted the E10 marketing on limited basis. The plan to manufacture E10-blended petrol was to be undertaken jointly by Ministry of Petroleum and Ministry of Industries and Production. ECC proposed that GST should be reduced, whereas petroleum levy should also be exempted. Later on, Petroleum Ministry proposed that PSO will initiate marketing E10 in 2010 in Karachi (Ali et al. 2012; PSO 2010).

In 2010, the E10 program was planned to be expanded to other cities including Rawalpindi, Sheikhupura, Gujranwala, Sialkot, Jhelum, and Mirpur Khas. The Oil and Gas Regulatory Authority (OGRA) fixed the price of E10 at PKR 62.61 per liter, which was less by PKR 2.5 per liter than the price of petrol at that time, to offer an economic incentive for promoting the blended fuel. Government also fixed 15% duty on export of molasses to encourage its domestic use in ethanol production, instead. Even the move to assess pure ethanol for public transport was under consideration. In 2010, PSO expanded the E10 availability at some outlets in Punjab province (Ali et al. 2012; PSO 2010).

In spite of significant efforts during 2006–2010, the policies did not remain consistent. Also, Pakistan aggressively initiated indigenous oil explorations. Investments in the petroleum sector were increased and several multinational companies are still conducting the oil reserves surveys in the country. Hence, till date, the E10 venture did not progress, majorly because of the lack of coordination among involved stakeholders and improper planning and implementation. On an optimistic side, renewable fuels projects are again being highlighted by the Government of Pakistan, and it can be hoped that role of renewable fuels, including cane ethanol, might increase in the coming years.

Pakistan has also suffered from extreme electricity crisis in the past decade and has explored various possible ways of energy extraction, including cane bagasse. J-tariff was launched by the government of Pakistan in 1990s for export of electricity from sugar industry to national grid on "as and when delivered" basis. However, only 4 MW of energy could be supplied. According to the tariff, sugar mills were supposed to bear the cost of interconnectivity, and in lieu of that, industry was allowed to adjust electricity consumption from the national grid. Some sugar mills acknowledged the tariff and connected their facilities with 11 kV grids. The tariff was set at PKR1.70 kWh^{-1} (for fuel cost only) and remained fixed for many years, leading to decline in interest of the sugar industry with the passage of time (Arshad and Ahmed 2016).

In 2002, new policy was formulated by the government which curtailed the industry benefits; as a result, electricity generation from sugar industry was reduced to very low level by 2007. The renewable policy of 2002 did not include biomass in its priorities of renewable energy sources. During the last 10 years, government has made many changes in the power generation policies, but no fruitful results were obtained (Mirjat et al. 2017). In 2007, the "National Policy for Power Co-Generation by Sugar Industry" was notified. In this policy, incentives were offered to the sugar industry to encourage mills to contribute toward power production. Purchase of power and payments for the same were guaranteed; moreover, tax cuts and concisions on import of technology were offered. Additionally, to address the investment issues, State Bank of Pakistan was requested to offer loans at lower interest rates of 6% for the renewable projects, instead of 12% (Khan 2018).

In 2012, a dynamic energy policy dealing with all sectors, i.e., bagasse, biomass, solar, and energy from waste, was introduced. The policy also introduced prominent financial and fiscal motivations to investors. Exceptional emphasis was put on the industries that could produce more than 50 MW of electricity. Moreover, prompt payment to energy producers was ensured. The said policy also encouraged independent power producer (IPP), which was adopted by many of the sugar mills. The tariff was linked with the natural gas prices, making it cost-effective for the industry. This policy also focused on development and initiation of the energy projects at a greater pace. Private Power and Infrastructure Board (PPIB) and NEPRA were directed to make decisions on such cases in a set time frame. Sugar mills, through this policy, were requested to complete the power projects within a period of 3 years, while NEPRA was advised to complete the feasibility report in a period of 1.5 months (Arshad and Ahmed 2016). NEPRA, in 2015, amended the upfront tariff approved in 2013, adjusting the new levelized tariff to PKR 10.7291 kWh^{-1} for bagasse-based cogeneration projects (NEPRA 2016, 2017).

Pakistan is still suffering from energy shortfall which becomes extreme in summers and when water reservoirs are low in winters. The winter period positions parallel to cane crushing season, suggesting that cane energy can help Pakistan tackle its blackouts when the hydropower production is low. Pakistan has still not explored the significant capacity of cane crop for adding energy to the grid, in spite of the fact that sugar industry's potential role in power production is very promising. Upgradation of technology at the sugar mills and higher incentives for bagasse-based IPPs can indeed enhance the industry's contribution toward energy sector of the country.

9.9 Advantages of Sugarcane-Based Fuels and Energy for Pakistan

The role of sugarcane sector in energy production is important for Pakistan for economic, social, and environmental reasons. As a source of biofuel, sugarcane-derived ethanol can significantly reduce country's oil imports, which are one of major burdens on economy. Transport sector of the country is the biggest consumer of imported petroleum, accounting for more than 50% (Arifeen 2018). Adopting ethanol-blended fuel in the country can substantially reduce the import burden of the country as this ethanol will come from indigenous crop source. Current molasses capacity of the country can meet the requirements for E10 blending, which does not require any amendment in vehicles' engines (Ali et al. 2012).

The energy demands of the country are expanding continuously, while the domestic reserves are limited. Sugar sector can help in overcoming the electricity shortage which has adversely affected the country for more than a decade. Power sector needs support from diverse sources so that uncertainty toward domestics use, business, and industrialization could be eliminated. Sugarcane sector has great potential for power generation, which can be enhanced even more by installing efficient power plants and high pressure boilers, replacing the conventional ones used currently (Valasai et al. 2017; Zuberi et al. 2013). Bagasse, a by-product of cane processing, can provide 3000 MW for national grid in current scenario (PSMA 2016).

Job creation is another important benefit Pakistan can achieve from adopting sugarcane biofuels and bioenergy. Being the second largest industry of the country, the sugar industry is spread across the country indicating that such jobs will be generated in rural and economically deprived areas of the state—giving this strategy a unique edge over oil imports for the purpose which does not provide socioeconomic opportunities. Such jobs will not only be created in mills and distilleries for skilled and non-skilled workers, but farmers and labor involved in cane production in the country will also benefit. Moreover, sugarcane production will return higher profits, enhancing the livelihood of rural communities involved in cane production (Arshad and Ahmed 2016).

Bagasse electricity production is also important because of the fact that it does not only limit the use of fossil fuels for power generation, but also reduces the impacts of sugar mills on environment by decreasing amounts of environmentally hazardous materials disposed of otherwise. Natural decay of bagasse generates methane gas, which impacts the ozone layer negatively (Janke et al. 2015). Pakistan is among the list of countries which are most vulnerable to the climate change. Hence, global, as well as internal, attempts to mitigate climate change are extremely important for the country (Khan et al. 2016). Furthermore, cane ethanol blending also cuts the carbon monoxide and hydrocarbons' exhaust as an advantage toward environmental aspects (Goldemberg et al. 2008).

Air pollution in Pakistan is several times high as compared to the international recommended standards. The life cycle analysis of well to wheels for ethanol has shown that ethanol has least CO_2 emissions among the transport fuels. Moreover, octane number of ethanol is 120, while, on the other hand, that of petrol is around 108.6, suggesting that ethanol blends can enhance the octane number of the fuel mitigating the use of hazardous substances like methyl tertiary butyl ether (MTBE). Therefore, adopting ethanol-based biofuels can help Pakistan limit greenhouse gases' (GHG) emissions as well (Arshad 2010; Shahad et al. 2008).

9.10 Limitations and Challenges

In spite of being a huge importer of petroleum on one hand, and a substantial producer of cane ethanol on the other, no significant use of fuel blending highlights the shortcomings at policy level. Absence of mandatory blending requirements at national level has limited the use of ethanol in fuel sector. Consistent policies and strict implementation are necessary for launching and adoption of ethanol-blended fuel. Proper marketing to build trust in the drivers for new fuel type is another challenge. Moreover, such blends need also to be provided at lower costs, so that the consumers could prioritize opting for blended fuel (Ali et al. 2012).

Financial reasons have been the greatest hindrance for mills to progress toward cane fuel and energy production. Upgradation of technology at distilleries and mills' boilers is necessary for Pakistan's case to enhance the efficiency and production capacity of such projects. However, the payback period of these huge investments is long, making the investors reluctant to involve in such programs. Low profit loans must be provided to encourage investments in this sector.

Regarding power production, government and mills have differed on tariff issues as the mills demanded higher tariffs keeping in view the large investments required in upgrading their boilers. Duration for launching the project, fuel availability, technical hurdles, and necessity of using demineralized water put barrier toward this industry. Also, remote location of mills, although an advantage from certain aspects, necessitates infrastructure development in some cases. Costs of connecting with the grid lines also represses the export of surplus energy to the national grid (Arshad and Ahmed 2016).

Challenges exist at the level of cane farming as well. Per hectare yield of the country is low as compared to many of the other cane-growing countries. Being a perennial and water-loving crop, sugarcane requires intensive agronomic practices for obtaining high cane yield and sugar recovery. Unapproved varieties are being planted, while other factors like limited irrigation resources, lack of technology adoption, irregular use of fertilizers, and poor management practices also introduce issues at cane production level. (Buzacott 1965; Dunckelman and Legendre 1982; Haq et al. 1974).

9.11 Future Perspectives

In spite of increase in local production and imports of oil and liquefied natural gas, Pakistan does not have enough supplies of energy to meet its demands. Power breakdowns happen routinely, especially when water reservoirs are low; CNG for transport sectors is available only on limited days; and gas supplies for domestic consumption are also not enough to satisfy the requirements. Thus, Pakistan needs to explore new possible routes of energy extraction for meeting the supply and demand gaps, which is expected to enhance renewable sources' (including sugarcane) role in energy matrix of the country.

Moreover, Pakistan is a signatory to various international environmental commitments and is one of the most actively involved countries of the world in mitigating climate change. Therefore, the country is anticipated to exploit renewable sources of energy for environmental reasons as well. Pakistan has recently completed Billion Trees Project in one of its provinces and is now on its way to planting 10 billion trees—showing the commitments of the nation to combat climate change (Constable 2018). Projects employing renewable energy in transport sector have already been planned for country's largest and highly populated city, i.e., Karachi. Hence, it can be expected that the national priorities are set to increase the renewable fuels' usage in the country.

Energy security and lower dependence on imported gasoline are other incentives ethanol fuels can offer. Having huge quantities of molasses available, and already well-set sugar industry, it can be estimated on an optimistic approach that ethanol may find applications for blending purposes in future. Ethanol blends can offer several advantages like reduction in air pollution and lower GHG emissions, complete burning of fuel, and the cuts in CO_2 emissions. Moreover, ethanol blends in the country can provide higher economic returns to distilleries against its exports. Hence, it can become a priority fuel of the country in coming years (Arifeen 2014).

Several measures can be helpful in enhancing sugarcane's role in bioenergy sector of Pakistan. Imposing higher taxes on molasses' export, and removing the same on industrial alcohol for boosting its production, can help. Financial support toward power plants and distilleries is another essentiality. Moreover, blending mandates need to be launched for ensuring sustainability toward ethanol fuel production. PSO can play significant role in marketing and expanding blended fuel availability.

9.12 Conclusion

Ethanol's role has remained limited in Pakistan's energy matrix. Attempts to enhance its position as a fuel blend have not produced significant results because of lack of planning and implementation in this multi-stakeholders sector. Nevertheless, keeping in view the availability of molasses, current economic scenario of the country, and its commitment toward climatic and socioeconomic goals, it can be anticipated that sugarcane bioethanol may be emphasized again in upcoming polices. The scope of sugarcane-based cogeneration of bioelectricity also holds great potential to tackle the electricity deficit in Pakistan; however, this phenomenon also has remained largely underexploited. Changing national policies and the insecurity of the investors are major reasons in this regard. Some of the mills are already supplying the cogenerated electricity to national grid; however, many others may follow if better incentives and economic support are offered. Pakistan is suffering from energy shortage, and therefore, renewable sources like sugarcane can contribute significantly toward ethanol-blended fuels as well as cogenerated electricity for the country.

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