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AGRICULTURAL WASTE BIOMASS ENERGY POTENTIAL IN PAKISTAN

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ABSTRACT: Pakistan has a major electricity supply problem with urban areas having a very intermittent supply of electricity. The supply gap at periods of high demand is 6 GW. Pakistan has a large agricultural economic sector and produces a substantial amount of waste material that has little current economic use. This work shows that these agricultural wastes are a significant energy resource that could be used to generate electricity using relatively small biomass generator sets that could take all the waste biomass from the surrounding agricultural area. Pakistan currently imports most of the oil used for electricity generation. The cost of this result in high cost electricity and it is shown that bio-electricity could be generated competitively in Pakistan. It was estimated, based on 30% thermal efficiency of electric power generation, that the annual production of crop residues have the potential to generate 76% of the annual electricity requirements of Pakistan. For this to come from agricultural wastes in farmland, transport costs would have to be minimised. It is proposed that a series of about 10MWe plants should be established (which are commercially available) with all farms in about a 10km radius delivering their agricultural solid waste to the plant at the farmers cost with direct payment by the power generator.
Keywords: Agricultural residues, Renewable energies, biofuel

1 INTRODUCTION

The current total population of Pakistan is about 190 million, with an annual growth of 1.9%. It is much larger than any individual European country. Pakistan currently faces a crisis of electrical energy supply with demand outstripping supply and frequent power cuts. Pakistan has over 30% of its 55 million population with no access to electricity [3]. The summer monsoon season has the peak electricity demand [4], due to the extensive use of air conditioning.

People in urban areas are facing 6-12 hours load-shedding whereas in the rural areas, it is worse. According to official statistics there is no electricity shortage, as the total production potential of energy in Pakistan was 94.65 billion KWh in 2014 utilizing all the available sources, whereas the energy consumption was 70.1 billion KWh [5]. However, this electricity consumption is that paid for and is not the real used of electricity. In reality at times of peak demand there is insufficient supply of electricity.

The trend in supply and demand for electricity in Pakistan is shown in Fig. 1 for 2008 – 2015 [6]. Every year in Fig. 1 there was an electricity delivery shortfall and this has got worse in recent years. The production of electricity has increased since 2008 in every year but the demand is increasing faster [6]. The shortfall of electricity was 6 GW in 2012 and ranged from 4 to 6 GW between 2008 and 2015. The main reason for this shortfall in electricity is the line losses and electricity theft. Also 45% of the total electricity generated is wasted as revealed by the water and power ministry [6]. Fig. 2 is an example of the electricity theft in Pakistan, where there is no control of connections to the grid distribution of electricity. However, the new Government of Pakistan has taken actions against this and a task force is tackling this.

Pakistan has reduced its demand for imported oil for transportation by utilizing compressed natural gas as fuel for road transport vehicles [7]. Pakistan generation of electricity is currently dominated by hydro, oil and natural gas [8]. The electricity supply shortfall is worst in winter when hydro plants start losing capacity due to the freezing temperature of hydro reservoirs. This leads to a demand for more electricity from gas plants to balance the gap between supply and demand. In summer the high consumption of electricity due to the use of air conditioners in the hot humid climate, compels the government to import large amounts of furnace oil for the diesel electric power generation. This cost is not affordable for the Government and the import cost of the furnace oil destabilizes the economy. Industrial investors are not willing to invest in factories in Pakistan as the electric power supply cannot be guaranteed. About 60 to 70% of the local textile industry has shifted to China, Bangladesh and India [9].

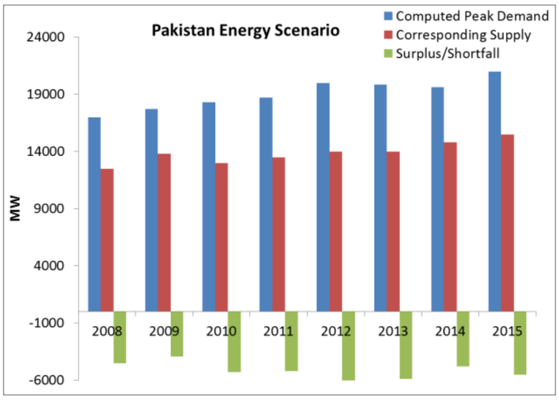

Figure 1: Pakistan yearly energy scenario [6, 10]

Figure 2: An example of distribution losses due to electricity theft in Pakistan

2 GHG EMISSIONS FROM ELECTRICITY GENERATION

2.1 Fossil fuels

The major source of greenhouse gases in Pakistan is from the combustion of fossil fuels in electricity generation power plants and road vehicles, 151.6 MMT in 2010 [11]. The major component of GHG's was carbon dioxide [12]. Fig. 3 shows the fuel sources of electric power in Pakistan in 2011. Expensive fuel oil accounts for 35% of electricity generation [10]. The other major fuels are gas, hydro and nuclear. There is currently no use of biomass to generate electricity and negligible use of coal. During 2011-2012, 19.2 million metric tons of petroleum products of worth US $ 15.2 billion were imported, 40 % of which was used for the generation of electricity [13]. Little attention has been given to the renewable electricity options, including the use of biomass. As the limited fossil fuels reserves start to be depleted [14] and no new reserves of fossil fuels have been discovered, the Government of Pakistan is now showing an interest in the renewable energy options and especially bio based energy options.

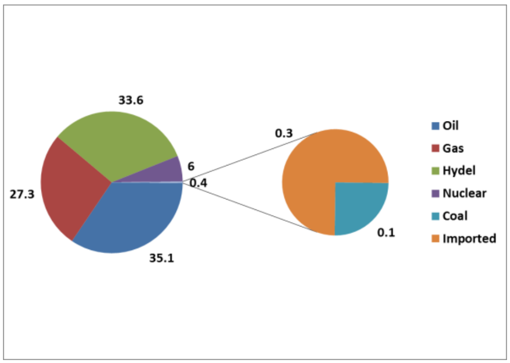

Figure 3: Fuel sources of electricity generation in Pakistan in 2011 [8].

2.2 Renewable Energy in Pakistan

The current status of fossil fuel in Pakistan is shown in Table I. More than half of the proven reserves have been consumed. The limited reserves of oil and natural gas force Pakistan to seriously consider renewable sources of energy. Farooq and Kumar [15] assessed the potential of renewable source of energy for Pakistan. They studied the current and the future potential of solar, wind, small hydro and biomass. The statistics of each

Table I: Fossil fuels reserves statistics in Pakistan

	Oil	Natural Gas	Coal
	Million Tonnes of Oil Equivalent 'MTOE'		
Resource potential	3622	6849	78450
Proven recoverable reserves	130	1067	845
Cumulative production so far	88	568	89
Remaining recoverable reserves	41	499	797
Annual Production	3.3	29.3	1.6
Reserve to Production ratio (# of years)	12	17	528

renewable source was estimated and calculations for generation of electricity generation potential were carried out. The total technical potential of solar based electricity was estimated to be 358 TWh in 2010 with a projected potential of 708 TWh for 2050. Clearly Solar is a renewable energy source that should be developed in Pakistan, but there is currently no infrastructure to install solar panels and no government subsidy to do so. Wind energy potential is mainly in the southern coastal areas of Pakistan and Farooq and Kumar [15] estimated the potential wind electrical power generation to be 34 TWh per year. The total potential of small hydroelectricity was identified to be 3 GW.

Farooq and Kumar [15] estimated the total potential of bio based electricity generation to be 20.3 TWh for 2010 and the projected potential for 2050 was 55.6 TWh. They used an assumed thermal efficiency of the biomass electricity plants to be 30%, which is conservative but realistic for small scale plant. A 30% thermal efficiency of small scale biomass steam generation electricity generating plant has also been assumed in the present work. However, it is shown in the present work that Farooq and Kumar [15] underestimated the current potential of biomass electricity in Pakistan. Biomass energy was rated by Farooq and Kumar [15] at the top of the list of the various renewable energy technologies for the generation of electricity and we agree with this.

If all of these renewable fuels were utilized then the current reliance on fossil fuels could be minimized [15]. The Government of Pakistan has taken steps towards liquid biofuel utilization in transport fuels by approved a policy to have the minimum 5% by volume of biodiesel in diesel and targeted this to increase to 10% in 2025 [16]. This is essentially the European policy with the implementation date for 10% biofuels five years later than Europe. However, there is currently no policy on the encouragement of biomass for electric power generation.

Among the various renewable energy sources, bio based energy is attractive for Pakistan, as substantial agricultural biomass residues are generated each year and their disposal is already a problem [17, 18]. The size of these residues is estimated in the present work based on the published yields of food crops. Renewable biomass is a very important alternative source of energy contributing 10-14 % of the energy needs of world today [19]. Pakistan is a major agricultural country with multiple crops produced every year as a result of its favorable climate. More than 70% of the population of Pakistan live in rural areas and are farmers [20]. Urban areas of Pakistan generate ~20 MT/yr of solid wastes, ~82.12 MT/yr of crop residue and over 365 MT/yr of animal manure [21].

Agriculture is the mainstay of Pakistan's economy. It accounts for 24% of the GDP and employs 48.4% of the total labour force. Agriculture contributes to growth as a supplier of raw materials to industry as well as a market for industrial products and also contributes 60% to Pakistan's export earnings [22].

Pakistan is in a geographic location that has all the climates. The cool dry winter season is from December to February and from March to May, there is a warm spring, then from mid-May to November is summer and the monsoon season [23]. There are two principal crop seasons in Pakistan namely "Kharif", with sowing beginning in April and harvest between October and December and "Rabi" beginning in October-December and ending in April-May. Rice, sugar cane, cotton, maize and millet are Kharif crops, while wheat, gram, tobacco, rapeseed, barley and mustard are Rabi crops.

2.3 Previous Estimates of Biomass Energy Potential in Pakistan

Amur and Bhattacharya [24] estimated biomass and their residues for various applications in Pakistan. The major application of biomass is in the household sector which is 86% of total biomass energy. The traditional cooking stoves employed in rural areas of Pakistan are currently the major end users of biomass energy and utilizes 80% of current bioenergy. About 64% of the population in Pakistan is utilizing biomass for cooking [3]. In proposing an increased use of agricultural waste biomass for electric power generation in this paper, we are referring to agricultural wastes that are not currently used for domestic cooking.

Mirza et al. [25] surveyed the potential of biomass to contribute to Pakistan's energy needs and concluded that biomass was a potential source of significant energy in Pakistan. They advocated that biomass based energy could be made more efficient using advanced co-generation (power and heat) technology. However, as Pakistan has a negligible building heating requirement and a significant building cooling requirement, the advocacy of CHP is inappropriate as it needs a heating load greater than the electric power demand in order to achieve the best overall thermal efficiencies of around 80%.

Mirza et al. [25] advocated that municipal solid waste and animal dung could be utilized in electric power generation. The use of municipal waste for power generation is established technology, but needs capital investment to build the plants and reduce waste going to landfill. However, animal dung is a dispersed source of fuel and needs collecting by farmers. The transport cost to distance large power generation plants is not realistic and hence it has the same issues as the utilization of agricultural wastes that are discussed in this work. Plants that can burn agricultural waste biomass can also burn dried animal dung. It will be shown in this work that agricultural waste biomass and waste wood biomass in Pakistan are a much greater resource than those discussed by Mirza et al. [25].

Bhutto et al. [26] demonstrated biomass as a major renewable source of energy, with some issues in implementing, as it has a lower calorific value with slow burning compared to coal or hydrocarbon fuels. They presented biomass statistics and the scope of contribution to energy output. The possible transportation means for the biomass were elaborated. The potential energy conversion of these biomasses was estimated using assumed electric power conversion efficiencies, depending on the type of biomass and the route/technology used.

The existing and future projects of the generation of biogas from the animal dung were discussed by Bhutto et al. [26]. Although biogas can be generated by anaerobic digestion from animal waste, it is a very high capital cost intensive solution to the energy crisis. Current costs are approximately £5B per GW of generating capacity, roughly the same as offshore wind generation costs. Also the process costs more for small scale of the plant and for a 100 cow farm is about £100K for 10 kW electric, which is roughly 10 times the current cost of solar electric energy. Advocating expensive solutions to the Pakistan energy problem is not helpful. The direct burning of biomass to generate steam and then electricity in small scale powerplant, which is advocated in the present work is considered to be a lower cost option, that would nevertheless require Government funding to make the local generation of electricity strategy, that is advocated, work in a large number of areas.

Currently there is little industrial application of biomass. The purpose of this work is to demonstrate that the potential for biomass electricity in Pakistan is greater than has been estimated in previous publications. It is advocated that biomass generation of electricity should be adopted as a major part of the Government of Pakistan's renewable energy policy.

2.4 Advantages and Disadvantages of biofuel

Biofuel has following advantages such as;

- It is renewable
- Environmental friendly
- Biomass production and consumption follow the cyclic process so the net effect of carbon dioxide generation is negligible.
- Can be substituted with coal in existing power plants.
- Economically feasible.

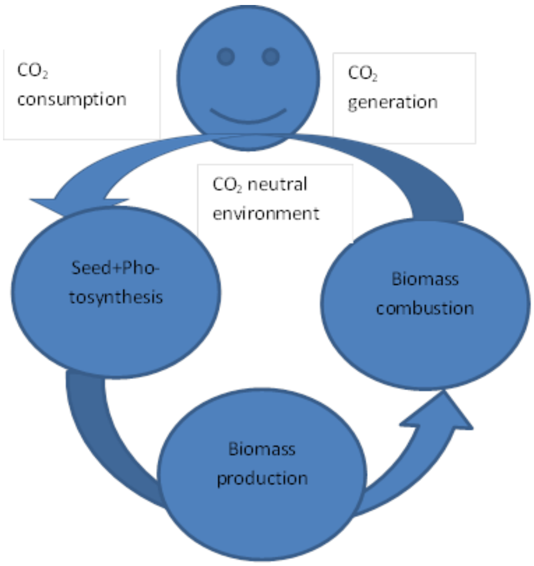

Figure 4: Carbon cycle for biomass

Fig. 4 shows the cyclic process of CO_2 absorption during the growth of plants and trees and the release of this CO_2 when it is burned. Biomass in the presence of sunlight absorbs carbon dioxide and water for their growth (photosynthesis process) and in the combustion phase, this stored sunlight energy and absorbed Carbon dioxide is a carbon neutral cycle and thus biomass combustion for energy generation is deemed to be carbon neutral and biomass is treated as a renewable fuel for GHG audit purposes. In practice energy is used by farmers in planting and harvesting crops and so the process is not strictly carbon neutral and auditing this upstream CO_2 leads to figures on the sustainability of biomass or the efficiency of the CO_2 reduction. The EU and USA have drawn up sustainability criteria for biomass and any biomass used for power generation has to meet the approved sustainability criteria. Similar procedures would have to be adopted in Pakistan to ensure that the production of biomass was sustainable.

The main drawback of biomasses is its handling as it is a low bulk density fuel with a high moisture content [27]. The long distant transport of these biofuels requires large volumes and hence high cost as the bulk density is low and hence for a given energy content occupies a larger volume than coal. The higher moisture content makes shipping and road transport expensive, as essentially water is being transported which leads to poor transport economics. Also the biomass materials are very reactive and need careful attention in handling, storing, conveying, milling and combustion. Fire and explosion hazards in biomass storage, transport and utilization is a significant hazard and there have been many fires and explosions on biomass plant [28-33].

2.5 Techniques to improve biofuels for its exploitation

2.5.1 Use of Raw Biomass

Raw biomass dried by solar energy is the most cost effective use of biomass. Raw biomass such as logs or bales of agricultural waste is normally burnt in stoker fired moving grate combustion systems with two stage combustion using under fired for the gasification first stage and overfired air for combustion of the hydrogen, CO and hydrocarbons from the gasification stage. This process is economically feasible, as it has the minimum biomass pretreatment costs, if the source of the biomass is close to that of the power plant, which is the scenario we are advocating for Pakistan. The key factor in the biomass fuel composition is the quality of the solar drying or the water content of the biomass and the ash content of the biomass, which will be discussed later. Wood is normally low in ash (<1%) and agricultural waste materials are normally high in ash (6% can be typical). Water and ash content of biomass on a mass basis directly reduces the fuel calorific value on an as received basis. Ash can be reduced by water washing the biomass and this would be advocated for all agricultural waste biomass [34].

Where the biomass power station is remote from the source of the biomass, as it is in most UK applications of biomass for electric power generation, then the issue of the transport costs of the biomass is critical in the costs. Transporting raw biomass with relatively high water content, high ash content (for agricultural biomass) and low bulk density would be prohibitively expensive. To overcome this problem biomass is washed to reduce ash, dried using external heat and densified by being formed into pellets [35].

2.5.2 Densification

There are two types of densification available: simple compression of dried biomass into briquettes, as available in China, and pulverisation of the biomass into a powder which is dried and then compressed into pellets [36, 37]. The compact shape of pellet or briquetted biomass enables more biomass to be stored in a fixed volume and hence increase the energy density of the transport costs. As pellets are pre-pulverised at source and only need to be broken up in the coal mills, they are the preference for large scale use in pulverized coal power stations as is currently done in the UK. However, for smaller power generation steam cycles using briquettes of dried compressed biomass is more practical.

2.5.3 Fouling issues of biofuels

Biomass based on wood is generally low in ash, but biomass based on agricultural wastes, as advocated in this work have variable ash content. Ash is a problem in that it reduces the CV per kg of biomass. However, its main problem is the ash consists of various metals such as potassium, iron, magnesium, manganese, sodium etc. and this creates boiler fouling and corrosion problems.

Table 2: Water and Ash Content of a Range of Biomass [28, 31, 38]

Biomass	H_2O (%)	Ash (%)	CV (MJ/kg)
Rice Husk	7.7	17.9	15.2
Rice Husk <63µm	6.56	31.2	14
Bagasse	7.2	20.1	15.6
Bagasse (<63µm)	6.85	23.4	15.05
Wheat Straw	6.8	22.8	14.5
Wheat Straw <63µm	3.98	49.2	13.93
Lycopodium	1.6	4.1	29.6
Corn flour	11.6	3.8	16.4
Walnut Shells	4.95	6.3	18.75
Pistachio nut shells	2.7	8.3	17.8
Pine wood	4.27	4.4	19.2

Some typical biomass ash and water contents from the work of the authors are shown in Table 2. Some of the agricultural waste samples are very high in ash and this would have to be reduced by a pretreatment water washing process, which will increase the cost. Table 2 shows a feature of biomass ash that has not been reported before and this is that milling of the biomass into a finer powder <63 µm, concentrates the ash in the finer fraction.

The alkaline earth metals are released from the soil into the biomass in the growing process and potassium is one of the key ingredients in agricultural waste ash. For the utilization of agricultural waste biomass for power generation, washing is applied to reduce these alkali metals. Washing by water or acid leaching techniques are the most effective in controlling the alkali metals release from biomass [34]. Simple water leaching can reduce alkali metals of up to 70-80% [34].

2.5.4 Torrefaction of Biomass

Torrefaction is a pretreatment process of biomass that is carried out by heating the biomasses in the absence of air or in an inert environment at a temperature in the region of 200-300^{0}C for 20 minutes. The resultant process gives a very dry biomass and drives off some volatiles [39], that may be used for the heating requirements of the process. The main effect is to destroy the fibrous nature of woody biomass and makes the fibres brittle. The material is more easily pulverized in coal mills at power plants. A further benefit of torrefaction is to enhance the calorific value and to reduce the moisture contents. This extensive pretreatment of biomass can lead to better boiler performance and hence to a higher thermal efficiency of the power generation plant. However, initially it will be considered to be a process too expensive for biomass utilization in Pakistan. It may need to be considered if the combustion of raw biomass proves to be too problematic in poor thermal efficiency in the steam generator.

Table 3: Summary of Agricultural Waste Resources in Pakistan (Updated from [26, 40])

Name of the crop	Annual production 1000 MT*	Type of residue	Crop to residue ratio residue /kg crop	Total residue 1000 MT	Energy Potential MTOE **
Rice	6160[1]	Husks	0.2[(3)]	1232	0.529
		Stalks	1.5[(3)]	9241	3.973
		Straw	1.5[(3)]	9241	3.973
Cotton lint and cotton seed	6605[1]	Boll shell	1.1[(3)]	7266	3.124
		Husk	1.1[(3)]	7266	3.124
		Stalks	3.8[(3)]	25100	10.791
Wheat	25,214[1]	Pod	0.3[(3)]	7564	3.252
		Stalks	1.5[(3)]	37820	16.260
Sugar cane	55,309[1]	Bagasse	0.33[(3)]	18252	7.847
		Top and leaves	0.05[(3)]	2766	1.189
Maize/Corn	4270.9[1]	Cobs	0.3[(3)]	1281	0.551
		Stalks	2[(3)]	8542	3.672
Millet	304[1]	Cobs	0.33[(3)]	100	0.043
		Husks	0.3[(3)]	91	0.039
		Stalks	2[(3)]	607	0.261
Barley	71.2[1]	Stalks	1.3[(3)]	93	0.040
Dry chilly	203[1]	Stalks	1.5[(3)]	304	0.131
Walnuts	10.4[1]	Shells	0.5[(E)]	5.2	0.002
Pistachio nuts	0.7[1]	Shells	0.5[(E)]	0.4	0.0002
Pine nuts	21[2]	Cone	50[(4)]	1050	0.451
		Shells	0.3[(E)]	6.3	0.003
Peanuts	87.9[1]	Shells	0.3[(E)]	26.4	0.011
Coconut	10.1[1]	Shells	0.5[(E)]	5.1	0.002
Castor oil seed	4[1]	Residue after oil extraction	0.55[(E)]	2.2	0.001
Peaches and nectarines	54.4[1]	Pit	0.5[(E)]	27.2	0.012
Papayas	7.8[1]	Seeds	0.2[(E)]	1.6	0.001
Plums and sloes	54.5[1]	Pit	0.3[(E)]	16.4	0.007
Rape seed	195[1]	Residue after oil extraction	0.5[(E)]	97.4	0.042
Sun flower seed	404[1]	Residue after oil extraction	0.5[(E)]	202.2	0.087
Total					59.42
Biomass energy conversion efficiencies[(5)]					20%
Transmission and distribution losses[(6)]					20%
Total energy available					9.51
Energy consumption per year [(6)]					6.37
Total energy available from a year collection of residues = 1.5 years					

(1) [41], (2) [42], (3) [40], (4) [43], (5) [44]
(6) [45], (E) Estimated this work
* Annual production data for the year 2012- except for pine nut shells where 1994 data is used
** 1 MTOE = 11.6 TWh [46]

3. BIOMASS ENERGY RESEOURCES IN PAKISTAN

3.1 Distribution and share of biomass materials

Fig. 5 shows the major uses of the 80M ha of land in Pakistan [47]. 44M ha is identified agricultural land, but there is a large proportion (>40%) of range land, which has potential for an expansion of this sector, particularly as grazing land.

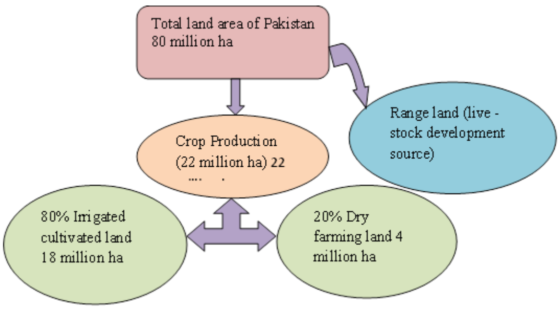

Figure 5: Pakistan land distribution [47]

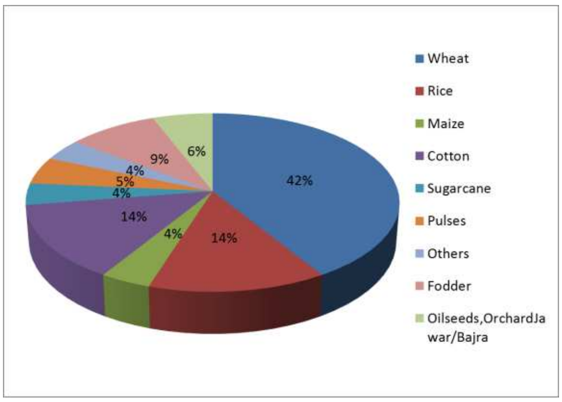

Figure 6: Percentage of crop area under various crops [48]

Fig. 6 classifies the proportion of different crops in Pakistan [48]. Five major crops: wheat, cotton, sugar cane, rice and maize account for about 87% of fertilizer consumption [47]. Wheat accounts for about 45% of fertilizer use followed by cotton with a share of 23%. Sugar cane is the third crop; nutrient use per ha is highest for this crop.

4 YEARLY GROWTH OF CROPS AND THE ELECTRICITY GENERATION POTENTIAL

4.1 Agricultural Waste Crop Residues Potential for Electricity Generation

The statistics for growth of biomass can be explained on the basis of three main terms: the area available, the production and the crop yield [49]. Crop area is the surface of land on which a crop is grown. In general, the area measured for cadastral purposes includes, in addition to the area cultivated, headlands, ditches and other non-cultivated areas may give additional crop growing areas. Crop production is obtained by multiplying the average yield per unit of area by the corresponding crop area harvested.

Crop yield is the measurement of the amount of a

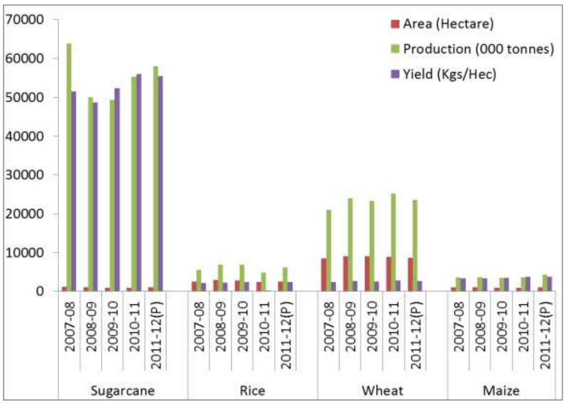

Figure 7: Production trends of major crops in Pakistan [50]

Crop that was harvested per unit of land area. This measurement is often used for a cereal, grain or legume and is normally measured in metric tons per hectare (or kilograms per hectare). Crop yield can also refer to the actual seed generation from the plant. For example, a grain of wheat yielding three new grains of wheat would have a crop yield of 1:3. It is also referred to as "agricultural output".

The production of most of the crops in Pakistan with their respective residues and their energy potential is summarised in Table 3, which is based on the present work and previous estimates [24, 38]. Energy potential is calculated assuming heat capacity of 18MJ/kg for all the biomass and assuming a very poor thermal efficiency of the power generation plant of 20%. It can be seen in Table 3 that if Pakistan collects all the residues for a year, these are alone sufficient to fulfil the requirements for energy production for up to 1.5 years (this calculation assumes 100% collection efficiency).

Table 3 shows that the most import agricultural waste crops in Pakistan for power generation are rice, cotton, wheat, sugar cane and maize. However, the other smaller amounts such as nut shells are significant as the process of collection of this biomass is already organised for the production of nuts. Thus the nut shells are all in one place and could be used for power generation there. Nut shells pulverise in a sumilar way to coal as they are brittle and Sattar et al. [31]has shown that they are quite reactive and will propagate flames.

Memon et al (2006) estimated the energy potential crop residues as shown in Table 4. This shows that that if Pakistan utilised its agricultrual crop wastes could produce all its electricity from biomass.

Tables 3 shows that four of the main crops which are abundantly grown in Pakistan are sugarcane, wheat, rice and maize [5, 50]. Fig. 7 shows the trends in production of these four main crops in Pakistan from 2007 to 2012. The residues obtained from these major crops are enormous, as shown in Tables 3 and 5, but are currently wasted. Utilization of these residues for biomass energy is a valuable potential source of renewable electricity.

Fig. 7 shows that sugarcane is a major crop in Pakistan and has the greatest yield per hectare. During 2010-11, the area under sugarcane cultivation was 1,029,000 hectares which is 4% of the total cropped area. Sugar cane waste, which constitutes 10% of the sugarcane, is currently burned in the fields. During 2010-11, around 64 MMT of sugarcane was grown in Pakistan, which resulted in biomass waste generation of around 6 MMT. The bioenergy potential of cane waste is around 9.5 TWh per year [52].

Table 4: Projection of energy potential crop residues in Pakistan. [51]

Year	Total Energy Projections (MTOE = 11.6 TWh)
2005	35.5
2010	38.2
2015	41.1
2020	44.3
2025	47.7
2030	51.5

For each 10 tonnes of sugarcane crushed, a sugar factory produces nearly 3 tonnes of wet bagasse [20]. Since bagasse is a by-product of the cane sugar industry, the quantity of production in each country is in line with the quantity of sugarcane produced [53]. There are more than 70 sugar producing factories in Pakistan that are generating million tonnes of bagasse and should be the basis of electric power generation from this waste [54]. Utilization of bagasse in cogeneration could enable sugar mills to provide 700 MW surplus power to the national grid [55]. The potential annual electricity production from bagasse has been estimated to be 5700 GWh [56].

Table 5 shows different biomass crop residues production for Pakistan in the year 2010-2011 that were calculated from the production mass of the food part of the crops [50] and using crop to residue ratios [26]. The residues of biomass were conservatively assumed to be collected with a 35% collection efficiency [15]. Table 5 shows that the total energy that could be produced from these four biomass samples in Pakistan with 30% electrical generator efficiency was 40 TWh/y and this is 56% of the demand for electricity in Pakistan.

4.2 Woody (forestry) biomass energy resource

The forest area of Pakistan has been estimated by the Food and Agricultural Organization of United Nations (FAO) in 2010 as 16,870 km^2 which is 2.19 % of the total land area (770,880 km^2) of Pakistan. Other wooded land estimated by FAO was 14,550 km^2, which is 1.88 % of the total land area of Pakistan [57]. The forest area of Pakistan includes coniferous and non-coniferous forests while scrub forests fall in the category of other wooded land. Linear plantations, farmland trees and miscellaneous plantations are categorized as other land which contributes further 1% to the total land area of Pakistan. The contribution of total tree area towards the total land area of Pakistan is 5.1 %. Categories of forests and the total tree area of Pakistan are provided in Table 6.

4.2.1 Sustainability and tree rotation period for forests in Pakistan

The rotation period of an even age stand of tree is the period between the plantation and a time when that stand becomes ready to be cut. This period, usually called the "optimum" rotation period, becomes important when a forester tries to determine the most beneficial harvest conditions. The rotation period is usually reached when a stand is economically mature or growing beyond natural maturity.

The Pakistan Forest Institute in Peshawar has undertaken a study on the rotation and economic

Table 5: Yearly Energy yield from four major crop residues

Major Crops	Crops Production ($x10^3$) 'tonnes'	Crop wastes	Residue to Crop ratio	Residue Production ($x10^3$) 'tonnes'	Collection ($x10^3$) 'tonnes'	Calorific Value 'MJ/Kg'	Heat Contents ($x10^6$) 'GJ'
Rice	4823.3	Husks	0.2	964.7	337.63	15.16	5.12
		Stalks	1.5	7234.95	2532.23	10.05	25.4
		Straw	1.5	7234.95	2532.23	10.05	25.4
Wheat	25213.8	Pod	0.3	7564.14	2647.45	14.49	38.4
		Stalks	1.5	37820.7	13237.2	16.5	218.4
Sugar-cane	55308.5	Bagasse	0.33	18251.8	6388.13	15.63	99.8
		Top and Leaves	0.05	2765.4	967.9	18.4	17.8
Maize/Corn	3706.9	Cobs	0.3	1112.0	389.22	16.12	6.3
		Stalks	2	7413.8	2594.83	14.65	38
Total heat contents of the four major biomass residues 'GJ/y'							$4.7x10^8$
Total energy obtained TWh/y							1300
With 30% Efficiency TWh/y							40
Total average requirement in Pakistan in 2014 TWh/y [5]							70

Almost 56% of the annual demand for electricity can be met by the utilisation of agricultural waste in Pakistan for an electrical generator steam turbine thermal efficiency of 30%.

Table 6: Yearly energy potential from the forests and wood lands of Pakistan

Category		Area km^2	Growing Stock m^3/km^2	Growing Stock ($x10^6$) m^3	Growi-ng Stock ($x10^9$) kg	Annual cutting rate %	Annual cutting rate of total growing stock ($x10^9$) kg/y
Coniferous Forests		11,110	12380	137.5	96.3	2	1.93
Non-Coniferous forest	Riverain forest, Mangrove forest	2,360	3900	9.2	6.4	2	0.13
	Irrigated Plantations	3,400	3900	13.3	9.3	6.5	0.60
Other wood land (Scrub Forest)		14,550	3900	56.7	39.7	2	0.79
Other land (Linear plantations, Farmlands, misc. Plantations)		7,980	-	97.0	67.9	6.5	4.4
Total		39,400		314	220		7.87
Heating value of green wood with moisture contents 50% 'MJ/kg' [58]							9.5
Total energy contents from wood per year 'GJ/y'							$74.74 x10^6$
Total energy obtained 'GWh/y'							$2.08 x10^4$
With 32% efficiency 'GWh/y'							6650
Total average requirement in Pakistan in 2014 'GWh/y' [5]							$7.0x10^4$
Contribution of wood towards annual consumption of electricity							9.5 %

Table 7: Yearly energy potential from the oilseed residues of Pakistan

Crops	Seeds Production (x10⁶) kg	Oil production (x10⁶) kg	Seed waste (x10⁶) kg	Residue type	Residue Production (x10⁶) kg	Calorific Value 'MJ/Kg'	HEAT (x10⁶) MJ
Cottonseed	3592	431	3161	Cake	1006	20.8	20920.64
				Hull	2155	17.5	37716.00
Rapeseed / Mustard	218	68	150	Cake	150	20	3000.00
Sunflower	265	101	164	Cake	131	15.8	2072.96
				Hull	33	17.6	577.28
Canola	16	6	10		10	23.6	236.00
Total heat contents of the r oilseed residues 'GJ/y'							64.5×10^6
Total energy obtained 'GWh/y'							17.92×10^3
With 32% efficiency 'GWh/y'							5734
Contribution of oil seeds residue towards annual consumption of electricity							8.2 %

management of the coniferous forests of Pakistan. It was found that the financially best rotation period ranged between 50-70 years. Studies suggest that if a longer rotation period is employed, the process becomes uneconomic and valuable resources are underutilized. The study suggested a period of 50 years over which all over mature trees are cut down and a new system of management introduced [59]. Using a rotation period of 50 years the forest may be sustainably used if 2% of the forest is cut down annually, along with the plantation of 2% new forest trees.

The most common trees in the irrigated plantations and other land include Eucalyptus camaldulensis, Dalbergia sissoo, Bombax ceiba, Populus deltoids and Acacia nilotica [57]. The optimum rotation period for these trees have been found to be 10 years for Eucalyptus camaldulensis [59], 22 years for Dalbergia sissoo [60],15 years for Bombax ceiba [61], 10 years for Populus deltoids and 9-14 years for Acacia nilotica [62].

An average rotation period for trees in irrigated plantations as well as for trees in the other land is about 15 years, which allows 6.5% of the forest to be harvested annually provided the equivalent number of trees are planted annually.

4.2.2 Growing Stock in the different Forests

FAO defines growing stock as the "Volume over bark of all living trees more than 4 cm in diameter at breast height (or above buttress if these are higher). This includes the stem from ground level or stump height up to a top diameter of 1 cm, and may also include branches to a minimum diameter of 5 cm" [57]. Growing stock for coniferous forests as well as non-coniferous forest as reported by FAO is given in the Table 6. Total growing stock for the other land has been estimated to be 97 million m^3 [63]. Wood density used for the calculations is taken to be 700 kg/m^3 as is used by FAO. The conversion efficiency of a gasification plant is taken to be 32% [64, 65]. The calculations in Table 6 show that the total energy potentially obtainable from wood is 6.65 TWh/y, which would contribute 9.5% towards the annular electricity demand of Pakistan.

4.3 Estimation of Energy from Oil Seed Residues in Pakistan

The major oilseed crops grown in the Pakistan include Sunflower, Canola, Cottonseed and Rapeseed/ Mustard. Although the cotton crop is grown for its lint, cottonseed contributes 50 to 60 % of local edible oil production [66].

In Pakistan oil seed extraction is done by oil expellers (traditional kohlus), low and high pressure expellers and solvent extraction plants. Oil expellers (kohlus) are used for the extraction of oil from rapeseed and mustard and these are located in the villages [67]. Extraction of cotton seed oil and sunflower seed oil is done by low and high pressure expellers. The residue from this process is then exposed to a solvent for further oil extraction [68].The quantities of oil seed crop residues in Pakistan and the energy contents of these residues are summarised in Table 7 [69-73]. Cotton seed and sunflower seed residues consist of hulls and cakes, while mustard, rapeseed and canola seeds residues consist of compressed cake. Cotton seeds hull is 37-60% of the total weight of the seed depending upon the type of the seeds [74], while sunflower hull makes 18-20 % by weight of the processed seed [75]. Table 7 shows that oilseed crop residue have the potential to generate 8.2% of the annual electricity demand in Pakistan.

4.4 Estimation of Energy Obtained From Banana Tree Waste in Pakistan

In Pakistan banana cultivation started after independence. The major banana producing area is Sindh province and 90% of bananas in Pakistan comes from this province[76]. The banana plant is has a large residue after that banana crop has been picked with 100% of the waste burnt in the field. Banana plants are cut every four months and thrown into the field side or along the road side. When they are dry they are burnt with no use of the energy released. Table 8 summarises the energy potential of banana tree waste in Pakistan.

Table 8: Yearly energy potential from banana tree residues in Pakistan

Area Km^2	No of banana tree per Km^2	Frequency of cutting per year	Weight of air dried banana tree kg	Total banana tree waste ($\times 10^6$) Kg/y	Calorific value 'MJ/kg'	Energy content from banana tree waste ($\times 10^6$) MJ/y
296 [77]	173000	3	7 [78]	1075	17.8 [79]	1908
Total heat contents from banana tree residue ''GWh/y'						5300
With 32% efficiency 'GWh/y'						1696
Contribution of banana tree residue towards annual consumption of electricity						2.4 %

5 COST COMPARISON

Among the different renewable energy technologies, biomass conversion to energy is one of the most economical and simple technology. The size of the plant for the biomass conversion to energy can be built in the 1-20 MW capacity range or higher [21]. The use of smaller plant sizes is advocated so that they can be located where the waste biomass resources are. This enables the transport costs to be minimized.

Fig. 8 shows the comparison of the cost of renewable energy options for various countries [80]. The large coloured bars represent the typical LCOE (Levelized Cost of Energy) range by technology and the coloured horizontal lines the weighted average. Biomass renewable energy is lower capital cost than wind energy and considerably lower than diesel electric power generation. Biomass energy thus has significant potential Pakistan.

6. LOCAL ELECTRIC POWER GENERATION IN SMALL UNITS

Fig. 9 shows the overview of the envisaged small scalebiomass power generation based in the locality in which the agricultural waste materials are generated so that the transportation costs are minimised. A radius of 10 km around a small power plant would have sufficient waste biomass material to operate a 10 MW power plant. The summation of the above four main agricultural waste materials could generation a total of 76.1% of Pakistan's electricity supply. The peak electricity demand is 20 GW and about 15GW could be generated from biomass. If 10 MW small scale biomass electric power plants are installed then to meet the 15GW peak demand 1500 units would be required. The total farmed land area in Pakistan is 240,000 km^2 and all the waste biomass is assumed to come from this area. This would give a farmed area of 160 km^2 to supply the biomass for each 10 MW power plant. This is a square around the power plant of 13 km and would give a journey length of at most 7km for the most distant farmer. This is a practical distance for animal driven carts to transport the biomass to the plant and hence is feasible from a low cost transport viewpoint.

Pakistan has already made a start on a biomass electricity generation strategy and Tables 9 and 10 list the biomass power plants which are being built (Table 9) and co-firing (Table 10) for the generation of the electricity [1]. Most of these power plants are establishing by the private investors or the industrial stakeholders. Three of the biomass plants are of the above size of about 10 MW for the biomass feedstock to come from farm agricultural waste in easy animal powered transport distance of the plant. Other power plants are larger and being built to supply power to the industry that has generated the biomass waste.

As Pakistan has substantial coal reserves, and if these are exploited and coal fired powerplants built then these can be used for co-firing with waste biomass. Some of the cogeneration projects using biomass under considerations in Pakistan generating heat and power simultaneously as shown in Table 10 [2].

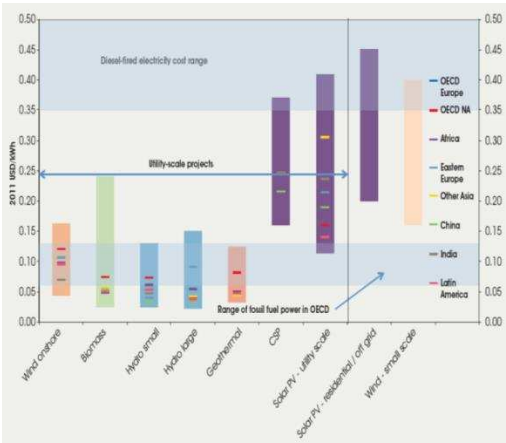

Figure 8: Cost comparisons of different energy options [64]

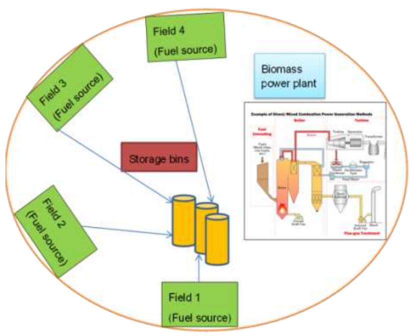

Figure 9: Imaginary layout of small plant in the vicinity of agricultural land

Table 9: Biomass Power plants in Pakistan in progress [1]

Location of Plant	**Power generation**	**Size of Plant (fuels utilization) 'tonnes' (x10^3)**	**Agricultural crops**	**Sponsorship & Cost in $**	**Biomass supply source**
Jhang, Punjab	12 MW (Steam turbine)	90-110 at 70-80% plant capacity factor in a year	Cotton stalk, rice husk, sugarcane trash, bagasse, wheat chaff and other crops as multi-fuel sources	Lumen Energia Pvt Ltd U.S $ 14.38 Million on debt / equity ratio of 80:20	Rice & Sugar factories in the vicinity
Mirwah Gorchani Town, Mirpurkhas, Sindh.	12 MW (Steam turbine)	**Open yard storage**:24.5 (equivalent to 45days full load operation), **Covered storage**: 2.2(Equivalent to 4 days full load operation)	Primary fuels: Bagasse, Rice husk Secondary fuels: Cotton Stalks, Wood Chips	Investors from US and local entrepreneurs the SSJD Bioenergy Generation	Al-Abbass sugar Mills Ltd, Tharparkar Sugar Mills Ltd,Digri Sugar Mills Ltd, Najma (Thar) Sugar Mills Ltd,Mirpurkhas Sugar Mills Ltd
Faisalabad, Punjab	12 MW	-------	rice husk, corn cob, cotton sticks, agricultural by-products	M/s Masood Textile Mills	-------
Mardan, Khyber Pakhtunkhwa	200 MW	-------	-------	M/s Greensure Environmental Solutions (Pvt) Ltd	TMA, Mardan
Matli, Sindh	9 MW	-------	Biogas (Based on sugar molasses)	Pak Ethanol (Pvt) Ltd	-------

Table 10: Biomass Co-generation Power plants in Pakistan in progress [2]

Sr. No.	Project	Sponsor/Company Name	Feedstock	Location	Net Capacity (MW)
1	JDW Cogeneration Project	JDWP/JSML	Bagasse/Coal	Near Rahim Yar Khan, Punjab	80
2	Ramzan Cogeneration Project	Ramazan Energy/Sharif Group, Ramaz Sugar Mills	Bagasse/Coal	Bhawana, Jhang Road Chiniot, Punjab	100
3	Janpur Cogeneration Project	Janpur Energy/RYK Mills	Bagasse/Coal	Janpur, District Rahim Yar Khan, Punjab	60
4	Fatima Cogeneration Project	Fatima Energy/Fatima Sugar Mills	Bagasse/Coal	Sanawan, Kot Addu, Muzaffargarh, Punjab	100
5	Chishtia Cogeneration Project	CPL/CSML	Bagasse/Coal	Sillanwali - Sahiwal road District Sargodha, Punjab	65
6	Dewan Cogeneration Project	Dewan Energy Ltd	Bagasse/Coal	Dewan City 20 Km from Sujawal on Sujwal-Badin Road, Sindh	120
7	Etihad Cogeneration Project	Etihad Power Generation Ltd	Bagasse/Coal	Karamabad District Rahim Yar Khan Punjab	60

National Electric Power Regulatory Authority 'NEPRA' has taken a landmark decision of supporting bagasse based co-generation projects. In order to attract the sugar mills to generate 3GW of potential biomass electricity through the use of waste bagasse. An IRR of 18% will be given as an incentive which is 3% higher than the IRR allowed to thermal projects on RFO/Gas [10].

7 CONCLUSION

Pakistan is one of the developing countries which are struggling hard to meet the demand for electric power generation. Pakistan currently relies on fossil fuel sources of energy that are expensive and bad for climate change. Renewable and sustainable biomass was shown to have the potential to generate 76% of the peak demand for electricity in Pakistan. Sugarcane, wheat straw, rice husk and maize are the main agricultural waste materials that could generate 56% of Pakistan's electricity. Also it was shown that woody biomass could sustainably generate 9.5% of the peak demand for electricity. The remaining significant biomass resources were seed oils (Cottonseed, Rapeseed Mustard, Sunflower and Canola) that could generate 8.2% of electricity. Banana trees that are widely spread in southern areas of Pakistan could generate 2.4% of electricity.

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