Assessment of biomass energy resources potential in Pakistan for power generation

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Abstract— **Pakistan is facing severe economic crises due to continuous increasing gap between energy demand and supply. Demand is increasing exponentially and expected to increase more than 66000 MW by 2030 while the supply is observed to remain constant over the last few years due to frozen capacity in spite of having significant renewable/alternate energy resources. Current electricity shortfall has reached up to 6000 MW. This paper investigates the potential of two major biomass energy resources available in Pakistan: Livestock and Bagasse. These resources, if utilized to their full extent for power generation, can contribute up to 42% in the current scenario. The biomass resource quantification is done along with its environmental impact assessment in terms of methane emissions pre and post production of biogas. Economic appeal of biomass energy is demonstrated by a comparative cost analysis among heavy fuel oil, natural gas and biomass (i.e. dung). The ongoing policies and incentives on biomass energy usage, and bottlenecks in making the biomass a component of energy portfolio of Pakistan are also reviewed. The outcomes of this paper might also be applicable to other developing countries having similar resources.**

Keywords- Renewable energy; Biomass; Biogas; Electricity; Pakistan.

I. INTRODUCTION

Pakistan lies between latitude 23°N and 27°N and longitude 60°E and 76°E. The total population of Pakistan is 180.71 million out of which 62.6% is living in rural areas. Population continues to grow at a rate of 2.03% [18]. The fast growing population and economy has put an immense pressure on the government to invest in the energy sector of Pakistan because energy is a key component that is required for sustainable development and prosperity of any nation. Pakistan has plenty of renewable energy resources but these resources have not been exploited yet. Biomass energy is one unique resource that has de-centralized availability all over the country. Agriculture plays a vital role in the economy of Pakistan and registered a growth of 3.1% in 2011-2012 [10] providing employment to 45% of the total labor force of the country [1].

Energy generation from biomass resources is a well-known technology; in fact a lot of effort has already been done in this field and improving it further to get maximum benefit out of it. Biogas industry is well developed in China, Nepal and India. China produced 2 million cubic meter of biogas i.e. 5% of the total gas energy in China, from 6.8 million household and 1000 big and medium size digesters by 2007 [1]. Biomass fuels have contributed 92.2% of the total energy consumption in Nepal during 1992-93 [3]. In 1992, Biogas Support Program (BSP) in Nepal was initiated with the financial support from Netherlands Directorate-General for International Cooperation (DGIS). An average biogas plant through this program saves up to 2000 kg of firewood and 32 liters of kerosene per year and also reduces 4600 kg of greenhouse gas emissions. Over 180,000 biogas units have been installed throughout the country since 1973-74 to 2006-07 [4]. Up till 1996, 2.7 million biogas units have been installed throughout India and an extensive work is still going on utilizing this potential to its maximum [5]. In Germany, following the European Union (EU) Renewable Energy Roadmap, biomass constitutes 70% of the renewable energy used for heat, fuel and electricity production [6]. Also, biogas plants are widely in production in Sudan and Taiwan [7]. In spite of having successful examples, Pakistan remains at the lower side in harvesting its biomass potential. (Amer & Daim; 2011) used Analytic Hierarchy Process (AHP) model to compare four types of renewable energy alternatives for power generation in Pakistan and ranked them according to their priority weightage. Biomass energy was prioritized first with a weight of 0.315 over wind, solar thermal and solar photovoltaic [2] supporting the fact that the use of biomass energy on large scale can reduce the dependency on conventional fossil fuels to a significant level and overcome the electricity shortage.

Being an agricultural country, livestock and sugarcane are the two most abundant biomass energy resources available in Pakistan for producing biogas that can be used for power generation. This paper quantifies the contribution of biomass energy resources in the current energy portfolio of Pakistan and investigates the economical and environmental appeal of this energy resource. The current energy profile of Pakistan has been analyzed and the energy demand for next eighteen years i.e. up to 2030 is predicted in Section II. An assessment of the biomass energy resources potential is done in the next section based on the data collected from Pakistan Economic Survey 2011-2012. Benefits associated with the utilization of biogas produced from biomass are discussed further in the same section. Section IV reflects on the policies and targets made by the local government for development in this area followed by a brief discussion on the shortcomings which need to be overcome. Conclusions and recommendations are summarized in the final section.

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II. CURRENT ENERGY PROFILE OF PAKISTAN

A. Energy Supply and Demand Situation

Pakistan is facing severe energy crises for last few years. The energy supplies are insufficient and failed to fulfill the demand. Table I shows that the energy supply for year 2010-2011 is increased by 2.3% but energy available per capita remains same 0.36 tons of oil equivalent. Supply of coal, natural gas, electricity, petroleum products and crude oil grew at an average rate of 7.5%, 5.7%, 3.4%, 2.1% and 0.4% respectively during the last decade [8]. Pakistan will have to face 29.06% of its energy deficit in 2021-2022 with current resources and pace [1].

TABLE I. PRIMARY ENERGY SUPPLY AND PER CAPITA AVAILABILITY

	Energy		Per Capita	
Year	*Million TOE*	*Change%*	*Availability (TOE)*	*Change %*
2001-2002	45.07	1.5	0.32	-1.25
2002-2003	47.06	4.4	0.32	0
2003-2004	50.85	8.1	0.34	6.25
2004-2005	55.58	9.3	0.36	5.88
2005-2006	58.06	4.5	0.37	2.78
2006-2007	60.62	4.4	0.38	2.70
2007-2008	62.92	3.8	0.39	2.63
2008-2009	62.55	-0.6	0.38	-2.56
2009-2010	63.09	0.9	0.36	-5.26
2010-2011	64.52	2.3	0.36	0

Source: Pakistan Economic Survey 2011-2012

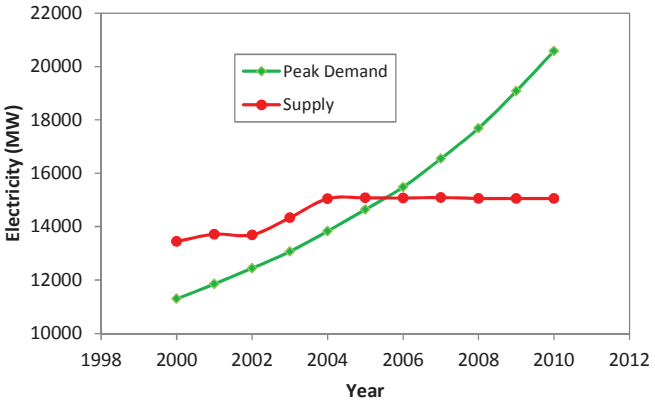

Figure 1. Annual Demand & Supply from Year 2000 to 2010

B. Electricity Shortfall and Forecast

Table II shows that the electricity demand is increasing while the supply remains on the lower side because the installed capacity in Pakistan is at a standstill for the past few years. Swelling demand escalate deficit every year resulting into load shedding and power crises. According to National Transmission and Dispatch Company Limited, during July-March 2011-2012, electricity peak demand was 18,860 MW while the supply remained 12,755 MW creating a deficit of almost 6000 MW [8].

Increasing trend of demand is exponential as shown in Figure 1. In order to estimate the peak demand for upcoming years neglecting uncertainties, the trend is extrapolated by fitting an exponential curve over the data given in Table I and a demand function is determined according to which demand may rise in future. Demand function found out to be as follows;

$$y = 10376.48e^{0.05984x} \quad (1)$$

Where,

y = Predicted Peak Demand
x = No. of year after base year 1999-2000 taken as 1

Figure 2 shows the estimated peak demand projections for next 18 years i.e. up to 2030. If we take uncertainties into account then by 2030 the demand is expected to intensify more than 66000 MW approximately.

TABLE II. ELECTRICITY DEMAND & SUPPLY SITUATION FROM 1999-2000 TO 2009-2010

S No.	Year	Firm Supply (MW)	Peak Demand (MW)	Surplus/ Deficit (MW)
1	1999-2000	13445	11296	2149
2	2000-2001	13716	11852	1864
3	2001-2002	13693	12443	1250
4	2002-2003	14336	13071	1265
5	2003-2004	15046	13831	1215
6	2004-2005	15082	14642	440
7	2005-2006	15072	15483	-441
8	2006-2007	15091	16548	-1457
9	2007-2008	15055	17689	-2634
10	2008-2009	15055	19080	-4025
11	2009-2010	15055	20584	-5529

Source: Pakistan Energy Sector Overview, SARI/Energy, USAID

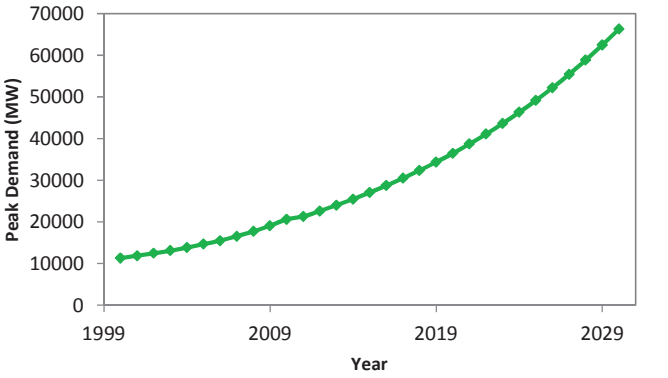

Figure 2. Peak Demand Projections from Year 2000 to 2030

C. Percent Share of Various Technologies in Electricity Generation

Pakistan generated 94,653 GWh (10805 MW approx.) of electricity in year 2010-2011. Hydel power contributed 33.6% of the total generation in 2010-2011 as compared to 29.4% in 2009-2010 as shown in Figure 3. Similarly, oil and gas shared

35.1% and 27.3% respectively as compared to 38% and 29.4% in the previous year. Share of coal remained stagnant at 0.1% [8]. Approximately 7 billion USD have been spent on imports of conventional energy resources annually equivalent to 40% of the total imports by Pakistan to congregate its energy needs [1]. It is obvious that the share of renewable energy i.e. Solar, Wind, Biomass etc. is so small that it is not even shown in the chart. It is imperative that if Pakistan has to cope with its energy crises, then renewable resources for energy must be explored.

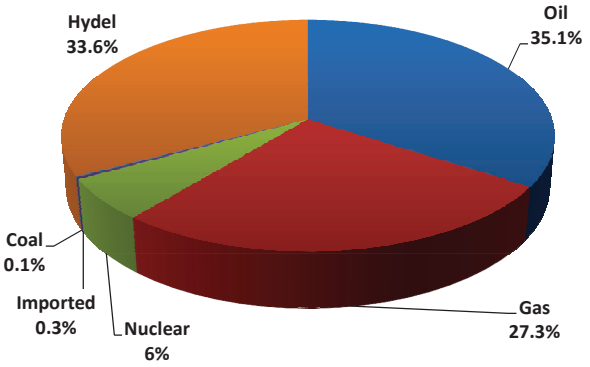

Figure 3. Current Scenario of Electricity Generation by Source

III. BIOMASS POTENTIAL IN PAKISTAN

A. Potential Analysis

Pakistan's agriculture and livestock sector produces huge amounts of biomass resources in the form of crop residues, animal waste such as bagasse, dung, rice husk, etc. [9]. Electricity generation using biomass is one of the most viable options; approximately 9 GW of electricity is generated from biomass worldwide. Pakistan is world's 5th largest producer of sugarcane with an average production of nearly 50 million tons of sugarcane annually leaving behind 10 million tons of bagasse which is a massive power resource [1]. In year 2011-2012, Pakistan produced nearly 57 million tons of sugarcane [10]. There are an estimated number of 80 sugar mills in Pakistan having potential to generate 3000 MW of energy in the form of biogas but currently only 700 MW has been utilized [11].

Annual growth rate of Pakistan's livestock sector is 4% [1]. There are almost 167.5 million animals and their manure can be used for the production of biogas in rural areas [10]. Table III shows that cumulative population of cattle and buffaloes are 69.6 million. If these animals produce on an average 10 kg of manure daily would result in 696 million kg of dung. Assuming half of this manure that will be 368 million kg is collected and utilized for biogas production. According to an estimate about 20 kg wet mass of dung can generate 1 cubic meter of biogas [12] therefore producing 18.4 million cubic meter of biogas daily. The analysis of biogas being produced by the plants in Pakistan has shown following composition of the gas: Methane (CH_4) 60–70%; Carbon Dioxide (CO_2) 30–35%; Nitrogen (N_2) 1%; Hydrogen (H_2) 0.1–0.5%; Carbon Monoxide (CO) 0.1%; Hydrogen Sulfide (H_2S) Traces [12]. Pure methane has a higher heating value (HHV) of about 37256.97 kilo joules per cubic meter (1000 Btu/SCF) [13]. Keeping in mind, the composition of methane in biogas produced in Pakistan gives a HHV of 22354.18 – 26079.88 kJ/m^3. Assuming that all of the biogas produced will be used for power generation, Pakistan has the potential to produce 4761 to 5554 MW of electricity from manure only.

TABLE III. LIVESTOCK POPULATION IN MILLION

Species	2009-10	2010-11	2011-12
Cattle	34.3	35.6	36.9
Buffalo	30.8	31.7	32.7
Sheep	27.8	28.1	28.4
Goat	59.9	61.5	63.1
Camels	1.0	1.0	1.0
Horses	0.4	0.4	0.4
Asses	4.6	4.7	4.8
Miles	0.2	0.2	0.2

Source: Pakistan Economic Survey 2011-2012

With a potential of 3000 MW from bagasse and on an average approximately 5000 MW from livestock, biomass can make a huge difference in energy portfolio of Pakistan. If Pakistan succeeds to produce 18.4 million cubic meter of biogas annually then biomass resources can contribute up to ~42% in electricity generation reducing the percentages of production from natural gas and oil from 27.3 to 16% and 35.1 to 20% respectively as shown in Figure 4. Pakistan can also explore biogas potential of poultry waste, citrus pulp, paper industry, slaughter house and street waste as well [8].

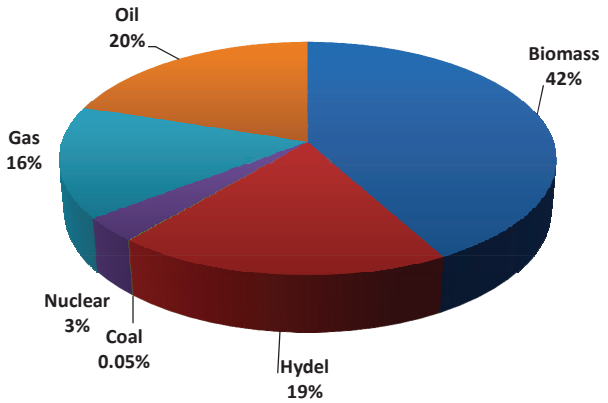

Figure 4. Estimated Potential Contribution of Biomass for Electricity Generation in Future for Pakistan

B. Benefits Associated with Biomass Resources

1) Economic Benefits: Pakistan utilizes 37.1% crude oil and 27.3% natural gas in its total power generation as shown in Figure 3, which indicates that Pakistan is heavily dependent on conventional fossil fuels. Unfortunately, Pakistan is an energy deficient country spending 7 billion USD on the import of conventional energy resources which is equivalent to 40% of the total imports of the country [1]. Biomass resources utilization increase security of national energy supply and shrink reliance on fossil fuels. Considering fuel cost only neglecting capital cost for new plants and their operation & maintenance cost, dung is found to be most economical as

shown in Table IV. The total fuel cost of dung to overcome the electricity deficit is approximately 31 and 4.5 times lesser than heavy fuel oil and natural gas respectively.

TABLE IV. COMPARISON OF FUELS FOR POWER GENERATION

Fuel	Price (PKR)	Calorific Value (MJ)	Energy Cost (PKR/MJ)	Fuel Cost (Million PKR)
Heavy Fuel Oil	368.5/gal [14]	368.5/gal [17]	2.5	470.4
Natural Gas	12.24/m^3 [15]	12.24/m^3 [17]	0.36	67.70
Dung	0.95/kg [16]	0.95/kg [16]	0.08	14.98

Note: 1 USD = 98 PKR

2) Employment opportunities: The total labor force is approximately 57.24 million of the total population of Pakistan. According to Labor Force Survey 2010-2011, 3.4 million people are found to be unemployed as shown in Table V. The unemployment rate has increased from 5.6% in 2009-2010 to 6.0% in 2010-2011 [18]. Biomass power plants in the U.S. create an average number of 36,055 jobs per 500 MW of power [2]. Assuming the same ratio for Pakistan, 8000 MW of potential from livestock and sugarcane can produce 576,880 jobs which will result in approximately 17.1% reduction in the total number of people unemployed in the country.

TABLE V. UNEMPLOYMENT RATE BY AREA

Year	Unemployed Labor Force (in million)			Unemployment Rate (%)		
	Total	*Rural*	*Urban*	*Total*	*Rural*	*Urban*
2008-2009	2.93	1.76	1.17	5.5	4.7	7.1
2009-2010	3.12	1.89	1.23	5.6	4.8	7.2
2010-2011	3.40	1.85	1.55	6.0	4.7	8.8

Source: Pakistan Economic Survey 2011-2012

3) Environmental Benefits: Combustion of biogas also produces CO_2 as by-product. Comparing it with conventional fossil fuels, carbon present in biogas was lately absorbed from the atmosphere by the photosynthetic phenomena of the plants. Thus, combusting biogas minimizes global warming impact since zero net CO_2 is emitted. Also, biogas production by anaerobic digestion lessens methane emissions from utilization and storage of untreated manure [19]. Considering Intergovernmental Panel on Climate Change (IPCC) Guidelines recommended Tier 1 approach, following equation has been used to estimate the CH_4 emissions from livestock [20].

$$CH_4 \text{ manure} = \sum \frac{EF \times N}{10^6} \quad (2)$$

Where,

CH_4 manure = CH_4 emissions from manure management, for a defined population, Gg CH_4 per year
EF = emission factor for the defined livestock population, kg CH_4 per head per year
N = the number of head of livestock species

Pakistan is characterized as a warm country in the Indian subcontinent region with annual average temperatures greater than 25°C. Therefore, IPCC estimated livestock emission factors for cattle and buffaloes are taken as 2 and 5 respectively [20]. The estimated CH_4 emissions from the dung of 69.6 million cattle and buffaloes are found to be 237.3 Gg per year. When methane is emitted to the atmosphere, it traps the radiated heat from the earth more effectively and has a 23-fold greater greenhouse gas effect as compared to CO_2. Hence, it is essential to keep methane losses at lower levels [19]. Assuming the period of interest is 100 years, the equivalent amount of CO_2 emissions to be curtailed is 4983.3 Gg per year.

If the dung cake of the same number of cattle and buffaloes converted to biogas and used in combustion engines for power generation, 80.86 Gg of CO_2 emissions will be observed annually assuming that the associated CO_2 with the biogas will come out in the same amount as entered. Therefore, manure conversion to biogas is environmentally a viable option.

C. Utilization of Biogas

Direct burning of the animal dung is an inefficient way of biomass utilization; the conversion efficiency of biomass can be improved by producing biogas through anaerobic digestion. Combined Heat and Power (CHP) generation is considered to be the standard and efficient utilization of biogas for power production. An engine based power plant has an efficiency of up to 90% with a break up of 65% for heat and 35% for electric power [19]. Gas engines, diesel engines, gas turbines and stirling motors are the most common types of combustion engines used for power generation.

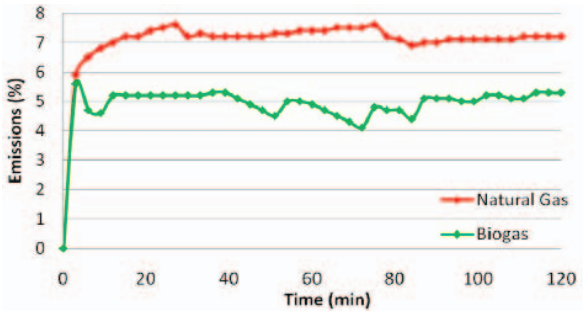

Figure 5. CO_2 emissions for natural gas and biogas [22]

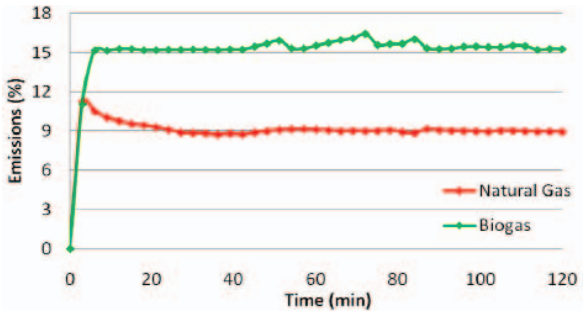

Figure 6. O_2 emissions for natural gas and biogas [22]

Biogas produced in Pakistan consists of 30-35% CO_2 [12] as compared to natural gas containing CO_2 in trace amounts. With this percent of CO_2 going into the engine, more emissions are anticipated from the engine exhaust. Stirling

motors are non-fuel specific external combustion engines having electrical and thermal efficiencies 24% and 72% respectively for an average 100 kW unit [21]. According to a research carried out by running Stirling engine on both biogas and natural gas, the experimental results revealed that the CO_2 emissions for biogas were less and O_2 emissions were more than that for natural gas as shown in Figure 5 & 6 respectively [22]. Oxygen is essential to the environment and not considered as a pollutant. Pakistan can sustain the healthy environment of its rural areas rich in fresh and clean atmosphere by adapting the similar technology to meet the electricity need of those regions.

IV. ROLE OF GOVERNMENT OF PAKISTAN IN BIOMASS ENERGY DEVELOPMENT

A. Policies and Incentives

To increase investment in Renewable Energy, the Government of Pakistan has made a number of policies. In May 2003, Alternative Energy Development Board (AEDB) was formed to promote renewable energy in Pakistan and set a target to generate 5% of the total power (9700 MW) from renewable energy by 2030 [23]. In 2006, for the first time in Pakistan, AEDB introduced policy specifically targeting the development of renewable energy technologies (RETs) for power generation. The objective behind this policy is to provide 10% of the total energy supply from RETs by 2015 [24]. AEDB is currently working on a project for biogas production from the waste of 400,000 cattle in Landhi cattle colony, Karachi. The pilot phase is funded by New Zealand Aid (NZAID) that will generate 250 kW of electricity through biogas while the project is aimed to extend further to generate 30 MW in future. AEDB is also providing technical assistance for the construction of a biogas power plant with a generation capacity of 8.25 MW in Shakarganj Mill [25]. AEDB has issued letter of intent (LoI) to M/s Lumen Energia Pvt. Ltd. to set up 12 MW power plant based on agricultural waste at Jhang. Similar LoI is issued to M/s Pak Ethanol Pvt. Ltd. to establish a 9 MW biogas power plant at Pak ethanol Pvt. Ltd., Matli, Sindh. Another LoI has been issued to build a 12 MW power plant based on biogas and agricultural waste in Sindh sponsored by the investors from U.S. and local entrepreneurs [8]. Pakistan Council of Renewable Energy Technologies (PCRET) is also playing a vital role in the development of biogas plants in the country. PCRET is aiming to produce 0.3 million cubic meter of biogas by installing 50,000 units throughout the country [8].

B. Bottlenecks

Fossil fuels such as oil and gas are highly subsidized and the government generates power at higher rates making renewable energy assets less competitive to conventional energy resources [27]. Also, due to the absence of domestic manufacturing industry, the equipments are imported that drives the costs of renewable energy projects up [24]. High capital cost of biogas plants tied with smaller capacity and less efficient models make them unacceptable. No clear policy has yet been made from the government over renewable energy resources for making them feasible to use over conventional fossil fuels [1]. Government support is strictly needed to make these alternative energy resources especially biomass more popular [26].

V. CONCLUSION

Energy is mostly produced from fossil fuels which are not only finite and expensive to extract but also contribute towards environmental pollution. Renewable energy technologies are environmentally friendly and now getting economically attractive with every passing day. Biomass energy can serve as a viable alternative to meet the hiking demands of electricity in rural areas of Pakistan. Biomass power plants are decentralized and resources are widely available all over the country. If these resources are utilized to their full extent for power production, can provide a share up to 42% in the total electric power generation in the current scenario. Penetration of this technology into the energy portfolio of Pakistan can contribute immensely towards economic crises reducing not only the oil and natural gas imports and carbon emissions but also the fraction of unemployment by 17.1%. However there are some socio-economic challenges associated with the technology which requires direct governmental involvement and dedication.

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