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Pecuniary Optimization of Biomass/Wind Hybrid Renewable System

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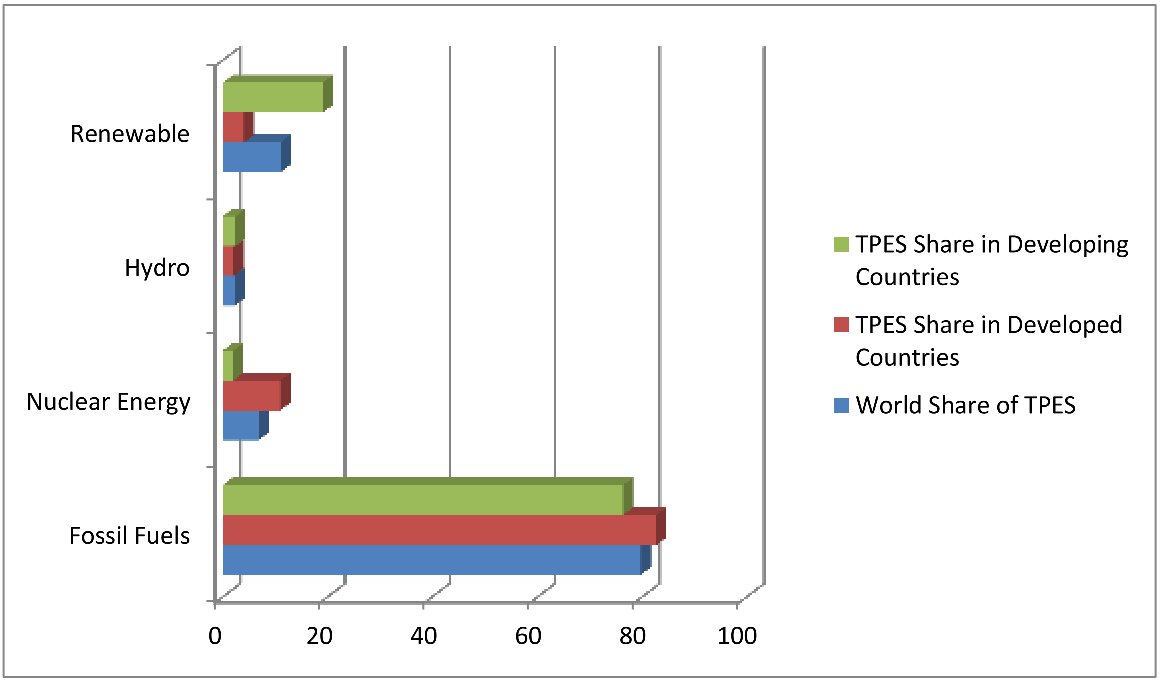
Abstract: Electric power shortfall in Pakistan is 2000MW in winter and it reaches 6000MW in summer season. Conventional energy sources are used to provide 80 % of Pakistan electric power. This paper gives the solution of shortfall by utilizing wind and biomass sources in Punjab province of Pakistan. The hybrid system of biomass and wind energy is modeled in this paper for the Punjab. The technical and economic analysis was presented for the rural areas. The animal manure was used as the feedstock of biomass. The biogas from the anaerobic digestion of the biomass was used to fulfill the energy needs. The wind potential location in Punjab was highlighted in this paper. The optimization of the model is performed irrespective of fossil fuels share. A sensitivity analysis of at least 27 % share from renewable sources is executed and the results are discussed. A comparative study of different RES hybrid systems is being discussed with respect to net present cost. It was found that the biomass wind hybrid system is the most comprehensive alternative to be adopted among other RE systems.

Keywords: Hybrid renewable energy sources; Optimization; Bio-energy; Total primary energy supply

1. Introduction

Energy plays an important role in the economics of a country. Nowadays it is very difficult to meet the energy requirements without the reasonable renewable share for the developing countries. Therefore the potential of renewable energy sources is the key to explore. According to International Energy Agency (IEA), renewable energy represents 14 % of total world consumption in 2010 [1]. This is the average world consumption. But this share varies for developing countries as well as developed countries as shown in Fig 1 and Fig 2. Thus it is observed that it is better option for the developing countries to enhance the production of energy supplies than the developed countries. Renewable energy resources should therefore be key energy sources for the future. Renewable energy sources and systems can have a beneficial impact on the following essential technical, environmental, economic, and political issues of the world.

Figure 1. TPES of different fuels.



In [2], the authors presented the study of renewable options in Ireland and they concluded that the wind energy share is 10 % till 2010. [3] presented the strategic methodology for the community based energy system of a village. They conducted a survey and outcomed that social, economic and environmental constraints are in match with the energy requirements. Wind and solar hybrid can be found well having the good compensation characteristics [4]. However the batteries over-discharge occurred many times during the lifetime of the project. Bangladesh wind and solar resources and their characterization were studied in [5]. They found that hybrid renewable system is the option which is the most suitable in developing countries for enhancing the quality of life of their people. There had been an extensive research carried out on the running power system [6]. They explored how economical it would be by increasing the renewable fraction in the system. It is also concluded that the system becomes cleaner and climate benign. In [7], the case for china household biogas plant was discussed and it resulted the need of comprehensive subsidy at Government level. The life cycle assessment of biomass gasifier was presented in [8]. Biomass technologies in Pakistan were demonstrated critically in [9]. It is obvious that the rural areas need more attention to discover the renewable biomass technologies due to the availability of different feedstock. Pakistan being an agricultural country has a large stock of animal dung. It is estimated that 0.12 Mt animal dung can be collected from the rural areas of the country [10]. The direct use of biomass resources for domestic cooking and heating line it at the bottom of preferred energy sources. In the same way, 67 % of the collected dung wastes every year either by inefficient use or not being used. Industrial hemp can have the potential to produce bio-energy to meet the energy requirement and to decrease the import bill [11]. Khanji Harijan et al. [12] forecasted the penetration of wind power in Pakistan under different policy scenarios. They concluded that the 73 % of total wind potential can be exploited till 2030. Nonetheless, it needs comprehensive strategy on Government level.

Spanish wind park was studied with real data and concluded that there were fluctuations in the output power due to the uncertain speed of the wind [13]. Hence, there is a need of the hybrid system to compensate the low output power when the wind speed is minimal. The comparative study of different renewable sources was presented and he found that the wind energy was the lowest cost followed by concentrating solar power [14].

This paper focuses on the hybrid renewable energy options available in Pakistan, their current status and future potential in general and especially on wind and biomass resources. A simulation model of the hybrid stand-alone system for Kallar Kahar (32.6° N, 73.0° E), a rural area of the province Punjab, Pakistan was developed in this study. The main objective of the study was to investigate the potential of animal dung and wind characterization. The net present cost of the hybrid system excluding transportation cost was the major outcome. The increase of use of renewable energy improves the security of energy supply in Pakistan.

2. Wind and biomass resources in Pakistan

Pakistan is situated in the south Asian region covering a total land area of 7,96,000 km^2. It has a population of 173.51 million with an annual growth rate of 2.05%; it is expected that Pakistan will become the fourth largest nation on earth in population terms by 2050 [15]. Pakistan is an agricultural country. Nearly 62% of the country’s population resides in rural areas, and is directly or indirectly linked with agriculture for their livelihood. In order to reduce pressure on import bills of fossil fuels, country must focus on the renewable sources of energy, which are abundant in nature. Among those, Pakistan is rich with wind, solar and biomass.

a. Biomass animal dung Resources

Pakistan, being an agricultural country, has a tremendous potential to utilize biomass feedstock. It has been estimated that Pakistan has 40 million animals, including horses, cows, buffaloes, goats, sheep, camels and mules. Table 1 shows the biogas yield from different feedstock through anaerobic digestion.

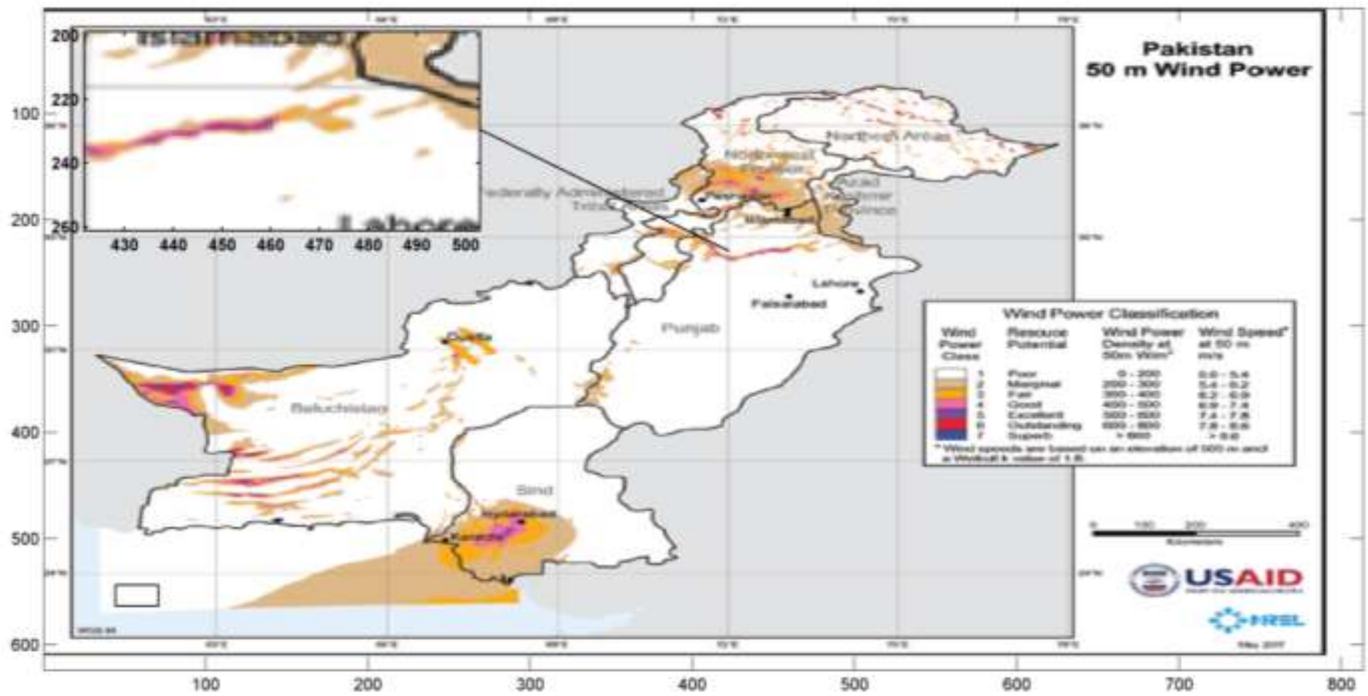
Table 1. Biogas yield from different feedstock. [16]

Feedstock	% of DM (Kg)	Biogas Yield (m^3 /Kg)
Animal manure	20	0.3-0.4
maize	20-48	0.25-0.4
Barley	25-38	0.62-0.86
Hemp	28-36	0.25-0.27
Alfafa	14-35	0.43-0.65
Rice straw	87	0.18
Baggasse		0.165

b. Wind Resources

Kallar Kahar is one of the remote areas located in the north-west of Punjab province of Pakistan. The location of this village in Pakistan is shown in Fig. 2 by magnification of a figure on the left upper corner. The town is located at 32.6° N latitude and 73.0° E longitude. This town has a tremendous potential of wind as shown by the red line in the figure. The legend tells us that the red line corresponds to wind power intensity of 600-800 W/m^2.

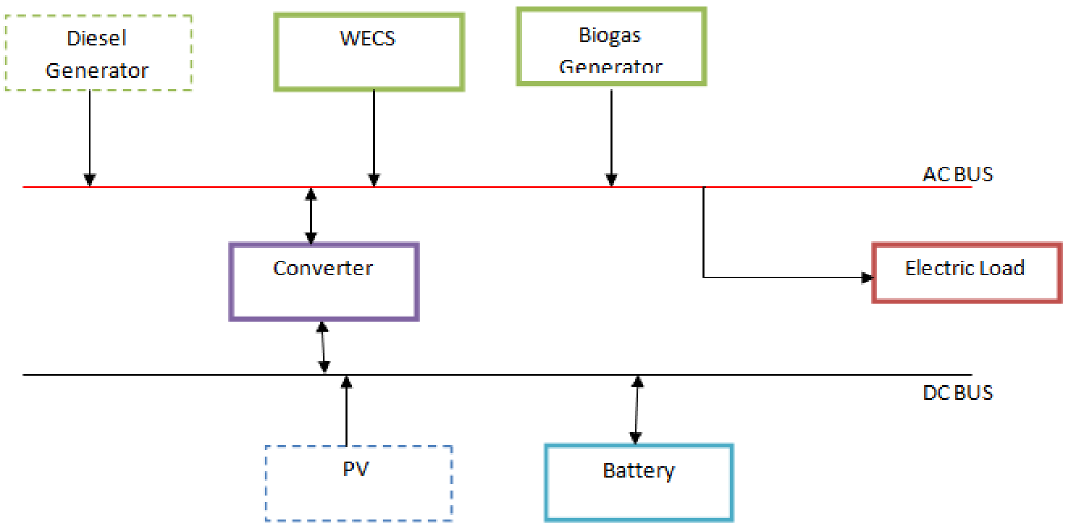
Figure 2. Wind resources map of Pakistan. [17]



3. Proposed Hybrid configuration

The proposed system consists of biomass generator and wind turbine with diesel generator. The PV system is being added for comparison purpose. The block diagram of the system is given in figure 3.

Figure 3. Block Diagram of proposed system



The The wind turbine used in the system has the specifications shown in table 2.

Table 2. Wind turbine specifications.

Wind turbine type	Rated power (KW)	Capital cost ($)	Turbine Life (years)	Maintenance cost ($/y)	Hub height (m)
Wind 500W	0.5KW DC	780 $	20	100	30

The conversion process of animal dung into useful energy is supposed to be anaerobic digestion. The Hydraulic Retention time (HRT) is taken as 40 days and the temperature remains high in most time of year. Hence it is taken from 30 °C to 45°C. The details are given in the table 3 below. The following expression can be used for the radius of area of supply of animal dung [18]:

$$R = \sqrt{\frac{Total\ no.of\ animals}{\pi * \rho}} \quad (1)$$

Where ρ= density of animals in one Km^2

Table 3. Anaerobic digestion specifications.

Biomass feedstock	Conversion process	type	Feedstock price ($/t)	Slope (Intercept coefficient Kg/hr/KW)
Animal dung	Anaerobic digestion	mesophilic	5-8	1

a. Mathematical Modelling

The total cost of the system is the cost of each components installed plus the other annual costs. It can be defined as

$$TC_i = C_{i,w} + C_{i,Bio} + C_{i,PV} + C_{i,DG} + C_{i,B} + C_{i,C} \tag{2}$$

Where

TC_i = Installed total cost
$C_{i,w}$ =Installed wind Cost
$C_{i,Bio}$ = Installed biogas Cost
$C_{i,DG}$ = installed Diesel generator cost
$C_{i,C}$ =installed converter cost

It can also be written in general form as

$$TC_i = \sum_n C_{i,n} \tag{3}$$

Where n = W, Bio, PV, DG, B, C
= No. of components in the system

The installed wind and biogas Costs can be defined interms of Eq 3.

$$C_i = C_c * CRF\ (i, T) \tag{4}$$

Where C_c = capital cost and cost recovery factor isdefined as follows.

$$CRF(i, T) = \frac{i(1+i)^T}{(1+i)^T-1} \tag{5}$$

i = interest rate
T= total lifetime of the project

4. Results and discussion

The model is simulated for the fitness function as defined in Eq. 5.

$$\text{Minimum} \quad {}^{C_{ann,t}}\Big/_{CRF(i,T)} \tag{6}$$

Fig. 4 shows the daily average load from 00 to 12 and 12 to 24 hours throughout the year. The load is high in summer which starts from April and ends in late September. The profile shows the low load in winter season. The fig. 4

Figure 4. Monthly Load profile with 373 KW peak

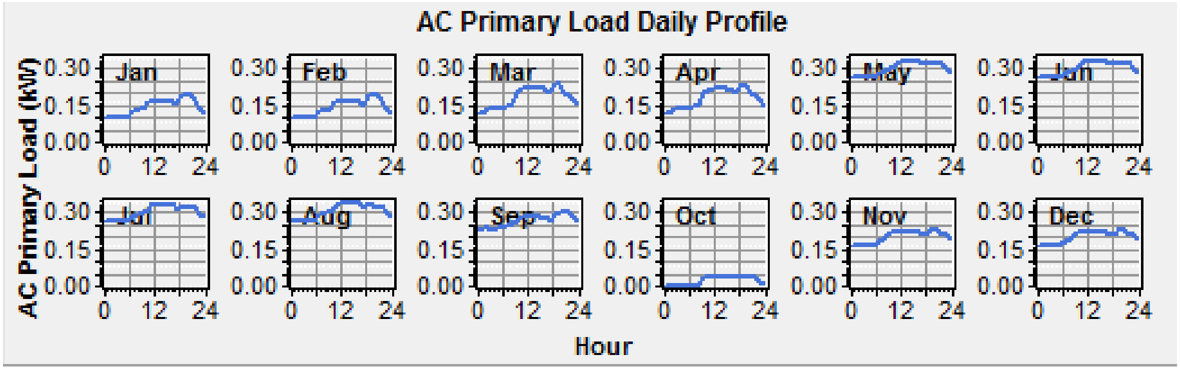
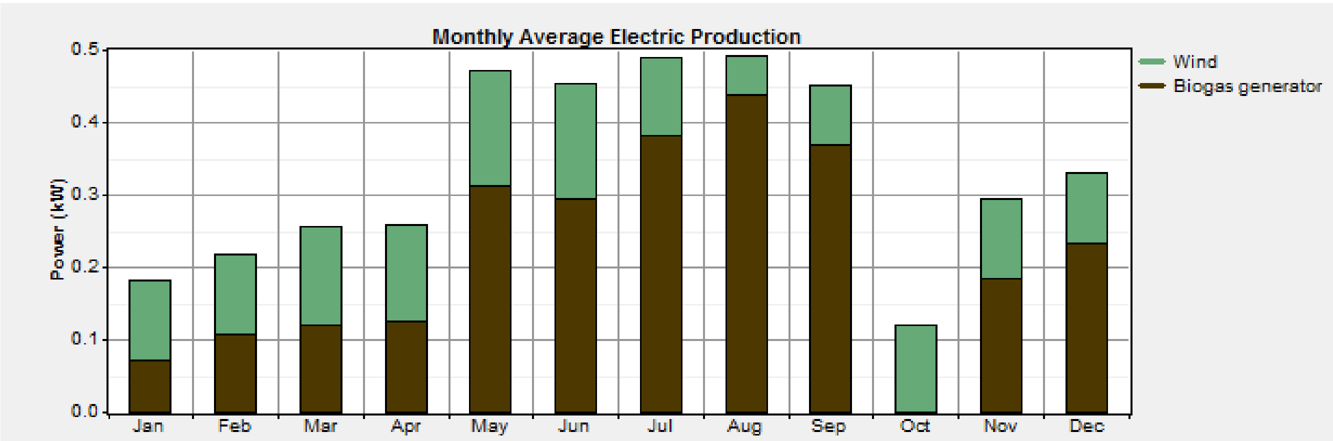


Fig. 5 shows the mean monthly biogas generator and wind energy output variations of the proposed system for the whole year. In October, the entire load is met with the energy generated by wind turbine as the load is low in winter. In summer season, biogas generator contributes mainly 2/3 of the load.

Figure 5. Monthly average electric production of hybrid biomass-wind system.



a. Pecuniary Analysis

The proposed system can be compared with respect to net present cost (NPC) with other RES (Renewable energy sources) system. It is obvious from the table 4 that for the standalone system for small community or for five households, the biomass alone is the most economical system which works under the mesophilic conditions. The most economic hybrid option is the system with biomass-wind hybrid. The results are shown as in table 4. The system in serial No.1 contains wind and biomass resources with storage type. It has the least fitness function. Hence this is the best system among all.

Table 4. Comparison of different hybrid systems w.r.t NPC.

							NPC ($)	COE	Biogas Generator hours
1							6687	0.268	1289
2							7397	0.296	1503
3							8013	0.321	941
4							7065	0.283	1819
5							16,315	0.654	0
6							17979	0.720	0

b. Sensitivity Analysis

The contribution of renewable energy sources in the hybrid system depends upon different factors. The wind energy contribution depends on the intensity and duration of availability of wind sources. For wind speed of 7 m/s, the contribution of wind is above 50 % as evident from the table. The contribution also depends on the other non-renewable sources available as far as the economics of the system is concerned.

The biomass energy contribution depends on the availability of feedstock and the storage type. It is evident from the table that biomass remains the main energy source if hybrid with other sources. It was observed that for the standalone small scale hybrid system, the biomass anaerobic and wind was the best option to be adopted.

Diesel generator contribution ranges from 0 to 100 % in the systems under consideration. As the diesel generator contribution increases, the fitness function also increases. In other words, the total cost of the system increases due to the large variations in the diesel prices throughout the world. The system does not remain the first option in terms of economic feasibility.

Table 5. Effect of Renewable energy fraction (REF) on overall systems.

							Renewable fraction (%)	Diesel generator (hours)	Wind energy	Biomass energy	Solar energy	Excess energy (%)
1		+	+		+	+	1.00	0	35	65	0	21.3
2	+		+		+	+	1.00	0	0	86	14	5.68
3	+	+		+	+	+	0.97	3	86	0	11	39.3
4		+		+	+	+	0.92	8	92	0	0	33.8
5	+			+	+	+	0.88	12	0	0	88	13.6
6	+	+		+	+		0.66	34	48	0	18	81.4
7		+		+	+		0.50	50	50	0	0	80.8
8	+			+	+		0.26	74	0	0	26	83.7
9				+	+	+	0.00	100	0	0	0	0

5. Conclusion

Due to the high prices of fossil fuels, the energy from the renewable sources is gaining importance. In this paper, a hybrid system comprising of wind and biomass sources was modeled for the small town of Kallar Kahar in the Punjab province of Pakistan. The anaerobic digestion of animal dung was used in mesophilic temperature conditions with efficient biogas generator. The wind-biomass hybrid system with the 100 % renewable energy penetration (65 % biomass and 35 % wind) was found to be the most economical system with COE of 0.268 $/KWh. The COE for Diesel-biomass system was found to be 0.425 $/KWh at the diesel price of 1.2 $. A comparison between the biomass-wind-diesel-PV systems was established in terms of net present value and COE. A sensitivity analysis showed that the net present value increased as the renewable energy fraction decreased linearly. It was found that biomass contributes more than any other source if in the system.

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