269. Municipal Solid Waste to Energy in Pakistan: A case study of Haripur District (Pakistan)

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Abstract

This study attempts to estimate the energy recovery potential from Municipal Solid Waste (MSW) in Haripur district. The data gathered in this study revealed that Municipal Authorities (MAs) are failing to treat the collected waste and it is disposed without reuse, recycling or recovery. It is estimated that approximately 3600 metric tons of highly combustible waste is disposed by the MAs in Haripur district, which could be used to produce up to 3,222,960 kWh of energy every year. If recovered recyclable only, the amount of waste going to landfill can be reduced by 59%. However, with the help of energy recovery, the total volume of waste can be reduced by 90% while contributing to meet the ever-rising energy demand of the country. Based on the quantity and composition of waste available in the district, this study recommends the use of gasification technology for energy recovery although the gasification plant requires comparatively frequent cleaning and maintenance than other thermo-chemical waste to energy conversion techniques. In terms of cost and benefit of waste to energy, the Levelized Cost of Electricity (LCOE) was identified to be 10.87 Pakistani Rupees (PKR) per kWh. The current selling price of residential electricity is between 12-13.33 PKR per kWh. Though the overall economic profit from the sale of electricity is low, the environmental public health benefits and the potential rise in energy consumption prices in future makes the adoption of waste to energy technology promising.

Keywords: *Municipal Solid Waste, Waste to Energy, Environmental Public Health*

1. Introduction

The state of Municipal Solid Waste Management (MSWM) in most developing countries is dismal. MSW produced in developing countries is either not collected, or it is inadequately disposed after the collection. Poorly managed MSW releases pathogens and toxic compounds into the environment affecting the environmental quality. In turn, poor environmental quality threatens public health [23].

In the context of Pakistan, JICA and PK-EPA [14] estimates that 55000 tonnes of MSW is produced in urban areas of Pakistan every day. A large quantity of this waste is dumped in unscientific way without treatment. According to Batool and Chaudhry [5], relevant MSWM authorities collect 60% of total waste generated in the cities of Pakistan. A large quantity of this waste (up to 90%) is dumped openly. Such waste management practices are causing serious environmental public health damage. Environmental Protection Department of Pakistan highlights that poor MSWM is causing skin diseases, eye infections, and dust related breathing problems in children and adults [8].

In contrast, MSW in developed world is not only collected efficiently but also used as a resource preserving the public health and the environment. Hoornweg and Perinaz highlights that the average MSW collection rates in developed world are nearly 98% [13]. The waste collected by waste management authorities is mostly reused, recycled and recovered. A good example of MSWM can be seen in Germany. It produced 47.7 million tonnes of MSW in 2010. Approximately, 62% of total waste produced was recycled, 37% was incinerated to produce energy and the land filling was almost 0% [7].

Pakistan is facing serious energy crisis. According to Kugelman [15], the energy deficits of Pakistan are around 5,000 MW that sometime soared up to 8,500 MW. Power shortage not only affected the lives of ordinary citizens but business also suffered, causing serious economic damage. Deterioration in the power sector was identified to be a major cause of GDP decline and it shaved off 2 percent of annual GDP growth [19]. The existing literature suggests that a major cause of energy crisis is the cost of electricity production that exceeds the revenue generated from the sale of electricity [4]. For example, the cost of electricity production from Residual Fuel Oil (RFO) is estimated to be 17 Pakistani Rupees (PKR) per unit. In case of High Speed Diesel (HSD), it is 23 PKR per unit [18]. Lahore Electric Supply Company estimates that, an average household consuming 200-700 unit of electricity per month pays between PKR 11-13.33/unit [16]. It suggests due to expensive fuels to produce energy, the cost of production is higher than its sale price. A stabilized, economically feasible, and environmental friendly energy production system may help to fulfil energy demand, grow national economy and improve the quality of life of people. In this context, MSW is an alternative source of energy that can contribute to fulfil the energy demand of country while helping to protect the environment and public health.

The following section presents the current waste management practices in Haripur district, the quantity of waste collected and Energy Recovery Potential (ERP) of collected waste.

2. Methodology

2.1 Introduction of study area

Haripur district is situated in the Khyber Pakhtunkhwa province of Pakistan. The area of the district is 1725 Sq. km [20]. It has 3 Municipal Authorities names Khalabat, Haripur and Ghazi managing MSW in their allocated areas. Fig. 1 shows the geographic location of the district.

Fig. 1. Geographic location of Haripur district

2.2 Surveying Questionnaire

A survey questionnaire was developed to assess the current MSW management practices by local MAs in the district and to estimate the quantity and composition of waste. It included open and close-ended questions. All MAs in the district participated in this survey. The data about the composition of waste was gathered in collaboration with Khalabat Township Municipal Authority (MA).

2.3 Energy potential modelling

To estimate ERP of mixed MSW; firstly, total quantity and composition of waste was determined and the weight of inert contents was subtracted from total weight to facilitate the estimation of ERP. Inert contents are inappropriate to be used in WtE system due to lack of energy content. ERP of waste was calculated on the basis of dry mass that is, Total Moisture Content (TMC) of waste was determined and subtracted.

In order to calculate TMC of various components in a sample of mixed waste, the total quantity of each waste component in 1kg of sample was determined in g/kg. The information about the average moisture content of each waste component was taken from the literature [1]. By using the equation (1), specific moisture contents of each component in 1kg of sample was calculated and subtracted from normal weight (as collected by MAs) to identify dry weight.

$$\text{TMC} = \frac{NW}{100} MC \quad (1)$$

Where TMC is Total Moisture Contents, NW means Normal Weight of each component in g/kg and MC is Moisture Contents in percent.

In a sample of dried mixed waste, each component possesses specific energy contents. Han [11] estimated the Lower Calorific Value (LCV) of various waste components based on dry weight. By using the information about LCV of each waste component, the Total Energy Contents (TEC) of each component was calculated by using equation (2);

$$TEC = (LCV)DW \tag{2}$$

Where TEC is Total Energy Content in MJ/kg, LCV is Lower Calorific Value in MJ/kg and DW is Dry Weight in kg.

Based on TEC of mixed waste, ERP of MSW was calculated by using equation (3);

$$ERP = (LCV)W \tag{3}$$

Where ERP means Energy Recovery Potential in MJ, LCV is the Lower Calorific Value of waste and W is total waste quantity in kg.

To facilitate the estimation of total ERP and the selection of appropriate waste to energy conversion technology, characteristics of various technologies were consulted.

2.4 Waste to energy: Cost benefit analysis

Lastly, based on the total ERP, financial cost benefit analysis was performed to assess the economic feasibility of waste to energy in the district. To identify the Levelised Cost of Energy (LCOE), firstly, Fixed Charge Rate (FCR) was determined by the using equation 4.

$$FCR = \frac{k_d.(1+k_d)^n}{(1+k_d)^n - 1} \tag{4}$$

Where K_d is real debt interest and n is number of years in terms of plant's operating life.

The LCOE was calculated by using equation 5.

$$Simple\ LCOE = \frac{CAPEX.FCR + OPEX}{Annual\ Output} \tag{5}$$

In this formula, CAPEX is Capital Expenditure of plant, FCR is Fixed Charge Rate, OPEX is Operating Expenditure and annual output is electricity output in kWh.

3. Results

3.1 MA Survey

MAs were collecting the waste 6 days a week and up to 80% waste was reported to be collected from allocated urban areas. Inadequate bins, deficiency of waste collection staff and vehicles were identified as major causes preventing efficient waste collection.

To dispose the collected waste, MAs leased land where waste was simply spread on the ground. Occasionally, it was set on fire to reduce its volume. No waste segregation was performed for material recovery and no risk assessment was made in terms of potential environmental damage due to open waste disposal.

3.2 Quantity and Composition of Waste

The quantity and composition of MSW in Haripur is shown in table 1 and 2.

Table 1. Quantity of waste in Haripur District (MAs Khalabat, Haripur & Ghazi, 2015)

Municipal Authority	Quantity of waste collected
Khalabat Township	10 metric tons per day
Haripur	12-14 metric tons per day
Ghazi	10 metric tons per day

Table 2. Composition of waste in Haripur District (Khalabat MA, 2015)

Waste Type	% of total waste	Waste type	% of total waste
Food/kitchen waste	5	**Metals**	2
Paper	10	**Glass**	2
Textile	5	**Garden waste**	2
Wood	10	**Carrier Bags**	10
Plastics/Rubber	8	**Inert waste**	46

3.3 Estimation of reuse and recycling potential from MSW in the Haripur district

The following calculation is based on approximately 30 metric tons of waste collected in the district per day. Inert contents of 13.8 metric tons are excluded with 16.2 metric tons of waste available for recyclables extraction.

Table 3. Estimated material recovery potential from collected MSW in Haripur

Waste Type	Percent of total waste (by weight)	Price per kg (Rs)	Quantity of each component kg/metric ton	Estimated income potential (PKR/metric ton/day)
Food/kitchen waste	9	---	90	---
Paper/card board	18	8-12	180	1440-2160
Textile	9	---	90	---
Wood	18	8-14	180	1440-2520
Plastics/Rubber	15	7-22	150	1050-3300
Metals	4	20-35	40	800-1400
Glass	4	2	40	80
Garden waste	4	---	40	---
Carrier Bags	19	---	190	---
	100		1000	4810-9460

Based on the quantity and composition of waste collected and current market price of various recyclables (as suggested by respondents); material recovery for recycling can help to generate 4810 to 9460 PKR/ day/metric ton of waste collected. As 16.2 metric tons of mixed waste collected per day in the district (approximately 9.6 tons of recyclables), the income potential from recyclables may range from Rs 46,176 to 90,816 per day depending on quality of recyclables. Segregation of recyclables can help to reduce the quantity of waste going to landfill by 59%.

3.4 Waste to Energy: ERP of MSW collected by MAs in Haripur District

In order to determine ERP, dry weight of each component was determined by identifying and subtracting TMC using equation (1) as shown in table 4.

Table 4. Dry mass weight of each component in a normal sample of mixed MSW

Waste Type	Percent of total waste (by weight)	Normal weight (g/kg)	TMC (%)	Moisture loss (g/kg)	Dry mass weight (g/kg)
Food/kitchen waste	9	90	58.6	52.74	37.26
Paper/card board	18	180	3.27	5.886	174.11
Textile	9	90	5.3	4.77	85.23
Wood	18	180	5	9	171
Plastics/Rubber	15	150	2.3	3.45	146.55
Metals	4	40	0.9	.36	39.64
Glass	4	40	1.2	.48	39.52
Garden waste	4	40	16.2	6.48	33.52
Carrier Bags	19	190	1.9	3.61	186.39
	100	1000		86.78	913.22

It is estimated that the mixed waste collected by MAs in Haripur district possesses approximately 8.6% of moisture content by weight. By removing moisture from 16.2 metric tons of normal MSW, 14.81 metric tons per day of dry waste becomes available for energy recovery.

TEC of various waste components in 1kg of dry waste sample was determined using equation (2). These values are shown in table 5.

Table 5. Total Energy Contents of various waste components in 1kg of dry waste sample

Waste Type	Energy content for dry mass MJ/kg	Dry Weight in sample (kg)	Total Energy Content MJ/kg
Food/kitchen waste	13.9	0.0407	0.5657
Paper/card board	17.6	0.1906	3.354
Textile	20.5	0.0932	1.910
Wood	19.3	0.1872	3.612
Plastics/Rubber	25.6	0.1604	4.106
Metals	0.7	0.0433	0.030
Glass	0.2	0.0432	0.008
Garden waste	15.1	0.0366	0.543
Carrier Bags	33.4	0.2040	6.813
		1	20.94

The TEC of waste (LCV) in Khalabat Township was estimated as 20.94MJ/kg based on 1kg of dried mixed MSW sample. By using LCV of waste and an assumed Weight unit of 1 metric ton in equation (3), ERP is equal to 20,940 MJ/metric ton.

Theoretically, 1 metric ton of mixed dried MSW can produce 5800 kWh of gross energy.

This ERP value is based on 100% energy extraction from the waste. By using RDF, total ERP can be improved as RDF is normally composed of highly combustible material such as paper, plastic, wood and textile. The table (6) shows the ERP of waste using RDF.

Table 6. Estimation of TEC of RDF

Waste Type	Total Energy Content MJ/kg	Quantity of each component (kg/metric tons)	Total Energy Content MJ/metric tons
Paper/card board	17.6	227.8	4009.28
Textile	20.5	113.9	2334.95
Wood	19.3	227.8	4396.54
Plastics/Rubber	25.6	189.8	4858.88
Carrier bags	33.4	240.5	8032.7
		1000	23632

From total MSW collected by the MAs in Haripur district, a total of 11.69 metric tons of material can be obtained as RDF per day. Each metric tons of dried RDF on average possesses 23,632 MJ of energy (6546 kWh/metric tons). As gasification system can extract up to 90% of total available energy [6], a steam turbine can covert at least 15% of this energy into electricity [2&3]. As a result, RDF can help to produce 10,330 kWh of electricity per day. If waste is collected over 6 days a week, the total annual electricity output will be approximately 3,222,960 kWh.

3.5 Cost benefit analysis: Estimating LCOE and revenue potential of waste to energy

To estimate LCOE, FCR was initially calculated by using equation 4. The K_d for this study was identified as 6.5% [22] whereas; n was assumed as 20 years. As a result, FCR was calculated as 0.09.

LCOE was calculated by using the CAPEX as addition of RDF processing plant and a gasification plant. The cost of RDF processing plant is taken from an operational RDF plant in Pakistan that is 320,000,000 PKR [9]. The cost of a 1MW capacity Gasification plant is suggested by Saini et al [21] as 10,000,000 Indian Rupees (15,000,000 PKR). Likewise, the O&M is estimated as 5.5% of total investment cost of gasification plant which totals as 825,000 PKR/year. The O&M cost for RDF plant is estimated at 435 PKR/metric tons [10]. As collected waste in the district is 9300 metric tons/year, the total O&M cost of RDF processing is calculated as 4,071,600 PKR/year. The total annual electricity output using RDF as feedstock in gasification plant is estimated to be 3,222,960 kWh. By using equation 5, the LCOE is 10.87 PKR/kWh.

4. Discussion

Although waste collection efficiency in Haripur district is significantly higher (80%) than many other places in Pakistan, the collected waste is inadequately disposed by local MAs. Such waste disposal practices in Pakistan are highlighted by researchers in the existing literature [5]. The composition of waste suggests that the percentage of inert contents is significantly higher. The food contents of waste were surprisingly low in contrast to a number of other studies [5&12]. High amount of inert contents in waste are likely due to dry weather resulting into formation of dust. Likewise, as MA Khalabat particularly serves residential area, low commercial activities such as few food markets appeared to be contributing to the production of low food waste. A number of contents in the waste were highly combustible, suitable for waste to energy. The presence of high combustible components is also observed by a number of other studies conducted on MSW in Pakistan [12&17]. The results of survey revealed that a significant amount of recyclables can be recovered and sold in the market from the waste disposed by MAs previously overlooked by many researchers.

The existing literature suggests that bio-chemical processes requires high organic components. Since organic components are identified to be low in the collected waste, only thermo-chemical waste to energy technologies are considered for energy recovery. Incineration and gasification are among most prominent technologies used to recover energy from the waste. However, World Bank highlights that mass burn incineration requires at least 50,000 metric tons of waste to sustainably operate an incineration plant [24]. As the amount of waste collected in the district is approximately 9300 tons/year (3600 metric tons as RDF), a small-scale 1MW gasification plant appeared to be most suitable option to recover energy from the waste in the district. A gasification plant require frequent cleaning than an incineration plant that adds to the cost of maintenance. However, the existing literature suggests that the capital cost of gasification plant is 3 times lower than incineration plant [21]. It favours the installation of a gasification plant for waste to energy recovery.

5. Conclusion

This study revealed a greater potential of energy recovery from the waste collected in Haripur district by MAs. MSW can offer a renewable source of energy reducing the dependency on non-renewable sources such as fossil fuels which helps to protect the environment.

The results of survey revealed that the waste collected by MAs in Haripur district possesses a high calorific value. Energy content of RDF was identified to be 6546 kWh/metric ton, enough to produce 3,222,960 kWh of energy every year. As the aim of MSWM is to reduce the amount of waste going to landfill, the results of this study revealed that waste to energy is most appropriate option to significantly reduce the amount of waste going to land fill that is up to 90%. Recycling only can reduce the amount of waste going to landfill by 59%. Waste to energy process also allows the segregation and collection of recyclables during RDF production facilitating additional revenue generation. The waste characteristics revealed that gasification was most suitable technology to use in the district. Unlike the utilization of fossil fuels, the revenue generated from the sale of electricity can compensate the cost of production. However, further research is required to assess the quantity and composition of waste involving other districts to effectively manage MSW on national level in Pakistan.

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