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Original Research

Municipal Solid Waste as a Renewable Source of Energy: an Overview from the Lahore District in Punjab, Pakistan

Shabnam Shahzad[1, 2]*, Aleem Butt[1, 3], Shahzad Anwar[1], Sajid Rashid Ahmad[3], Tehmina Sarwar[4], Nihal Asghar[1]

[1]Solution Environment and Analytical Laboratories, Kot Lakhpat, Lahore, Pakistan
[2]University De Liege, Belgium
[3]College of Earth and Environmental Science
[4]Institute of Business Management, UET, Lahore

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Abstract

Pakistan is currently facing a severe energy crisis. According to the latest 2016 figures issued by the government of Pakistan (GOP), electricity demand of the country is about 21,200 MW against the maximum generation 16,000 MW, with a shortfall of about 5,000 MW. The presented study was carried out to find an environmentally friendly renewable source of energy to fill this gap. For this purpose Lahore municipal solid waste was used to calculate the power generation potential. Sampling was completed from all three economic zones – high income (H), medium income (M), and low income (L) – during the whole year, capturing the impacts of all seasons. These samples were brought to a laboratory and analyzed for their calorific values with the help of a bomb calorimeter according to WTE-thermal treatment process. Gross calorific and theoretical energy recovery potential value (from H, L, and M) areas were 3,670, 2,753, and 1,960 kcal/kg, and 5,872, 4,405, and 3,136 kwh/ton, respectively. This waste-to-energy (WTE) treatment is the most suitable solution for pollution-free LMSW conversion into a renewable energy generation source.

Keywords: incineration, gross calorific value, municipal solid waste, ash, moisture

Introduction

Economic development and growth of a nation depends mainly on the energy sector, which is a driving force for the progress of a country. The increasing energy needs and its fulfillment through conventional and renewable resources is a great challenge [1]. Pakistan is under severe energy crises and depends on imports of fuels in order to meet needs, but still we are facing a huge load-shedding. Industries have been ruined due to this situation, i.e., many textile mills are closed. We are mainly using conventional fossil fuels for energy generation, i.e., 50.4% of natural gas, 29% oil, 11% hydro power, and about 7.6% coal, and it has been recognized globally that their consumption has raised many environmental issues. In Pakistan energy plays a vital role in strategic planning sectors, and various concerns such as prices of energy, climate change, and population growth has led us toward

*e-mail: shabnamshahzadkhan@gmail.com
shabnam.shahzad@ulg.ac.be

alternative energy sources. It is recognized worldwide that greenhouse gases from fossil fuels are the main cause of global warming. Fossil fuel alternatives are globally encouraged and renewable energy strongly contributes to sustainable development and in this respect waste-to-energy (WTE) technology is very important [2]. Pakistan has many sources for renewable energy generation but they need to be explored. Industrialization of human society has resulted in waste discharge in huge quantities in urban areas. This has caused environmental pollution due to non-specific management.

Among many environmental issues such as air, noise, and water pollution, etc., MSW disposal is the most challenging, and urban areas are highly affected by its accumulation in an open environment. There is a great opportunity in MSW to produce gas or electricity, but developed countries mostly generate electricity as well as MSW volume, which may be reduced by a factor of 10 and approximately 80% by weight via thermal treatment procedure [3]. This utilization of natural resources will address the problems of waste disposal and energy generation, which is one of the broadest objectives of sustainable development. Gas and electricity generation from renewable resources can lead a country several steps ahead. MSW holds the ability to become a fuel for sustainable energy development and an attractive investment as, contrary to other fuels, MSW is a fuel received at a gate fee. This study was designed to make Lahore a pollution-free city along with fulfilling its ever-growing energy demands and to control pollution due to open dumping of solid waste.

Lahore is the largest district of Punjab Province, the second largest metropolitan area in Pakistan, and the 14th most populous city in the world. It lies between 31.5546°N and 74.3572°E. It is bound at the north and west by the Sheikhupura District, on the east by Wagah (India), and to the south by the Kasur District (Fig. 1). The Ravi River flows along its northern side and it has been an important historical center in south Asia since the ancient times of the Mughal emperors. Lahore is a regional urban center of key commercial activities of financial, industrial, and socio-economic significance. A projection is that by year 2025 there will be almost 25 million people living in the city. The unplanned expansion of the city, competing land use, and exponential population growth with rate up to 3.72 had put the burden on the existing infrastructure of Lahore, causing energy crises, traffic congestion, and pollution, and as a result destroying the beauty of this city, which is known as the city of gardens.

With the rise in community living standards and the generation rate of solid waste, this has become the most challenging issue and a burden on the municipal budget. The management of solid waste is the responsibility of Lahore Waste Management Company (LWMC). Due to little knowledge of various factors and the high costs involved for MSW disposal, currently LWMC relies only on landfilling [4-7], which has resulted in unattractive environmental degradation like poor sanitation, pollution of water bodies, etc. LWMC is now trying to find better ways for waste treatment [9-10], according to worldwide rapidly growing and preferred strategies of MSW management like segregation, recycling, and incineration [11-14].

LWMC has divided the city into nine towns for MSW collection: Data, Ravi, Samanabad, Iqbal, Gulberg, Shalamar, Aziz Bhatti, Wagah, and Nishtar. The total waste generated in Lahore is approximately 8,500 tons per day with a rate 0.6-0.80 kg/c/day, and it is generally composed of plastic, rubber, paper, metal, cardboard, textile waste, food waste, glass, animal waste, leaves, grass, straws and fodder, wood, bones, stones, and fines to various extents. In the presented study we have categorized Lahore waste collection areas into three economic classes: high (H), medium (M), and low (L) income areas (Fig. 2), with the aim that although the main constituents of domestic solid waste are similar worldwide, the generated quantity, density, and proportion of constituents vary widely,

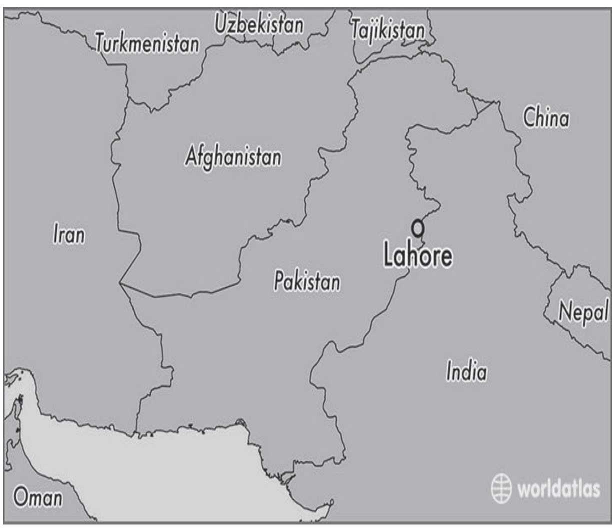

Fig. 1. Geographical map of Lahore.

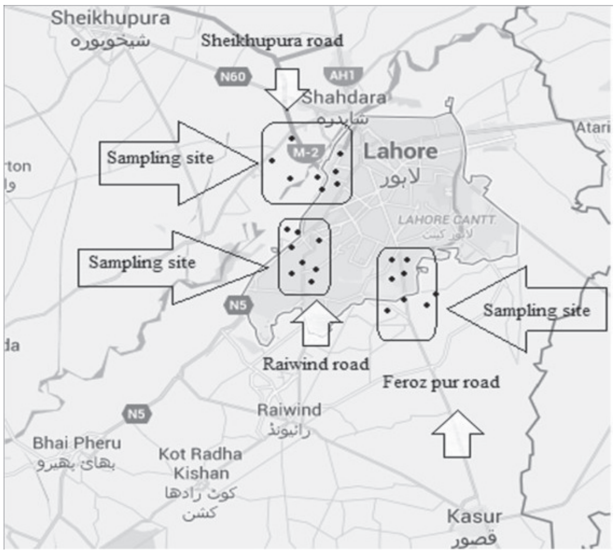

Fig. 2. Sampling sites of Lahore.

even within a city according to the level of economic development, geographic location, weather, and social conditions [15-16]. Sampling was completed in one year during all seasons from H, M, and L areas. These samples were collected on a daily basis, brought to a laboratory, and assessed using a bomb calorimeter. Gross calorific values (GCV) and theoretical energy recovery potential (ERP) were calculated according to WTE technology. And it is recognized worldwide that waste-to-energy (WTE) technology has the power to solve both problems of pollution and energy generation simultaneously [1, 17].

Materials and Methods

The study methodology consists of the following:

a. Data collection, i.e., division of study area into three economic classes (L, M, and H) based on location of home, property value, and income of households.
b. Sample collection with waste characterization.
c. Analysis of solid waste to calculate gross calorific value (GCV), moisture, and ash contents.

Data Collection

Data income was collected from nine towns of Lahore district by taking 3% of a representative sample population in each town. The low salary group families have per-month wages up to Rs. 7,000 (£64), the middle pay family units have a per-month wage of Rs. 7,001-14,000 (£64-129), and the high pay group family units have a per-month pay of >Rs. 14,000 (£129). The survey leads Nishtar, Data, Wagah, Aziz Bhati, and Mehmood Booti as the low-income group, Gulberg and Defence as the high-income group, and Samnabad and Iqbal as the medium-income group. After completing the survey, the solid waste dumps were chosen on the premise of financial divisions [18]. Samples collected from every group cover all seasons so as to consider the infrequent and occasional variations. This random stratified and regular examining was completed over a time period of one year from March 2015 to April 2016 during all weather conditions.

Sample Collection: Waste Characterization

A total of 6,480 kg representative samples were collected in the whole year comprising 180 kg per month from H, L, and M (60 kg each) sampling points (Fig. 2). To prepare the representative sample of 2 kg, 25-50 kg MSW samples were collected from bins of H, L, and M income groups. At random, three samples (2 kg each, 3×2 = 6 kg) were prepared daily from each income group. This sample was mixed well before being placed in a container for standard weight. The samples were then segregated into 14 categories by placing them in separated plastic bags (Tables 1-2): plastics, nylon, pet, diaper, biodegradable, textile, paper, glass, metal, electric or electronics, non-

Table 1. Characterization of MSW in low- and medium-income areas.

Months		April 2015-March 2016		
Town		M. Booti and Samanabad		
S.No	Components	Actual Weight of Waste (kg)	Percentage of components	Representative Sample 2 kg
1	Combustibles	2.41	1.69	0.03
2	Diaper	1.20	0.84	0.02
3	Electronic.W	0.17	0.12	0.00
4	Glass	0.55	0.39	0.01
5	Hazardous W	0.21	0.15	0.00
6	Biodegradable W	90.01	63.27	1.27
7	Metals	0.53	0.37	0.01
8	Non-combustibles	24.94	17.53	0.35
9	Paper-Cardboard	5.00	3.51	0.07
10	Pet	0.00	0.00	0.00
11	Nylon	9.67	6.80	0.14
12	Plastics	0.41	0.29	0.01
13	Tetrapack	0.96	0.67	0.01
14	Textiles	6.21	4.36	0.09
Total		142.27	100.00	2.00

Table 2. Characterization of MSW in high-income areas.

Months		April/2015-March/2016		
Town		DHA		
S. No	Components	Actual Weight of Waste (kg)	Percentage of components	Representative Sample 2 kg
1	Combustibles	2.08	8.21	0.16
2	Diaper	1.31	5.17	0.10
3	Electronic W	0.11	0.43	0.01
4	Glass	0.55	2.17	0.04
5	Hazardous W	0.17	0.67	0.01
6	Biodegradable W	9.86	38.92	0.78
7	Metals	0.05	0.20	0.00
8	Non-combustibles	2.58	10.18	0.20
9	Paper-Cardboard	1.61	6.35	0.13
10	Pet	0.05	0.20	0.00
11	Nylon	4.96	19.57	0.39
12	Plastics	0.16	0.63	0.01
13	Tetrapak	0.49	1.93	0.04
14	Textile	1.36	5.37	0.11
Total		25.34	100.00	2.00

combustible, hazardous waste, combustible, tetra packs [19]. After separation, each category of sample was weighed in order to calculate the percentage of each category from total percentage of the solid waste and, according to the percentage of each category, 2 kg of representative sample was prepared. The plastic bag was labeled and closed. The bagged samples were placed in a plastic pail and sealed with a tight-fitting lid. The pails were then secured and transported to a laboratory for analysis.

Analysis of Solid Waste Samples

Waste samples were received at the lab called L, M, and H (as per their income groups), and were mixed well, i.e., LL, HH, and MM, cut, ground to "O" (high income), "P" (medium income), and "Q" (low income), compressed to form palettes, and subjected to bomb calorimeter for GCV calculations. Preparation of small palettes is a requirement of the bomb calorimeter and to calculate GCV accurately. The flow sheet diagram of the mixing, cutting, and GCV calculation is shown in Fig. 3. Samples mean that GCV, moisture content, and ash content were calculated.

Calculating Gross Calorific Value (GCV)

The municipal solid waste sample was desiccated and then broken down into small particles. The particles were sieved and compressed to form pallets. The gross calorific values of pallets were measured by using a Parr oxygen

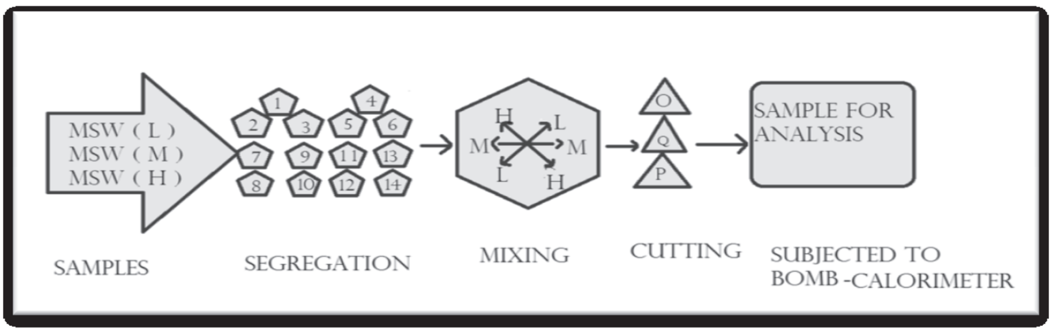

Fig. 3. Flow chart of methodology.

bomb calorimeter (Model 6400). GCV was calculated according to ASTM 5468 [20]:

$$\text{ERP (L or M or H)} = \text{GCV}\times\text{W}\times1.6 \quad (1)$$

…where (GCV) is gross calorific value of the representative sample in kcal/kg; ERP (H/M/L) is energy recovery potential of MSW from high, medium, and low income groups in kWh; and W is the weight of MSW in kg.

Calculating Moisture Content

The moisture content was calculated according to ASTM 1756-0 [21]. The waste was weighed and placed in an oven at 105°C for 2 hours and weighed again. The percentage of moisture was calculated by the following equation:

$$M = (IM - FM)\times 100/IM \quad (2)$$

…where IM is initial mass of solid waste, FM is final mass of solid waste after drying, and M is percentage moisture content.

Calculation of Ash (%±SD)

Ash content is calculated by ASTM 2584 [22]. The dried sample was taken in a pre-weighed crucible, placed in a muffle furnace, and ignited at 950°C for 30 minutes. The crucible with ash was removed from the muffle furnace and carefully weighed again. The percentage of ash was calculated using the following equation:

$$\text{Percentage Ash} = WR / DSW \times 100 \quad (3)$$

…where WR is weight of the residue after ignition and DSW is dry solid waste.

Results and Discussion

Recently, conversion of waste to energy has attained great attention as this technology will reduce greenhouse gas emissions, environment pollution, fossil fuel use, and landfill dumping. To generate energy from waste, advanced technologies may be utilized and it will reduce the country's dependence on expensive and rapidly scarce fossil fuel resources (non-renewable). In addition, energy generation from waste reduces pollution caused by the burning of fossil fuels, and the land used for landfill purposes could be utilized for many other useful purposes.

Selection of Appropriate Technology

In order to find the best-suited technology for MSW treatment we have to compare a few of the available popular techniques. Although different technologies have been used for energy recovery in Asia [23], the most popular remains the sanitary landfill. Its benefits are open burning and reduction of waste quantity, and drawbacks are doubtful gas extraction and leachate and significant impacts on global warming, photochemical oxidation, and acidification [24]. Studies showed that sanitary landfills produced 1.2 tons of CO_2 from one ton of MSW [25], and deteriorated surrounding water quality (due to continuous reactions in landfill) [26]. To avoid these problems and to get a renewable and environmentally friendly source, WTE has been selected. Worldwide, 130 million tons of solid waste is burned per anum (in plants) to generate electricity through WTE. WTE have two types of processes: a) thermal and b) biological conversion [27-30]. Biodegradable materials of MSW can be treated through biological conversions like anaerobic conversion, composting, etc. [31], but digested MSW-organic-fractions when used for agriculture may damage soil and groundwater [32]. Therefore, the thermal treatment process should be used. Thermal treatment of MSW includes different WTE technologies, with the most popular one being the oxidation of MSW combustible material, which is further divided in two types: c) advanced thermal treatment and d) conventional combustion.

Conventional combustion technology is superior and has been used in England since 1870. Conventional combustion is sub-divided into three categories: e) mass burn incineration, f) fluidized bed, and g) modular. Fluidized bed and modular are less common techniques as these are two-step complex processes compared to single-step mass burn incineration [33]. Thus mass burn incineration (grate-fired) is the most famous treatment worldwide, and 750,000 tons/annum MSW was treated through mass burn incineration in Europe only [34]. Other advanced thermal treatments include plasma gasification, pyrolysis, and gasification. These technologies are less common on a commercial scale and showed more low-energy recovery efficiency than mass burn incineration. The underlying fact is that complete combustion [35], and uncertainties associated with advanced treatment are higher than mass burn incineration [36]. As an inference keeping in mind ERP, area, and one-stage simple process, mass burn incineration technology is the most suitable choice for MSW conversion into power generation.

Gross Calorific Values of H, M, and L

GCV is the measure of energy available from fuel and important when considering the thermal value of the product for producing power or heat. Results of gross calorific value, moisture content, and ash content of the representative samples are given in Table 3. Mean calorific values from L, M, and H income groups were also calculated and compared as shown in Table 3. This shows that the H group waste samples showed highest mean GCV at 3,670 kcal/kg, the L group showed second-highest values for GCV at

Table 3. Gross calorific value, moisture content, and ash content of the representative samples.

Sr. No.	Sample ID	Gross Calorific Value ±SD (Kcal/Kg)	Total Moisture ±SD (%)	Ash ±SD (%)
1	1-Apr-M (2015)	1,868±1.4	55.5±0.99	16.92±1.56
2	1-May-M (2015)	1,948±0.89	62.4±0.98	14.21±1.58
3	1-June-M (2015)	2,050±1.1	59.89±1.25	16.72±0.68
4	1-July-M (2015)	2,055±0.78	68.00±0.77	18.25±1.64
5	1-Aug-M (2015)	1,890±0.45	60.80±0.55	6.19±1.80
6	1-Sep-M (2015)	1,964±1.0	52.37±1.29	26.17±0.62
7	1-Oct-M (2015)	1,958±0.79	61.70±0.63	11.93±1.67
8	1-Nov-M (2015)	1,806±1.3	72.7±1.1	8.4±0.243
9	1-Dec-M (2015)	1,924±0.92	65.3±1.5	13.5±0.78
10	2-Jan-M (2016)	1,940±1.3	69.6±0.98	6.24±0.49
11	2-Feb-M (2016)	2,003±0.87	72.3±0.98	6.29±1.76
12	2-Mar-M (2016)	2,135±1.4	58.8±0.99	10.84±0.78
	Mean Values	1,960± 1.4	54.6±0.98	12.97±0.78
13	3-Apr-L (2015)	2,580±0.98	61.5±0.89	14.45±1.18
14	3-May-L (2015)	2,602±1.32	58.82±1.23	13.23±1.69
15	3-June-L (2015)	2,630±1.11	52.56±1.2	14.22±0.154
16	3-July-L (2015)	2,645±0.99	51.34±0.93	9.32±1.90
17	3-Aug-L (2015)	2,542±1.50	64.06±1.3	8.69±1.85
18	3-Sep-L (2015)	2,992±0.88	60.83±0.78	18.55±0.85
19	3-Oct-L (2015)	2,958±1.1	67.8±1.0	9.5±0.165
20	3-Nov-L (2015)	2,974±1.33	75.5±1.4	5.56±1.65
21	3-Dec-L (2015)	2,962±0.34	69.83±1.42	18.55±1.35
22	1-Jan-L (2016)	2,990±1.2	75.3±1.1	5.22±0.99
23	1-Feb-L (2016)	2,508±0.88	62.5±1.5	9.56±0.87
24	1-Mar-L (2016)	2,648±1.0	60.4±1.1	9.66±0.78
	Mean Values	2,753±1.5	60.3±1.1	11.37
25	2-Apr-H (2015)	3,640±1.3	71.4±1.1	20.30±1.98
26	2-May-H (2015)	3,741±0.65	79.6±0.63	20.50±1.42
27	2-June-H (2015)	3,650±1.12	66.20±0.97	21.27±0.0
28	2-July-H (2015)	3,734±1.2	67.90±1.0	17.02±1.905
29	2-Aug-H (2015)	3,554±1.45	69.39±1.2	10.18±1.15
30	2-Sep-H (2015)	3,749±0.78	70.41±1.38	29.27±0.58
31	2-Oct-H (2015)	3,647±0.49	56.012±1.2	13.53±1.79
32	2-Nov-H (2015)	3,782±1.2	63.7±0.93	9.7±0.32
33	2-Dec-H (2015)	3,549±0.82	58.6±1.43	20.5± 1.87
34	3-Jan-H (2016)	3,608±0.98	71.88±1.0	7.42±1.89
35	3-Feb-H (2016)	3,716±1.1	68.6±1.25	7.69±0.45
36	3-Mar-H (2016)	3,668±1.4	72.5±0.99	13.23±0.78
	Mean Values	3,670±1.5	68.016±1.09	11.83± 1.3

Table 4. Relationships between mean GCV of M, L, and H and ERP.

Energies	Mean Values-M	Mean Values-L	Mean Values -L
GCV	1,960 Kcal/Kg	2,753 Kcal/Kg	3,670 Kcal/Kg
ERP	3,136 kWh/ton	4,405 kWh/ton	5,872 kWh/ton

2,753 kcal/kg, and the M group showed lowest GCV at 1,960 kcal/kg.

Calculating Theoretical Energy Recovery Potential from LMSW

Energy recovery potential (ERP) is calculated with Eq. (1) and its values for H, L, and M income groups are 5,872, 4,405, and 3,136 kWh/ton, respectively. Results showed that ERP of MSW from all samples (H, M, L) is directly proportional to their GCVs, and both have a good correlation, i.e., data showed that as GCV increases, ERP also increases. The trend of GCV and ERP is shown (mean GCV for M, L, H) in Table 4.

Net Power Generation (NPG) from Low-, Medium-, and High-Income Groups

NPG from Medium-Income Group

Net power generation is calculated by the following method:
Energy recovery potential (ERP) = 3,136 kWh/ton
If we consider that conversion efficiency is (E) = 25%, total energy generated (TEG) = ERP ×0.25 kWh/ton = 3136 x 0.25 = 784 kWh/ton
If service station allowance (SSA) is 11% of TEG = 86.24 kWh /ton
…and uncounted heat losses (UHL) is 9% of TEG = 70.56 kWh / ton
…then net power generated (NPG) = TEG – (SSA + UHL)= 784 - (86.4+ 70.56) = 627.04 kWh/ton

NPG from Low-Income Group

In the same way as mentioned above NPG was calculated for the low-income group:
Energy recovery potential (ERP) = 4,405 kWh/ton, and considering conversion efficiency = 25% and total energy generated (TEG) = 4,405×0.25 = 1101.25 kWh/ton
…then net power generated (NPG) = 1,101.25-(121.14+99.11) = 881 kWh/ton

NPG from High-Income Group

In the same way energy recovery potential (ERP) for high income = 5,872 kWh/ton and total energy generated (TEG) = 5,872×0.25 = 1,468 kWh/ton, while net power generated (NPG) =1,468-(161.5+132.12) = 1,174.38 kWh/ton

Average NPG from (L, M, and H) was 894.14 kWh/ton and total power generated from the municipal waste of the Lahore region was approximately 7,608.69 MW per day, which could be vital in solving the energy crisis of Lahore as well as the country.

Conclusions

Pakistan has an urgent need to develop alternative energy resources as well as facing the problem of MSW disposal. WTE incineration of this useless MSW will serve as a renewable source of energy and a solution for its management and environmentally friendly disposal. Our study showed that GCV of LMSW was 2,753, 1,960, and 3,670 kcal/kg, attributed to L, M, and H income areas, respectively. ERP was 5,872, 4,405, and 3,136 kWh/ton from H, L, and M, respectively. Net power generated (average) is 894.14 kWh/ton and power generated from total LMSW was about 7,608.69 MW per day, which is sufficient against the city and country shortfalls of 1,000 MW and 5,000 MW, respectively. This conversion of MSW to power generation would be beneficial to meet power demand as well as for the reduction of environmental pollution up to a certain extent. Among the other thermal sources of energy generation, municipal solid waste is one of the cheapest and most environmentally friendly sources for electricity generation. So it is suggested that government should utilize the LMSW to fill the energy gap of the country and make its environment pollution free.

Abbreviations

GOP: Government of Pakistan
MW: Megawatt
LMSW: Lahore municipal solid waste
LWMC: Lahore Waste Management Company
WTE: Waste-to-energy
MSW: Municipal solid waste
GCV: Gross calorific value
ASTM: American standard test method
ERP: Energy recovery potential
NPG: Net power generation
SD: Standard deviation
TEG: Total energy generated
UHL: Uncounted heat loss
SSA: Service station allowance
WR: Weight of residue after ignition
DSW: Dry solid waste

IM: Initial mass of solid waste
FM: Final mass of solid waste after drying
M: Moisture content

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