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ENERGY POTENTIAL FROM MUNICIPAL SOLID WASTE (MSW) FOR A DEVELOPING METROPOLIS

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Abstract: In many developing cities around the world, the shortage of energy and environmental degradation are currently two vital issues affecting sustainable development. The migration of people from villages to one of Africa's rapidly growing city Lagos, Nigeria has led to the generation of thousands tons of municipal solid waste (MSW) daily, which is one of the important contributors to environmental degradation. Harnessing the useful potential of MSW for power generation adopting the incineration technology will enhance the intermittent power supply and also help with waste management, which has threatening effect on the populace. Therefore this paper focuses on energy stored in waste generated and the power potential of this MSW through an energy recovery method to generate other forms of energy for use has an alternative energy. From the waste characterization exercise, the main components of the Lagos MSW were found to be food, metal and plastic; making the average moisture content of the MSW high. It was illustrated from analysis that a high power potential of over 10,000 MW can be obtained adopting the incineration process, starting with data from 2016 with an exponential increase over the years.
Keywords: Solid municipal waste, site selection, waste forecast, energy recovery potential, Lagos metropolis

1. INTRODUCTION

Waste arises from human activities such as domestic, commercial, industrial, and agricultural and so on. These wastes if channeled to resourceful applications can make meaningful contribution to energy generation but when not properly utilized, it will have a negative impact on the living conditions. Municipal solid waste contains glass, paper, plastic, food waste amongst other putrescible. A wide range of substrates are available for conversion to bio-energy. The most common used methods include incineration, biomethanation/anaerobic digestion and gasification [1- 4]. The incineration technology involves burning of solid waste which is capable of reducing waste to 70% by mass and 90% by volume, producing steam for electricity and cogeneration. Biomethanation or anaerobic digestion process, an environmentally friendly energy conversion process utilizes micro-organism in decomposing biomass to produce biogas which may be used for combined heat and power generation while the gasification process involves the partial combustion of shredded wastes to generate biogas. However several solid waste mainly agricultural produce, wood and plastics are types of waste that can be gasified without pre-treatment, where the producer gas obtained is used for energy production.

In the effort to study power production Wien [1] analyzed municipal solid waste power potential, presenting an exhaustive comparative analysis of power generation in Taiwan from year 2000 till 2008 was investigated. Kathirvale [2] showed the energy potential that can be derived from solid municipal waste in Malaysia, particularly Kuala Lumpur and did the energy recovery from the waste of incineration using gasification technology with heat recovery of gases. Economic models for solid municipal waste was developed by Murphy[3] for Ireland, where they analyzed th e energy value in Municipal solid waste, greenhouse gas production from residual components and the most suitable technology based on the waste character. An overview was carried out by Singh [4] exploring the various possibilities of power generation based on incineration, pyrolysis and gasification. Omari [5] carried out a thorough characterization of municipal solid waste of the city of Arusha, Tanzania where he showed the higher heating value, thermo-degradation analysis to determine the activation energy. The possibility of increasing the energy production was investigated by Alex [6] using waste through the solid waste to energy advanced thermal technology system and analytical cost models. Porteus [7] did a review of energy generation from waste incineration with emphasis of the effect of greenhouse gas emissions which is compared with emerging practices such Pyrolysis and gasification. Sheng [8] showed that municipal solid waste separating magnetic metal can provide about 4 to 13 times more electricity than it consumes hence concluded that the fuel value produced depends on the moisture and ash content. Haley [9] presented a review of energy recovery from burning solid municipal waste; here he reviewed the use of energy component obtained in form of steam, electricity or sale as solid fuel. Kalanatarifard [10] evaluated the composition and characteristics of solid waste for the purpose of obtaining information about the quantity of plastic that can be recovered at Bukit Bakin landfill, Malaysia. Gohlke [11] presented how greenhouse gas produced as a result of waste treatment can be described in simplified manner using energy indications. Themelis et al. [12] presented a study that showed technology implications of managing municipal solid waste in New York, where they showed that Waste to Energy (WTE) processing of solid municipals reduces fuel consumption and is better compared to landfilling.

With respect to past research, the present paper aims to investigate the energy potential from solid municipal waste which may be obtained from landfills in Lagos state, Nigeria due to its peculiarity, as the commercial center of Africa, its rapid urbanization, meteoric population rise and problem of proper waste disposal methods. Therefore the potential in municipal solid waste for energy generation could serve as a source of alternative energy to the intermittent power supply experience across the state.

2. SITE SELECTION

The site selection for any waste to energy (WTE) technology which could be incinerator plants with energy recovery, biomethanation/ anaerobic digestion or gasification should be based on factors other than the mere availability of land due to the effect of carbon footprints on high population density. For most developing countries the practice has being mass burning of wastes i.e. to have an open piece of land for burning the large amount of waste produced daily. This practice has produced it numerous environmental effects such as environmental degradation and spread of contagious diseases. The design of the WTE site significantly impacts the cost of the facility, the control of and the efficiency of the truck traffic flow. Location of a site can significantly affect dispersion of the plume from the chimney in the case of the incinerator, which in turn affects ambient concentrations, deposition and exposures to workers and the community. The population needs to be studied to determine the density and projected estimate for a known period into the future taking into consideration its mode of population growth. This information needs to be available because of it necessity knowing that population determine to a large extent the amount of waste to be considered and therefore total incineration needs of the community, both present and future.

The following are some other factors that need to be considered in site selection for a WTE technology: Present and anticipated use of the land in the neighborhood under consideration, Accessibility of the location, Present and projected needs of the community, Availability of nearby areas requiring landfill, Coordinated road network around the intended plant and plants should be at least 300 to 500 meters from residential zones.

Figure 1. Map of Lagos state showing all local government [13]

Based on the above considerations with respect to geomorphological terrains of Lagos state. Eti Osa, Lagos Mainland and Ojo Local government areas are the most suitable location for waste to energy (WTE) site having a low population density [15], accessible road network and nearness to coastal regions.

3. WASTE GENERATION FORECAST

Waste incinerators are used to destroy solids, sludge's, liquids, and tars. Depending upon the physical, chemical characteristics of the waste and the handling they require. It been estimated that the average waste generated per person per day is about 0.65kg/person/day [13],with a growing population of about 18,000,000 as at year 2015 with an increase rate in population of about 3.2 % [15]. Therefore the amount of solid municipal waste generated daily with the population growth rate can be projected as follow in the Table 1, assuming the average waste generated per person remains constant. It obvious there will be an increasing amount of solid waste available throughout the state as shown on Table 1, which will create a chronic problem for residents if not properly and efficiently managed. However these massive quantity of solid municipal waste though largely wet are good source of Refuse derived fuels for electricity generation.

With the rapidly increase in waste generator across various parts of the state over the years, the tonnage of combustible waste can be used to support the electric power production across the state. This will further boost developmental projects, assist small and medium enterprises, and also complement the intermittent power supply from the various electricity distribution companies.

Table 1. Trend in waste generation

Year	Population	Waste/day(kg)	Waste/year(Ton)
2015	18000000	11700000	4270500
2016	18576000	12074400	4407156
2017	19170432	12460780	4548185
2018	19783886	12859526	4693727
2019	20416970	13271031	4843926
2020	21070313	13695704	4998932
2021	21744563	14133966	5158898
2022	22440389	14586253	5323982
2023	23440389	15053013	5494349
2024	23899553	15534709	5670169
2025	24664339	16031820	5851614
2026	25453598	16544839	6038866
2027	26268113	17074273	6232110
2028	27108692	17620650	6431537
2029	27976171	18184511	6637347
2030	28871408	18766415	6849742

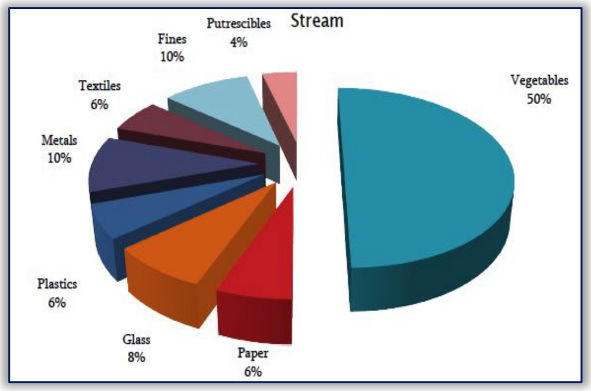

Figure 2. Chart showing the waste structure of Lagos State [13]

4. ENERGY POTENTIAL FROM MUNICIPAL SOLID WASTE

The bulk of solid waste in Lagos state are food wastes as shown in Figure 2 which as high moisture content. This is due to the lack of proper waste treatment and disposal method. However a high tonnage of waste is available for energy generation which will be of immense benefits to both domestic and commercial/industrial consumption.

— Estimation of carbon component of solid waste

The combustion product of solid municipal waste which is mainly carbon(C), hydrogen (H), oxygen (O), nitrogen (N) and sulphur (S) with its molecular weight is expressed in Table 2 with the ultimate analysis of flue gas of various solid waste compositions given in Table 3.

Table 2. Molar composition of the waste yields [16]

Combustibles	C	H	O	N	S
Mass,Kg	255.5	32.2	178.3	7.7	0.85
Kg/moles	12.01	1.01	16.00	14.01	32.06
Moles	3066	34	3080	108	27

Table 3. Ultimate Analysis of Solid Municipal Waste [16]

Combustibles	C	H	O	N	S
Vegetables	48	6.4	37.6	2.6	0.4
Paper	43.5	6.0	44	0.3	0.2
Plastic	60	7.2	22.8		
Textiles	55	6.6	31.2	4.6	0.15
Others[a]	49.0	6.0	42.7	0.2	0.10
Total	255.5	32.2	178.3	7.7	0.85

a: putrescible, glass, fines, etc.

Here we proceed by determining the various proportions in solid municipal waste generated across the state per year (tonnage) as shown in the Table 1 using the waste structure of Lagos state as illustrated in the Figure 2. Thereafter the carbon component of the various waste structure is determined with respect to the ultimate analysis of solid municipal waste in Table 3, where it can be easily shown from analysis that 1kg of municipal solid waste will generate 0.6683 kg of Carbon i.e. 1 tonnage of MSW will generate 668.3kg of carbon. This is illustrated in the Figure 3 below.

The Figure 3 which shows the yearly generation of carbon constituent in tons from solid waste illustrates that the yearly Carbon constituent increases steadily due to the increase in waste generation across the state.

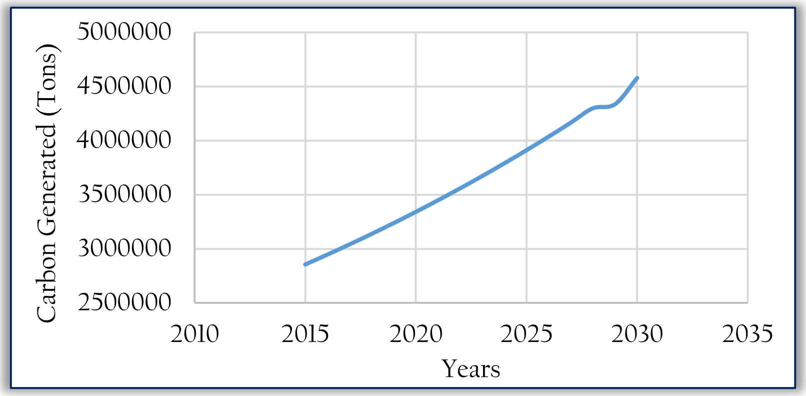

Figure 3. Analysis of Carbon component in Lagos State solid waste

— Estimation of methane (CH_4) from carbon generation

From the above chemical reaction, it can be demonstrated that 1 mole of carbon (C) reacting with 2 moles of water will yield 1 mole of Methane, releasing 2 moles of oxygen.

$$C + 2H_2O \rightarrow CH_4 + 2O_2 \quad (1)$$

With the aid of Table 2, it is illustrated that 1 kg of carbon (C) will produce 1.333Kg of Methane, which is applied to the yearly output of carbon produced. Therefore the yearly Methane obtained from MSW is demonstrated in the Figure 4 below.

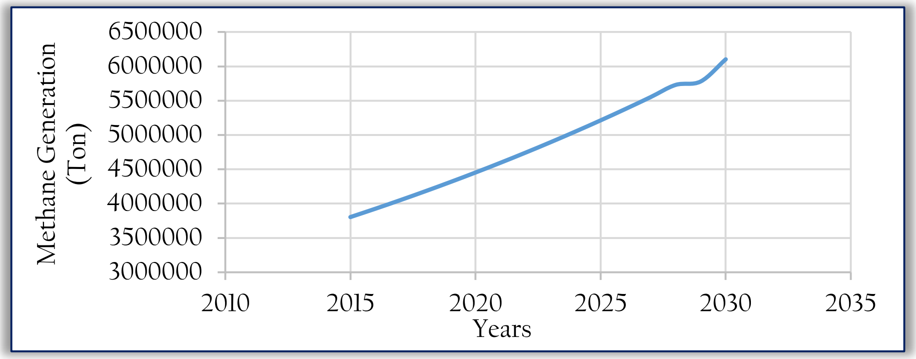

Figure 4. Estimation of Methane obtained from chemical reaction

It can be depicted from the Figure 4 that Methane production from chemical reaction of Carbon with water under thermodynamically stable condition yields an increasing production of Methane which increases steadily each year as a result of increasing release of carbon constituent form solid waste.

— Estimation of energy generation potential

To determine energy generation potential from MSW, mass burn incineration is adopted where total waste is considered. However due to the high moisture content in Lagos State waste created by lack of proper sorting method and waste disposal. It is assumed 35% of total wastes/day as expressed in Table 1 is dry waste. Where the energy content in various waste material are expressed in the Table 4 where the last two column depicts the total energy content and lower heating value (LHV) of waste constituent.

Table 4. Energy content of different waste constituents [14]

Material	Kwh/Kg in material	Kwh/Kg in waste
Paper	4.39	1.21
Plastic	9.05	0.46
Glass	0.00	0.00
Textile	5.20	0.22
Organic matter	1.55	0.10
Others	3.36	0.28

Total energy content of mass burn can be depicted from the energy content of waste constituent, Table 4 as 2.27(Kwh/Kg). Therefore for a ton of MSW considering the waste structure of Lagos state as expressed in Figure 2, it can be easily interpreted that a ton of MSW contains 313.4Kwh/day energy content. Energy recovery potential (ERP) is expressed in Gwh/day as adopted by [14]:

$$ERP\left(\frac{GWh}{day}\right) = \left(Drywaste\left(\frac{Kg}{day}\right) xLHVofwaste\left(\frac{KWh}{Kg}\right)\right) \quad (2)$$

Adopting the expression in Eq.(2) with respect to the above stated condition the energy recovery potential from MSW can be expressed as Figure 5.

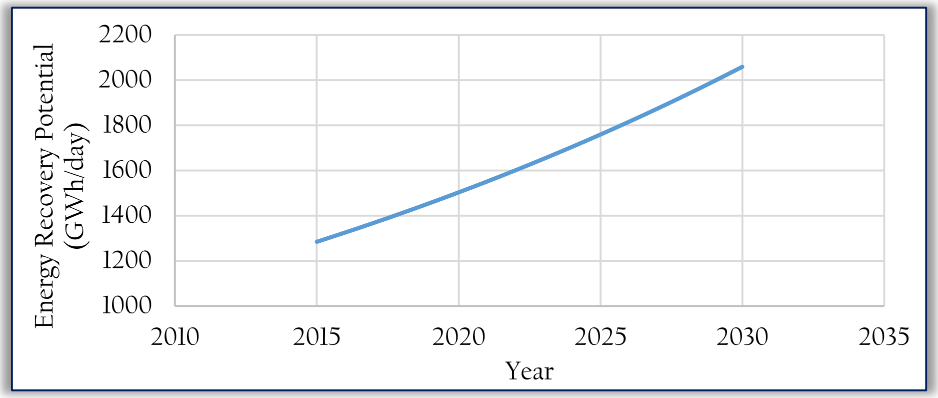

Figure 5. Energy recovery potential forecast for Lagos metropolis

As observed in the energy recovery potential (ERP) Figure 5, it is evident that despite low dry waste, the energy potential is sufficiently high for daily generation, which increases steadily for year output production. The net generation potential (NGP) for electrical power is defined as [14]:

$$NGP = \eta PGP = \eta x ERP x \frac{10^3}{24} \quad (3)$$

Utilizing electrical power efficiency as low as 18%. Substituting values of appropriate parameters into the Eq. 3.The NGP forecast is expressed for yearly output as Figure 6.

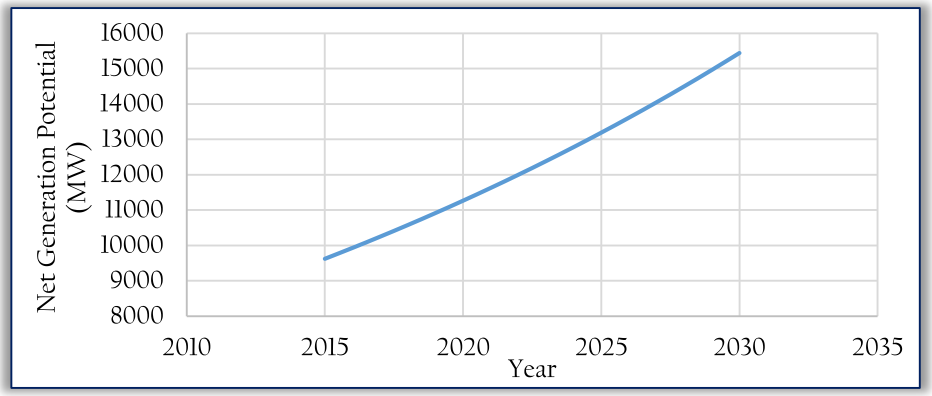

Figure 6. Net generation potential forecast for Lagos metropolis

Figure 6 illustrates a promising power generation potential from MSW for the Lagos community, where it is observed that a high power potential of over 10,000 MW of power can be obtained through MSW. Rather than the mass burning of waste in landfills creating atmospheric pollution and other forms of environmental degradation with no particular benefit obtained from the huge solid waste.

4. CONCLUSION AND RECOMMENDATION

In many growing cities in which population rate over shoots infrastructural development, solid waste, a domestic energy resource with the potential to provide a significant amount of energy [2], is often over looked and pushed aside. Taking 2016 as a reference, it is illustrated that there is an energy recovery potential of over 1300 GW/day with a high power potential of over 10,000 MW of power. This is observed to only increase due to corresponding increase in population of the metropolis over the years as well as solid waste. This is not to spell doom but to create a channel of alternative resource for the Lagos metropolis if the various landfill sites can be converted to waste to energy (WTE) technology sites and in turn energy resources can be harnessed for other uses to serve the growing population. In this article, a relationship between the parameters that makes up a proximate analysis with energy content of MSW and its conversion to power is presented but to further this research it is essential to compare this data with result from experimental analysis, physical composition and elemental analysis models.

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