Determination of the calorific value of municipal solid waste in enugu, nigeria and its potential for electricity generation

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Abstract: The work aimed at determination of calorific value of municipal solid waste in Enugu, Nigeria and its potential for electricity generation. Random truck sampling was used according to American Society for Testing and Materials (ASTM) in the collection of samples at Ugwuaji landfill site, Enugu, Nigeria and calorific value was determined using oxygen bomb calorimeter. Enugu has a present population of 882,178 and the amount of municipal solid waste generated in Enugu was estimated to be 420 tonnes daily and this resulted in waste generation rate of 0.48 kg per capita per day. The average composition of the municipal solid waste was 39% putrescible, 11% paper, 21% plastics, 5% textile, and 2% metal, 3% glass and 19% others. The average moisture content Volatile matter content, Ash content and fixed carbon content of the waste stream were 38.28%, 47.48%, 2.58% and 13.25% respectively. The gross calorific value was obtained as 5655837600 kJ day^{-1} which is equivalent to 1571066 kWh^{-1} day^{-1} .This energy is equivalent to about 2.16% of the total annual Electricity used in Enugu and would result in an annual saving of US$ 560 Thousand in case of utilization, giving an alternative to the unsteady supply of electricity and ensuring a hygienic, clean and aesthetically friendly environment. The results of this research showed that energy recovery is a feasible option as part of an integrated solid waste management plan in Enugu, Nigeria. However, it is recommended to perform a detailed economic analysis before making a decision on such option.

Keywords: municipal solid waste, calorific value, composition, energy content, electricity

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1 Introduction

The Electricity distribution grid in Nigeria consisted of 23,753 km of 33 kV lines and 19,226 Km of 11 kV lines. In turn, these fed 679 substations of 33/11kV rating and 20,543 substations of 33/0.415 and 11/0.415 kV ratings. In addition, there were 1,790 distribution transformers and 680 injection transformers. The transmission network is overloaded with a wheeling capacity less than 4,000 MW. It has a poor voltage profile in most parts of the network, especially in the North where inadequate dispatch and control infrastructure, radial and fragile grid network, frequent system collapse, and exceedingly high transmission losses are prevalent. Access to electricity services is poor in Nigeria. About 60 percent of the population – approximately 85 million people are not served. Per capita consumption of electricity is approximately 100 kWh in comparison to 4,500 kWh, 1934 kWh and 1379 kWh in South Africa, Brazil and China, respectively (Federal Ministry of Power and Steel, Federal Republic of Nigeria, 2006). Under a

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business-as-usual scenario, the proportion of Nigerians without access to electricity services will continue to increase over time. Switching to the use of renewable resources wherever the appropriate technology is available is a more sustainable and environmentally responsible approach. The vision for the use of municipal solid waste-based resources is optimistic. With the appropriate research and development of new approaches, we can discover economically viable solutions to meet the needs of a full planet. This vision sets the direction and calls for coordinated programs to identify and implement the actions required to build a renewable resource based utilizing the energy systems inherent in municipal solid wastes.

One option of utilizing Municipal Solid Waste (MSW) is energy recovery through various processes such as, combustion, pyrolysis, and refuse derived fuel (RD). In order to evaluate the feasibility of energy recovery as an integral part of a solid waste management system, it is of great importance to determine the energy content or calorific value (CV) of the solid waste, which is defined as the number of heat units evolved when unit mass of material is completely burned and is measured in joules per gram ($J\ g^{-1}$) or British thermal units per pound ($Btu\ lb^{-1}$). The energy content of any material, such as solid waste, is a function of many parameters, namely, physical composition of the waste, moisture content and ash content (Abu-Qudais and Abu-Qdais, 2000).

There are several experimental and empirical approaches available for determining the calorific value (CV) of materials such as MSW. Calorimetric measurement is the common method for determining the energy content of MSW (Harker and Backhurst, 1981). Because MSW is a heterogeneous material and its production rate and physical composition vary from place to place as they are a function of socio-economic level and climatic conditions (Abu-Qdais et al., 1997), the energy content of one country will be different from that of another.

Due to human activities in the cities, municipal solid waste (MSW) is produced which may result in various environmental problems (Dong et al., 2003; Abu-Qudais and Abu-Qdais, 2000). Although landfilling method has capability to control the wastes, there are several disadvantages such as hazardous gas emissions and leachate production arisen from landfilled wastes (Dong et al., 2003; Abu-Qudais and Abu-Qdais, 2000). Landfilling is the widely used method for solid waste disposal (Sumiani et al, 2009). The existing dumping sites in Nigeria mostly are not properly engineered and managed (Ogwueleka, 2009), pollutant that are released or discharged from the disposal sites eventually caused direct and indirect impact to human’s life (Zahari et al, 2010). Municipal solid wastes, collected continuously from cities, have recently thought as one of the important renewable energy resources. Recovering energy from municipal solid waste is feasible by means of a number of energy generation processes such as combustion, pyrolysis and gasification (Dong et al., 2003).

Design and operation of the mentioned energy systems based on municipal solid waste are highly related to heating value of the used municipal solid waste materials. Thus, determining heating value of municipal solid waste is a key work to perform the efficient design and operation of the waste to energy conversion based technologies (Akkaya and Demir, 2009; Kalantarifard and Yang, 2011).Usually, the heating value is experimentally determined by a bomb calorimeter.

Recently, Ojolo et al. (2007, 2008) studied the potential of biogas production using municipal solid waste in Nigeria. But this study focuses on prediction of lower heating value of municipal solid waste in Nigeria. Hence the general objective of this work is to determine the energy content of waste generated in municipality of Enugu, Enugu State Nigeria. The specific objectives were to:(i) determine the physical composition of individual waste from Enugu municipality, (ii) determine the moisture content, volatile matter and ash content of municipal solid waste at landfill site , (iii) determine experimentally the calorific value of the characterized waste using bomb calorimeter and, (iv) estimate the potential of this waste for electricity generation.

2 Materials and methods

2.1 Description of study area

Enugu is the capital of Enugu State in Nigeria. It is located in the south-eastern area of Nigeria. The city has a population of 722,664 according to the 2006 Nigerian census with a population density of 17,000 sq mi (6,400 km^2) (Nigerian Population Commission, 2007). It has a city area of 44 sq mi (113 km^2) and the metropolitan area of 80 sq mi (200 km^2). Enugu is located in a tropical rain forest zone with a derived savannah (Reifsnyder and Darnhofer 1989). The city has a tropical savanna climate. Enugu's climate is humid and this humidity is at its highest between March and November. For the whole of Enugu State the mean daily temperature is 26.7°C (80.1°F). As in the rest of West Africa, the rainy season and dry season are the only weather periods that reoccur in Enugu. The average annual rainfall in Enugu is around 2,000 millimetres (79 in), which arrives intermittently and becomes very heavy during the rainy season. Other weather conditions affecting the city include Harmattan, a dusty trade wind lasting a few weeks of December and January. Like the rest of Nigeria, Enugu is hot all year round. The municipality is empirically divided into six waste management zones namely New Heaven, Abakpa, Agbani road, Coal camp, Ogui and Emene zone (Figure 1). Each zone takes responsibility for collection and transportation of waste to the landfill at Ugwuaji.

Large quantity of the municipal solid waste (MSW) generated in municipality of Enugu, Enugu State, Nigeria is disposed of in open dumpsite at Ugwuaji, Enugu. Some disadvantages associated with this method are: high emission of methane and leachate production. Therefore, it would be of interest to study energy recovery strategies of waste treatment to decrease the burden on the environment.

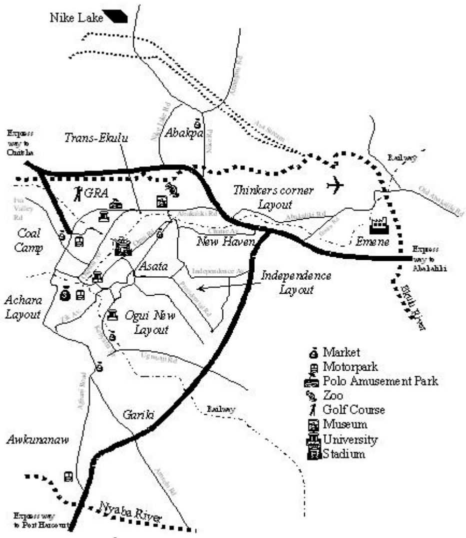

Figure 1 Map of Enugu municipality Enugu State Nigeria

2.2 Collection of sample

2.2.1 Method of fresh garbage sampling

Random truck sampling methods was applied in this work to identify the fresh waste characteristics. This method published by the American Society for Testing and Materials (ASTM D5231) and used to identify the waste composition of fresh garbage (incoming waste to landfill per day) was used.

2.2.2 Method of random truck sampling

The procedure is applicable for collecting the representative municipal solid waste in waste stream. The first step in this method is a random pick up of the garbage bag from arrival waste loads (compactor trucks) which is usually in the amount of 15 or 20 kg per unit. A total of 100 kg of solid waste was collected each day and this process was repeated for 6 days. Only two MSW compactor trucks were considered each day for each of the six zones in the sample collection. Each Compactor truck has a capacity of 30 tonnes (Figure 2). The waste was separated according to the selected classification of solid waste components. The target sort categories included the following: putrefaction (food waste), plastics, paper, textile, metals, glass, others (dust, ash, ceramics, soil, bones). Sampling and sorting team was made up of one field supervisor and six sorters. Individual waste component and composite samples were prepared and sealed in plastic bags and was taken back to laboratory for chemical analysis.

2.3 Physical composition analysis

The waste was processed as recommended in Wilson et al. (2001). The waste was weighed in pre-weighed bins using a weighing scale with a sensitivity of 0.1 kg.

2.4 Proximate analysis

The proximate analysis gives the moisture content, the volatile content (when heated to 600°C), the free carbon remaining at that point and the ash (mineral) in the sample. The analysis was done as per the ASTM standard method which is as follows.

2.4.1 Moisture content determination

The percent moisture of the MSW samples were determined by weighing 100 g of the samples into a pre-weighed dish and drying the samples in a digital oven (Fisher Scientific: Isotemp® oven, model 665F) at 105°C to a constant weight. The percent moisture content (MC) was calculated as a percentage loss in weight before and after drying as follows:

$$\%MoistureContent = \frac{Wetweight-Dryweight}{WetWeight}x100\% \quad (1)$$

For each sample, triplicate samples were analysed for moisture content determination. After determination of the moisture content, the samples were further tested for volatile matter content as explained in the section that follows. All the moisture content values that were used in this research were on the wet basis, unless otherwise mentioned.

2.4.2 Volatile matter content

The volatile matter content was determined by the method of ignition of the sample at 550 °C. The triplicate samples of MSW material used in the moisture content determination were weighed and placed in an Isotemp® Muffle furnace (Fisher Scientific: Model 186A) for 24 h at 550 °C. After combustion, the samples were weighed to determine the ash dry weight, with volatile solids being the difference between the dried solids and the ash as follows:

$$VM(\%) = \frac{DrySampleWeight-AshWeight}{DrySampleWeight} \times 100\% \quad (2)$$

2.4.3 Fixed carbon

The carbon content in the ash sample was calculated using the following equation:

$$FC = 100 - (MC + ash + VM) \quad (3)$$

Where *FC*= Fixed carbon content (wt %), *MC*= Moisture content (wt %), *ash*= ash content (wt %), and *VM*= Volatile matter content (wt%).

2.5 Determination of calorific value

2.5.1 Sample preparation for bomb calorimeter testing

Combustible part of the MSW was used for the experiment. A sample of 100 g was taken from combustibles after separating non combustibles. They were kept in oven for 24 hrs under 105ºC for calculating the moisture contents. The dried samples were size reduced using a blender and separated using a 1 mm sieve for achieving complete combustion in the Bomb Calorimeter tests that were carried out at the National Centre for Energy Research and Development(NCERD), University of Nigeria Nsukka, Enugu State Nigeria. Two replicates of each type of waste (food waste, textile, plastic and paper) were tested to obtain the calorific values in the apparatus. The samples were burnt in pure oxygen in an enclosed volume and the energy given off was measured as the temperature increase of the bomb and its surroundings (ANSI Standards, 1977).

2.5.2 Procedure for determining the calorific value

Using oxygen bomb calorimeter (model XR-IA) manufactured by Finlab Nigeria Limited. Solid samples 1g was pressed into pellets before introducing metallic cup contained inside the bomb. A fuse wire of 10 cm was passed through the sample material. The fuse wire concentrates heat on the sample and served as a rigid support for holding the sample in place while handling the bomb prior to ignition.

The bomb head was set on the cup; then the cup was slide into the body sleeve and the screw cap was attached. After clamping these parts together by hand, the bomb in the bench socket was set and the screw cap tightened firmly with the octagon wrench furnished with the calorimeter. The set up was handled carefully during this operation so that the sample will not be disturbed. The quantity of water added in the bath covered the top of the bomb. The needle valve and pressure relief valve on the oxygen filling connection was closed; then the oxygen tank valve was opened **not** more **than** one quarter turn from the closed position. The filling hose was attached to the gas inlet tube on the bomb head by pressing the coupling onto the valve cap. The coupling was pushed downwards until it rests firmly against the collar on the valve cap.

The valve on the filling connection opened slowly and the gage observed as pressure rises in the bomb and connecting hose. When the pressure reached 2-3 MPa, the control valve was closed immediately and the pin wrench was used to close the valve cap on the inlet tube. The relief valve on the filling connection was used to release the residue pressure in the filling hose. After the pressure gauge returns to zero, the pin wrench was removed and the filling line was lifted from the bomb head.

The bomb calorimeter was opened and allowed to stabilize for about 2-3 minutes and the initial temperature, readings were taken. The sample was fired by depressing the button on the ignition unit. Thereafter a distinct temperature rise was observed on the chart as evidence that the sample has burned. The ignition cord was removed and the valve cap was opened while the pin wrench, releasing pressure slowly over a period of about one minute. After all pressure has been released, the bomb was opened and the inside of the cup was examined and the underside of the head for any unburned sample.

2.5.3 Equation for calculation of calorific values from experimental results

Caloric value was calculated using Equation 4:

$$W = \frac{\varepsilon \Delta T - \emptyset - V}{M} \quad (4)$$

Where W= calorific value (kJ kg^{-1}), ε =bomb calorimeter (XR-IA) standardization (13039.308), ΔT= Temperature difference (^{0}C), Ø= fuse wire correction (3.2), V= acid correction (m^3), and M= mass of sample (kg).

2.5.4 Fuse correction

All unburned pieces of fuse wire head were collected and measured. A correction of 2.3 calories per cm of wire burned must then be applied in all standardization and calorific value determination. The unburned part is determined by subtracting the burnt part from 10 cm. That is length of the unburned fuse wire multiplied by 2.3.

$$unburnedwire = 10 - burnedwire \quad (5)$$

$$Fusecorrection = 2.3 \times unburnedwire \quad (6)$$

2.5.5 Acid correction

Corrections for the heat of formation of nitric and sulphuric acids are significant for most samples. These can be determined using sodium carbonate as base and methyl orange as an indicator for titration to get the volume of acid present in the process. Residue from the bomb after burning was rinsed using distilled water. The solution from the rinsed bomb was used as the acid while sodium carbonate served as based in the titration. Two drops of methyl orange were added in the acid. The volume of base used to reach the end point was the volume, v used in calculated calorific value.

2.6 Collection of secondary data

The population of Enugu and its distribution was collected from the National Population Commission (NPC) website, (www.population.gov.ng/) according to Nigeria census in 2006. The rate of electricity consumption and electricity charge rate in Enugu was supplied by Enugu Electricity Distribution Company (EEDC) formerly Power Holding Company of Nigeria (PHCN), Ogui station Enugu, Enugu State Nigeria.

3 Results and discussions

The quantity, nature and characteristics of the waste fluctuate with the respect to time, region and condition prevailing there. Similarity is the solid waste which showed wide variation in the present study. Waste from different categories can have different chemical and physical characteristics which is directly depend on the type of wastes source.

3.1 Result of random truck sampling

Solid waste characterization from random truck sampling method was done for a period of one week starting from Monday until Saturday which would cover the characteristics for whole week. The total amount of the waste to be sorted in a day was approximately 100 kg.

Table 1 Number of trucks and the waste sorted per trucks

Days	Number of Selected Trucks	Amount of Waste Sorted per truck kg	Total amount of waste sorted per Day, kg
Monday	12	8-15	100
Tuesday	12	8-12	110
Wednesday	12	10-15	120
Thursday	12	7-10	100
Friday	12	8-10	100
Saturday	12	10-15	150

Two trucks were selected from each zone per day and the amount of waste were equally distributed among the number of trucks which were selected to collect the sample that day. Table 1 shows the number of trucks and the waste sorted for each one.

Obtained result from sorting process and quantity of each individual component of the solid waste at Ugwuaji Landfill based on zones of generation was shown in Table 2. The waste composition result is presented in Figure 2. An average between 5 to 7 different categories of solid waste was found at landfill waste stream during one week.

Table 2 Physical composition of municipal solid waste in Enugu distributed in zones

Components	Independence Lay-out (wt%)	Agbani Road (wt%)	Ogui Road (wt%)	Coal Camp (wt%)	New-Heaven (wt%)	Emene (wt%)	Average (wt %)
Putrefaction	59	32	34	55	24	31	39
Paper	16	7	9	5	5	23	11
Plastic	19	35	7	12.5	31	22	21
Textile	-	9	18	0.5	5	-	5
Metal	2	2	-	1	4	-	2
Glass	4	2	1	8	4	-	3
Others	-	13	31	18	27	13	19

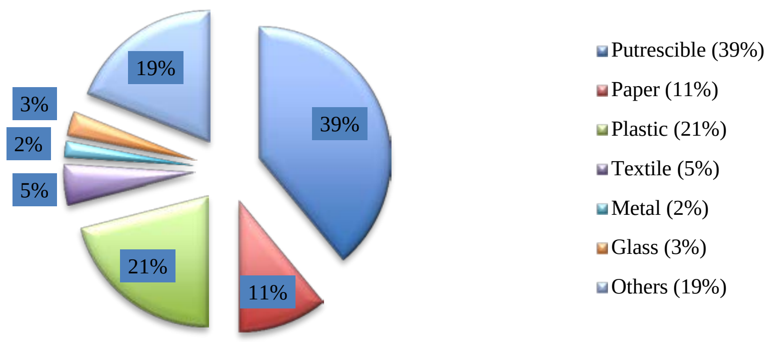

Figure 2 Composition of municipal solid waste in Enugu

The average composition of the municipal solid waste (MSW) was: 39% putrefaction, 11% paper, 21% plastics, 5% textile, and 2% metal, 3% glass and 19% others. Physically, the putrescible material was characterized with high fraction of food waste and vegetable straps. The result showed that putrefaction is the major constituent of MSW in municipality followed by plastics. The plastic constituent is majorly the lower dense polyethylene such as packs sachet water, biscuits, bread and other packaging materials. Others such as soil, ceramics, bones, are the third prominent constitute of MSW with 19%. These materials occupy small volume but have high weight content. Paper is the fourth with 11% followed by textile (5%), glass (3%) and lastly metal with 2%. Metals are regarded as one of the most valuable components of MSW because it is recyclable. Scavengers collect metal products from their primary point of disposal before they reach the land fill site. In the landfill site at Ugwuaji, many scavengers also trade on the recyclable components of MSW especially metals. That is the reason for its low composition in MSW. Industrial zone like Emene has negligible amount of glass, metal and textile generated. Most of their products and by-products were centred on plastics and papers. The inhabitants at Independence lay-out may consider burning textile materials as the best way of getting rid of them. The Physical composition result for the waste stream in Enugu municipality is compared using Table 3 and Figure 3. with the results of other researchers presented by Ogwueleka (2009) for other major cities in Nigeria.

It can be seen from Table 3 and Figure 3 that the result of this work in terms of the physical composition of the waste stream in Enugu municipality followed the same trend as the work of previous researchers in Nigeria (Diaz and Golueke, 1985; Ogwueleka, 2003; Ogwueleka, 2009; Agunwamba, 1998; Cointreau, 1982; Dauda and Osita,2003).

Table 3 Compositions of waste stream characteristics in Nigeria

	Nsukka β	Lagos μ	Makurdi ±	Kano μ	Onitsha ¥	Ibadan α	Maiduguri #	Enugu PR
Putrescribe	56	56	52.2	43.0	30.7	76	25.8	39
Plastics	8.4	4	8.2	4.0	9.2	4.0	18.1	21
Paper	13.8	14.0	12.3	17.0	23.1	6.6	7.5	11
Textile	3.1	--	2.5	7.0	6.2	1.4	3.9	5
Metal	6.8	4.0	7.1	5.0	6.2	2.5	9.1	2
Glass	2.5	3.0	3.6	2.0	9.2	0.6	4.3	3
Others	9.4	19.0	14.0	22.0	15.4	8.9	31.3	19

Note: Others=dust, ash, ceramics, rubber, soil, bones

[α]Diaz and Golueke (1983), [β]Ogwueleka (2003), [±]Ogwueleka (2009), [¥]Agunwamba (1998), [μ]Cointreau (1982), [#]Dauda and Osita (2003), PR=present Research

Source: Ogwueleka (2009)

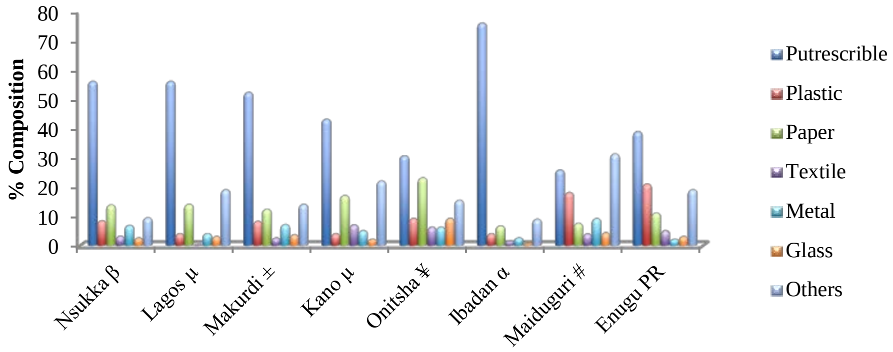

Figure 3 Comparison of waste composition of MSW in Enugu with MSW composition in other cities in Nigeria

From Table 3 and Figure 3, it is obvious that putrescible (food waste) constitutes the highest proportion across the major cities in Nigeria except in Maidugri. This is expected, since Nigeria is a developing country, and putrescible is the major component of the solid waste stream generated in developing countries (Diaz and Golueke, 1985). In Makurdi, the paper composition was determined to be 12.3% against 11% , Maiduguri has plastic composition of 18.1% against 21%, the percentage of textile generated in Onitsha is 6.2% against 5%, while Ibadan has a metal composition of 2.5% against 2% in Enugu, the values for glass and others (dust, ash, ceramics, soil, bones) in Lagos is the same with the value from Enugu with result of 3% and 19% respectively.

3.2 Estimation of the amount of MSW generated in Enugu

According to Enugu State Waste Management Agency (ESWAMA) an average of seven trucks transport MSW from the generation source to the landfill site at Ugwuaji. These trucks dispose waste at least two times daily .Therefore we assumed that a total of 14 trips of MSW is being disposed at the Ugwuaji landfill site daily. Each truck has a carrying capacity of 30 tonnes of MSW. Therefore quantity of MSW generated in Enugu municipality daily was calculated to be: (14 × 30 tonnes of MSW) per day and this gives 420 tonnes per day or 153300 tonnes of MSW per year. The daily waste generation in kilogram is presented in Table 4 as composition of each fraction by weight using the various percentage compositions presented in Figure 2.

Table 4 The amount of waste in kg generated per day from each component daily in Enugu

Component	Weight (kg)
Putrescible	163,800
Paper	46,200
Plastic	88,200
Textile	21,000
Metal	8,400
Glass	12,600
Others	79,800

3.2 Result of proximate analysis

Proximate analysis involves determination of moisture content, volatile matter, ash content and fixed carbon of composite sample. The most significant result is probably the moisture content (Table 5 and Figure 4), which indicates that it is very wet. Nigeria, being a country with a tropic climate, enjoys an abundant amount of rainfall throughout the year. Coupled with this is the fact that resident of Enugu municipality generally disposes of their garbage in makeshift containers, which allow rainfall to get in, causing the garbage to collect water. This affects the calorific value of the waste.

Table 5 Moisture content of waste in Enugu municipality

Components	Independence Lay – out (wt%)	Agbani Road (wt%)	Ogui Road (wt%)	Coal-Camp (wt%)	New – Heaven (wt%)	Emene (wt%)	Average (wt%)
Putrescible	80.5	80.6	80.6	78.3	58.1	72.3	75.1
Paper	10.5	51.8	44.9	30.2	7.7	11.4	26.1
Plastics	29.4	6.2	27	6.7	36.7	11.4	19.6
Textile	18	37.6	11.1	38.9	35.8	48.7	31.7
Average Moisture Content of Waste in Enugu							38.125%

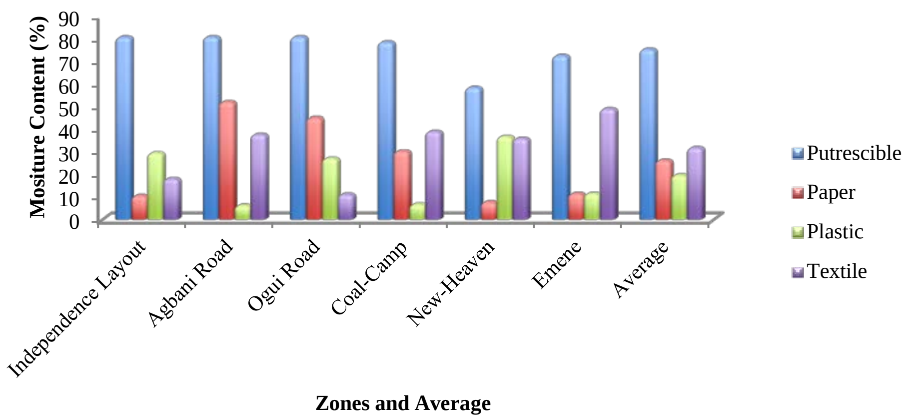

Figure 4 Moisture content in each zone

Moreover, the experiment was performed at the peak of rainy season, giving rise to a high moisture content value of the component materials. The materials can either get in contact with water at the primary disposal point, during transportation or at the landfill site. Putrescible that is food waste had the highest average moisture content with a value of 75.1%, textile (31%) followed by paper with 26% and finally 31.7%. The moisture content of plastic materials is as high as 31.1% because almost all the sachet water pack contains visible water molecules inside them. Some of the sachets water packs have water content as much as 20cl. The result of volatile matter content is given in Table 6. The average volatile matter percentage by weight for putrescible, paper, plastic, and textile were 19%, 58%, 53.9%, 59.0% respectively.

It shows that textile has the highest volatile of 59% of its total weight followed by paper is has 58% while plastics has a volatile content of 53%. From Table 6, it is evident that putrescible has the least volatile Matter content of 19.0% by weight due to its high moisture content.

Table 6 Volatile content waste in Enugu municipality

Components	Independence Lay-out (wt%)	Agbani Road (wt%)	Ogui Road (wt%)	Coal Camp (wt%)	New-Heaven (wt%)	Emene (wt%)	Average (wt%)
Putrescible	17.3	16.3	17.0	19.1	24.7	19.4	19.0
Paper	61.5	45.3	49.9	63.4	65.1	62.6	58.0
Plastics	58.6	55.0	51.1	50.8	53.5	53.9	53.9
Textile	65.3	52.6	66.3	56.7	58.9	58.4	59.0
Average Volatile Matter Content of Waste in Enugu							47.475%

From results of Ash content, as shown in Table 7, putrescible, paper, plastic and textile were 1.3,1.9,4.6 and 2.5 respectively. It is evident that plastic has the highest ash content followed by textile, paper and putrescible in order of magnitude.

Table 7 Ash content waste in Enugu municipality

Components	Independence Lay-out (wt%)	Agbani Road (wt%)	Ogui Road (wt%)	Coal Camp (wt%)	New-Heaven (wt%)	Emene (wt%)	Average (wt%)
Putrescible	1.3	1.5	1.1	1.4	1.3	1.3	1.3
Paper	2.1	1.7	1.9	2.0	1.5	2.0	1.9
Plastics	5.6	4.3	4.6	4.1	4.8	4.4	4.6
Textile	2.3	2.2	2.9	2.3	2.6	2.5	2.5
Average Ash Content of Waste in Enugu							2.575%

The sum of the moisture content, volatile content and Ash content were subtracted from 100 to get the value for the fixed carbon of the different components of the MSW. The fixed carbon content for putrefaction, paper, plastics and textile were 4.0, 13.5, 27.0 and 8.5 respectively (Table8).

Table 8 Fixed carbon content

Components	Independence Lay-out (wt%)	Agbani Road (wt%)	Ogui Road (wt%)	Coal Camp (wt%)	New-Heaven (wt%)	Emene (wt%)	Average (wt%)
Putrescible	0.9	1.6	1.3	1.2	11.9	7.0	4.0
Paper	25.9	1.2	3.3	4.4	25.7	24.0	13.5
Plastics	9.9	34.5	17.3	38.4	5.0	30.0	27.0
Textile	14.4	7.6	19.7	2.1	2.7	4.6	8.5
Average Fixed Carbon Content of Waste in Enugu							13.25%

3.3 Result of calorific value

The result of Calorific value of the different waste components is presented in Table 9. From Table 9 it is obvious that Plastic materials had the highest calorific value with an average calorific value of 26,948 kJ kg^{-1}. The plastic was made up of a mixture of low density and high density plastics. The paper ranked second with a value of 16,295.7 kJ kg^{-1} followed by putrescible and textile with values of 13,909.8 kJ kg^{-1} and 11,796.6 kJ kg^{-1} respectively. The average calorific value in kJ kg^{-1} and kJ day^{-1} is presented in Figures 5 and 6 respectively.

Table 9 Calorific value of MSW

Components	Calorific Value (kJ kg^{-1})	Calorific Value (kJ kg^{-1})	Average CalorificValue (kJ kg^{-1})
Putrescible	12752.31	15067.30	13909.8
Paper	17820.72	14770.60	16295.7
Plastic	13362.87	40533.38	26948.1
Textile	13235.88	10357.29	11796.6

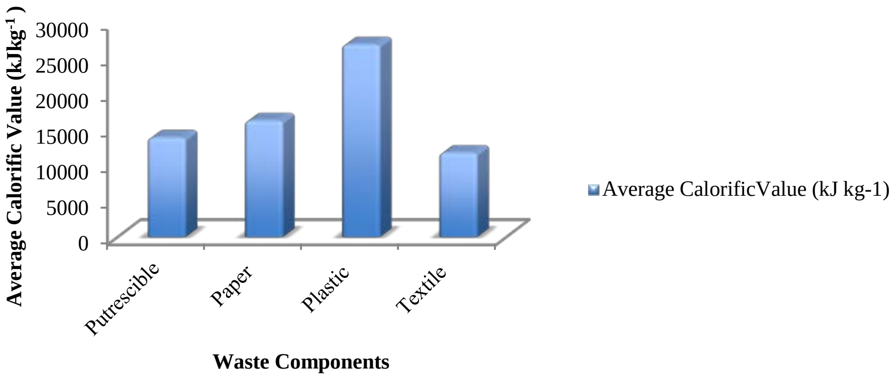

Figure 5 Calorific value of MSW

Metals, glass and 'others' requires high heating energy. Unfortunately, the oxygen bomb calorimeter available cannot be used to determine their calorific value. From Table 4, the daily generation of putrescible, paper, plastic, textile were estimated to be 163800,46200,88200 and 21000 kg day^{-1} respectively. Multiplying the calorific values in kJ kg^{-1} (Table 9) with the daily waste generation in kg day^{-1}(Table 4) gives the calorific values in kJ day^{-1} for these components. Values for putrescible, paper, plastic and textile were obtained as

2278425240 ,752861340, 2376822420 and 247,728,600 kJ day^{-1} respectively. Therefore, the gross calorific value based on these four components was obtained as 5655837600 kJ day^{-1} for Enugu municipality. The gross calorific value obtained is low when compared to that obtained from cities in developed countries. The waste in developing countries contains so much moisture that fuel has to be added to maintain combustion. Low calorific value and low combustible components of solid waste in Nigeria make incineration uneconomical (Ogwueleka, 2003).

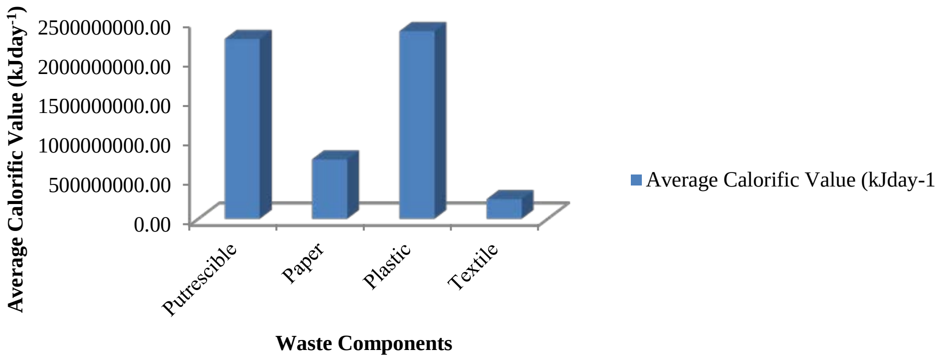

Figure 6 Calorific value of MSW generated daily

Using the conversion factor of 1 kWh= 3.60x10^{6} J=3,600 kJ gave the total daily gross energy from MSW in Enugu municipality as 1571066 kWh per day. Therefore, the electric energy that can be generated in a year using MSW in Enugu is 573439090 kWh per year.

3.4 Forecasting solid waste generation in municipality of Enugu

Many factors interplay to influence the volumes of solid wastes generated in our cities. However, the consensus is that the critical factors to consider in making projections of future waste quantities are (Sha'Ato et al., 2007):

- Current city population,
- Population growth rates, and
- Per capita waste generation.

In essence, other factors contributing to generation of urban waste are presumed to remain stable; only the population dynamics are considered critical (Filani and Abumere, 1986). This is reflected in the population growth formula of the form (Sha'Ato et al., 2007):

$$P_n = P_0(1+r)^n \quad (7)$$

where P_n is the population in the intervening (projection) period, P_o the base population generating current waste quantities, r the average annual city population growth rate (percent) and n the projection period (in years). Once the future population is computed, multiplication by solid waste per capita affords the projected waste quantity for the envisaged future period. The 2006 National Population Census in Nigeria will be used as the base Year. The population of Enugu is as shown in Table 10.

Table 10 Population of Enugu municipality in 2006 Nigerian population census

LGA	Land Size(km^2)	Male	Female	Total
Enugu East	388,395	131,214	145,905	277,119
Enugu North	107,773	118,895	123,245	242,140
Enugu South	68,287	93,758	104,274	198,032
	Total Population			717291

Note: Sources:www.population.gov.ng/

P_o = P_{2006}=717291(From Table 4);r = 3% (UNFPA, Enugu state);n = 7 years (From 2006 to 2013)

Using Equation 7 gives P_n=P_{2013}=717,291(1+0.03)^7 =882,178

The expected population of Enugu in 2013 =882,178

Estimated Daily Waste Generation in Enugu =420tons=42000 kg

Therefore, Waste Generated per capita per day in Enugu= 0.48kg per cap per day

The waste generation rates ranged from 0.66 kg per cap per day in urban areas to 0.44 kg per cap per day in rural areas as opposed to 0.7-1.8 kg per cap per day in developed countries (Cointreau, 1982).It is evident that the waste generation rate for Enugu fall within this range.

3.5 Estimation of the potential of the MSW for electricity generation

Average Monthly Electric Energy distributed in Enugu (EEDC (Formerly PHCN), Ogui station) = 22,151,390 kWh. Therefore Annual Energy consumption=265816680 kWh

Charge Rate for Electricity = N14.82 per kWh (Power Holding Company of Nigeria PLC, Enugu Electricity Distribution Company)

VAT = 5%

Annual cost of Electricity = Rate x kWh+ VAT = N4136373358

Quantity of energy in kilowatt hour generated by MSW daily = 1571066 kWh

Quantity of energy in kilowatt hour generated in a year using MSW = 573439090 kWh

Therefore, $\% \, Contribution \, of \, MSW = \frac{573439090kWh}{265816680kWh} \times 100 = 2.16\%$

This shows that municipal solid waste (MSW) in Enugu has the potential to generate more than 2.16% of electric energy distributed annually in Enugu municipality.

Therefore 2.16% of N4136373358=N89345664.53. So, about ₦90 Million naira (US$560 Thousand US Dollars) can be saved annually by using MSW as a source of renewable energy in municipality of Enugu.

4 Conclusions

The work aimed at characterization and determination of energy content of municipal solid waste in municipality of Enugu, Enugu Sate Nigeria. Random truck sampling was used according to ASTM in the collection of samples at Ugwuaji landfill site, Enugu, Enugu State Nigeria. The samples were separated into various components and weighed before they were taken to laboratory to determine the moisture content, ash content and volatile matter content. Because of the adverse environmental impacts associated with the MSW landfilling process, integrated solid waste management calls for reduction and minimization of these waste before eventual landfilling. One aspect of waste minimization is energy recovery from MSW. Enugu has a present population of 882,178 and the amount of municipal solid waste been generated in Enugu municipality has been estimated to be 420 tonnes daily and this resulted in waste generation of 0.48 kg/capita/day. The waste components have been characterized into seven different parts namely putrefaction, plastic, textile, metal, glass and others. The average composition of the municipal solid waste (MSW) was: 39% putrefaction, 11% paper, 21% plastics, 5% textile, and 2% metal, 3% glass and 19% others. The percentage moisture content for putrefaction, paper, plastic and textile were 75%, 26.1%,19.6% and 31.7% respectively. This gives an average percentage moisture content of 38.28% for the waste stream. The volatile matter contents for putrefaction, paper, plastic and textile were 19%, 58%, 53.9% and 59% respectively and this also gave an average volatile matter content of 52.48% for the MSW. Moreover, the ash content was found respectively to be 1.3%, 1.9%, 4.6% and 2.5% for putrefaction, paper, plastic and textile. On the average this gives 2.58% ash content. The calorific value of the characterized municipal solid waste was also determined using oxygen bomb calorimeter. Plastic materials have the highest calorific value of 26,948 kJ kg^{-1}. The second is paper with a value of 16,295.7 kJ kg^{-1} followed by putrescible with 13,909.8 kJ kg^{-1} and textile having 11,796.6 kJ kg^{-1}. Therefore, the gross calorific value based on these four components was obtained as 5655837600 kJ day^{-1} for Enugu municipality which is equivalent to 1571066 kWh day^{-1} .This energy is equivalent to about 2.16% of the total annual Electricity used in Enugu municipality and would result in an annual saving of US$ 560 Thousand in case of utilization, giving an alternative to the unsteady supply of electricity and ensuring a hygienic, clean and aesthetically friendly environment. The results of this research show that energy recovery is a feasible option as part of an integrated solid waste management plan in Enugu municipality. However, it is recommended to perform a detailed economic analysis before making a decision on such option. Detailed survey of waste generation per capita per day in Enugu municipality is suggested as a further research.

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References

Abu-Qdais, H. A., M. F. Hamoda, and J. Newham. 1997. Analysis of residential solid waste at generation sites. *Waste Management and Research*, 15(4): 395-406.

Abu-Qudais, M., and H. A. Abu-Qdais. 2000. Energy content of municipal solid waste in Jordan and its potential utilization. *Energy Conversion and Management*, 41(9): 983-991.

Agunwamba, J. C. 1998. Analysis of scavengers' activities and recycling in some cities of Nigeria. *Environmental Management*, 32(1): 116-127.

Akkaya, E., and A. Demir. 2009. Energy content estimation of municipal solid waste bymultiple regression analysis. In *Proceedings of 5th International Advanced Technologies Symposium (IATS'09)*. Karabuk, Turkey, 13-15 May. https://www.researchgate.net/publication/228503014

ANSI *Standards*. 1977. SSTM D3286-77. Gross calorific value of solid fuel by the isothermal jacket bomb calorimeter. American: American Society for Testing and Materials.

Cointreau, S. J. 1982. *Environmental Management of Urban Solid Waste in Developing Countries: A Project Guide. Urban Development Technical Paper No 5*. Washington, DC.: The World Bank.

Dauda, M., and O. O. Osita. 2003 Solid waste management and reuse in Maiduguri, Nigeria. In *Proceedings of 29th WEDC International Conference towards the Millennium Development* Goal, 20-23. Abuja, 22-26 September.

Diaz, L.F. and C.G. Golueke,1985. Solid waste management in developing countries, *BioCycle*, 26:46-52.

Dong, C., B. Jin, and D. Li. 2003. Predicting the heating value of MSW with a feed forward neural network. *Waste Management*, 23(2): 103-106.

Federal Ministry of Power and Steel, Federal Republic of Nigeria. 2006 Renewable Electricity Policy Guidelines.Abuja Nigeria www.iceednigeria.org.

Filani, M. O., and S. I. Abumere. 1986. Forecasting solid waste magnitudes for Nigerian cities. In *Development and the Environment – Proceedings of a National Conference*, 193-208. Nigerian Institute of Social and Economic Research (NISER), Ibadan, 17–19 January

Harker, J. H., and J. R. Backhurst. 1981. *Fuel and Energy*. London: Academic Press.

Kalantarifard, A., and G. S. Yang. 2011. Energy potential from municipal solid waste in Tanjung Langsat landfill, Johor, Malaysia. *International Journal of Engineering Science and Technology (IJEST)*, 3(12): 8560-8568

Ogwueleka, T. C. 2003. Analysis of urban solid waste in Nsukka, Nigeria. *Journal of Solid Waste Technology and Management*, 29(4): 239-246.

Ogwueleka, T. C. 2009. Municipal solid waste characteristics and management in Nigeria. *Iran Journal of Environmental Health Science and Engineering*, 6(3): 173-180.

Ojolo, S. J., S. A. Oke, K. Animasahun, and B. K. Adesuyi. 2007. Utilization of poultry, cow and kitchen wastes for biogas production: a comparative analysis. *Iran Journal of Environmental Health Science and Engineering*, 4(4): 223-228.

Ojolo, S. J., A. I. Bamgboye, B. S. Ogunsina, and S. A. Oke. 2008. Analytical approach for predicting biogas generation in a municipal solid waste anaerobic digester. *Iran Journal of Environmental Health Science and Engineering*, 5(3): 179-186.

Reifsnyder, W.E., and Darnhofer, T., 1989. Meteorology and agroforestry. World AgroforestryCentre, pp. 544. ISBN 92-9059-059-9.

Sha'Ato, R., S. Y. Aboho, F. O. Oketunde, I. S. Eneji, G. Unazi, and S. Agwa. 2007. Survey of solid waste generation and composition in a rapidly growing urban area in Central Nigeria. *Waste Management*, 27(3): 352-358.

Sumiani, Y., C. Onn, D. M. Mohd, and J. W. Wan. 2009. Environmental planning strategies for optimum solid waste landfill siting. *Sains Malaysiana*, 38(4): 457-462.

Wilson, D. C., A. Whiteman, and A. Tormin. 2001. *Strategic Planning Guide for Municipal Solid Waste Management*. 2nd ed. Washington, DC.: The World Bank.

Zahari, M. S., W. M. F. W. Ishak, and M. A. Abu-Samah. 2010. Study on solid waste generation in Kuantan, Malaysia: It's potential for energy generation. *International Journal of Engineering Science and Technology*, 2(5): 1338-1344.