AN OPTIMIZATION OF THE MUNICIPAL SOLID WASTE IN ABUJA, NIGERIA FOR ELECTRICAL POWER GENERATION

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ABSTRACT

Currently, Abuja, the capital of Nigeria, is experiencing an exponential increase in municipal solid waste (MSW) generation due to its rapid population growth, level of development, and its socioeconomic status among others. Moreover, MSW is an overburden to the Abuja environment in terms of its management and health risk to the inhabitants. However, MSW is utilized by some countries as fuel for energy generation through the waste to energy (WTE) approach. In view of this, the study aims at assessing the MSW in Abuja as a potential resource for electrical power generation and distribution. This study is focused on incineration with energy recovery as an immediate solution for MSW reduction, and a supplementary answer to erratic electric power supply to the people. The proximate and ultimate analyses in combination with the modified Dulong equation were employed to determine the gross calorific value (GCV). Results showed that the GCV was evaluated as 9,085 kcal/kg and the net calorific value (NCV) was evaluated as 9,067 kcal/kg. Furthermore, the power generation potential was enumerated using 10 and 50 tons of combustible MSW to arrive at 966 kW and 4,832 kW, respectively.

Keywords: Dump site, Environment, Municipal solid Waste, Waste to Energy.

1 INTRODUCTION

In recent times, global communities are making efforts toward achieving environmental sustainability and circular economy. However, the problem of managing Municipal Solid Waste (MSW) persists especially in many developing countries. The quantity and rate of MSW generation in every community is associated with increasing population growth, rapid urbanization, level of industrialization, rising level of affluence, and resource scarcity [1, 2]. Currently, the waste management concept in most developed nations is directed towards a common goal, which is the diversion of reusable waste from landfills. According to Dri *et al*. [3] report, nations like Netherlands, Sweden and Denmark put a ban on landfilling combustible waste that could be utilized as fuel for the energy generation. Recovering energy from MSW is feasible by means of a few energy generation processes such as combustion, pyrolysis and gasification [4]. Waste to Energy (WTE) encompasses thermal and biological conversion technologies that unlock the usable energy stored in solid waste [5]. In Abu-Qudais and Abu-Qdais [6], it was reported that thermo-chemical conversion is preferably used due to its ability to ensure that the contribution of both biodegradable and non-biodegradable components of the waste are used for the energy output. Several studies have explained the concept of WTE from a sustainable perspective that it reduces the volume of MSW and the greenhouse gas emissions into the environment simultaneously. Consequently, the utilization of WTE for electrical power generation has received much attention in recent times. More so, the generation of electricity from domestic biomass and other related materials that make up MSW enhances fuel diversification, mitigates environmental pollution and GHG emissions [7]. Amber *et al*. [8] reported that the exploitation of the non-conventional energy locked-up in the urban solid waste into grid energy through WTE is likely to provide advantages such as minimizing waste, emission in the environment, and recovering the hidden energy.

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Several studies have demonstrated that energy can be recovered from MSW. For instance, Kumar *et al*. [9] used the MSW in Eleru City of Andhra Pradesh, India for a laboratory analysis with the help of a bomb calorimeter equipment to determine the gross calorific value (GCV) as 1080 kcal/kg, and net calorific value (NCV) as 940 kcal/kg. As a result, 60 tons of the MSW was estimated to produce about 3 MW of power. Also, Sivapalan *et al*. [10] used a simple evaluation to establish the amount of energy that can be recovered from the MSW in Malaysia when incinerated. The calorific values that were evaluated with the MSW samples were put through characterization, proximate and ultimate analysis, and a laboratory analysis with the use of a bomb calorimeter equipment through the ASTM E711-87. It was found out that calorific value in Malaysian MSW ranges between 1500 and 2600 kcal/kg, with an average moisture content of about 55% which might make incineration a challenging risk. Again, Kuleape *et al*. [11] conducted a study to evaluate the energy recovery potential of MSW generated in Akosombo, Ghana. The study utilized the MSW of both wet and dry seasons, separating them into organic and inorganic components. The proximate and ultimate analyses were conducted to obtain the chemical characteristics, and the heating values were determined using Dulong equation. The result shows that the moisture content at 58% during the wet season and 36% during the dry seasons. Also, the calorific values ranged between 1.39×10^4 kJ/kg to 2.99×10^4 kJ/kg which makes it suitable for energy generation.

Nigeria as a nation has struggled for years to meet its populace electrical power demand due to limited technologies and its inability to diversify into multiple sources of electrical power generation. Abuja is experiencing an exponential increase in MSW generation due to its rapid population growth, level of development and its socioeconomic status among others. Also, the electricity supply in the city has become erratic to almost no supply to households and commercial activities. This has raised a lot of concern by the authorities and the inhabitants of the city but quite a little effort is being done to tackle this menace in the power sector. Studies have shown that renewable energy is considered the solution to meet the power demand of the populace of any society. However, WTE option is a worthy prospect and likely to contribute strongly to the sustainable development of the society. In view of this, the study aims at assessing the MSW in Abuja as a potential resource for electrical power generation and distribution. The harnessing of energy from MSW resources is likely to improve the basic electricity supply to residence, other commercial activities and services in Nigeria. The study focused its investigation on the MSW generated in the two populated local government area in Abuja which includes Abuja Municipal Area Council (AMAC) and Bwari area council.

2 MSW MANAGEMENT IN ABUJA

Abuja has been regarded as one of the fast-growing cities in Nigeria, and as a result, its rapid urbanization has contributed to the exponential increase in the quantity of MSW. The common method of MSW disposal practices in Abuja is majorly the open dumping system. It is unfortunate that regardless of the aim of the Abuja Master Plan as a model city to other cities in Nigeria, there is no existing sanitary landfill [12]. Abuja Environmental Protection Board (AEPB) has its jurisdiction to operate in AMAC but contracted some part of Bwari to some waste management firms. However, Bwari area council has more indiscriminate dumpsites than its manpower and financial capability can sustain since it accommodates more of the low-income earners of the city. There are four major disposals site (Mpape, Gosa, Ajata and Kubwa) under the management of AEPB and the usual complaints from the inhabitants within the environs are associated with the problems of odour and air pollution from the combustion wastes. This is usually a practice used to reduce the volume of MSW in order to

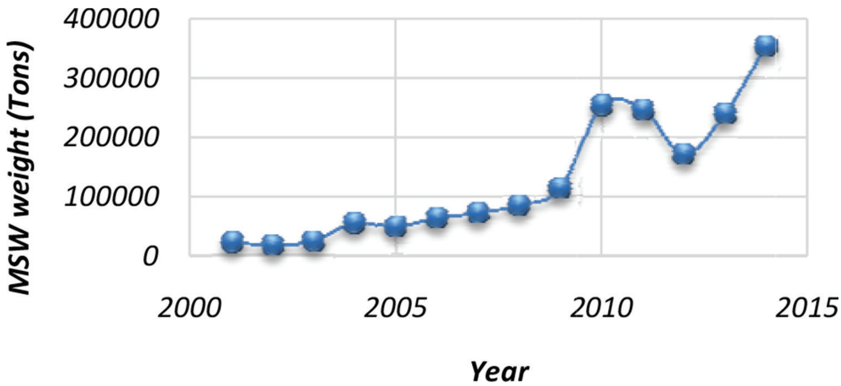

Figure 1: MSW yearly data (2001–2014). (*Adapted from AEPB, 2015.*)

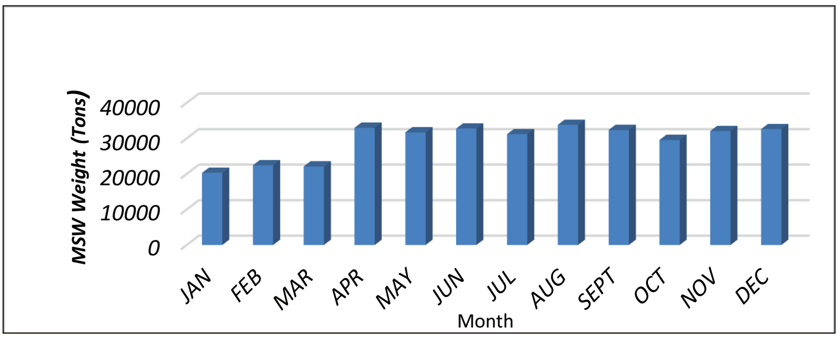

Figure 2: MSW monthly collection in 2014. (*Adapted from AEPB, 2015.*)

accommodate more. According to AEPB data, the average yearly quantity of MSW collected in the Abuja environs between 2001 and 2014 is displayed in Fig. 1. Furthermore, it was observed that in 2014, the trend of the monthly data collection of MSW (tons) in Abuja and disposed in designated dumpsites by AEPB was found to be above 30,000 tons in most of the months of the year (see Fig. 2). The average per capita generation of MSW in Abuja was estimated to be at 0.76 kg/person daily [13].

2.1 MSW in Energy Recovery

In the quest for a sustainable solution for energy for the people in the society, it has been discovered by previous researchers that MSW, which was perceived as a burden to man and his environment is a likely complementary solution to the global energy issue. WTE is recognized as a promising alternative for waste management to overcome waste generation problems as well as a potential renewable source [14]. Over 130 million tons of MSW are burnt annually in 600 plants based on WTE for generating electricity, steam for heating purpose and recovery of metals for recycling [15]. It is important to understand that combustion is feasible only for MSW with moisture content less than 50% otherwise a pre-drying process is required [16]. In a WTE process, MSW is thoroughly mixed to ensure that the energy output to the combustion chamber is consistent. Also, the combustion process requires enough oxygen to oxidize fuel (MSW). Energy recovery from incineration of MSW utilizes the combustion heat through a boiler generation steam with temperatures in excess of about 850°C such that the MSW is converted into CO_2 and water. About 80% of the available energy in the waste stream can be retrieved in the boiler to produce steam and the steam is used for power generation through a steam turbine [17]. In a report by DEFRA [18], it was stated that due to technological advancement and strict pollution regulations, modern WTE facilities are cleaner than most of all manufacturing industries.

3 METHODOLOGY

This study is based on utilizing MSW in Abuja Municipal Area Council (AMAC) and Bwari Area Council for electricity. This study intends to demonstrate a possible concept to evaluate, predict and project the power generation potential (P_{GP}) of the MSW in Abuja through estimation of the calorific values of the MSW samples and the energy recovery potential for Abuja.

3.1 Study Area

Abuja is the capital city of Nigeria which is in the center of Nigeria in the Federal Capital Territory (FCT) within latitude 7° 25’ N and 9° 20° N of the equator and longitude 5° 45’E and 7° 39’E of the meridian (see Fig. 3). The Federal Capital Territory has a land area of 7,753.85 km^2. It has a population of about 2,238,800 persons [19]. The city experiences an

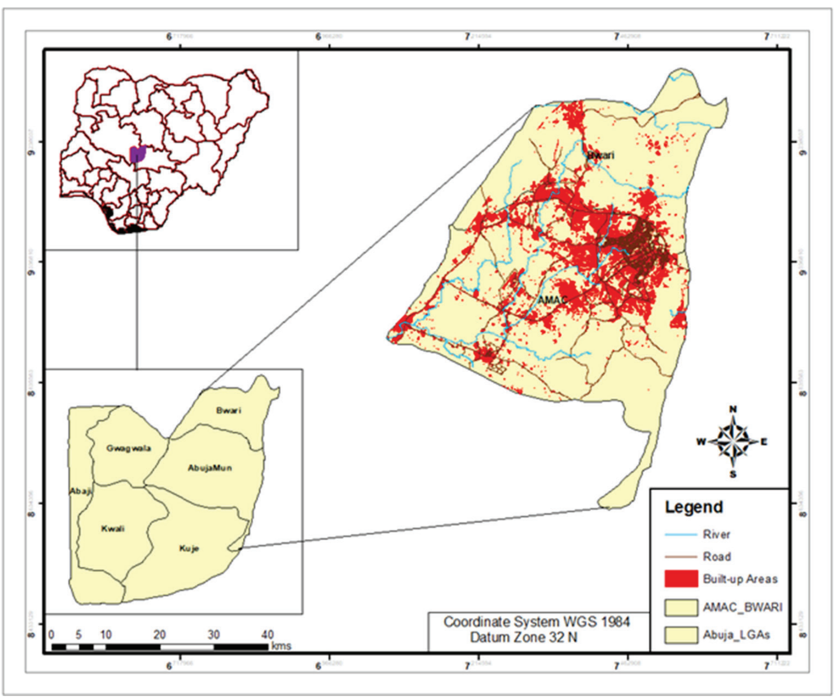

Figure 3: Study area map.

Source: *Aderoju and Dias (2018).*

average daily minimum and maximum temperature of 20.5ºC and 30.8ºC, respectively. This has its minimum in August and September and the highest in January to March. It has a mean rainfall and humidity of about 119.2 mm and 58.4%, respectively with the highest in August and lowest between November and March, respectively [20].

3.2 Physical Analysis of MSW in AMAC and Bwari Area Council

The major dumpsites in the study area (AMAC and Bwari Area Council) namely: Gosa, Karshi, Kubwa and Dutse dumpsites were visited in order to carry out MSW characterization. The American Standard Test Method [21] was adopted for the characterization of the MSW in this study. A manual collection of 10 kg of freshly mixed MSW in all the dumpsites 3 times a week for 4 weeks during the wet and dry seasons of the year. The collected samples were thoroughly mixed and weighed with a handheld weight device after every collection at each dumpsite. Samples were subjected to manual sorting into eight categories, and then each category of MSW type was reweighed to determine the composition of MSW in a mix. The physical analysis was done based on a weight ratio of different components in the MSW stream. The percentage of sample composition was categorized into eight different components, namely food waste/organic, textile, paper, plastics, glass/ceramics, metal, rubber and other waste materials. The mean weight ratio for each of the dumpsites for both dry and wet seasons is shown in Fig. 4.

3.3 Proximate analysis and ultimate analysis

Proximate analysis determines the moisture, volatile matter, fixed carbon and ash content of the waste sample [22]. A subsample of 100 g was drawn from the original MSW sample from each of the dumpsites S_G, S_D, S_{Kar}, S_{Kub} in AMAC and Bwari area council. Each of the subsamples was sorted into different components representing the ratio percentage of the components in their original sample. The sorted subsamples with combustible features includes, plastics, paper, food waste/organics and textile and were utilized, while the noncombustible components (ceramics and metals) were removed. Some other combustibles present in other waste such as diapers and sanitary pads (with pulp features); rubber;

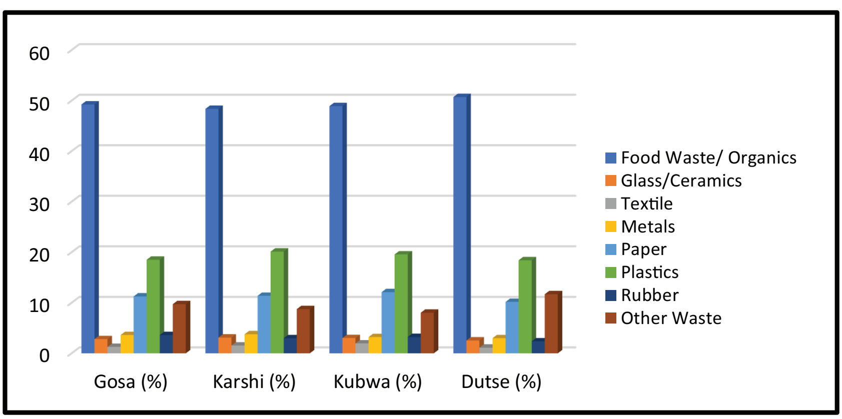

Figure 4: Dumpsites composition in study area.

Source: Aderoju and Dias (2017).

tiny pieces of wood/garden waste among others, were categorized under organics. Furthermore, the individual subsamples were weighed in order to validate their original weights in % as represented in the original sample. Again, all the sorted combustibles in the subsamples were mixed and shredded in smaller particles for individual category of MSW collected from all the dumpsites, and the mean weight in percentage for each category was obtained to be used for the proximate analysis. The individual mean subsamples (for example, average of the mixed subsample for plastics in all the dumpsites) were placed in petri dishes and heated separately in an oven for 1 hour at 105°C to determine the moisture content and dry mass of each component in the MSW subsample. For an additional loss of weight, 50% of each category of dry mass of the mean subsample was placed in the crucible after the initial weight of the crucible had been obtained and later reweighed before it was placed into the SXL-1200°C benchtop Muffle furnace on ignition at 950°C for 30 min to determine the % volatile matter (dry basis) and % ash content. All the experiments were conducted 3 times for each subsample and the mean result was arrived at as shown in Table 2. Eqns (1), (2) and (3) were used for the calculations in proximate analysis.

$$\mathrm{M} = \left[\left[(w-d) * 100 / \mathrm{w} \right]\right] \tag{1}$$

where M is the wet-mass moisture content (%); w the initial mass of MSW subsample (kg); d = mass of subsample after drying (kg).

$$\%\ \mathrm{V}\_m\,(\text{dry basis}) = \left[\left[((\mathrm{d}-\mathrm{n})*100) / \mathrm{d} \right]\right] \tag{2}$$

$$W_{Ash}\,(\%) = \left[\left[(\mathrm{w}*100) / \mathrm{d} \right]\right] \tag{3}$$

where V_m = % volatile (dry basis); W_{Ash} = % Ash (dry basis);
d is the weight of dry MSW subsample; n the weight of the residue after ignition.

This analysis was used to determine the percent of carbon, hydrogen, oxygen, nitrogen, sulfur and ash present in the MSW sample. Since the dry mass of each component in the MSW sample is determined, the elemental contents like carbon, hydrogen, oxygen, nitrogen, sulfur and the ash content for the waste sample can be determined using the standard table of ultimate analysis of combustible waste in [23,24] and is expressed as

$$\mathrm{EC}(\mathrm{kg}) = (\mathrm{d}*\mathrm{EV})100 \tag{4}$$

where EC is the elemental content (kg); d the dry mass; EV the element value (to be obtained using the standard elemental table).

The element content (C/H/O/N/S) value in the MSW components are obtained from the standard table of ultimate analysis of combustible waste. This was computed for each component present in the waste sample and cumulated to arrive at a (C, H, O, N, S) value of the sample and subsequently it was substituted into the modified Dulong equation [25] to determine the energy content (GCV) of MSW and is expressed as

$$\mathrm{GCV}(\mathrm{MJ/kg}) = 337C + 1419(H\_2O - 0.125O\_2) + 93\mathrm{S} + 23N \tag{5}$$

where C is the carbon (%), H the hydrogen (%), O the oxygen (%), S the sulfur (%) and N the nitrogen (%).

3.4 Energy output estimation from MSW

The calorific value is classified into the GCV and NCV. GCV is described as the quantity of heat generated by a complete combustion of a unit mass of sample in air or oxygen, such that the product of combustion cooled down to the room temperature and remains in liquid form [26]. However, NCV is the net heat produced when a unit mass of the sample is completely burnt in air or oxygen, such that the product of combustion can escape as steam. In this study, the NCV of the MSW sample was calculated using eqn (6) as it was done in [27] as

$$\text{NCV}\left(\text{kcal / kg}\right) = \text{GCV} - 9H * LHS \tag{6}$$

where NCV is the net calorific value of MSW, GCV the gross calorific value of each component; *LHS* the latent heat of steam which is 587 (kcal/kg) and *H* the Hydrogen (%).

3.5 Energy recovery potential and PGP

In the case of energy recovery, thermochemical conversion utilizes all its organic matter, biodegradable as well as non-biodegradable for energy output. In addition, Tsunatu *et al*. [28] reported that the amount of energy recovered from MSW based on different conversion methods is a function of its calorific value and organic content. Again, when MSW is combusted in waste-to-energy plants, it uses the heat from the fire to make steam (NCV) for generating electricity. Therefore, the energy recovery potential for the thermo-chemical conversion of MSW is expressed as

$$\text{E}_{rp}\left(\text{kWh}\right) = \text{NCV*Wt}\left(1000 / 860\right)\text{*}\sigma \tag{7}$$

where, E_{rp} (kWh) the energy recovery potential of MSW sample, Wt the weight of waste (tons), σ the conversion efficiency which ranges between 22 and 28% [29].

Furthermore, the PGP is simply the amount of energy that can produce electric power supply or heat system daily (24 hours) and is expressed as****

$$\text{P}_{GP}\left(\text{kW}\right) = E_{rp} / 24 \tag{8}$$

Therefore, the PGP can also be expressed as it is in eqn (9);

$$\text{P}_{GP}\left(\text{kW}\right) = \text{NCV*Wt*0.04845*}\sigma \tag{9}$$

4 ANALYSIS AND RESULTS

The result of the physical analysis shows the mean MSW composition in the dumpsites resident in the study area and is shown in Table 1. It was observed that there is an obvious difference between the food/organic waste, which is the most common amongst all other categories during the seasons.

To calculate GCV and NCV

Given (C, H, O, N, S) data for Abuja includes;

C = 0.02761 kg; H = 0.003534 kg; O = 0.01755 kg; N = 0.000773 kg; S = 0.0001220 kg

Recall that from eqn (5);

$$\text{GCV}\left(\text{MJ / kg}\right) = 337C + 1419\left(H\_2O - 0.125O\_2\right) + 93\text{S} + 23N$$

Table 1: Elemental composition % for (dry basis) of MSW

MSW category	**Carbon (%)**	**Hydrogen (%)**	**Oxygen (%)**	**Nitrogen (%)**	**Sulphur (%)**
Food waste / organics	48	6.4	37.6	2.6	0.4
Plastics	60	7.2	22.8	0.0	0.0
Paper	43.5	6.0	44	0.3	0.2
Textile	55	6.6	31.2	4.6	0.15

Source: Tchobanoglous et al. (1993).

$$\text{GCV} = 337\ (0.02761) + 1419\ (0.02462 - 0.0043875) + 23\ (0.000773)$$
$$\text{GCV} = 38.0401(\text{MJ/kg})$$
Converting to (kcal/kg) from (MJ/kg)
$$1\ (\text{MJ/kg}) = 238.8459\ (\text{kcal/kg})$$
$$\text{GCV} = 38.0401(\text{MJ/kg}) = 9085.7219\ \text{kcal/kg}$$

Recall that from eqn (6):
$$\text{NCV}\left(\text{kcal / kg}\right) = \text{GCV} - 9H * LHS$$
Recall that the LHS = Latent heat of steam = 587 kcal/kg
$$\text{NCV} = 9085 - 9\ (0.003534) * 587$$
$$\text{NCV} = 9085.7219 - 18.6701$$
$$\text{NCV} = 9067.0518\ \text{kcal/kg}$$

To estimate the P_{GP}

Recall that from eqn (9):
$$P_{GP}\left(\text{kW}\right) = \text{NCV*Wt*0.04845*}\sigma$$
Using 10 tons of combustible MSW,
$$= 9067.0518 * 10 * 0.04845 * 0.22$$
$$= 966.457\text{kW}$$
$$= 966\text{kW}$$
Using 50 tons of combustible MSW:
$$= 9067.0518 * 50 * 0.04845 * 0.22$$
$$= 4832.285\text{kW}$$
$$= 4832\text{kW}$$

5 DISCUSSION AND CONCLUSION

From the physical analysis, the waste characterization was categorized into combustible and noncombustible components. Thus, it was deduced that the mean results have combustible components of about 81.35% (see Fig. 6). It is also noticed in Fig. 5 that food waste/organics is of higher percentage when compared to the rest of the MSW types. The result of the proximate analysis in Fig. 7 shows that food waste/organics clearly have a moisture content of 48.88% likewise plastics (2.16%), paper (32.76%), textile (8.90%), etc. As reported in several studies, the moisture content and the constituents of the MSW play a significant role in any WTE project. Therefore, from Table 2, it is observed that summation of the moisture content

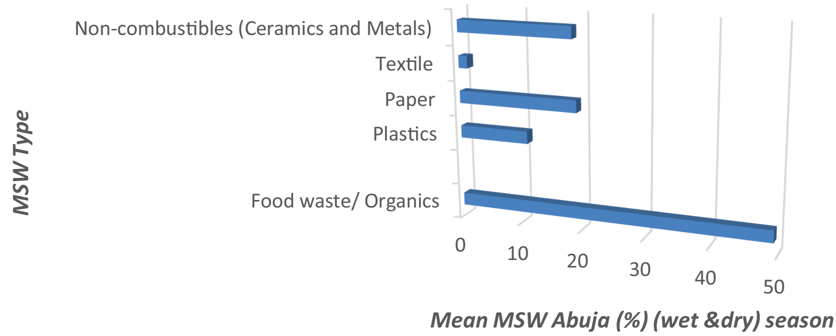

Figure 5: MSW characterization in Abuja.

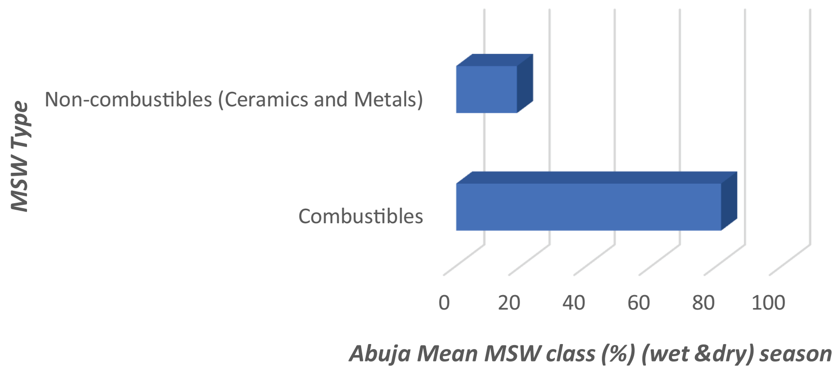

Figure 6: Abuja combustible and non-combustible MSW.

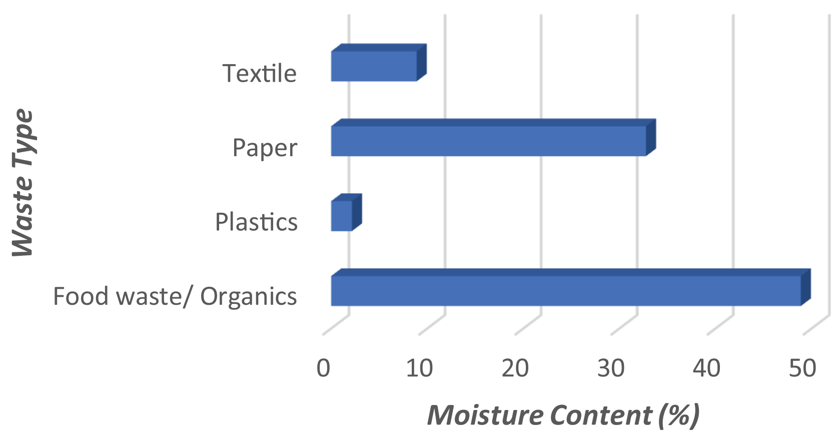

Figure 7: Moisture content (%) for Abuja combustible MSW.

Table 2: Ultimate analysis result of MSW sample for Abuja.

Waste type	Wet mass(g)	Dry mass(g)	Moisture content(g)	C(g)	H(g)	O(g)	N(g)	S(g)	Ash(g)
Food waste/ Organics	49.375	26.669	22.706	12.801	1.707	10.028	0.693	0.107	1.333
Paper	11.2088	6.4003	4.8085	2.784	0.384	2.816	0.019	0.013	0.3843
Plastics	19.30	18.8355	0.4645	11.301	1.356	4.295			1.8835
Textile	1.45	1.3202	0.1298	0.726	0.087	0.412	0.061	0.00198	0.0322
Total	**81.3338**	**53.225**	**28.1008**	**27.612**	**3.534**	**17.551**	**0.773**	**0.12198**	**3.6330**

present in all the combustible subsample (food waste/organics, plastics, paper, textile) of MSW when subjected to heat at 105°C for 1 hour in the oven was 34% which is 28.10 g of the total mass of combustible components in the sample. The individual combustible MSW-type dry mass value was used to calculate the elemental composition (C, H, O, N, S) in each of the combustible MSW type. This was done by utilizing eqn (4) and the parameters in Table 1 in order to arrive at the results in Table 2. The Dulong equation was used to determine the GCV using eqn. 5. The (C, H, O, N, S) value for combustible MSW is substituted into the Dulong equation, and the GCV was found to be 9085.7219 kcal/kg. Furthermore, since the energy required for the estimation of the P_{GP} should be in form of steam, which is the NCV, therefore from eqn (6), it was evaluated that the NCV was 9067.0518 kcal/kg. The P_{GP} in this context is the amount of energy that can produce electric power supply for 24 hours (daily). The estimation of P_{GP} using 10 and 50 tons of combustible MSW in AMAC and Bwari area council was 966.457kW and 4832.285kW using eqn (9).

Based on the analyses of the study and the results presented, it was concluded that moisture content affects energy recovery from MSW, hence, proper covering of the waste bins and the use of mechanical aeration technologies after collection is likely to improve the quality of MSW to be used as fuel in a WTE technology. This study can guide the scope of planning energy projects with the Abuja MSW stream and Nigeria at large. Furthermore, this study will help in the sanitation of the environment; estimate and predict energy from MSW stream in the society; and expand the economy by creating and expand the economy by creating an alternative arm of the energy sector. Lastly, employing the concept of WTE in Nigeria at large is likely to improve electricity supply and distribution in a sustainable way.

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