Evaluation of Energy Potentials from Municipal Solid Waste: A Case Study of Yola, Nigeria

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Abstract

The dumpsites in Yola town have piled up with over 4393 tons of municipal solid waste generated in 2014 alone and 0.60 kg/capita/day as at the time of this research. This is alarming and obviously, some treatment needs to be put up. In this work, municipal solid waste in the town was sorted, characterized and subjected to exploration of energy potentials estimation. Proximate analysis was conducted to determine the calorific value of each component. Methane (a chief component of energy) was estimated using Inter-Governmental Panel on Climate Change (IPCC) Methodology. Characterisation of the waste revealed the following compositions: food waste (42.45%), plastic (25.66%), paper (14.37%), rubber (1.93%), textile (2.69%), yard waste (7.71%), wood (0.90%), metal (0.81%), glass (1.83%), battery (1.56%) and diaper (0.09%). Proximate analysis (moisture content, volatile organic matter, ash content and fixed carbon) were carried out according to the random sampling method based on American Society of Testing and Materials (ASTM, 1998). The waste was found to have calorific value of (118.58 MJ/Kg). Results also showed that 685.69 tons of methane was estimated from municipal solid waste generated from Yola between 2004-2014.

Keywords: Solid Waste, Energy Potential, Proximate Analysis, Moisture Content, Calorific Value

INTRODUCTION

The provision of sufficient amount of energy is a global challenge faced both by developed and developing countries. The limited supply of natural resources with ever growing demand for energy and raw materials has prompted the development of energy recovery from municipal solid waste (Amber, *et al*., 2012). Furthermore, Solid waste handling has become a pressing problem in Nigeria. Piles of wastes are often found by roads, rivers and many other open spaces in cities. This is causing significant health and environmental concerns. The urban population is growing at an alarming rate. While the Nigerian population is increasing by about 2.8% per annum, the rate of urban growth is as high as 5.5% per annum (Imam *et al.*, 2008). This is increasing the difficulties associated with providing an effective solid waste management system. As cities grow, land use becomes increasingly complex and the wastes generated increase in volume and variety (Imam *et al*., 2008).

Solid waste management systems (waste storage, collection and transport, resource recovery, reduction, reuse and recycling, waste treatment and disposal) in Yola, the capital city of Adamawa, have been assessed and found to be lacking adequate attention (Ishaku, *et al*., 2015). Problems associated with existing waste management systems and facilities have been identified such as indiscriminate littering of waste along streets (refer to plates 1 and 2), lack of knowledge of treatment systems by authorities, inadequate supply of waste containers, insufficient financial resources for safe disposal of waste that is well-equipped and an engineered landfill (Ishaku, *et al*., 2015). The legal, administrative and institutional framework and the role of informal recycling/scavenging have been reported to be inadequate as well.

The total solid waste generation in Yola has been on a steady increase over the years. This can be attributed to an increase in population from 159,779 persons in 1991 to 234,472 persons in 2006 and 271,818 persons in 2014 with a growth rate of 3.2% (Ishaku, *et al*., 2015). Adamawa State needs a change in the current treatment of waste. Currently, waste is disposed of indiscriminately everywhere; along streets, roads, drains and so on (refer to plates 1 and 2). Before now, open dumping was the primary practice in Yola and no sufficient information was available regarding amounts and places of disposal. However, from 1994 onwards the Adamawa State Environmental Protection Agency (ASEPA) started collecting data on MSW. In 2004, a survey conducted in the city revealed that there were more than 36 waste depots and 3 dumpsites with a generation rate of 0.6 kg per person per day (Ishaku, *et al*., 2015).

Plate 1: Waste dump-site at Mbamoi, Yola Town

Plate 2: Waste dump-site at Yolde-Pate, Yola Town

These figures are overwhelming and the waste need immediate attention. An integrated management approached need to be embarked (via, waste minimization, exploitation of benefit by energy derivation and proper disposal practices). This paper attempts to explore the benefits that could be derived from the composition of the stock of the waste produced by assessing the energy potentials there from. Energy potentials in the current paper are based on physical and chemical properties of generated waste using suitable model equations adopted from previous studies. The paper specifically examines the determination of waste composition, moisture content, volatile organic matter, fixed carbon content and calorific values for energy potentials by proximate analysis as well as estimation of methane emissions using Intergovernmental Panel on Climate Change (IPCC) methodology.

Study Area

Yola town, is situated within latitudes 9°11’59’’N and longitudes 12°28’59’’E and at an altitude of about 192m. The area has a tropical climate with rainy season from April to October and dry season November to March or April. The area is characterized by broadly flat topography with gentle undulations and hilly ranges. The area has a population of about 271,818 according to Ishaku *et al*. (2015) as at 2014. The major occupation of the people is agriculture. Small-scale metallurgical works, numerous water sachet activities and traditional textile factories are practiced in the area. The waste disposal practiced in the area is through open dump for solid wastes. The growth in population has affected the land use pattern, which has subsequently resulted in more waste than is manageable.

Data collection

Date from the laboratory analysis was used as input to the model equations used. Samples for laboratory analysis were taken after the waste characterisation Information was also obtained from a variety of relevant groups and organizations including the National Environmental Standards and Regulation (NESREA), the Adamawa Environmental Standard and Regulation (2015), private sector companies, local residents and the informal waste sector.

METHODS

Proximate Analysis Procedure

Proximate analysis is conducted to determine the moisture content, ash content, volatile matter and fixed carbon. It is achieved by subjecting the selected sample to different range of temperatures, between 100°C to 950°C. The proximate analysis is based on ASTM standard reported by (Johari et al., 2012) as follows:

a) ***Moisture Content:*** The percentage moisture of the Municipal Solid Waste (MSW) sample was determined by weighing 5 g of the samples into a pre-weighed dish and drying in an oven at 105°C to a constant weight according to ASTMD 3173 standard

b) ***Volatile Matter Content:*** The volatile matter content was determined by combusting the sample at 950°C. The triplicate samples of MSW material used in the moisture content determination were weighed and placed in a muffle furnace for 7 minutes at 950°C (ASTMD3175).

c) ***Ash and Fixed Carbon:*** Ash content of waste is the non-combustible residue left after waste is burnt, which represents the natural substances after carbon, oxygen, sulfur and water. Procedure includes drying the samples at 750°C for 1 hour (ASTMD 3174). Fixed Carbon is calculated using the following equation: Fixed carbon (weight % wet basis) = 100 – (wt % moisture content + % ash + weight % volatile matter). Thus, FC = Fixed carbon (wt% wet basis), MC = Moisture content (Wt %), Ash = ash (wt %), VM = volatile matter (wt %) (Kalantarifard and Yang, 2011).

Determination of Calorific Value

Energy content of MSW is usually described in terms of High Heat Value (HHV), Lower Calorific Value (LHV), Net Heating Value or Gross Heating Value (Kalantarifard and Yang, 2011). Determination of the heating value of MSW samples can be found either experimentally or by using mathematical models. Experimental determination using a bomb calorimeter utilizes a sample size of 1 g. This is inadequate to account for the vast variance in MSW composition, thus requiring bigger sample size (Kalantarifard and Yang, 2011). In addition, experimentation is drudgery and requires expertise in equipment handling and maintenance. For these reasons, mathematical models were created to reduce over reliance on lengthy experimental techniques

(Kalantarifard and Yang, 2011). Thus the current calorific value (higher heating values) was determined using the Bento's equation as follows: $HHV = (44.75VM - 5.85W + 21.2)kcal/kg$

Estimation of Methane Emission Using Intergovernmental on Climate Change (IPCC) Method

The method proposed by the intergovernmental panel on climate change (IPCC) for the estimation of methane emission from waste disposal sites by the default method is given by Noor *et al*. (2013).

$$CH_4 = \left(MSW_T * MSW_F * MCF * DOC * DOC_F * F * \frac{16}{12} - R\right)(1 - OX) \quad (1)$$

Where,
MSW_T = Total solid waste generated in (tones/year)
MSW_F = Fraction of solid waste disposed to dumpsites
MCF = Methane correction factor (fraction)
DOC = Degradable organic carbon (fraction)
DOC_F = Dissimilated organic fraction
F = Fraction of methane in landfill gas
16/12 = Molecular weight ratio methane to carbon
R = Recovered methane (tones/year)
OX = Oxidation factor

RESULTS AND DISCUSSION

Composition of MSW in Yola

The composition of municipal solid waste in Yola was obtained through the hand sorting process. The component sorted were food wastes, paper, polyethylene, polypropylene, rubber, textile, yard trimmings, wood, metals, diaper, battery, and miscellaneous materials. Table 1 shows a wide variation in the components therein. Food waste (42.45%) constituted the major constituent of the waste in all dumpsites under study. This is attributed to the level of income of the community as reported by Othman *et al*. (2012) and Abba *et al*. (2013). Furthermore, the dump site is located close to the central city's market. There are a lot of food wastes and items disposed of in the dump sites. The second most abundant material found in the waste was plastic material (25.66%). The high percentage of plastic could be due to excessive use of plastic for sachet water widely uncontrolled in the area. Most items purchased either from the market and other places use plastic materials for parceling.

Lack of recycling plant for plastics and other material is also a factor. This part of waste material is a good source of raw material for energy potential as observed by Abba *et al*. (2018) and Kalantarifard and Yang (2011). It can also be recycled to reproduce more useful polythene bags to minimize the wastage of petroleum materials. Paper constituted third most abundant waste component (14.37%), yard waste (7.71%), and textile (2.69%) respectively. Other wastes accounted for 8.33% of the overall waste stream components included rubber (1.93%), wood (0.90%), metals (0.81%), glass (1.83%),battery (1.56%) and diapers having 0.09% each. Components such as paper, wood, metal, glass and others were low which typifies a low income waste generation community as observed by De Feo and De Gisi, (2010). The waste composition has 65.43% biodegradable and 32.69% non-biodegradable waste. This shows that energy can be generated from Yola waste as typically reported by Kalantarifard and Yang (2011).

Table 1: Average weight composition of municipal solid waste in Yola town

S/N	Component	Weight (%)
1	Food wastes	42.45
2	Paper	14.37
3	Plastic low density	24.67
4	Plastic high density	0.99
5	Rubber	1.93
6	Textile	2.69
7	Yard waste	7.71
8	Wood	0.90
9	Metal	0.81
10	Glass	1.83
11	Diaper	0.09
12	Battery	1.56

Analysis

As stated earlier, proximate analysis is done to determine the calorific value of the municipal solid waste and the parameters involved were moisture content, volatile matter, fixed carbon and ash content. Details are presented below:

Moisture Content

Moisture content in a material signifies the measure of the amount of moisture present in it. The higher the moisture content, the lower is its calorific value of waste and vice-versa. High moisture content can lead to poor ignition and hinder the combustion of waste, thus affecting the quality of combustion. In the present study, food waste has the highest percentage of moisture (40.00%), followed by yard trimmings (21.50%), wood (19.30%), paper (18.20%), and the least includes textile (0.09%), glass (nil), metals (nil) and the remaining materials constituted the remaining percentages as presented in Table 2. Moisture content was higher probably because of the reasons below:

a) The surrounding neighbourhoods are predominantly of low income status. Their activities such as trade and commerce are largely dependent on food stuff and vegetables; thereby generating a lot of food waste (Abba, 2014).

b) The assessment was conducted at the pick period of food produce harvesting season which were increasingly brought to the market where the dump site was located.

c) There are few other manufacturing industries instead, most material processing activities consist of food processing machines such as corn milling, rice milling and ground nuts milling machines and as such, most waste are of these food waste sorts.

Volatile matter, Fixed Carbon and Ash Content

The results showed that metals contain minimum volatile organic matter (12.78%) whereas rubber contains the maximum (91.20%). The high volatile organic matter content means that it can ignite at relatively low temperatures and also possess high heating value (Kalantarifard and Yang, 2011). Rubber contains minimum fixed carbon (0.20%) while the maximum (15.20%) was obtained from metals. Furthermore, the ash content in the study revealed that wood contains the minimum (2.80%) while metals contain maximum 81.60%. The result also shows that the percentage of volatile matter, ash content, fixed carbon and moisture content were 59%, 26% 6%and 9% respectively.

Table 2: Proximate analysis of Yola MSW

S/N	Waste component	Moisture content (%)	Volatile matter (%)	Ash content (wt %)	Fixed carbon (wt %)
1	Textile	0.09	78.01	16.60	5.30
2	Glass	0.00	19.69	69.80	10.40
3	Low density plastic	3.40	76.40	7.80	12.40
4	Paper	18.20	75.20	4.40	2.20
5	Yard waste	21.50	70.10	5.20	3.20
6	Metals	0.00	12.78	81.60	15.20
7	Wood	19.30	76.70	2.80	1.20
8	Food wastes	40.00	51.20	5.60	3.20
9	High density plastic	0.94	82.86	13.80	2.40
10	Rubber	0.60	91.20	8.00	0.20

Calorific Values of Yola MSW

The calorific value of each component of MSW was determined using Bento's equation as shown in (Table 3). It represents the calorific value of plastic (15.58MJ/kg), rubber (17.15MJ/kg) and textile (14.69MJ/kg). Metals (2.483MJ/Kg) and glass (3.77MJ/kg); possess the lowest calorific value than all other waste components in the sample. This indicates that organic compounds have higher contents of calorific value (Abba, 2014).

Yola waste was found to have an energy value of about 118.95 MJ/kg from Table 3. This showed that Yola waste would be adequately used for energy recovery since it has met the minimum standard of 12MJ/Kg (Whiting, 2002). This could be used in electricity generation as well.

Table 3: Calorific values of Yola MSW composition using Benton's equation

S/N	Waste Component	Calorific Value
1	Textile	14.69
2	Glass	3.77
3	Low density plastic(polyethene)	14.31
4	Paper	13.72
5	Yard waste	12.69
6	Metals	4.35
7	Wood	13.98
8	Food wastes	8.70
9	High density plastic (PVC)	15.58
10	Rubber	17.15
	Total	118.95

Estimated Methane Generated from Dumpsites in Yola town from 2004 to 2014

Methane generated from MSW dumpsites in Yola town was estimated using the IPCC methodology (Noor *et al*, 2013). Table 4 presents the estimated methane from dumpsites in Yola town from 2004 to 2014 as indicated earlier. The highest estimated amount of methane was in 2014 with 94.48 tons/yr and the least amount was in 2008 with 29.96 tons/yr. The total methane estimated from 2004 to 2014 is 685.69 tons/yr. The annual estimated amount of methane showed an increasing trend from 2004 to 2014. This indicates an increasing waste generation as well.

Table 4: Estimated methane generated from dumpsites in Yola from 2004-2014

Year	MSW_T tonnes/Yr	MSW_F	MCF	DOC	DOC_F	F	$16/12$	CH_4 tonnes/Yr
2004	3304	0.70	0.4	0.15	0.77	0.5	1.33	71.06
2005	2015	0.70	0.4	0.15	0.77	0.5	1.33	43.33
2006	1953	0.70	0.4	0.15	0.77	0.5	1.33	42.00
2007	2674	0.70	0.4	0.15	0.77	0.5	1.33	57.51
2008	1393	0.70	0.4	0.15	0.77	0.5	1.33	29.96
2009	3150	0.70	0.4	0.15	0.77	0.5	1.33	67.74
2010	2554	0.70	0.4	0.15	0.77	0.5	1.33	54.93
2011	3344	0.70	0.4	0.15	0.77	0.5	1.33	71.92
2012	3404	0.70	0.4	0.15	0.77	0.5	1.33	73.21
2013	3699	0.70	0.4	0.15	0.77	0.5	1.33	79.55
2014	4393	0.70	0.4	0.15	0.77	0.5	1.33	94.48
Total								**685.69**

Methane projected from dumpsites in Yola from 2015 to 2025 using intergovernmental panel on climate change (IPCC) method was carried out and presented in Table 5. The estimation was based on the assumption that the current generation rate will be increasing with corresponding increase in the population. The highest amount of methane estimated is in 2025 with 1448.29 tons while the least is in 2015 with 49146 tons. When projected to 2025 the quantity significantly increased to 13,377.6 tons. The projection is based on the weight of percentage of the volatile matter and fixed carbon in the MSW. The advantage here is that it gave result based on sample sizes and the positive point is that, these projections do give accurate estimation of the calorific values of the waste expected in the future.

According to Noor *et al*. (2013), the values were generated by substituting values into Eq. (1) based on certain assumptions. Total waste generated, MSW_T was considered for the estimation. It was observed that 70% of the total MSW in Yola were taken to the dumpsites, thus the value of waste fraction (MSW_F) was taken as 0.7. Furthermore, MCF has a default value ranging between 0.4 and 1.0 depending on the type of landfill/disposal practices. Since Yola does not have landfills inventory data, a value of 0.4 could be used (Noor *et al*., 2013). Likewise, a default value of 0.08–0.21 is allowed for DOC based on locality (Amber, (2012). In the same vein, DOC of 0.15 was taken. In addition, biodegradation of DOC does not occur to completion, for this reason, (DOC_F= 0.77) is assumed. Moreover, a conservative value of 0.5 was used for F based on characterization. Other factors are standards from (Amber, (2012) and Noor *et al*. (2013). The increasing trend of the emission is very evident. From a value of 212,000 tons in 2004 and is projected to 233334 tons in 2025. This highlights the potentiality in the rise in methane emission with time.

Table: 5 Estimated methane generated from dumpsites in Yola from 2015 to 2025 using Intergovernmental panel on climate change (IPCC) method

YEAR	MSW_T tonnes/Yr	MSW_F	MCF	DOC	DOC_F	F	16/12	CH_4 tonnes/Yr
2015	47941	0.7	0.4	0.15	0.77	0.5	1.33	1031
2016	49500	0.7	0.4	0.15	0.77	0.5	1.33	1064.6
2017	51120	0.7	0.4	0.15	0.77	0.5	1.33	1099.4
2018	52772	0.7	0.4	0.15	0.77	0.5	1.33	1134.9
2019	54488	0.7	0.4	0.15	0.77	0.5	1.33	1171.8
2020	56260	0.7	0.4	0.15	0.77	0.5	1.33	1209.9
2021	58089	0.7	0.4	0.15	0.77	0.5	1.33	1249.3
2022	59978	0.7	0.4	0.15	0.77	0.5	1.33	1289.9
2023	61928	0.7	0.4	0.15	0.77	0.5	1.33	1331.8
2024	63942	0.7	0.4	0.15	0.77	0.5	1.33	1375.1
2025	66021	0.7	0.4	0.15	0.77	0.5	1.33	1419.9
Total								**13377.6**

CONCLUSIONS

A comprehensive study on the evaluation of energy potentials of municipal solid wastes in Yola town was made. The result has indicated that it is highly heterogeneous material, which composed of plastics, textile materials, polythene, papers, wood, food wastes, yard trimmings, glasses, metals, aluminum, and other miscellaneous components. Overall, food wastes, polythene, and papers are the main constituents by weight of MSW in Yola town. The food waste composition has the highest which was about 42.45%. The average moisture content has 9.49%. These results indicated that the MSW has a high-grade fuel potential. Since the outcome has shown a high amount of biodegradable wastes, utilizing the wastes in electricity generation will be a way to getting rid of all the wastes. Going by the result of this analysis, Yola waste was determined to have an energy value of about 118.95 MJ/kg from Table 6. Models based on proximate analysis were also compared, the results show that the total calorific value obtained by Bento model is (118.95MJ/Kg), Traditional model (118.58MJ/Kg) and Goutal model (82.58MJ/Kg). The results show that only Bento and Traditional models were the most suitable for the determination of energy potentials in Yola town. Methane emission from MSW disposed of in dumpsites was estimated using Intergovernmental Panel on Climate Change (IPCC) methodology. From the study, revealed that based on 289, 47 tonnes of MSW generated in Yola town from 2004-2014, emitted about 685.69 tons of methane. The total methane emission is projected to reach 13,677.31 tons in 2025 provided the average population growth rate of 3.2% and waste generation rate of 0.60kg/person/day continues.

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