Nigerian Research Journal of Engineering and Environmental Sciences 6(2) 2021 pp. 764-775
p ISSN: 2635-3342; e ISSN: 2635-3350

Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

Original Research Article

Modeling of Energy Generation from Municipal Solid Waste

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http://doi.org/10.5281/zenodo.5805388

ARTICLE INFORMATION

Article history:
Received 16 Oct, 2021
Revised 13 Nov, 2021
Accepted 16 Nov, 2021
Available online 30 Dec, 2021

Keywords:
Modeling
Energy
Generation
Municipal
Solid wastes

ABSTRACT

This study determined the energy content of municipal solid waste (MSW) and derived the models for prediction of energy content as a guide for future power generation. Standard methods were used for characterization and analysis of samples collected from 15 dumpsites. The results showed 28.38% moisture content and 88.25 kg/m^3 as density of MSW. Energy contents based on unit, ash-free and ash-free dry basis were 30572 kJ/kg, 42937.73 kJ/kg and 47588.98 kJ/kg respectively. Energy to be generated in the years 2021 and 2041 were 1.032 $\times 10^9$ and 1.759 $\times 10^9$ Watt hour respectively. The chemical formula of MSW were $C_{592.8}H_{914.3}O_{384.9}N_7S$ and $C_{84.9}H_{131}O_{55.1}N$ for that with and without sulfur. For the model describing energy generated as a function of projected population, the coefficient of correlation after calibration and verification were $r = 0.9410$ and $r = 0.9998$ respectively. The model describing waste generated as a function of time, gave $r = 1.00$ after calibration and $r = 1.00$ after verification. Also model for energy generated as a function of time, gave $r = 0.522$ after calibration and $r = 0.999$ after verification. These strong fits attest that the models are perfect for predicting energy generation in the future. It is concluded that MSW have high content of energy and should not be disposed indiscriminately instead, it should be recycled.

1. INTRODUCTION

Many developing countries of the world are faced with the biggest challenge of solid waste management, mainly due to increase in solid waste generation (SWG) from homes which is a burden on the municipal budget (Abdel-Shafy and Mansour, 2018). Currently, the global municipal solid waste (MSW) generation is estimated at about 1.3 billion tonnes per year, and is expected to increase to approximately 2.2 billion tonnes per year by 2025 (Abdel-Shafy and Mansour, 2018). A significant increase of the waste generation rates per capita has also been projected, from the current 1.2 kg per person per day to 1.42 kg per person per day until 2025 (Liyala, 2011). Incessant solid waste generation in urban cities have serious impact on sanitation facilities like water supply, waste management and transport infrastructure (Liyala, 2011). Studies have shown that collection, storage, transportation and disposal of solid wastes are the major problems in many cities (Okot-Okumu, and Nyenje, 2011). Many African countries are poor and as a result, cannot afford the huge cost of solid waste management (Okot-Okumu, and Nyenje, 2011). Factors affecting SWG include average family size, number of rooms, monthly income and employment status (Sankoh et al., 2013). Solid waste composition is directly related to the social class in any given community (Gidarakos et al., 2006). Areas dominated by high income earners are more likely than not, to generate more solid wastes than those with low income earners who live in shanty towns (Gu et al., 2015). Wastes can be transmuted to energy by incineration, a system known as waste-to-energy (WTE) incineration in which energy is recovered from municipal solid waste (MSW) to produce electricity and/or steam for heating, being a renewable source of energy (Cheng et al., 2010).

Municipal solid wastes (MSW) are an integral part of any society, which is usually managed by landfilling method in order to abate such problems like air, water and land pollution, though, the inherent problem associated with it are hazardous gas emissions and production of leachate from landfilled wastes (Abu-Quadis and Abu-Quadis, 2000; Dong et al., 2003; Shu et al., 2006). Municipal solid waste can be utilized by recovery of its energy content through such processes like, combustion, pyrolysis, and refuse derived fuel. However, many approaches, experimental and empirical, exist for determination of calorific values (CV) of MSW of which calorimetric method is the most common (Harker and Backhurst, 1981). From the empirical approach, three models are available for prediction of CVs based on, physical composition, ultimate and proximate analytical methods respectively (Liu et al., 1996). However, no matter which kind of MSW management strategy is chosen, modeling MSW generation according to influencing factors is very important in solid waste management, as it can provide more accurate predictions of future MSW generation (Bosire et al., 2017). In general, gross domestic product (GDP), population, and income are major factors contributing to MSW generation. In recent years, some researchers have shown that consumption level of resources is an important factor affecting the MSW volume (Bosire et al., 2017; Han et al., 2018).

Calculating MSW generation per capita enables data on MSW generation to be normalized and eliminates the effects of changes in population (EEA, 2013). Per capita data are widely used to compare the intensity of MSW generation among different places (Abu-Quadis et al., 1997; Gomez et al., 2009; Troschinetz and Mihelcic, 2009; Karak et al., 2012; OECD, 2013). MSW generation per capita ranged from 0.09 kg day^{-1} in Ghana to 5.50 kg day^{-1} in Antigua and Barbuda; the median was 0.94 kg day^{-1}, and it was 0.58 kg day^{-1} in Nigeria (Kawai and Tasaki, 2016). Therefore, this study was aimed at determining the energy content of MSW and the derivations of models for prediction of energy generation from MSW to assist in the management of MSW to mitigate the impact of indiscriminate disposal into the environment by recycling.

2. MATERIALS AND METHODS

2.1. The Study Area

The study area covers World Bank Housing Estate (WBHE) located in Umuahia North Local Government area in Umuahia capital territory of Abia State, Nigeria. It lies between latitudes 5° 20" and 5° 33" North and longitudes 7° 25 and 7° 35" East. Major sampling locations were dumpsites close to Noble Hotel, Orpet Filling Station, TGBG Guest House, Church Road, St. Peter's Presbyterian Church, CKC-WBHE, WBHE Primary School, All Saints Anglican Church, KOLPING Media and Event Center, Anglican Church Low Cost, Golden Guinea, Exclusive Bar and Club, Mobil Petrol Station, Pal-Tori Hotel, and Presbyterian Church Emmanuel Parish respectively.

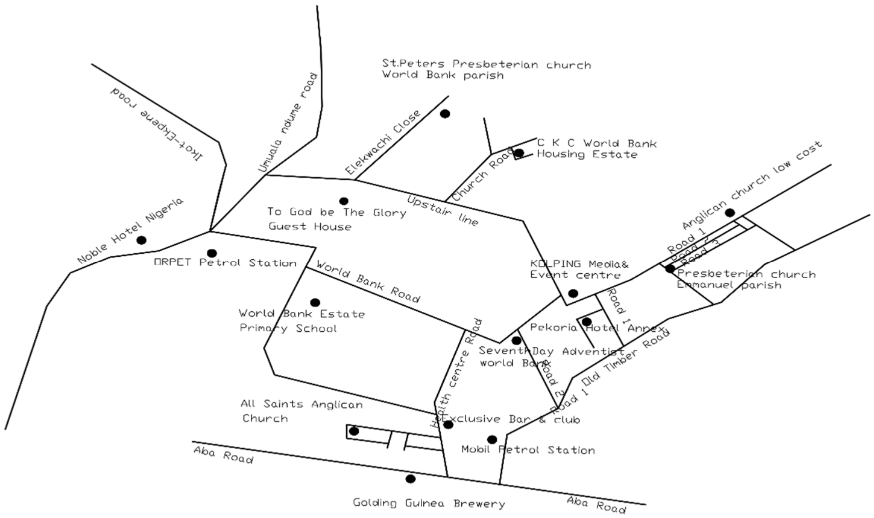

Figure 1: Map of study area

2.2. Samples and Sampling Techniques

Waste samples were randomly collected from fifteen dumpsites close to some locations within the study area as indicated with dots in the map of study area shown in Figure 1. These samples were collected in 200 liters capacity bins from 15 dumpsites. For the determination of the amount of municipal solid waste components (MSWC), the MSW samples collected, were manually separated into different components namely; paper, cardboard, metals, glass, plastics, food wastes, ash, textiles, rubber, leather, garden trimmings, wood, tin cans, and miscellaneous.

2.3. Moisture Content of Waste Samples

Moisture content of samples were determined in the laboratory by heating 10 g of each sample in GALLENKAMP hot box oven with fan (Model: Size 2 CHF097 XX2.5) in accordance with the British Standard method (BS1377, 1975). Each sample was heated in the oven at temperature of 105℃ until a constant weight was obtained after two successive weighing. Moisture content of MSW was determined from Equation 1.

$$\text{Moisture content } (\%) = \left(\frac{a-b}{a}\right) \times 100 \quad (1)$$

Where a = initial mass of sample as delivered (kg) and b = mass of sample after drying (kg)

2.4. Calorific Values of Waste Samples

The calorific values of each of these components were measured by burning 1.0 g weights samples of wastes in an oxygen bomb calorimeter (Model-IKA C2000), which was electrically ignited to burn in the presence of pure oxygen in line with standard procedures (ASTM D3173, 2011).

2.5. Volatile Material Content of Waste Sample

Volatile solids (VS) content of MSW was determined by igniting the dry weight samples used for moisture content test in a high temperature muffle furnace (Nabertherm: Model- LHT 08/18, Tmax 1800℃) to a temperature of about 600℃ for 24 hours. The procedure was in accordance with ASTM D 271-46 (1954) method. Subsequently, the combusted samples were weighed to determine the weight of the dry ash. Volatile solids content was calculated from Equation 2.

$$\%VS = [(w_d - w_a)/w_d]100 \quad (2)$$

Where w_d = weight of dry sample (kg) and w_a = weight of ash (kg)

3. RESULTS AND DISCUSSION

3.1. Characterization of Municipal Solid Waste

Table 1 presents the properties of the various components that make up MSW in Umuahia North local government area of Abia State, Nigeria. These are the percent mass, moisture content, dry mass, volatile matter content, density and volume respectively. Densities of components are typical of values obtained from Tchobanoglous et al. (1977), while volumes were determined based on 1000 kg sample of each component of MSW. Results from Table 1 were used in computation of MSW moisture content and density respectively.

Table 1: Properties of components of municipal solid waste

Component	% Mass	% Moisture	Dry mass (kg)	Volatile matter (%)	Density (kg/m^3)■	Volume (m^3)*
Paper	31	10	27.90	82.14	60	5.167
Cardboard	7	12	6.16	84.65	50	1.400
Plastics	7	2	6.86	92.97	65	1.077
Food wastes	11	75	2.75	81.45	290	0.379
Textiles	5	7	4.65	80.89	65	0.769
Rubber	5	3	4.85	88.40	130	0.385
Leather	7	5	6.65	81.54	160	0.438
Garden trimmings	10	65	3.50	89.56	105	0.952
Wood	5	30	3.50	90.32	240	0.208
Tin cans	5	4	4.80	1.76	90	0.556
Total	93		71.62			11.331

* Based on 1000-kg of waste sample, ■ Typical values of waste sample densities

The dry mass of sample based on 100 kg of MSW sample was 71.62 kg, so that moisture fraction of waste was 100 – 71.62 = 28.82 kg, therefore, percent moisture content and density of MSW are computed and given as follows.

Moisture content = $\left(\frac{100-71.62}{100}\right)100 = 28.38\%$, Density of waste sample = $\frac{1000}{11.331} = 88.25\, kg/m^3$

Table 2 show the percent mass and energy contents of components of MSW in Umuahia North local government area of Abia State. Sum total of energy contents in 100 kg of the nine components that made up MSW in this area was 3,075,200 kJ. This was used to compute the unit energy of the MSW, which is a very important information in solid waste management.

Table 2: Energy contents in components of municipal solid waste

Component	Mass (%)	Total energy (kJ)*
Paper	31	519,250
Cardboard	7	114,100
Plastics	7	228,200
Food wastes	11	511,500
Textiles	5	463,950
Rubber	5	523,500
Leather	7	461,700
Garden trimmings	10	65,000
Wood	5	183,500
Tin cans	5	4,500
Total	93	3,075,200

* Based on 100-kg sample of waste

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From Table 2, based on 100 kg sample, unit energy content of MSW was $3075200 kJ/100kg$, which gives $30752\ kg/kJ$. Energy content on dry mass being when moisture content of 28.38% in MSW has been completely removed is computed as follows.

$$30752 \frac{100}{100-28.38} = 42937.73 \frac{kJ}{kg} \text{ (dry basis)}$$

This result is an indication that energy content of MSW increases as its moisture content decreases. Even in ash-free dry basis when both moisture and ash are completely removed from MSW, energy content increases further. In this study, percent ash was 7% and computation of energy content on an ash-free dry basis gave;

$$30752 \frac{100}{100-7-28.38} = 47588.98 \frac{kJ}{kg} \text{ (ash-free dry basis)}$$

These results indicate that the freer MSWs are from impurities, the higher the energy contents and hence higher calorific values.

Table 3 present the fractional composition of the elements that make up the dry mass of various MSW components. Essentially, this information aided vitally in determination of chemical formula of MSW which can be used in estimation of approximate energy content of MSW.

Table 3: Computation of the chemical composition of municipal solid waste

Component	Wet mass (kg)	Dry mass (kg)	Composition (kg)					
			C	H	O	N	S	Ash
Paper	31	27.9	12.13	1.68	12.27	0.09	0.05	1.68
Cardboard	7	6.16	2.71	0.36	2.75	0.02	0.01	0.31
Plastics	7	6.86	4.24	0.42	1.61	-	-	0.59
Food wastes	11	2.75	1.32	0.18	1.03	0.07	0.01	0.14
Textiles	5	4.65	2.87	0.28	1.09	0.02	0.01	0.38
Rubber	5	4.85	2.26	0.29	2.13	0.06	0.01	0.10
Leather	7	6.65	2.44	0.40	3.22	0.03	0.02	0.54
Garden trimmings	10	3.50	1.67	0.21	1.33	0.12	0.01	0.16
Wood	5	3.50	1.52	0.21	1.61	0.01	0.01	0.14
Tin cans	5	4.80	2.30	0.31	1.90	0.04	0.02	0.23
Total	93	71.62	33.46	4.34	28.94	0.46	0.15	4.27

Information in Table 4 are the molar compositions of the elements contained in the MSW, which were determined by computing the ratio of mass of the elements to mass per molecule of the respective elements in MSW. The elements involved are carbon, hydrogen, oxygen, nitrogen and sulfur. Data from Table 4 can be used as an alternative method of estimation of calorific value and potential power generation from MSW based on modified Dulong's formula as in Equation (3) (Khurmi and Gupta, 2016)

$$\text{Heating value } (kJ/kg) = 338.2C + 1430\left(H - \frac{O}{8}\right) + 95.4S \quad (3)$$

Where C = carbon (%), H = hydrogen (%), O = oxygen (%), and S = sulfur (%)

Table 4: Elemental compositions in municipal solid waste

Element	Mass (kg)	Molar mass (kg/kmol)	Moles
Carbon	33.46	12.01	2.7860
Hydrogen	4.34	1.01	4.2970
Oxygen	28.94	16.00	1.8088
Nitrogen	0.46	14.01	0.0328
Sulfur	0.15	32.06	0.0047

Table 5 present the computation of chemical formula of MSW with and without sulfur. The chemical formulas are very important when trying to find information about the chemical compound that make up MSW, because they provide what elements are present and also the proportion of the atoms of elements found in MSW compound.

Table 5: Computation of chemical formula of MSW with and without sulfur

Element	Mole ratios	
	Sulfur = 1	Nitrogen = 1
Carbon	592.8	84.9
Hydrogen	914.3	131.0
Oxygen	384.9	55.1
Nitrogen	7.0	1.0
Sulfur	1.0	0

Chemical formula of MSW with sulfur was $C_{592.8}H_{914.3}O_{384.9}N_7S$, while chemical formula of MSW without sulfur was $C_{84.9}H_{131}O_{55.1}N$. Population of Umuahia North by 2021 = 208162, growth rate = 2.7% (NPC, 2021). Population projection using compound formula is given as (NPC, 2021):

$$p_f = p_i(1 + k)^n \tag{3}$$

Where p_f = future population, p_i = initial population, k = growth rate and n = design period or any given time. Waste generation in Nigeria per capita per day = 0.58 kg day^{-1}.

3.2. Model Calibration and Verification

Data showing projected population for 20 years from the base year 2021 sourced from National Population Commission (2021) were used in this study. Data for the first ten years corresponding to years 2022 to 2031 were used for calibration as shown in Table 6, while data for the remaining ten days corresponding to years 2032 to 2041 were used for verification as shown in Table 7.

Assumptions:

A linear relationship exists between generated energy E and population P, thus:

$$E = a + bP \tag{4}$$

A linear relationship exists between generated waste W and time t, thus:

$$W = a + bt \tag{5}$$

A linear relationship exists between generated energy and time t, thus:

$$E = a + bt \tag{6}$$

Where, E is the energy generated (kJ), P is projected population, W is generated waste (kg), a and b are constants in Equations (4), (5) and (6) respectively.

3.2.1. Calibration of model for relationship between generated energy and population

In Table 6, calibration of relationship which exists between generated energy and projected population was performed. Data for the first ten days corresponding to years 2022 to 2031 were used for this, after which coefficient of correlation 'r' was computed in order to ascertain the fit as presented.

$\sum E = 43.113, \sum P = 24.170, \sum E^2 = 186.961, \sum P^2 = 58.760$

$\sum EP = 104.778, E = a + bP$

$b = \frac{n\sum EP - \sum E \sum P}{n\sum P^2 - (\sum P)^2}$, $a = \bar{E} - b\bar{P}$, $\therefore b = \frac{10(104.778) - 43.113(24.170)}{10(58.760) - 24.170^2} = 1.682$

$a = 4.3113 - 1.682(2.417)$

Solving, $a = 0.246$

Therefore, the model for relationship between generated energy and population is given by the expression:

$$E = 0.246 + 1.682P \quad (7)$$

Coefficient of correlation, $r = \frac{n\sum EP - \sum E \sum P}{\sqrt{[n\sum E^2 - (\sum E)^2][n\sum P^2 - \sum(p)^2]}}$

$$r = \frac{10(104.778) - 43.113(24.170)}{\sqrt{[(10 \times 186.961) - 43.113^2][(10 \times 58.760) - 24.170^2]}} = 0.941$$

Table 6: Calibration of relationship between energy generated and projected population for 2022 to 2031

Year	$E\ (\times 10^9\ kJ)$	$P(\times 10^5)$	E^2	P^2	EP
2022	3.813	2.138	8.152	4.571	14.539
2023	3.916	2.196	8.600	4.822	15.335
2024	4.022	2.254	9.066	5.081	16.176
2025	4.130	2.316	9.565	5.364	17.057
2026	4.242	2.378	10.087	5.655	17.995
2027	4.356	2.442	10.637	5.963	18.975
2028	4.474	2.508	11.185	6.290	20.017
2029	4.595	2.576	11.837	6.636	21.114
2030	4.917	2.645	12.482	6.996	22.269
2031	4.846	2.717	13.167	7.382	23.484

3.2.2. Verification of model for relationship between generated energy and population

Let experimental energy generated E_{exp} be represented by the letter x, and predicted energy generated E_{pred} be represented by the letter y. By substituting the values of population from 11 to 20 years in Equation (7), corresponding to years 2032 to 2041 as shown in Table 6, predicted values of generated energy were determined. These values were used for verification of the model as presented in the Table 7. The model $E = 0.246 + 1.682P$ after calibration as shown in Table 6, coefficient of correlation, $r = 0.941$ an indication of a very strong fit. Verification of the model as shown in Table 7 gave an r- value of 0.9998 which shows that the model is adequate.

Table 7: Verification of model for relationship between generated energy and predicted energy for 2032 to 2041

Year	x	y	x^2	y^2	xy
2032	4.977	4.939	24.771	24.394	24.581
2033	5.111	5.073	26.122	25.735	25.928
2034	5.250	5.191	27.563	26.946	27.253
2035	5.391	5.326	29.063	28.366	28.712
2036	5.537	5.460	30.658	29.812	30.232
2037	5.686	5.612	32.331	31.495	31.910
2038	5.840	5.746	34.106	33.017	33.557
2039	5.998	5.898	35.976	34.786	35.376
2040	6.159	6.049	37.933	36.590	37.256
2041	6.326	6.217	40.018	38.651	39.329

$\sum x = 56.275, \sum y = 55.511, \sum x^2 = 318.541, \sum y^2 = 309.792, \sum xy = 314.134$

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - \sum(y)^2]}},\ r = \frac{10(314.134) - 56.275(55.511)}{\sqrt{[(10 \times 318.541) - 56.275^2][(10 \times 309.792) - 55.511^2]}} = 0.9998$$

Therefore r-value of 0.9998 is a very strong fit and indicate that the model is adequate. Figure 2 is plot of the verification of the relationship between generated energy and population, in which both experimental energy generated and predicted energy generated curves exhibited very high affinity attesting to the adequacy of the model.

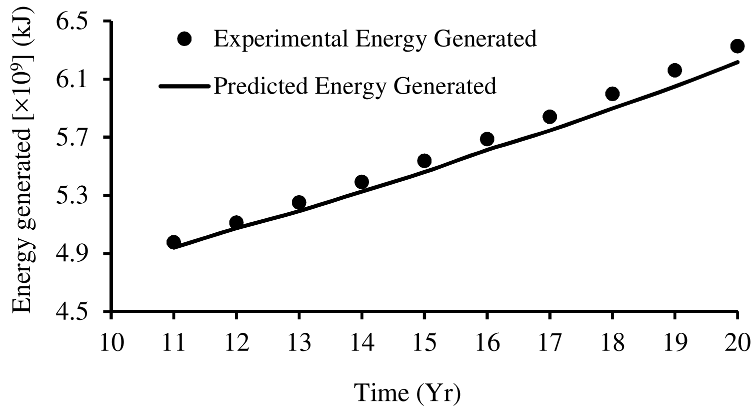

Figure 2: Verification plots for generated energy as a function of population

3.2.3 Calibration of model for relationship between generated waste and time

Similarly, data for the first ten days corresponding to years 2022 to 2031 were used for calibration for relationship between generated waste and time after which the r- value was computed.

Table 8: Calibration of relationship between generated waste and time for 2022 to 2031

t	w $(\times 10^5\ kg)$	t^2	w^2	tw
1	1.240	1	1.538	1.240
2	1.273	4	1.621	2.546
3	1.308	9	1.711	3.924
4	1.343	16	1.804	5.372
5	1.379	25	1.902	6.895
6	1.417	36	2.008	8.502
7	1.455	49	2.117	10.185
8	1.494	64	2.232	11.952
9	1.534	81	2.353	13.806
10	1.576	100	2.484	15.760

$\sum t = 55, \sum w = 14.019, \sum t^2 = 385, \sum w^2 = 19.768, \sum tw = 80.182$

$$w = a + bt,\ b = \frac{n\sum tw - \sum t \sum w}{n\sum t^2 - (\sum t)^2},\ b = \frac{10(80.182) - 55(14.019)}{10(385) - 55^2} = 0.037$$

$$a = \bar{w} - b\bar{t},\ a = 1.402 - 0.037(5.5) = 1.199,\ \Rightarrow w = 1.199 + 0.037t$$

$$r = \frac{n\sum tw - \sum t \sum w}{\sqrt{[n\sum t^2 - (\sum t)^2][n\sum w^2 - (\sum w)^2]}},\ r = \frac{10(80.182) - 55(14.019)}{\left[\sqrt{10(385) - 55^2}\right]\left[\sqrt{10(19.768) - 14.019^2}\right]} = 1.00$$

After calibration of model of the function $W(t)$, a linear function of the form $w = 1.199 + 0.037t$ was obtained. Let experimental waste generated W_{exp} be represented by the letter x, and predicted energy generated W_{pred} be represented by the letter y. The model was verified by substituting the values of time $t = 11$, to $t = 20$ years in the model $w = 1.199 + 0.037t$, so that predicted values of generated wastes were determined. These predicted values obtained from verification of the model are presented in Table 9, where the r- value of 1.0 evidenced that the model is adequate.

$\sum x = 18.298, \sum y = 17.725, \sum x^2 = 33.677, \sum y^2 = 31.531, \sum xy = 32.584$

$$r = \frac{10(32.584) - 18.298(17.725)}{\sqrt{[(10 \times 33.677) - 18.298^2][(10 \times 31.531) - 17.725^2]}} = 1.0$$

Figure 3 show the plot of verification of waste generated as a function of time $W(t)$. Curves of experimental waste generated and predicted waste generated also are in conformity with perfect alignment which proved the adequacy of the model.

Table 9: Verification of model for relationship between generated waste and time for 2032 to 2041

Year	x	y	x^2	y^2	xy
2032	1.618	1.606	2.618	2.579	2.599
2033	1.662	1.643	2.762	2.699	2.731
2034	1.707	1.680	2.913	2.822	2.868
2035	1.753	1.717	3.073	2.948	3.010
2036	1.800	1.754	3.240	3.077	3.157
2037	1.849	1.791	3.419	3.208	3.312
2038	1.899	1.828	3.606	3.342	3.471
2039	1.950	1.865	3.803	3.478	3.637
2040	2.003	1.902	4.012	3.618	3.810
2041	2.057	1.939	4.231	3.760	3.989

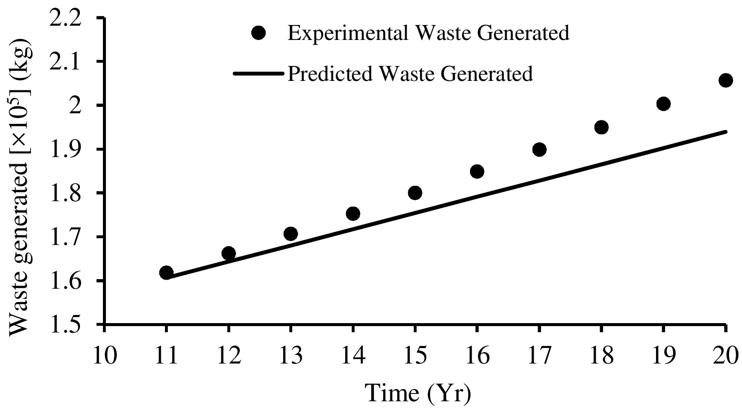

Figure 3: Verification of variation of waste generation model with time

3.2.4 Calibration of model for relationship between generated energy and time

Calibration of relationship between generated energy and time is presented in Table 10 in which data for the first ten years was used for calibration from the year 2022 to 2031, subsequently r- value was computed and found to be 0.522**.**

Table 10: Calibration of relationship between generated energy and time for 2022 to 2031

Year	t	$E\ (\times 10^9\ kJ)$	t^2	E^2	tE
2022	1	3.813	1	14.539	3.813
2023	2	3.916	4	15.335	7.832
2024	3	4.022	9	16.176	12.066
2025	4	4.130	16	17.057	16.130
2026	5	4.242	25	17.995	21.210
2027	6	4.356	36	18.975	26.136
2028	7	4.474	49	20.017	31.318
2029	8	4.595	64	21.114	36.760
2030	9	4.719	81	22.269	42.471
2031	10	4.846	100	23.484	48.460

$\sum t = 55, \sum E = 41.113, \sum t^2 = 385, \sum E^2 = 186.961, \sum tE = 246.196$

$E = a + bt$, $b = \frac{n\sum tE - \sum t \sum E}{n\sum t^2 - (\sum t)^2}$, and $a = \bar{E} - b\bar{t}$. $\therefore b = \frac{10(246.196) - 55(41.113)}{10(385) - 55^2} = 0.243$

$a = 4.1113 - 0.243(5.5) = 2.775$, $\therefore E = 2.755 + 0.243t$

$r = \frac{n\sum tE - \sum t \sum E}{\sqrt{[n\sum t^2 - (\sum t)^2][n\sum E^2 - (\sum E)^2]}}$, $r = \frac{10(246.196) - 55(41.113)}{\sqrt{[(10\times385) - 55^2][(10\times186.961) - 41.113^2]}} = 0.522$

Verification of model describing the relationship between generated energy and time is presented in Table 11, in which data for years 11 to 20 equivalent to years 2032 to 2041 were used for model verification. The r- value of 0.999 showed that the model is adequate. In this case, x and y represent experimental and predicted energy generated respectively. Similarly, the model, $E = 2.755 + 0.243t$ show that r- value after calibration was 0.522, a low value. However, r- value after verification was high at 0.999 an indication of a perfectly acceptable model.

Table 11: Verification of model for relationship between generated energy and time for 2032 to 2041

Year	x	y	x^2	y^2	xy
2032	4.977	5.428	24.771	29.463	27.015
2033	5.111	5.671	26.122	32.160	28.984
2034	5.250	5.914	27.563	34.975	31.049
2035	5.391	6.157	29.063	37.909	33.192
2036	5.537	6.400	30.658	40.960	35.437
2037	5.686	6.643	32.331	44.129	37.772
2038	5.840	6.886	34.106	47.417	40.214
2039	5.998	7.129	35.976	50.823	42.760
2040	6.159	7.372	37.933	54.346	45.404
2041	6.326	7.615	40.018	57.988	48.172

$\sum x = 56.275$, $\sum y = 65.215$, $\sum x^2 = 318.541$,

$\sum y^2 = 430.170$, $\sum xy = 369.999$

$$\frac{10(369.999) - 56.275(65.215)}{\sqrt{[(10\times318.541) - 56.275^2][(10\times430.170) - 65.215^2]}} = 0.999$$

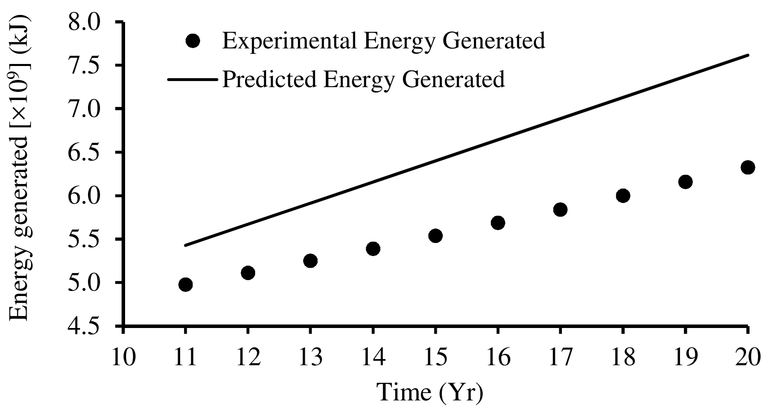

Figure 4: Verification plot of variation generated energy with time

Figure 4 present the plot of verification curves for experimental and generated energies as a function of time $E(t)$. The closeness and alignment of the two curves is evident that the model is adequate which is also reflective the high r- value of 0.999. Results also show that 3.713×10^9 kJ of energy equivalent to 1.032×10^9 Watt hour will be generated from MSW in the year 2021, and 6.326×10^9 kJ of energy equivalent to

1.759×10^9 Watt hour will be recovered from these wastes generated by this community in the year 2041 if effectively converted.

4. CONCLUSION

It is concluded in the analyses from this study that there is high content of energy in MSW in terms of unit, ash-free and ash-free dry basis. This implies that indiscriminate disposal of MSW should be discouraged since they can be recycled into useful form as energy supplies for homes and industries. The three models $E = 0.246 + 1.682P$, $W = 1.199 + 0.037t$ and $E = 2.755 + 0.243t$ derived in this research are perfect and can be used to predict the amount of energy to be generated for powering of appliances in homes and production processes in manufacturing industries in future. This information is very vital for management of municipal solid wastes.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Abdel-Shafy, H.I. and Mansour, M.S.M. (2018). Solid waste issue: Sources, composition, disposal, recycling, and valorization. *Egyptian Journal of Petroleum*, 27, pp. 1275-1290.

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

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

ASTM D 271-48 (1954). Standards on coal and coke: Sampling and analysis of coal and coke, p. 17.

ASTM D3173, (2011) Standard test method for moisture in the analysis sample of coal and coke.

Bosire, E., Oindo, B. and Atieno, J.V. (2017). Modeling household solid waste generation in urban estates using socioeconomic and demographic data, Kisumu City, Kenya. Available online: *https://repository.maseno.ac.ke/handle/123456789/441*.

British Standard 1377 (1975). Methods of tests for soils for civil engineering purposes. British Standards Institution, 2 Park Street London.

Cheng, H. and Hu, Y. (2010) Municipal solid waste (MSW) as a renewable source of Energy: Current and future practices in China. *Bioresource Technology*, 101(11), pp. 3816-3824.

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

European Environment Agency (FEA) (2013). Managing municipal solid waste - a review of achievements in 32 European countries. *European Environment Agency, Copenhagen,* 2013. *https://www.eea.europa.eu/publications/managing-municipal-solid-waste.*

Gidarakos, E. Havas, G. and Ntzamilis, P. (2006). Municipal solid waste composition determination supporting the integrated solid waste management system in the island of Crete. *Waste Management*, 26(6), pp. 668-679.

Gomez, G., Meneses, M., Ballinas, L.and Castels, F. (2009). Seasonal characterization of municipal solid waste (MSW) in the city of Chihuahua, Mexico. *Waste Management,* 29, pp. 2018-2024.

Gu, B., Wang, H., Chen, Z., Jiang, S., Zhu, W., Liu, M., Chen, Y., Wu, Y., He, S., Cheng, R., Yang, J. and Bi, J. (2015). Characterization, quantification and management of household solid waste: A case study in China. *Resources, Conservation and Recycling*, 98, pp. 67-75

Han, Z., Liu, Y., Zhong, M., Shi, G., Li, Q., Zeng, D., Zhang, Y., Fei, Y. and Xie, Y. (2018). Influencing factors of domestic waste characteristics in rural areas of developing countries. *Waste Management,* 72, pp. 45-54.

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

Karak, T., Bhagat, R.M. and Bhattacharyya, P. (2012). Municipal solid waste generation, composition, and management: the world scenario. *Critical Reviews in Environmental Science and Technology 42,* pp. 1509-1630.

Kawai, K. and Tasaki, T. (2016). Revisiting estimates of municipal solid waste generation per capita and their reliability. *Journal of Material Cycles and Waste Management,* 18, pp. 1-13.

Khurmi, R.S. and Gupta, J.K. (2016). A textbook of thermal engineering; S. Chand and Company Pvt. Ltd.: Ram Nagar, New Delhi, India.

Liu, J.I., Paode, R. and Holsen, T. (1996). Modeling the energy content of municipal solid waste using multiple regression analysis. *Journal of the Air and Waste Management Association*, 46, pp. 650-6.

Liyala, C.M. (2011). Modernizing solid waste management at municipal level: Institutional arrangements in urban centers of East Africa. PhD Thesis, *Environmental Policy Series. Washington University, The Netherlands*.

National Population Commission (NPC) (2021). Projected population of Umuahia North local government area, Abia state, Nigeria.

OECD (2013). Municipal waste. Environment at a glance: OECD Indicators.

Okot-Okumu, J. and Nyenje, R. (2011). Municipal solid waste management under decentralization in Uganda. *Habitat International,* 35(4), pp. 537-543.

Sankoh, F.P., Yan, X. and Tran, Q. (2013). Environmental and health impact of solid waste disposal in developing cities: A case study of Granville Brook dumpsite, Freetown, Sierra Leone. *Journal of Environmental Protection*, 4(7), pp. 665-670.

Shu, H-Y., Lu, H-C., Fan, H-J., Chang, M-C. and Chen, J-C. (2006). Prediction for energy content of Taiwan municipal solid waste using multilayer perception neural networks. *Journal of the Air and Waste Management Association,* 56(6), pp. 852-858.

Tchobanoglous, G., Theisen, H., and Eliassen, R. (1977*). Solid wastes: engineering principles and management issues*. McGraw-Hill, New York.

Troschinetz, A.M. and Mihelcic, J.R. (2009). Sustainable recycling of municipal solid waste in developing countries. *Waste Management,* 29, 915-923.