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ENERGY RECOVERY POTENTIAL AND GREENHOUSE GAS EMISSIONS FROM MUNICIPAL SOLID WASTE IN GOMBE, NIGERIA

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ABSTRACT

This study intends to estimate the potential amount of electrical energy that could be recovered from the solid waste disposed of at the only government operated dumpsite in the city of Gombe, Nigeria. The greenhouse gas emission into the atmosphere from the process is estimated. The American Standard of Testing and Measurements method was used to characterise the waste, a mathematical model based on the waste composition was then used to determine its caloric value –2,577.81 kJ/kg. Result of the characterisation study which showed that the waste contains about 65% inorganic materials and the calorific value estimated informed the choice of incineration as the most suitable waste to energy technology. When the potential amount of energy that could be recovered was estimated, it was found that for the 10-year period that the landfill has been in existence, on a daily basis an average of 232,160 kwh/day could be generated, this is capable of powering 42% of the houses in the city. It was also found that by using the electricity recovered from the waste, there is a potential to reduce emission of greenhouse gases from the use grid electricity by up to 49,742.19 $tCO_{2}e$ in a year. The study therefore recommended that results of the study can be used as a guide for the city's authorities and other stakeholders for the initiation of a waste to energy project.

1. INTRODUCTION

Globalisation has brought about increased job opportunities and better standard of living in urban areas thus a consequential rapid population growth in cities all over the world [1]. Relatively higher standard of living of urban dwellers coupled with a large population is not without its attendant consequences, these consequences form some of the most pervasive problems encountered by city administrators and their solid waste management (SWM) lieutenants. In developing countries where the municipal authorities do not have adequate funds for SWM, streets are seen littered and waterways clogged with solid wastes [2–3].

Another problem associated with cities in developing countries is incessant power outages, in Nigeria the power shortage is quite dire that it is considered normal for some cities to go days without electricity [4–6]. Gombe, the capital of Gombe state located in the north-eastern region of Nigeria is not exempted from the twin problems of SWM and electricity shortage – it has a solid waste management problem as it can be observed by the garbage littering the streets and also experiences constant power shortage like most other cities in the country. For a city which suffers from these mentioned problems, converting the solid waste to energy seems to be the silver bullet for solving these problems. Waste to energy is one of the emerging renewable energy sources at man's disposal [7–10].

To implement a waste-to-energy (WtE) policy, a feasibility study needs to be undertaken to determine the suitability of the waste generated in that location. The calorific value or lower heating value of the waste is the most important parameter for determining its suitability for energy generation. According to ASTM E711 - 87 standard, which is the most widely approved standard for determining the calorific value of refuse derived fuel, a bomb calorimeter is used for the process, usually a sample of the municipal solid waste (MSW) weighing 1 gram is to be used for the test [11]. Researchers however

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have suggested that 1 gram is inadequate to accurately ascertain the calorific value of MSW due to the vast variance in its composition, this brings about the growing popularity and usage of models [12–13]. There are three broad methods for determining the calorific value of MSW using mathematical models, these model types are based on the following parameters of the MSW: physical composition; ultimate analysis and proximate analysis [14]. Mathematical models are thereby used as cheaper and faster alternatives to using a bomb calorimeter for the estimation of heating value of waste [15].

Korai et al. [16] performed an assessment in order to estimate the power generation potential through utilization of MSW in Hyderabad City, Pakistan. The study was prompted due to the shortage in electricity supply in the state and the country at large. Samples were collected in accordance ASTM standard, the study found that about 1,600 tonnes of MSW were being generated every day in Hyderabad city with generation rate of about 0.7 kg/capita/day and that based on the net calorific value of 6,519 kcal/kg that the waste has, an estimated net power generation was 1,512 kWh per tonne of solid waste was possible for the city. In Turkey, Şentürk and Yildirim [17] set out to investigate the amount of LFG that can be obtained from the landfill site in Sivas city and its usability for electricity generation. They found that Sivas landfill site has a methane generation capacity of 116.7 m^3/Mg, they also found that the maximum quantities of total gas and methane emissions from the Sivas sanitary landfill were 7.976E+06 m^3/year and 4.068E+06 m^3/year, respectively. They also observed that the highest amount of energy to be generated for the period being studied was estimated to be 2,947 kWh in the year 2030 and that the operational life of the Sivas Landfill Gas Power Plant will nearly end in an economic sense after 2060. They concluded by saying that performing modelling studies are important in guiding municipalities and investors. On the African continent, Omari [18] estimated the amount of energy that can be recovered from the waste generated in Arusha, Tanzania. The researcher discovered that the waste generated in the city has an average calorific value of about 12 MJ/kg and has a capacity of generating up to 128.9 GWh of electricity for the city.

In Nigeria, a number of works have been done on the characterization of MSW, Tsunatu et al., [19] found out that when landfill gas (LFG) is recovered from the waste generated in Jalingo, the capital of Taraba state, 62,596 kWh of electricity could be generated from it. However, if it is incinerated instead, the potential net power that can be generated from it reaches 151,016 kWh in a year. In Lagos, the commercial capital of the country, Idehai and Akujieze [20] studied all the landfill sites in the city. Using models, they found that the LFG from these sites have the potential of generating 123.75 MW of electrical power, they estimated that this has the potential of catering for the electricity needs of about 230,000 inhabitants of the city. The researchers concluded that the concomitant benefits of LFG exploitation go beyond recovery of energy, it also covers the reduction of greenhouse gases and mitigation of environmental hazards.

Given that Gombe generates a large quantity of MSW and also suffers from electricity supply shortage, the need to estimate the potential for electricity generation from the city's waste becomes important. The major objective of this research is to estimate the amount of electrical energy that can be recovered from the solid waste generated in Gombe, the sustainability of the project from the environmental perspective will also be gauged by estimating the greenhouse gas emission from the energy recovery process.

2. MATERIALS AND METHODS

2.1. Description of Study Area

Gombe, the capital of Gombe State located on Latitude 9°30' and 12°30'N, Longitude 8°5' and 11°45'E has a population of 367,500 and a land area of 52km^2. The Bajoga Road open dumpsite which lies on a 40,000m^2 piece of unfenced land is the termination point for all solid waste generated in the city, it has been in operation since 2009 [21]. The dumpsite is being managed by Gombe State Environmental Protection Agency (GOSEPA) – the agency saddled with the responsibility of SWM in the whole state. It was observed from field study that asides the occasional burning of waste in the dumpsite, no form of treatment occurs at the site.

An inquiry into the means of evacuation of MSW from the city to the dumpsite found that wastes originating from houses and businesses are dumped at designated collection points, GOSEPA then evacuates the waste from these collection points to the dumpsite. Such model of MSW evacuation is not unique to Gombe, it is pervasive in the country [10]. It was found from the records of GOSEPA that there are forty-nine (49) identical waste collection points around the city, and that GOSEPA's vehicles evacuates the waste from these points to the dumpsite on a daily basis with the exception of Sundays and public holidays. Figure 1 is the map of Nigeria with Gombe the case study highlighted.

Fig 1. Map of Nigeria showing all 36 states with Gombe highlighted

2.2. Description of Models for Waste to Energy Analyses

When models are employed, there are three broad methods for determining the calorific value of solid wastes, the calorific value of waste is a key in determining its usability for energy generation. These three broad methods are based on the following characteristics of the waste: its physical composition, ultimate analysis and proximate analysis [14].

The physical composition of waste is the main parameter needed to estimate the energy content of solid waste when models based on physical compositions are used. Eq. 1 shows a model based on the physical composition of the MSW [22]:

$$H_n = \left[88.2P_{pl} + 40.5\left(P_{ga} + P_{pa}\right)\right] - 6W \tag{1}$$

Where: H_n = Net calorific value (kcal/kg); P_{pl} = % weight of Plastics; P_{pa} = % Weight of Papers and cardboards; P_{ga} = % Weight of Garbage (textiles, woods, food waste, yard waste); W = % Weight of moisture content.

Models based on ultimate analysis use the composition of carbon (C), hydrogen (H), oxygen (O), Sulphur (S) and moisture content to determine the calorific values of the MSW. According to Abu-Qudais et al., [14], Abu-Qudais & Abu-Qdais (2000), Dulong's Model, Steuer's Model and Scheurer-Kestner's model are some of the ultimate analysis based models. The three models are presented in Eq. 2, 3 and 4.

$$H_n = 81C + 342.5\left(H - \frac{O}{8}\right) + 22.5S - 6(W + 9H) \tag{2}$$

$$H_n = 81\left(C - 3\frac{O}{8}\right) + 57\frac{O}{8} + 345\left(H - \frac{O}{16}\right) + 25S - 6(9H + W) \tag{3}$$

$$H_n = 81\left(C - 3\frac{O}{4}\right) + 342.5H + 22.5S + 57\left(3\frac{O}{4}\right) - 6(9H + W) \tag{4}$$

Models based on proximate analysis are models that utilise MSW data obtained from an ultimate analysis, these data include the percentage levels of moisture in the MSW, its volatile combustible matter content, fixed carbon and ash contents. Examples of such models are Benito's model and Traditional model, these two models are represented in Eq. 5 and 6 respectively [23].

$$H_n = 44.75V - 5.85W + 21.2 \tag{5}$$

Where: V = %Combustible volatile matter; W = %moisture content

$$H_n = 45V - 6 \tag{6}$$

The model based on physical composition was chosen for this study because it has been adjudged to be more reliable by researchers [24–26].

2.3. Characterization of Solid Waste and Determination of Moisture Content

The composition of solid waste being generated in the city was determined using ASTM D 5231-92 standard [15], this involved the collection of samples from the dumpsite using rakes and shovels as the immediately the evacuation vehicles discharge the waste at the dumpsite. These samples were then packaged in large polythene bags and labelled with the date of collection, the weight of each batch of MSW collected were recorded, the samples collected were sorted into different categories as stipulated by the standard being followed. The collection of samples from the unsegregated MSW at the dumpsite was done at three different times within the year (January, April and August 2019) so as to account for seasonal variation which influences vegetation, consumption pattern and consequently waste characteristics [27].

The percentage of each component of the MSW was then calculated using the formula in Eq. 7.

$$\%W_t = \frac{\text{Weight of Particular Category of Sample}}{\text{Total Weight of Sample}} \times 100 \tag{7}$$

The moisture content of the MSW was determined using ASTM 3173 method [11], 1kg of the MSW sample was placed in a dish whose weight was known, the dish was then placed in an oven and the temperature set at 105°C, it was left there until the sample reached a constant weight. The moisture content was then estimated using Eq. 8.

$$\%\ of\ Moisture\ content\ (W) = \frac{Wet\ Weight - Dry\ Weight}{Wet\ Weight} \times 100 \tag{8}$$

2.4. Energy Recovery Potential and Greenhouse Gases Emission

Results of the characterization study showed that the city's waste contains a low amount of biodegradable organic materials (putrescible), the calorific value of the MSW was also estimated to be 2,577.81 kJ/kg. Based on the composition of the waste generated in the city and its calorific value, precedence in literature pointed to incineration as the most suitable waste to energy technology to be used for the city [28–30]. Using 22% thermal efficiency of a heat engine, the amount of energy that can be recovered on a daily basis from the incineration of the MSW generated in Gombe was estimated using Eq. 9 [8].

$$E = H_n \times W \times \frac{1000}{859.4} \times \eta \tag{9}$$

where: E = Energy recovered (kwh/day); H_n = Net calorific value (kcal/kg); W = Average daily waste disposal (tonnes); η = Conversion Efficiency (22%).

Version 2.0 of Institute for Global Environmental Strategies (IGES) GHG emissions tool which is a Microsoft Excel based simulation tool for analyses of GHG emissions from different solid waste disposal techniques was used to analyse the data obtained. The input data required by the software for the estimation of GHGs emission from incineration include the quantity of waste generated, its composition and the estimated amount of electricity that can be recovered from the MSW [31].

3. RESULTS AND DISCUSSIONS

3.1. Waste Generated and its Characteristics

It was found from GOSEPA's records that in the ten years of existence of the dumpsite, a total of 1,412,519 tonnes of solid waste have been disposed of there. The average yearly quantity of MSW disposed of there is 128,411 tonnes. Table 1 shows the annual quantities of MSW disposed of at the dumpsite from its inception to the end of year 2019. It can be seen from Table 1 that the least amount of MSW was evacuated from the city to the dumpsite in the index year. The explanation offered by GOSEPA for this is that, at that inception there were fewer collection points and sanitary vehicles as such the waste collection efficiency was low.

Table 1. Annual quantities of waste disposed of at Bajoga Road dumpsite

Year	Quantity (Tonnes)
2009	29,022
2010	110,376
2011	115,920
2012	126,168
2013	71,568
2014	206,052
2015	184,548
2016	135,871
2017	139,404
2018	143,028
2019	150,562

The characterisation study found that inert materials constitute about a fifth of the waste generated in the city, this is unsurprising given that the city lies in the semiarid region of Nigeria where the weather is usually dry. It was also found that putrescible constitute less than a fifth of the total waste was generated in the city thus making it one of the reasons why incineration was chosen as the most suitable waste to energy technology.

It was found that a fifth of the composition of the MSW disposed of at the dumpsite was made up of inert materials, while woods and metals made up just about a tenth of its total weight. Papers and plastics constituted about 8.2% and 11.4% of the waste respectively, while yard/garden wastes and food wastes constituted 13.9% and 9% respectively. Plastics constituted just about 10% of the waste generated in the city, this is somewhat surprising giving the high usage rate of plastic packaging in the city. Table 2 is the composition of MSW disposed of at the city's dumpsite, it shows the weighted samples for the three different sampling periods and their average.

Table 2. Composition by weight of solid waste at Bajoga Road sanitary landfill

Category	Weight for Sampling Period and their Averages (kg)				Percentage Weight (%)
	April	August	December	Average	
Papers	58.23	56.96	60.14	58.44	8.2
Plastics	79.83	80.44	81.66	80.64	11.4
Yard wastes	98.33	99.03	98.57	98.64	13.9
Food Wastes	63.40	65.12	61.92	63.48	9.0
Woods	58.19	58.83	58.67	58.56	8.3
Metals	59.24	57.70	59.83	58.92	8.3
Glasses	62.53	62.63	63.49	62.88	8.9
Textiles	68.12	70.58	69.75	69.48	9.8
Inert Materials	156.38	158.90	158.49	157.92	22.2

3.2. Energy Recovery Potential and Greenhouse Gases Emission

The net calorific value for the MSW in Gombe was estimated using Eq. 1, it was found that the waste has a lower heating value of 2,577.81 kJ/kg. The potential for recovery of energy on a daily basis from the waste by thermochemical conversion within the period of the existence of the dumpsite is presented in Fig. 2. On average, 232,160 kwh/day could be recovered from the city's MSW. It can be inferred from Fig. 2 that the year the site was commissioned, 52,470 kwh/day could have been recovered from the city's waste, making it the year with the least daily energy recovery potential in its ten years of existence. In 2014, the site's highest potential daily energy recovery was recorded: 372,531 kwh/day. The fluctuation in the potential daily energy recovery rate for the period in which the site has been in existence is directly connected to the fluctuation in the amount of MSW disposed at the dumpsite. It was estimated that the waste generated in the year the study terminated has the potential of generating up to 97,995 GWh of electricity. This is equivalent to the energy contained in 39,835 tonnes of coal or 11,010,657 litres of petrol or 97,99,485 litres of diesel. Since the average household electricity consumption in Gombe is 10 kwh/day [32], the electrical energy recovered from the waste generated in the city in year 2019 has the potential to supply 26,848 houses in the city with electricity.

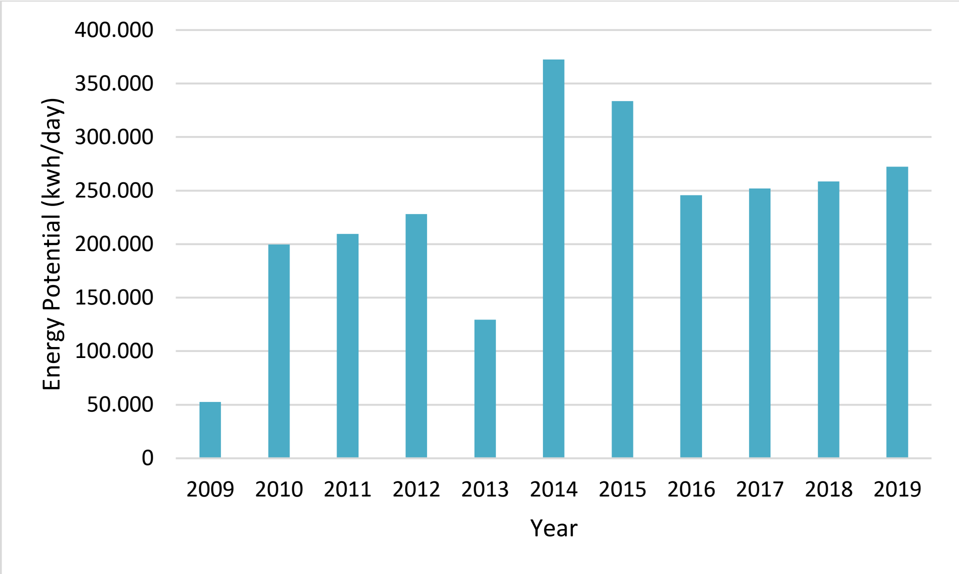

Fig 2. Daily energy recovery potential for Bajoga Road landfill

When electricity generation potential per tonne of waste disposed of is considered, it was found that for every tonne of waste generated in Gombe, 585.77 kWh of electricity can be recovered. This is somewhat almost similar to that obtained in Kano which is another state in the country, Daura [8] found that for every tonne of waste generated in Kano, 579.53 kWh of electricity can be recovered from it. Another study in Ilorin the capital of Kwara state which is another state in the country found that the waste generated there has a much higher electrical energy generation potential per tonne of MSW (5,555 kWh) [33], no logical reason could be pinpointed for this high energy content which is much higher than that of coal.

For the environmental implication of recovering electricity from the waste generated, it was estimated that in the index year, 11,529.64 tonnes of carbon dioxide equivalent (tCO_2e) were emitted into the atmosphere from the incineration of 29,002 tonnes of solid waste generated in the city. In the same vein, since the waste incinerated is used to generate electricity, it was found that by using the electricity generated from the waste, the emission of 9,588.19 tCO_2e from the use of grid electricity will be avoided. This means in the index year there was a net GHGs emission of 1,941.45 tCO_2e. In a relatable term, the amount of carbon dioxide emission that will be avoided by using energy recovered from waste instead of grid electricity in the year the study terminates is equivalent to the quantity of carbon dioxide absorbed by 1,989,687 trees in a year [34]. Table 3 shows the potential direct emissions from the generation of electricity from MSW, the avoided emission from using the electricity generated in place of grid electricity and the net emission (avoided emissions subtracted from direct emissions) for the period being studied.

Table 3. Emission from incineration of Gombe's solid waste

Year	**Direct Emissions (tCO_2e)**	**Avoided (tCO_2e)**	**Net Emission (tCO_2e)**
2009	11,529.64	9,588.19	1,941.45
2010	43,849.34	36,465.66	7,383.68
2011	46,051.82	38,297.27	7,754.55
2012	50,123.07	41,682.97	8,440.09
2013	28,431.99	23,644.40	4,787.59
2014	81,858.78	68,074.79	13,783.99
2015	73,315.83	60,970.37	12,345.46
2016	53,977.80	44,888.62	9,089.18
2017	55,381.37	46,055.84	9,325.52
2018	56,821.08	47,253.13	9,567.95
2019	59,814.13	49,742.19	10,071.95

4. CONCLUSION

An estimation for the potential amount of electrical energy that can be recovered from the MSW disposed of at the Bajoga road open dumpsite in Gombe, Gombe State, Nigeria was undertaken. Firstly, the record for the quantity of MSW disposed at the landfill was obtained from GOSEPA, thereafter, a sampling process in accordance to ASTM standard was undertaken so as to be able to characterize the MSW at the landfill. It was found that the MSW has a calorific value of 2,577.81 kJ/kg and largely constituted inorganic materials, these findings informed the choice of incineration as the most suitable waste to energy technology. A mathematical model which makes use of the composition of the MSW was then used to determine the potential amount of energy that could be recovered from it. It was found that for each tonne of waste generated in the city, 585.77 kWh of electricity could be recovered from it. Likewise, it was estimated that the waste generated in the city has the potential of providing electricity to 42% of the houses in the city. It was also found that using the electricity recovered from the waste has the potential to reduce emission of greenhouse gases from the use grid electricity by up to 49,742.19 tCO_2e in a year.

The potential for recovery of electricity from the waste generated in Gombe is high, it is also eco-friendly, it is therefore recommended that the economic feasibility of establishing such a project be studied. If it is economically feasible, a public-private partnership could be initiated by stakeholders to see to the fruition of such a project which will significantly improve the electricity shortage in the state while also taking care of its solid waste problems and also improving the general economy of the state.

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REFERENCES

[1] Kanai, J. M., Grant, R., & Jianu, R. (2018). Cities on and off the map: A bibliometric assessment of urban globalisation research. *Urban Studies*, 55(12), 2569–2585. DOI: https://doi.org/10.1177/0042098017720385

[2] Ziraba, A. K., Haregu, T. N., & Mberu, B. (2016). A review and framework for understanding the potential impact of poor solid waste management on health in developing countries. *Archives of Public Health*, 74(1), 1-11. DOI: https://doi.org/10.1186/s13690-016-0166-4

[3] Ikhlayel, M. (2018). Development of management systems for sustainable municipal solid waste in developing countries: A systematic life cycle thinking approach. *Journal of Cleaner Production*, 180, 571–586. DOI: https://doi.org/10.1016/j.jclepro.2018.01.057

[4] Moses, I., Christopher, I., Idehai, I. M., & Akujieze, C. N. (2015). Estimation of landfill gas and its renewable energy potential in Lagos, Nigeria. *International Journal of Energy and Environmental Engineering*, 6(3), 329–343. DOI: https://doi.org/10.1007/s40095-015-0178-9

[5] Oyedepo, O. S., Adaramola, M. S., Odunfa, M. K., & Aremu, O. T. (2015). Analysis of Energy Utilization in Selected Industries in Southwestern Nigeria. *Energy Engineering: Journal of the Association of Energy Engineering*, 112(6), 47–74. DOI: https://doi.org/10.1080/01998595.2015.11494386.

[6] Olatunji, O. O., Akinlabi, S. A., Madushele, N., Adedeji, P. A., Ishola, F., & Ayo, O. O. (2019). Wastage amidst shortage: Strategies for the mitigation of standby electricity in residential sector in Nigeria. *Journal of Physics,* 1378(4), 420-432.

[7] Shareefdeen, Z., Elkamel, A., & Tse, S. (2015). Review of current technologies used in municipal solid waste-to-energy facilities in Canada. *Clean Technologies and Environmental Policy*, 17(7), 1837-1846. DOI: https://doi.org/10.1007/s10098-015-0904-2

[8] Daura, L. A. (2016). Electricity Generation Potential of Municipal Solid Waste in Kano Metropolis. *Journal of Scientific and Engineering Research*, 3(4), 157–161.

[9] Gumisiriza, R., Hawumba, J. F., Okure, M., & Hensel, O. (2017). Biomass waste-to-energy valorisation technologies: A review case for banana processing in Uganda. *Biotechnology for Biofuels*, 10(1), 1-29. DOI: https://doi.org/10.1186/s13068-016-0689-5.

[10] Mshelia, R. B. (2020). Evaluation of greenhouse gas emissions from solid waste management practices in state capitals of north eastern Nigeria. *Journal of Engineering Studies and Research,* 26(4), 1-8.

[11] ASTM. (2004). Standard test method for gross calorific value of refuse-derived fuel by the bomb calorimeter. *Annual Book of ASTM Standards ASTM International*, *105*.

[12] Daura, L. A. (2017). *Potentials for Energy Generation and Greenhouse Gases Emission Reduction from Municipal Solid Waste in Kano Metropolis*. Bayero University, Kano.

[13] Abba, A. H., Babagana, U. M., Atiku, A. A., & Burmamu, B. R. (2019). Evaluation of Energy Potentials from Municipal Solid Waste : A Case Study. *FUTY Journal of the Environment*, 13(1), 36–45.

[14] Abu-Qudais, M., & Abu-Qdais, H. A. (2000). Energy content of municipal solid waste in Jordan and its potential utilization. *Energy Conversion and Management*, 41(9), 983–991. DOI: https://doi.org/10.1016/S0196-8904(99)00155-7.
[15] Oumarou, M. B., Shodiya, S., Ngala, G., & Aviara, N. (2016). Statistical Modelling of the Energy Content of Municipal Solid Wastes in Northern Nigeria. *Arid Zone Journal of Engineering, Technology and Environment,* 8(12), 103-109.
[16] Korai, M. S., Mahar, R. B., & Uqaili, M. A. (2014). Assessment of power generation potential from municipal solid wastes: a case study of Hyderabad city, Sindh, Pakistan. *Pakistan Journal of Analytical & Environmental Chemistry*, 15(1), 10-20.
[17] Şentürk, İ., Yıldırım, B. (2020). A study on estimating of the landfill gas potential from solid waste storage area in Sivas, Turkey. *Techno-Science*, 3(2), 63-76.
[18] Omari, M., Kichonge, B., John, G., Njau, K., & Mtui, P. (2014). Potential of Municipal Solid Waste, as Renewable Energy Source - A Case Study of Arusha, Tanzania. *International Journal of Renewable Energy Technology Research*, 3(6), 1–9.
[19] Tsunatu, D. Y., Tickson, T. S., Sam, K. D., & Namo, J. M. (2015). Municipal solid waste as alternative source of energy generation: a case study of Jalingo Metropolis–Taraba State. *International Journal of Engineering and Technology*, 5(3), 185–193.
[20] Idehai, I. M., & Akujieze, C. N. (2015). Estimation of landfill gas and its renewable energy potential in Lagos, Nigeria. *International Journal of Energy and Environmental Engineering*, 6(3), 329–343.
[21] Onuigbo, M. C. (2018). Waste to Energy, Key to Solving Nigeria's Epileptic Power Supply: A Case Study of Gombe Metropolis, Nigeria. *The Revitalization of Nigerian Industrial Sector for Rural Infrastructural Development: The Role of Mechanical Engineers*. Kano: NIMechE, 8-15.
[22] Kathiravale, S., Yunus, M. N. M., Sopian, K., Samsuddin, A. H., & Rahman, R. A. (2003). Modeling the heating value of Municipal Solid Waste. *Fuel*, 8(4), 1119–1125.
[23] Ogwueleka, F. N. (2010). Modelling Energy Content of Municipal Solid Waste. *Journal of Health Sciences and Environmental Engineering*, 7(3), 259–266.
[24] Lin, C.-J., Chyan, J.-M., Chen, I.-M., & Wang, Y.-T. (2013). Swift model for a lower heating value prediction based on wet-based physical components of municipal solid waste. *Waste Management*, 33(2), 268–276.
[25] Lin, X., Wang, F., Chi, Y., Huang, Q., & Yan, J. (2015). A simple method for predicting the lower heating value of municipal solid waste in China based on wet physical composition. *Waste Management*, 36, 24–32. DOI: https://doi.org/10.1016/j.wasman.2014.11.020
[26] Wang, D., Tang, Y.-T., He, J., Yang, F., & Robinson, D. (2020). Generalised models to predict the lower heating value (LHV) of municipal solid waste (MSW). *Energy*, 216, 119- 139. DOI: https://doi.org/10.1016/j.energy.2020.119279
[27] Kamran, A., Chaudhry, M. N., & Batool, S. A. (2015). Effects of socio-economic status and seasonal variation on municipal solid waste composition: a baseline study for future planning and development. *Environmental Sciences Europe*, 27(1), 16-24. DOI: https://doi.org/10.1186/s12302-015-0050-9
[28] Bosmans, A., Vanderreydt, I., Geysen, D., & Helsen, L. (2013). The crucial role of Waste-to-Energy technologies in enhanced landfill mining: a technology review. *Journal of Cleaner Production*, 55, 10–23. DOI: https://doi.org/10.1016/j.jclepro.2012.05.032
[29] Helsen, L., & Bosmans, A. (2010). Waste-to-Energy through thermochemical processes: matching waste with process. *1st International Academic Symposium on Enhanced Landfill Mining*, 133–180.
[30] Makarichi, L., Kan, R., Jutidamrongphan, W., & Techato, K. (2019). Suitability of municipal solid waste in African cities for thermochemical waste-to-energy conversion: The case of Harare Metropolitan City, Zimbabwe. *Waste Management & Research*, 37(1), 83–94. DOI: https://doi.org/10.1177/0734242X18804029
[31] IGES. (2016). *User Manual: Estimation Tool for Greenhouse Gas (GHG) Emissions from Municipal Solid Waste (MSW) Management in a Life Cycle Perspective*. (N. Menikpura & J. Sang-arun, Eds.). Tokyo: IGES.
[32] Olaniyan, K., McLellan, B. C., Ogata, S., & Tezuka, T. (2018). Estimating Residential Electricity Consumption in Nigeria to Support Energy Transitions. *Sustainability*, 10(5), 1–22. DOI: https://doi.org/10.3390/su10051440
[33] Ibikunle, R. A., Titiladunayo, I. F., Akinnuli, B. O., Dahunsi, S. O., & Olayanju, T. M. A. (2019). Estimation of power generation from municipal solid wastes : A case Study of Ilorin metropolis, Nigeria. *Energy Reports*, 5, 126–135. DOI: https://doi.org/10.1016/j.egyr.2019.01.005.
[34] Köhl, M., Neupane, P. R., & Lotfiomran, N. (2017). The Impact of Tree Age On Biomass Growth and Carbon Accumulation Capacity: A Retrospective Analysis Using Tree Ring Data of Three Tropical Tree Species Grown in Natural Forests of Suriname. *PloS One*, 12(8), 120–140. DOI: https://doi.org/10.1371/journal.pone.0181187