https://doi.org/10.5281/zenodo.20800009

Municipal Solid Waste Quantification for Biogas Production in Kano Metropolis

***Musa** Danladi*[1], ***Haruna** S. U*[2] *and **Kibiya** M. M*[3]

Abstract

Municipal Solid Waste is a heterogeneous substance that composed of a wide range of materials (organics and inorganics). In the Kano metropolis, 75% of the waste materials comprises organic waste that can be converted into useful renewable energy in the form of biogas-via anaerobic digestion technique. The bulk of the organic components in the dumpsites degrade, emitting greenhouse gases and foul odours. The daily waste generation rate of 3,018,886kg/day was obtained by interpolating the population of the study area and its growth rate (3.4%) with the daily waste per capita generation and its growth rate (2.7%). While the waste projection was made to the year 2038, the projected quantity for the year 2038 was estimated to be 7,885.304 tons/day. To determine the composition of the MSW, 200kg of MSW was randomly sampled from different locations of each of the four designated dumpsites in Kano metropolis and spread on wide polythene and sorted manually. The composition analyses show that averagely 75% of the waste component was organic, highly suitable for biogas production. It was assumed that only 74% of the generated MSW reaches dumpsites, and this was used for the assessment biogas generation potential in Kano metropolis.

Keywords: Waste Characterization, Organic Fraction of Municipal Solid Waste, Biogas, Renewable Energy.

1.1 Introduction

The world in the 21st century is facing challenges of increasing energy demand, waste management, high population growth, and global climate change. These challenges are more peculiar to cities in Africa. Substituting fossil fuel with municipal solid waste-derived energy in the form of biogas is a promising strategy to simultaneously meet part of our energy needs, manage municipal solid waste (MSW), and mitigate greenhouse gas (GHG) emissions. Moreover, the severe impacts of climate change can be reduced if efforts are made to transform current energy systems from fossil energy-based to renewable energy through biogas recovery from the organic fraction of municipal solid waste (OFMSW).

Generation and disposal of solid waste is unavoidable, as when there is life there must be generation of waste. To ensure sustainability, waste generation and management have to be done in an environmentally sound manner, to avoid its negative consequences which are detrimental the general ecosystem.

Waste management in Kano was not accorded due attention with regards to planning for a sustainable, healthy, and inclusive city. Open dumping of waste with open-air burning is currently the common management practice in the Kano metropolis. This practice is rudimentary, inefficient, and unsustainable, and cannot be considered as a long-term management method for the generated MSW. The method is associated with serious environmental and healthcare challenges. It is also characterized by inadequate waste management facilities, poor access to waste collection and

[1&2] *Department of Science, School of Continuing Education, Bayero University, Kano. P.M.B. 3011, Kano, Nigeria*

[3] *Department of Mechanical Engineering, School of Technology, Kano State Polytechnic, Kano, Nigeria*

management services.

Several efforts were made by the successive governments, multinational and international donors, the private sector, and individuals in the waste management process through the provision of waste conveyance trucks, loaders, buckets, tricycles, and street sweepers, among other machinery. There are also several technical interventions from development partners geared towards waste management, such as Invent-Germany, ICF/AfD-France, among others, and private companies (Capegate Investment Limited), but the interventions did not yield the desired goal of ensuring sustainable waste management.

The collected waste is usually dumped without any treatment at the waste collection points, and designated dumpsites; with numerous scavengers busy collecting some of it for onward sale to waste dealers who further sell to some companies for reuse and recycling, with the bulk of the waste (mostly organic) left lying in the dumpsites emitting greenhouse gases (Methane-CH4 and Carbon dioxide-CO2), including foul odor. These methods are neither efficient nor environmentally friendly, despite their position in the waste management hierarchy; as such they cannot be considered sustainable. These challenges and other associated problems necessitate the conduct of the study to assess the potentials of organic fraction of municipal solid for bigas generation in Kano metropolis.

1.2 Literature Review

Energy crisis and environmental degradation are currently some of the vital issues hindering the achievement of the global sustainable development (Rathi and Kumar, 2014). African cities are faced with the challenges of sustainable energy supply (Tanko, 2016). Consequently, energy is a critical issue in Africa, where numerous people do not have access to it; its recovery from solid waste can play a vital role in minimizing the negative impact of MSW on the environment (Scarlata, Motola, Dallemand, Monforti-Ferrario, Mofor, 2015). Energy plays a very vital role in the national development process as a domestic necessity and major factor of production, whose cost directly affects the price of other goods and services (Amigun, Sigamoney, and von Blottnitz, 2008).

To be environmentally wise, energy services must be provided with low environmental impacts, including reduction in Greenhouse Gases (GHG) emissions, and hence the need for efficient and sustainable energy sources, such as biogas from organic fraction of municipal solid waste (OFMSW) (Kaplan, Carolis, and Thorneloe 2009; Moomaw, Yamba, Kamimoto, Maurice, Nyboer, Urama, and Weir, 2011). A common strategy for reducing GHG emissions from energy use is to increase the supply of low-carbon energy alternatives (Hill, Tajibaeva, and Polasky, 2016), such as biogas from OFMSW.

There have been studies using different approaches in trying to solve waste management problems in Kano metropolis, including Ahmed (2007); Nabegu (2008); Bichi and Amatobi (2013); Nabegu & Mustapha (2014); Musa (2014); Nabegu (2014); Daura (2015) and (2016); Muhammad and Salihi (2018), among others. But their approaches targeted the solid waste management problem not holistically, neglecting the main problem posed by the bulk of the organic waste in the dumpsites.

Production of biogas through anaerobic digestion techniques from OFMSW would result in the reduction of fossil fuel consumption and greenhouse gas emissions, and may subsequently lead to carbon credit access of billions of Naira. In addition, energy generation from OFMSW could help in achieving Goals 7 and 13 of the United Nations Sustainable Development Goals. Considering biogas recovery from organic fraction of MSW in the study are geared towards solving social, economic, and environmental problems in Kano, which led to a sustainable environment for present and future generations.

2.0 Materials And Method

This section explains the materials and method used in conducting the study, sampling technique and data sources, and the brief description of the study area.

2.1 Data Sources: The primary data source for the study was gathered using quantitative methodology. This approach was selected to facilitate the collection of measurable numerical data from the large sample size.

2.2 Sampling Procedure: Random sampling was used to collect the MSW samples directly from the four designated dumpsites (Kuleape et al, 2014) and this involve randomly collecting the unsorted mix samples of 200 Kg at different locations of the dumpsites to represent the entire dumpsites based on the sampling method recommended by (Corbit, 1998).

2.3 Materials for Data Collection

Weighing scale for weighing the waste with high accuracy at each of the designated dumpsites

Buckets - (a) Used for measuring weight (wet weight) of the waste; and

(b) Used as a container for collecting MSW from the dumpsites.

Plastic Sheet (polythene) - use for spreading and sorting of waste for composition determination in each of the dumpsites.

Personal protective wares used; Hand Gloves, Nostril Cover, Goggles Glass

2.4 The Study Area

2.4.1 Location and Areal Extent

Kano is the largest city in the Sudan Savanna region of Nigeria (Nabegu, 2013). It is located between latitude 11 ° 52 N to 12 ° 80 N and longitude 8 ° 23 E to 8 ° 38 E (See Figure 1). It has for centuries been the most important commercial and industrial nerve center of northern Nigeria, attracting millions of people from all parts of the country and beyond (Nabegu, 2013). The present metropolitan Kano (sometimes referred to as 'Greater Kano') is the capital of the state. The old walled Kano, now called Kano city, is located at the center of Kano metropolis, which comprises Kano Municipal, Fagge, Dala, Tarauni, Nassarawa, Gwale, Kumbotso, and Ungogo Local Government Areas and parts of other local government areas close to metropolitan Kano (Figure 1 is the Map showing the location of the study area).

Kano State Urban Planning and Development Authority (KNUPDA) in 2006 redefined the metropolitan Kano to cover the whole of Dala, Municipal, Nassarawa, Gwale, Tarauni, and Fagge Local Government Areas, the entire districts of Kumbotso and Ungogo Local Government areas, parts of Dawakin Tofa, Gezawa, Kura, Madobi, Tofa, and Rimin Gado Local Government Areas (Kano State Government, 2009). Figure 1: Map of the Study Area.

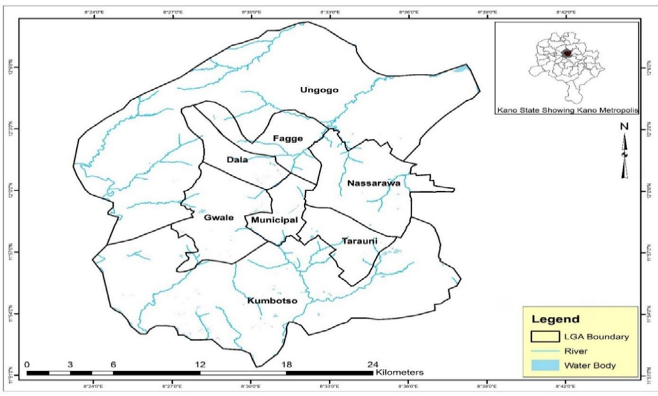

Figure 1: Kano Metropolis showing the Metropolitan Local Government Areas

2.4.2 Climatic Conditions

Climatic condition of the study area plays a significant role in the energy recovery processes using biogas conversion techniques, for instance rainfall and temperature are the two most important climatic elements having direct influence on the waste-to-energy conversion options of biogas generation, most especially when anaerobic digestion is the preferred conversion option. Due to the fact that higher temperature and moisture favours higher decomposition (biochemical conversion). In addition, it should be noted that the climate of the study area is the tropical wet and dry based on Aw Koppen's classification. Climatic factors (rainfall and temperature) are playing a crucial role in the generation and management of MSW; they also have a direct influence on the biogas generation options selected in the study.

2.4.2.a Temperature

In Kano the temperature is generally warm to hot throughout the year at about 27 oC ± 7 oC (Olofin and Tanko, 2002). This is ideal for bacterial growth leading to decomposition of the organic fraction of municipal solid waste (OFMSW), resulting in higher methane (CH_4) yield which can subsequently be used for biogas generation. However, there are relatively cool months usually from November to February when Harmattan prevails. The monthly mean temperature could be as low as between 21 °C and 23 °C ± 9 °C, particularly in December and January. Conversely, there are very hot months when the monthly mean temperature reaches over 32 °C.

2.4.2.b Rainfall

Rainfall in Kano usually falls in 90-120 days, there are only four real wet months (June-September) which have substantial rainfall, but in the year (2020) there was a shift with rainfall extending to October. This condition of a longer dry period is favorable for energy recovery if the option of (anaerobic digestion). Increases in the intensity of rainfall favour the decomposition of MSW, resulting in higher biogas generation. There is variability in the amount of rainfall during the dry months, but this varies from year to year. Almost 40% of the annual rainfall comes in August, which is the peak of the wet season (Olofin and Tanko, 2002), with an average annual rainfall of 650-700 mm per annum.

2.5 Method of Determining the MSW Quantity and its Future Projection

The generation rates of MSW were determined by the use of data on daily generation rates per person per day (per capita generation rates) obtained from the household survey in some selected residential densities. To obtain the daily generation rate of MSW in the Kano metropolis, the per capita generation rates were interpolated with the population of the study area using Equation (1).

Total Waste Generation (kg/day) = Present Population × Per capita Generation (kg/person/day) .... (1)

Equation (2) was used in computing the total mass of the MSW generated per year, where TM represents the total mass of MSW generated per year.

$$TM = P \times PWG \times 365 \quad (2)$$

Where, P is the population of Kano metropolis based on the population growth rate (r) of 3.4%, PWG is the waste generated per capita per day (kg/capita/day), 365 is the number of days in a year.

Moreover, the quantity of future MSW generation was projected for the next twenty (15-20) years, and this was also done using interpolation of the MSW generation rate with its anticipated annual growth rate and population of Kano metropolis with its average annual growth rate. Variables used in the interpolation include the present population, its assumed average annual growth, the most recent waste generation key figure, and the foreseen increase in the generation key figure. It was calculated using equation (3).

$$\text{Quantity } (Wq) = (Pp) \times (Wr) \quad (3)$$

Where, Wq is the projected waste quantity, Pp is the projected population (base population and its growth rate), and Wr is the predicted waste generation rate (kg/capita/day) based on the present generated figure, and it assumes an annual growth rate.

2.5.1 Method of Estimating Quantity of MSW Disposed to Dumpsites

It is important to note that not all MSW generated is disposed of in the dumpsites; some quantity remains in the streets, within vacant plots, and inside gutters and drainages. For this reason, equation (4) was used to compute the estimated quantity of MSW disposed of in the dumpsites, and it was considered for the computation of energy generation potentials.

$$TMD = PMD \times TMG \text{ (kg/day)} \quad (4)$$

Where TMD is the total mass of MSW disposed off at dumpsites, PMD is the estimated percentage of municipal solid waste disposed to dumpsites, and TMG is the total mass of MSW generated.

2.5.2 Method of Determining the Composition of Municipal Solid Waste

The two most widely used methods for waste characterization are the materials flow method and site-specific sampling method via sorting and weighing of MSW by its major categories (AbdAlqader and Hamad, 2012). The determination of MSW composition is a difficult task due to its heterogeneous nature (Al-Khatib and Monou, 2010). For this reason, this study adopted site-specific characterization, which involves manual sorting and weighing of MSW samples by major categories. The study covered both dry and wet seasons as done by (Amber et al., 2012; Aguilar-Virgen, et al., 2013; Whittey et al., 2016).

MSW sorting is the first step of an integrated waste management system because it determines the composition of materials and possible biogas to be generated from the municipal solid waste stream (Qui, 2012).

For the MSW composition determination, a sample of 200kg was drawn randomly from different locations of each of the three residential densities, and the content was spread on a wide polythene sheet and sorted manually. Different sorted components were measured and recorded. The procedures were based on random sampling techniques to determine the composition of MSW. The components were sorted manually into major categories of organics and inorganics as done by Kuleape, Cobbina, Dampare, Duweijuah, Amoako and Asare, (2014), the organics which will assess for biogas generation include food waste, bones, paper/cartons, textiles/rag, mixed organic, wood, leather, compostable organic matter and inert whereas the inorganics which are discarded include plastics, rubber, metals, glass/broken bottles, medical waste and aluminum, among others.

The separated waste constituents were put into a bucket for individual weight measurement; each and every major constituent of MSW was measured using digital weighing scale. The weight of each MSW sub-component was measured and recorded using Equation (5).

The MSW composition estimates represent the ratio of the components' relative weight to the total waste for each noted sub-stream or sub-component. They were derived by summing each component's weight across each of the sorted constituents, dividing by the sum of the total weight of waste, and then multiplying it by 100, as shown in equation (5) (Arazo,2015; Nadeem, Farhan, Ilyas, 2016; Adewumi, Ajibade, Lasisi, and Oguntuase, 2017):

Waste Component (Xi) (%) = ×100.. (5)

The organic composition of MSW for renewable energy generation was calculated using equation (6) (Ibikunle, Titiladunayo, Akinnulib, Dahunsic, Olayanjud, 2019b) as follows;

MF (organic) = OF × TMD (tons/day) .... (6)

Where, MF (organic) is the mass of organic waste fraction in the main MSW composition, TMD is the total mass of generated and disposed component of the MSW disposed on a daily basis, and OFMSW is the estimated percentage of organic MSW from the main sample of MSW.

3.0 Results And Discussions

3.1 Municipal Solid Waste Generation In Kano Metropolis

The daily as well as annual solid waste generation were quantified in the study area. The success of waste management requires accurate data on the generation and composition of waste, which are pivotal for the waste management decision-making, especially involving the energy recovery process (Gidarakos, Havas, Ntzamilis, 2006; Thitame, ·Pondhe, and Meshram, 2010; Thenmozhi and Hameed, 2014; Giang, 2017).

3.1.1 MSW Quantity Generation in Kano Metropolis

Data on the per capita waste generation based on the estimated population are used in estimating the quantity of municipal solid waste generation in Kano metropolis. This was done by relating key population data and per capita waste generation rates. The per capita generation rate of 0.64kg/person/day was obtained from the field survey conducted in 2023 and was correlated with the estimated projected population of the study area to obtain the total generated quantity of MSW. Based on this, the population projection was done from year 2006 with a population of 2,826,307(NPopC, 2006) as the base year for the projection, both the waste generation and population were projected up to the year 2038 with a population growth rate of 3.40% given by (NPopC, 2006) and per capita waste generation growth rate of 2.7% (Beede and Bloom, 1995).

The MSW generation rate was obtained by substituting the per capita generation rate of 0.64kg/person/day and the projected population of the year 2023 (5,037,554) in equation (1) given by Oumarou, Dauda, Abdulrahim, Abubakar (2012) Based on this the total estimated quantity of municipal solid waste generated daily in the year 2022 was calculated to be 3,224,034kg/day which is equivalent to 3,224 tons per day. Table 1 shows the per capita waste generation rates, projected population, and the projected quantity of MSW generated in Kano metropolis.

The per capita waste generation of 0.64 kg/person/day in Kano metropolis is the basis for the MSW per capita projection and, is within the waste per capita generation range of what was obtained in Kaduna, Akure and Onitsha (Amber et al., 2012) all in Nigeria and also in close range with what is obtained in other cities of the developing world (World Bank, 1999; Subramani and Murugan, 2014). World Bank (2012) reported that for several African countries, the per capita waste generation data were not readily available. Ogwueleka (2009) gave the average waste generation rates of Kano to be 0.55kg/person/day, below the value of 0.64kg/person/day and also above the 0.55kg/person/day obtained by ICF/AFD, (2018).

Moreover, the per capita waste generation rate is higher in income countries, which is as low as 0.50kg/capita/per day in low-income countries (Thitame et al., 2009). Meizah, Obori-Danso, Kadar, Fie-Biffoe, and Mensah (2015) found the average per capita waste generation of all the regional capitals in Ghana to be 0.51 kg/person/day, which agrees with what is obtained in this study. However, it is important to note that the per capita generation rates of MSW varies from cities to cities and from countries to countries depending on their level of urbanization and economic growth (Kuleape et al., 2014).

Based on the computation, the estimated annual generation in tons/year of MSW in Kano metropolis was obtained using equation (2) by relating the estimated population figure of the year 2023 with the projected per capita generation rate of MSW of the same year. By substituting the values in equation (2), the estimated total quantity of MSW generated in Kano metropolis on an annual basis was calculated to be 1,101,893 tons per year.

In comparison with other cities, the daily generated quantity of MSW in Kano metropolis is more than 5 times of what is generate daily in Ilorin, Nigeria with the figure of 584 tons/day (Ibikunle, et al., 2019b) and it also more than doubled the rate of generation in Kanpur city, in India with 1,200 tons/day (Rathi and Kumar, 2014), it is more than 2,5 of what was generated in the most celebrated Ethiopian waste-to-energy power plant of Reppi (Koshe) in Addis Ababa which is utilizing (1400 tons/day) (Abebe, 2018). The annual estimated quantity of municipal solid waste generation figure almost tripled what was generated at Abuja, 302,372 to 378,040 tons in 2014 (Abur., Emmanuel and Gideon., 2014), and far exceeded the World Bank quantity of 50,000 metric tons requirement for setting MSW incineration plant (World Bank, 1999). As such, if a sustainable waste management strategy is not put in place, the generated MSW will cause serious environmental challenges.

3.1.2 Projected Municipal Solid Waste Generation in Kano Metropolis

The projected quantity of municipal solid waste generation in Kano metropolis was computed in metric tons based on the projected population, and the projected per capita MSW generation rates were calculated using equation (3), taking 2023 as the base year of the estimation. The year 2006 is considered the reference year of the population projection, the last official population census was conducted in the year. Projections of municipal solid waste generation to the year 2038 were done by factoring expected growth in population, projected per capita MSW generation, and their estimated average growth rates (World Bank, 2012; Das and Bhattacharyya, 2014).

According to the 2006 population census data, Kano metropolis has an annual population growth rate of 3.4% per annum (NPopC, 2006; Nabegu, 2014). This increase was considered in the computation, and the growth rate was assumed to be the same up to 2038, because according to the World Bank (1999), a waste-to-energy generation facility should have a lifespan of between 15-20 years. For this reason, the MSW generation trend was projected to the year 2038. The population growth rate of Kano metropolis is higher compared to what is obtained in Kolkata, India, which stands at 1.4% per annum (Das and Bhattacharyya, 2014).

The per capita generation rate of 0.64kg/person/day was considered as the base rate for the computation, due to lack of waste generation per capita data, it was assumed that the amount of waste generated in Kano would increase at a growth rate of approximately 2.7% annually, the assumed growth rate was adopted in the computation from Beede and Bloom, (1995) for the study location. Because there was no documented data on MSW generation growth rate for Kano metropolis and it was assumed to be uniform throughout the projection years (2023 to 2038), The population growth versus increases of municipal solid waste per capita generation from 2023 to 2038 were correlated by factoring method as done in (World Bank, 2012) using equation (3) in the Microsoft Excel 2016 version working environment.

Based on the municipal solid waste projection, the population of Kano metropolis was expected to be almost double from 3,224,034kg/day in the year 2023 to 7,885,304 kg/day projected for the year 2038. This was foreseen to create serious environmental problems if a proper and sustainable management strategy was not put in place. Moreover, it is vital to note that the waste per capita growth rate was also expected to reach 0.94 kg/person/day by the year 2038 if growing at 2.7% per annum. The projected figure clearly indicates that if the generated MSW were used for renewable energy generation, it could serve as a sustainable feedstock for the sustainable energy generation process.

Municipal solid waste generation is directly proportional to the rate of change of population. With the population projections data and knowledge of waste generation per capita rates and their growth, the estimated future waste generation was done using equation (3) based on the procedure reported by the World Bank (2012). The future projections were made based on the projected estimated data of MSW generation and projected population for the years 2023- 2038.

3.1.3 MSW Quantity used in the Biogas Generation Assessment

Biogas recovery from organic fraction municipal waste is internationally recognized as a powerful tool to prevent the formation of greenhouse gas emissions and to mitigate climate change (Abebe, 2018). It is important to note that not all the municipal solid waste generated in Kano metropolis is disposed-off in the dumpsites. Aboyade (2004) stated that about 70% of the waste generated in Nigeria is collected and disposed-off to dumpsites. Due to a lack of reliable data on the quantity disposed of at the dumpsites daily, it is assumed that the same quantity (70%) will be ultimately disposed at dumpsites in Kano metropolis, so, the estimated quantity of MSW disposed to the dumpsite was obtained using equation (4). Total quantity of MSW disposed to dumpsites on a daily basis was, therefore, calculated using equation (4) to be 2,270.80 tons/day; annually, the figure will stand at 828,851 tons/day.

It is worth noting that 74.56% of the generated and disposed MSW in Kano metropolis forms the organic fraction of MSW, and is the proportion expected to generate biogas through anaerobic digestion. The fraction of organic composition of MSW that can be utilized for a renewable energy generation project was calculated using Equation (6). Based on the characterization of MSW in the study area, 74.56% (0.75) was found to constitute approximated proportion of the organic fraction of MSW generated in the dry season for the biogas generation assessment, and it was calculated using equation (6) to be 1,703 tons/day.

It was assumed that all the inorganic components which include plastic, metals and glass, rubber, mixed-polythene, aluminum and other inorganic MSW products, will be sorted out for recycling and reuse. Only the organic fraction of the

MSW composition is considered for the biogas recovery assessment, as it is the only source of renewable energy using anaerobic digestion technique.

4.0 Conclusion

The MSW quantification shows that waste generation is increasing with increase in population; thus, it is evident that Kano metropolis is facing multifaceted challenges with regard to managing the generated waste. The foreseen rate of generation is expected to pose a serious threat to the environment due to a lack of a sustainable management system. To ensure sustainability, efforts should be geared towards evolving a long-lasting waste management strategy, such as a biogas recovery option from the organic components of MSW in Kano metropolis, because of the fact that more than 70% of the MSW constituents is organic in nature capable of decomposing to release biogas (Methane and Carbon di Oxide). The GHG emission, in terms of methane an d carbon dioxide, could be avoided and they are also considered the gases that form biogas, which can be harnessed and utilized as a renewable energy for energy generation. The OFMSW could be utilized for the exploitation of the non-conventional energy locked up in the dumped OFMSW municipal solid waste in Kano metropolis.

Acknowledgement: The Authors wish to acknowledged Tetfund, for grant received through Institution Based Research (IBR), at the Directorate of Research, Innovation and Partnership (DRIP), Bayero University, Kano.

5.0 References

AbdAlqader, A. and Hamad, J. (2012) Municipal Solid Waste Composition Determination Supporting the Integrated Solid Waste Management in Gaza Strip, International Journal of Environmental Science and Development, Vol. 3, No. 2, April 2012

Abebe, M. A (2018). "Challenges of Waste to Energy facility in Reppi (koshe), Addis Ababa city, "International Research Journal of Pharmacy and Medical Sciences (IRJPMS), Volume 1, Issue 4, pp. 9-16, 2018.

Aboyade A. (2004) The potential for climate change mitigation in the Nigerian solid waste disposal sector: a case study from Lagos. Sweden: Lund University, Sweden: Lund University; 2004.

Abur Benjamin Ternenge, Emmanuel Enomena Oguche & Gideon Ayuba Duvuna, (2014) Characterization of Municipal Solid Waste in the Federal Capital Abuja, Nigeria. Global Journal of Science Frontier Research, 14: 1-7.

Adewumi, J. R., Ajibade, F. O., Lasisi, K.H., and Oguntuase, A. M. (2017) Characterization of Municipal Solid Waste Generated in Akure Metropolis. Proceedings of the 2017 Annual Conference of the School of Engineering & Engineering Technology (SEET), The Federal University of Technology, Akure, Nigeria, pp 584-595, 11-13 July, 2017.

Aguilar-Virgena, Q., Taboada-Gonzáleza, P., Ojeda-Benítezb, S., Cruz-Sotelo, S (2012). Power generation with biogas from municipal solid waste: Prediction of gas generation with in situ parameters. Renewable and Sustainable Energy Reviews 30 (2014) 412–419.

Al-Khatib, I. A, Monou, M (2010). Solid Waste Characterization, Quantification and Management Practices in Developing Countries. A Case Study: Nablus District-Palestine. Journal of Environmental Management 91 (2010) 1131–1138.

Amber, I., Kulla, D. M. Gukop, N (2012) 'Generation Characteristics and Energy potential of Solid Municipal Waste in Nigeria' Journal of Energy in Southern Africa Vol. 23 NO.3 August 2012.

Amigun, B., Sigamoney, R. & von Blottnitz, H. (2008). Commercialisation of biofuel industry in Africa: a review. Renewable and Sustainable Energy Reviews 12(3): 690-711.

Arazo, R. O (2015). Compositions of Solid Wastes Generated from a School Campus. Ijret: International Journal of Research in Engineering and Technology eISSN: 2319-1163 pISSN: 2321-7308 Volume: 04 Issue: 10, Oct-2015, Available @ http://www.ijret.org.

Beede, D.N., and Bloom, D.E. (1995). The economics of municipal solid waste. The World Bank Research Observer 10(2), August, 113-150.

Das, S. Bhattacharyya, B.K (2014) Estimation of Municipal Solid Waste Generation and Future Trends in Greater Metropolitan Regions of Kolkata, India Journal of Industrial Engineering and Management Innovation, Vol. 1, No. 1 (October 2014), 31-38.

Daura, L. A (2015) Energy Generation and Greenhouse Gas Reduction Potentials of Municipal Solid Waste in Kano Metropolis, Ph.D. Thesis submitted to the Department of Mechanical Engineering, Bayero University, Kano.

Daura, L. A. (2016) Electricity Generation Potential of Municipal Solid Waste in Kano Metropolis Journal of Scientific and Engineering Research, 2016, 3(4):157-161.

Giang, H. M. (2017) A Study on the Development of a

Methodology for Sustainable Solid Waste Management System by using a Multi-Objective Decision Making Model, a Case Study in Hanoi An City, Vietnam, Ph.D. Thesis. Graduate School of Environmental and Life Science, Okayama University.

Gidarakos E, Havas G, Ntzamilis P. (2006) Municipal solid waste composition determination supporting the integrated solid waste management system in the island of Crete. Waste Manage 2006; 26:668–79.

Ibikunle R.A., Titiladunayo, I.F., Akinnulib, B.O., Dahunsic, S.O., Olayanjud, T.M.A. (2019b) Estimation of power generation from municipal solid wastes: A case Study of Ilorin metropolis, Nigeria, Energy Reports 5(2019) 126–135.

ICF/AfD, (2018). Solid Waste Management in Kano City: Feasibility Study-Report on Waste Characterization and Treatment Options. Marché Subsequen à l'accord-cadre de présentation d'études et d'assistance technique pour (Technical Report) l'initiative villes et changement climatique en Afrique subsaharienne (CICLIA)- Réf. AfD/DOEEBC/CLD/ACH-2017-026.

Kano State Government (2009) 'Handbook on Procedures and Guidelines on Land Related Matters, Kano State Ministry of Lands and Physical Planning.

Kaplan, P.O., Carolis, J and Thorneloe, S (2009) Is It Better to Burn or Bury Waste for Clean Electricity Generation? Environ. Sci. Technol. 2009, 43, 1711–1717.

Kuleape, R.A, Cobbina, S.J, Dampare, S.B, Duweijuah, A.B, Amoako, E.E., and Asare, W (2014). Assessment of energy recovery potentials of solid waste generated in Akosombo, Ghana. African Journal of Environmental Science and Technology, Vol 8(5), pp 297-305, May 2014.

Meizah, K., Obori-Danso, K., Kadar Z., Fie-Biffoe, B., Mensah, M. Y. (2015) Municipal Solid Waste Characterization and Quantification as a Measure towards Effective Waste Management in Ghana. Waste Management. 46 (2015) 15-27.

Moomaw, W., F. Yamba, M. Kamimoto, L. Maurice, J. Nyboer, K. Urama, T. Weir (2011): Introduction. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C.von Stechow (eds.)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Nabegu A B (2008a) Municipal Solid Waste Characteristics in three Residential Zones of Kano Metropolis: Implications for Management Maiduguri Journal of Arts and Social Sciences (6)1.

Nabegu, A. B. (2013) Application of One-Way Analysis of Variance (ANOVA) in Exploring Municipal Solid Waste Characteristics in Kano Metropolis, Northwestern Nigeria. Greener Journal of Science, Engineering and Technology Research ISSN: 2276-7835 Vol. 3 (2), pp. 062-067, February 2013.

Nabegu, A. B., & Mustapha, A. (2014). Enhancing awareness and participation of municipal solid waste management in Kano Metropolis, Nigeria. World Scientific News, 5, 46-53.

Nabegu, A.B (2008b). The Role of Refuse Management and Sanitation Board (REMASAB) in Solid Waste Management in Kano Metropolis. Maiduguri Journal of Arts and Social Sciences Volume 6 Number 2 December 2008.

Nabegu, A.B (2014). The Potential of Municipal Solid Waste as a Clean Development Mechanism (CDM) Project in Kano Metropolis, Nigeria. Greener Journal of Social Sciences, ISSN: 2276-7800, ICV 2012: 5.99. Vol. 4 (2), pp. 130-138.

Nadeem K, Farhan K, Ilyas H (2016) Waste Amount Survey and Physico-Chemical Analysis of Municipal Solid Waste Generated in Gujranwala, Pakistan. Int. J Waste Resource 6: 196. doi: 10.4172/2252-5211.1000196.

NPopC (2006) 2006 National Population Commission Census, 2006. Federal Republic official Gazette, Government notice No 2. National Population Commission, Abuja, Nigeria.

Ogwueleka T. Ch. (2009) Municipal Solid Waste Characteristics and Management in Nigeria, Iran J. Environ. Health. Sci. Eng., 2009, Vol. 6, No. 3, pp. 173-180.

Olofin, E. A. and Tanko A. I. (2002) Laboratory of Areal Differentiation – Metropolitan Kano in Geographic perspective, Department of Geography Field Studies Series 1. Bayero University Kano.

Oumarou, M. B., Dauda, M., Abdulrahim, A. T., Abubakar, A. B. (2012) Characterization and

Generation of Municipal Solid Waste in North Central Nigeria. International Journal of Modern Engineering Research (IJMER) Vol. 2, Issue.5, Sep-Oct. 2012 pp-3669-3672.

Rathi, S., and Kumar, P (2014). Electrical Energy Recovery from Municipal Solid Waste of Kanpur City, International journal of scientific research engineering and technology (IJSRET), ISSN 2278-0882, Volume 3, Issue 5, 923-970, August 2014.

Scarlata, N., Motola, V., Dallemand, J.F., Monforti-Ferrario., Mofor, L. (2015). Evaluation of Energy Potential of Municipal Solid Waste from African Urban Areas. Renewable and Sustainable Energy Reviews 50 (2015) 1269-1286.

Tanko, A. I (2016) Urban Energy Challenges in Sub-Saharan Africa, Current Options in Environmental Sustainability 2016, 20: 80-85.

Thenmozhi Murugaian Palanivel and Hameed Sulaiman (2014). Generation and Composition of Municipal Solid Waste (MSW) in Muscat, Sultanate of Oman, APCBEE Procedia 10 (2014) 96 – 102, ICESD 2014: February 19-21, Singapore.

Thitame, S. N., ·Pondhe, G. M. Meshram, D. C. (2010) Characterization and composition of Municipal Solid Waste (MSW) generated in Sangamner City, District Ahmednagar, Maharashtra, India. Environ Monit. Assess (2010) 170:1–5 DOI 10.1007/s10661-009-1209-

Whitty, K., Smith, C., Quintero, M., and Benitez, S. O. (2016). Opportunities for Energy Production from Solid Waste in the Mexicali/Imperial Valley Region Project Number: Hw-06-3.

World Bank (1999) World Bank Technical Guidance Report: Municipal Solid Waste Incineration. The International Bank for Reconstruction and Development / THE WORLD BANK 1818 H Street, N.W. Washington, D.C. 20433, U.S.A.

World Bank (2012). What a Waste – A Global Review of Solid Waste Management, Urban Development Series Knowledge Papers, World Bank, Washington, DC, USA.