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Potentials of Waste to Energy in Nigeria

Atta A.Y., Aminu, M., Yusuf N., Gano Z.S., Ahmed O.U. and Fasanya O.O

National Research Institute for Chemical Technology, Zaria, Nigeria

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Address For Correspondence:
Atta A.Y., , National Research Institute for Chemical Technology, Zaria, Nigeria
Tel: +2347063365325; E-mail: zeezoatta@yahoo.com

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ABSTRACT

With growing population and rapid urbanization in Nigeria, appropriate waste management practices are becoming not only important but necessary. Improper waste management has led to heaps of wastes littering streets with adverse effect on health and aesthetic appealof our cities. Actual waste generation and disposal techniques are the main components that need to be properly studied in order to come up with an acceptable waste management plan for the country. This paper attempts to make a forecast on the quantity of waste generation in Nigeria between the years 2012 to 2020 and highlighting the potentials of the generated waste in contributing to the nation's energy mix. The two most important factors that affect the waste burden in Nigeria are socio-demographic (population) and economic (GDP per capita) factors. Thus, the equation used in this paper to forecast the total quantity of waste generated reflects these components. Population estimates were carried out by extrapolating the 2006 national census figures using 2.5% growth rate. The per capita waste generation rate was estimated by correlating it with the per capita gross domestic product (GDP) of Nigeria. With a population of about 158 million and an average waste generation rate of 0.5 kg/person/day, the nation's waste burden was estimated to be about 29 million tons in 2011. This formed the basis for subsequent forecasts; about 40 million tons is envisaged to be generated in 2020. The average calorific value of Nigerian waste was estimated to be about 9.6 MJ/kg based on the waste profile obtained. The results from this investigation also show that about 2300 MW of electricity could be generated from waste in 2012. This figure is expected to soar up to over 3000 MW by 2020.

KEYWORDS: Waste, Energy, Gasification

INTRODUCTION

The term "waste" connotes different meanings to different people. Waste can loosely be defined as any material that is considered to be of no further use to the owner, and is hence discarded [1]. Perhaps a most encompassing definition is the one proposed by the EU Framework Directive on Waste (91/156/EEC). The article defines waste as "any substance or object which the holder discards or intends to discard.and which falls into one of the these categories; production or consumption residue, product whose date for appropriate use has expired, contaminated or soiled materials and Substances that no longer perform satisfactorily [7].

Wastes generally exist in the solid, liquid and gaseous forms. Only the solid component of the waste would be considered in this paper. Municipal Solid Waste (MSW) has been defined as household waste and any other waste collected by Waste Collection Authority (WCA) or its agents, including wastes from parks, beaches, commercial establishments, offices, industries and fly tipping [7].

Exact figures relating to waste generation in Nigeria, and in fact a lot of developing countries are difficult to come by. The literatures available are sometimes fraught with inconsistencies in data recording, definitions, collection methods, seasonal variations, etc [9].

Appraisals of MSW quantities are usually based on amount of waste generated per person per day (kg/person. day). Estimations are generally preferable in weight basis because the use of volume as a measure of quantity could be misleading. A cubic meter of loose wastes for example is totally different from a cubic meter of compacted wastes as regards both generation and handling. In the event that a volumetric basis is used, the degree of compaction or the density of the waste has to be specified for the figure to be meaningful [8].

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Several investigations have been carried out to estimate Nigeria's per capita waste generation. Quantities ranging from 0.3 – 1.1 kg/person/day have been reported in various cities of the country [1] A number of researchers have put the average national figure at between 0.45 - 0.55 kg/person/day [21,15,5,19]. These quantities seem to tally with both weighted average of the various cities as well as the estimates made by some reputable international organizations with relative income level as a criterion [4,8].

As with most developing countries, the bulk of the waste generated in Nigeria consists of putrescible (food waste/garbage). Recently, however, there has been a marked proliferation of plastic in the overall waste pool due mainly to the high demand for sachet water and the increase in utilization of packaging materials such as polyethylene terephthalate (PET) bottles and grocery shopping bags [16]. Several researchers have reported various waste profiles across Nigeria [7,10,1]. Their findings show a strong agreement with the prediction made by Hoornweg for a middle income country in Asia (Fig 1).

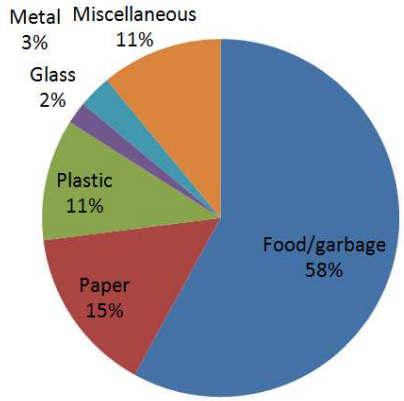

Fig. 1: Average estimate of waste composition for middle income countries (typical of Nigeria) [9].

Different methods are available for estimating waste generation, Ordonez-Ponce [17] reported socio-demographic, economic, geographic and waste related factors as global objective variables having strong links to waste generation. Equation 1, which gives a simplified relationship between the parameters affecting waste generation, could be used to estimate annual waste generation figures:

$$G_{Ti} = G_{Ri} \times 10^{-3} \times P_i \times 365 \quad (1)$$

Where: $G_{T\,i}$ is the total waste generation in year i (ton/annum)

$G_{R\,i}$ the per capita rate of waste generation in year i (kg/person/day)

P_i is the population of the country in year i.

Yusof et al. [24] used a linear function with number of family members, number of rooms, income and religious/cultural backgrounds as variables to estimate waste generation in Johor Bahru, Malaysia. They concluded that sociodemographic factors contributed more significantly to waste generation than economic factors in the study area.

Some researchers have estimated annual waste generation figures in Nigeria. CPE reported an overall waste generation of about 18 million tons in 2006. Ossai and Ogwueleka reported the annual waste burden in the nation as 50 million tones and 25 million tons respectively.

Forcasting future waste generation figures is a bit more complex precisely because it encompasses some uncertainties. Several researchers have developed mathematical models to estimate future waste generation quantum in some cities and countries.Kumar et al. [11] for instance used an Artificial Neutral Network (ANN) with population, urbanization and income as input variables to forecast waste generation in a city in India. Ordonez-Ponce [17] also used ANN, but included education and geography to the variables considered by Kumar *et al.* [11], to make the estimations for Chile. Both of them agree however, that the main parameters that affect waste generation are population and economy.

EUROPEAN COMMISSION [6] used the compound formula to estimate both future population and per capita generation rates (Equations 2 and 3). These were then substituted into Equation 1 to come up with forecasts for quantities of waste generated in some European cities.

$$P_i = P_O(1 + r)^n \quad (2)$$

Where: P_O is the population figure for the base year, P_i is the population figure for year i, r is population growth rate and n is the number of years between the base year and the year i.

$$G_{Ri} = G_{Ro}(1 + r)^n \quad (3)$$

Where: G_{RO} is the per capita generation rate at the base year (kg/person/day), G_{Ri} is the per capita generation rate for year i, r is the rate of growth of G_R and n is the number of years between the base year and the year i.

In Nigeria, population figures and growth rates are readily available from the National Population Commission and other planning agencies, hence forecasting population is relatively easy. However, estimating future per capita waste generation rates is a bit complicated because it has to be linked with other more tangible and measurable parameters. Based on a large number of statistical data analyzed, researchers found out that a direct proportional relationship exists between G_R and the Gross National Product (GNP) By collecting GDP and G_R data for several cities around the world, Guangyu(2000) determined a linear relationship (between GDP and G_R) with a correlation coefficient of about 0.869. This further reinforces the belief that the rate of growth of per capita waste generation is strongly dependent on economic factor (GDP in this case).Table 1 gives the G_R growth rates vis-a-vis GDP per capita for some countries/cities.

Table 1: Comparison between GDP per capita growth rate and G_R growth rate.

Country/City	GDP per capita growth rate (%) (Worldbank, 2011)	G_R growth rate (%)
Chile	4.2	1.48(Ordonez-Ponce, 2004)
Kuala Lumpur (Malaysia)	5.5	2 - 3 (Yusof, et al., 2002)
EU cities (France/UK)	1.0/0.7	0.6 – 1(EUROPEAN COMMISSION, 2003)
India	7.4	1.33 (Kumar, et al., 2011)
Nepal	2.7	0.8(Hoornweg, 1999)
Vietnam	5.7	1.0 (Hoornweg, 1999)
China	9.8	0.5 (Hoornweg, 1999)
Indonesia	5.0	1.2 (Hoornweg, 1999)
Philippines	5.8	2.1 (Hoornweg, 1999)
Bangladesh	4.9	0.9 (Hoornweg, 1999)

With population explosion in Nigeria and relative improvement in economic indices, annual waste generation is expected to keep on rising [3,23]. The need for a proper waste disposal is therefore becoming more important and necessary in order to diminish associated hazards. In most developing nations such as Nigeria, waste is usually dumped indiscriminately on roadsides and open pits without regards to the attendant health implications. The dumping of waste in streams, river channels and municipal drainages has also been linked to flood, pollution of groundwater and other attendant vices [13]. The generally acceptable disposal options are: land filling, incineration, composting and recycle/reuse.

An appropriate and viable option for waste disposal in Nigeria is incineration for electricity production. Energy crisis in Nigeria has been persistent for quite a long time. Sambo [20] reported that the primary energy consumption in Nigeria has dropped from about 19.106 mtoe in 2003 to about 11.387 mtoe in 2007. Owing to population growth, the decline in per capita energy consumption is even more glaring; 0.151 toe/capita in 2003 to 0.079 toe/capita in 2007. The world average as at 2007 was 1.78 toe/capita and the average for Africa is 0.68 toe/capita. The per capita electricity consumption in Nigeria which stood at about 136 kWh/capita (2007) is similarly low compared to figures for other countries [South Africa (4848 kWh/capita); Gabon (932 kWh/capita); Ghana (271 kWh/capita)]. In fact Nigeria's electricity consumption is about 4 times less than the African average and about 19 times less than the world average.

This paper looks at the potential of generating electricity from waste generated in Nigeria. With dwindling power generation and rising waste generation quantum in Nigeria, the prospects of generating electricity from waste is certainly worth considering.Wastes to energy plants currently have an electric efficiency of between 14 – 28% based on the intrinsic energy of the waste. Igoni et al. reported that the energy content of waste could be fairly represented by equation 4.

$$E = 0.051[F + 3.6(CP)] + 0.352(PLR) \quad (4)$$

Where: E is the energy content of the waste in MJ/kg

F is the fraction of Food/garbage in the waste (%)

CP is the fraction of Cardboard and Paper in the waste (%)

PLR is the fraction of Plastics in the waste (%)

Methodology:

Located in the West African sub-region, Nigeria lies between longitudes 2^O and15^O East and latitudes 4^O and 14^ONorth. It encompasses a total land area of 910,768 km^2 and comprises 36 states and a Federal Capital Territory, which are further partitioned into 774 local government areas. With an estimated population of 158 million, Nigeria is by far the most populous African country. The climate varies from equatorial in the south to tropical in the centre to arid sahel in the extreme north [7,23].

2.1 Estimating waste generation in 2011:

Equation 1 was used to estimate the amount of waste generated in Nigeria in 2011. From the foregoing literature survey, an average waste generation rate of 0.5 kg/person/day is assumed for the purpose of this work. A 2011 estimate of Nigeria's population was pegged at about 158 million based on the 2006 census figures of about 140 million and a growth rate of approximately 2.5% [23].

2.2 Estimating future quantity of waste:

The procedure used by EUROPEAN COMMISSION(2003) was adopted. Hence equations 2 and 3 were simply substituted in to equation 1 to forecast future waste generation in Nigeria. The estimations were carried out up to the year 2020, due to its significance as the year Nigeria hopes to realize her vision of becoming one of the top 20 economies in the world. The following assumptions were made for per capita waste generation G_R and population P:

a) P: Nigeria's population as at 2006 was about 140 million and is growing at annual rate of about 2.5% .Equation 2 was then used to make population forecasts.

b) G_R : Considering the Nigerian GDP per capita growth rate to be about 6.0%[23] and comparing this value to the figures given in Table 1, a reasonable approximation for G_R growth rate appears to be about 0.8 – 1.2%. Two scenarios were thus explored: low hypothesis with G_R growth rate of 0.8% and high hypothesis with G_R growth rate of 1.2%. Equation 3 was used to forecast G_R based on the two scenarios.

2.3 Estimating the quantity of recoverable energy from waste in the future:

Equation 4 was adopted for the estimation of the average energy content of Nigerian waste. Although a variation in the Nigerian waste composition is naturally expected with time, however, the change within the study period (i.e. 2012 – 2020) is unlikely to be significant enough to invalidate the results of forecasts made with the present waste profile. Hoornweg [9], for instance estimated only slight variations in waste composition for middle income countries in Asia. Thus the forecasts for recoverable energy from waste were carried out with the waste profile given in Fig. 1. Improvements in the waste-to-electricity technology are likely to increase the efficiency, for practical purposes however, 25% efficiency was used over the whole study period.

RESULTS AND DISCUSSION

By substituting the population and G_R figures of 2011 in Equation 1, the approximate quantity of waste generated in Nigeria was found to be about 29 million tons. Although both per capita waste generation rate and population have increased since 2006, the quantity reported by CPE [5] i.e. 18 million tons, still appears to be a bit pessimistic compared to the estimate made in this paper (29 million in 2011). The figure reported by Ossai i.e. 50 million tons,stands out as highly optimistic when compared with both the quantity reported by CPE and the estimate made here. The quantity reported by Ogwueleka [15] i.e. 25 million tons, however, almost matches with the estimate made herein when extrapolated to the year 2011.

Population is expected to increase by about 25% while per capita waste generation rate is envisaged to rise by about 8 – 12% within the time frame considered for the study (Table 1).This contrastswith the report by Kaushal et al. (2012) where increase in per capita waste generation is expected to outpace the population growth rate in most of India's big cities.The combined effect of these two indicators is a gradual increase in the waste generation quantum in Nigeria from 29 million tons estimated in 2011 to about 40 million tons expected in 2020.The results of this investigation show that collection and proper disposal of waste are critical issues that need to be addressed from now to 2020 and indeed beyond.

Table 2: Estimates of future waste generation figures.

Year	Projected population (million)	Rate of waste generation (kg/person/day)		Overall quantity of waste generated (million ton/annum)	
		Low (0.8%)	High (1.2%)	Low (0.8%)	High (1.2%)
2011	158	0.50	0.50	28.84	28.84
2012	162	0.50	0.51	29.79	29.91
2013	166	0.51	0.51	30.78	31.03
2014	170	0.51	0.52	31.80	32.18
2015	174	0.52	0.52	32.86	33.38
2016	179	0.52	0.53	33.95	34.63
2017	183	0.52	0.54	35.08	35.92
2018	188	0.53	0.54	36.24	37.26
2019	193	0.53	0.55	37.45	38.65
2020	197	0.54	0.56	38.69	40.09

Table 2 illustrates the estimates for the energy that could be derived from waste within the time frame considered, assuming complete collection of waste and state of the art incineration for electricity production. By

applying Equation 4 to the Nigerian waste profile, the average calorific value of the waste mix was found to be about 9.6 MJ/kg. This is only about three times lower than the heating value of coal, which stands at about 25 – 33 MJ/kg (depending on the type of coal). The implication of this is that enormous amount of energy is locked in the wastes that currently dot our cities in an obnoxious manner. Unlike coal whose location is limited however, solid wastes could be found everywhere.

Table 3: Estimates of the energy value of waste.

Year	Projected population (million)	Recoverable Energy from waste (mtoe/annum)*		Electricity generation from waste(MW ofelectricity)	
		Low (0.8%)	High (1.2%)	Low (0.8%)	High (1.2%)
2011	158	6.602	6.602	2191	2191
2012	162	6.821	6.848	2264	2273
2013	166	7.047	7.103	2339	2357
2014	170	7.281	7.368	2416	2445
2015	174	7.523	7.643	2497	2536
2016	179	7.773	7.928	2579	2631
2017	183	8.031	8.224	2665	2729
2018	188	8.298	8.531	2754	2831
2019	193	8.573	8.849	2845	2937
2020	197	8.858	9.179	2939	3046

*mtoe: Million tons of oil equivalent

The table shows that with proper collection and state of the art incineration, a significant amount of electricity could be obtained from Nigerian waste. The Nigerian government plans to increase electricity generation, transmission and distribution from the 3700 MW capacity as at the end of 2009 to 35000 MW by 2020 [22]. The estimates made herein show that waste incineration for electricity production could supply a significant proportion of the energy needs in Nigeria in the near future, to a large extent, and augment the optimistic plan of generating sufficient power for the citizens by 2020.

Conclusion:

Reliable estimates of past and present data on waste generation in Nigeria are difficult to come by. Projections of such figures are hardly available in the open literature. An attempt was made in this paper to forecast Nigeria's waste quantum generation up to the year 2020 by linking it with the two fundamental parameters affecting waste generation: Population and GDP per capita growth rates.Population increase is expected to be the main drive for the gradual increase in waste generation up to the year 2020. The model employed predicts that Nigeria's annual waste generation volume will surge up from the present 29 million tons (in 2011) to about 40 million tons (in 2020).

Out of the different methods available for waste management, composting and controlled incineration to produce power/heat are more suitable for Nigeria as power problems still linger in the country.

The average calorific value of Nigerian waste was estimated to be about 9.6 MJ/kg based on the waste profile obtained. If all the waste generated could be successfully collected and incinerated in a modern waste-to-energy facility, as much as about 2300 MW of electricity could be obtained in 2012. This figure could rise to more than 3000 MW of electricity by the year 2020. This will certainly augmentthe power problem in the country. Of course both figures are a bit optimistic owing to the inherent inefficiencies in collection and transportation of waste.

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