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Technical and Economic Analysis of Energy Recovery from Municipal Solid Waste in Yola Metropolis, Adamawa State, Nigeria

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ABSTRACT

There has been an increase in the general spending and consumption habit of people, the consequence of which is an increase in the quantity of municipal solid wastes (MSW) being generated particularly in urban areas. Yola, the capital of Adamawa State in the north-east region of Nigeria being an urban area also has its share of problems associated with solid waste management. In addition, the city like most other cities in Nigeria experiences inadequate electricity supply. Hence the need for this research - to assess the technical and economic potentials of recovering energy from the MSW generated in Yola using incineration as the technology of choice. The American Society for Testing and Materials (ASTM) method (ASTM D5231) was used to sample and characterise the waste disposed of in the city's dumpsites. It was found that the average calorific value of the MSW disposed of in the city's dumpsite is 1,515.67 kcal/kg. It was also found that if incineration is used as the preferred waste-to-energy technology, a total of 3,748.60 kW of electrical energy could be recovered from the three dumpsites studied. The economic analysis conducted showed that energy recovery via incineration has an average internal rate of return (IRR) of 252%. The following conclusions were drawn from the results obtained: The quantity and composition of MSW disposed of at dumpsites in Yola are suitable for energy generation via incineration; from an economic perspective, incineration of MSW is a viable waste-to-energy technology for Yola.

Keywords:
Calorific value; Electricity, Incineration; Municipal solid waste; Waste to energy; Nigeria

INTRODUCTION

Waste is an integral part of human existence, the rate of generation of these wastes produced by our daily activities centred around our homes, places of work and other public spaces has been on the rise globally as a result of the increase in global population and average household income [1]. Municipal solid waste (MSW) which can be defined as waste collected by the municipality or disposed of at the municipal waste disposal site and includes residential, industrial, institutional, commercial, municipal, and construction and demolition waste [2] has been a major burden to the finances of municipal authorities, especially in developing countries where such finances are very lean – almost non-existent [3]. Nigeria being a developing country has its share of municipal solid waste management woes. In almost every city in the country, the poor state of solid waste management is evident in the number of drainages clogged by waste and streets littered with waste.

Recovery of energy from MSW also known as waste-to-energy (WTE) is not an entirely new phenomenon, the first incinerator was developed and patented in 1874 by Albert Fryer [4]. Ever since humans have been burning waste and utilising the heat given off as energy sources. WTE technologies are based on two fundamental processes: thermochemical reaction (incineration, pyrolysis, and gasification) and biochemical reaction [5]. These processes recover energy from waste either by direct combustion of wastes or by processing wastes into combustible fuels. For thermochemical energy recovery processes, heat is used to disintegrate the waste to release its inherent energy. There are several types of thermal conversion methods, the most popular types include incineration, pyrolysis, gasification and plasma gasification. For biochemical processes, these technologies convert waste to energy by using microorganisms to break down solid waste, anaerobic digestion being the most popular biochemical technology.

Even though there are several methods of recovering energy from MSW, incineration has been found to be the most efficient and cost-effective method [6], especially for unsegregated wastes which happen to be the type of MSW disposed of at landfills and dumpsites in developing countries [7].

There is quite a large body of work that has been undertaken on waste to energy both locally and internationally. In the Pakistani city of Hyderabad, a study was intending to estimate the potential for power generation from MSW [8]. The study was necessitated due to the shortage in electricity supply in the state and the country at large. Samples were collected following the ASTM standard. The researchers found out that the city has a per capita waste generation rate of about 0.7kg/day and about 1,600 tonnes of MSW were being disposed of in dumpsites. The calorific value of the MSW generated in the city was determined by experimentation using a bomb calorimeter, it was found that the MSW has a net calorific value of 6,519 kcal/kg. The study was able to determine the estimated power generation potential of the city's MSW to be 1,512 kWh per tonne of MSW. The authors' conclusion based on the findings of the study was that the MSW generated in Hyderabad city is suitable for electricity generation. They recommended mass-burn as the most appropriate WTE technology for the city.

In Ilorin the capital of Kwara State – one of the 36 states in Nigeria, a study was conducted to characterize the dry season MSW generated in the city and determine the amount of energy that can be generated from it [9]. The researcher found that the MSW disposed of at the Eyenkorin dumpsite of Ilorin metropolis has an estimated heating value of 19 MJ/kg and that the dumpsite has the potential to generate 18MW of electrical energy.

Yola, the capital of Adamawa State in the north-eastern part of Nigeria which is an urban area, is not an exception to the twin problems of poor solid waste management (SWM) and the shortage of electricity supply that is generic to most cities in developing economies. The SWM technique practiced in the city involves the collection and transportation of wastes from communal dumpsites by the Waste Management Unit of the state's Ministry of Environment to open dumpsites a few kilometres away from the city centre. The disposed waste is managed by occasionally burning it or just allowing it to decompose, this pollutes the environment and also constitutes a health hazard to the inhabitants of the immediate surrounding communities and the society at large. This kind of SWM technique which is very popular in Nigeria [10], and in other developing countries has been found to lead to increased environmental contamination and risks to public health [11]. However, if properly managed, the MSW which is seen as a nuisance can be utilised in the generation of electricity which can greatly augment the amount of electricity allocated to the city from the national grid while also tackling environmental pollution and health risks posed by the current SWM techniques being practiced. For these reasons, a number of research works have been undertaken in the city. A study was conducted in a section of the city with the aim of determining the suitability of energy recovery from the MSW generated by households [12]. Using ASTM method, the researchers were able to determine that the household waste in the study location had a moisture content of 61.33% and therefore concluded that it was unfit for energy generation. In the same city, another group of researchers undertook a quite similar study with the aim of estimating the potential for energy generation from MSW [13]. The researchers found that MSW in Yola has a calorific value of 118.58 MJ/kg, thus it is suitable for the recovery of energy.

The popular saying "if it is not measurable, it is not manageable" equally applies in this context, the first step in checking the problems of SWM and shortage of electricity supply is by first assessing the situation on the ground i.e. by estimating the quantity and quality of waste generated in the study area, and then determining the amount of electricity that can be generated from it. After reviewing several literature, it was noted that even though some researchers have done studies on solid waste management and a bit of WTE studies in Yola, none of them has been able to quantify the amount of electricity that can be recovered from the waste disposed of in the city's dumpsites neither has any of them estimated the financial implication of a WTE project in the city – hence the novelty of this research which is aimed at determining the amount of electricity that can be recovered from the MSW generated in the state capital while also estimating the financial implications of such project. Incineration was chosen as the preferred technology because it has been proven to be the best technology for the type of waste generated in Yola.

MATERIALS AND METHODS

Study Area

Yola is the capital of Adamawa State is within latitudes 9°11'59''N and longitudes 12°28'59''E and at an altitude of about 192m [13]. The city lies within the Sudan savannah climatic zone which typically experiences dry season for a minimum of five months (November-March), its wet season typically spans between April and October [14].

Like most other urban centres in Nigeria and most other developing countries, the solid waste management sector is still undeveloped. Solid waste management in Yola is still done the traditional way – the collection of unsegregated wastes from collection points residents have disposed of them, evacuation to transfer stations and then evacuation to dumpsites where the wastes are openly dumped. The waste management department under the state's ministry of environment is responsible for SWM in the state. Their roles

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include the evacuation of wastes from collection points to transfer stations and then to dumpsites, the enforcement of waste management laws and the catering for the collection points, transfer stations and dumpsites.

Three dumpsites service the city, these dumpsites are located at the fringes of the city. They are Fombina dumpsite, Sebore dumpsite and Sangare dumpsite. The Fombina dumpsite which is the largest of the three dumpsites is located about 5 km from the city centre off Yola-Mubi Road in a suburb called Fombina (9°18'57.6"N 12°29'34.8"E). It is about 109 hectares large. It is also the proposed site for the establishment of a waste recycling plant. The Sangere dumpsite is located in Sangere, a suburb about 13 km from the city centre off the Yola-Numan Road (9°16'40.8"N 12°19'44.4"E). It is the second-largest site that caters for the solid waste generated in the state capital. It is about 28 hectares and has been in use since 2009. The Sebore dumpsite is the smallest of the three dumpsites, it is about 4.5 hectares and is located along Sebore town (9°08'06.0"N 12°34'19.2"E). In this study, these three dumpsites – Fombina Dumpsite, Sangere Dumpsite and Sebore Dumpsite have been code-named Site 1, Site 2 and Sites 3 respectively.

Data Collection

Secondary data regarding municipal solid waste management techniques being practised in the city, the ages and sizes of dumpsites in the city and quantities of wastes being disposed of in them were obtained from the Solid Waste Management Unit of the state's Ministry of Environment. Primary data regarding the geo-coordinates of the dumpsites were obtained using Google Map mobile apps at the sites. For solid waste samples from the dumpsites, samples were collected at three different times (December 2019, March 2020 and August 2020) to reflect seasonal variations [15]. The ASTM D5231 (Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste) method developed by the American Society for Testing and Materials (ASTM) was used for the collection of waste samples and characterization [16]. Small fractions of each of the categories of the wastes were then placed in different plastic bottles and labelled appropriately for further processing in the laboratory.

Technical Analysis

Proximate analysis of the waste samples collected was done according to the ASTM method [17]. The moisture content of the MSW samples was determined by sun-drying the samples for 24 hours and then placing 0.5 kg on a preweighed dish which thereafter was placed in an oven and the temperature set at 105°C till a constant weight was attained. The moisture content was then calculated thus:

$$\%of\ Moisture\,content = \frac{W_1 - W_2}{W_1} \times 100 \quad (1)$$

Where

W1 = Weight of the solid waste sample before placing it in the oven.

W2 = Weight of the solid waste sample after drying in the oven.

The volatile matter content of the sample was determined by placing 5g of the dried MSW sample in a muffle furnace for 7 minutes at 950°C following ASTM 3175 standard. After complete combustion, it was then cooled in a desiccator and weighed on the digital weighing balance to determine the dry weight of the residual ash. The Volatile matter content was then estimated thus:

$$\%Volatile\,matter = \frac{Dried\ Sample\,weight - Ash\,weigth}{Dried\ Sample\ weight} \times 100 \quad (2)$$

The ash content of the MSW samples was determined by heating the samples in an oven at 750°C according to ASTM 3174 method, the residue remaining which is the ash content was then weighed.

The fixed carbon content of the MSW samples was then estimated thus:

$$\%\text{Fixed Carbon} = 100 - \text{content}\begin{pmatrix}\%\text{ Moisture } + \\ \%\text{ash} + \\ \%\text{volatile matter}\end{pmatrix} \quad (3)$$

The calorific value or lower heating value (LHV) of MSW is the most important parameter for determining its suitability for energy generation [18]. Using a proximate analysis based model – Equation (4) [19], the LHV of the MSW generated in Yola was determined.

$$LHV = 45V - 6W \quad (4)$$

Where

LHV = lower heating value (kcal/kg)

V = Volatile matter content (%)

W = Moisture content (%)

The power that can be generated from the incineration of the MSW disposed of in dumpsites in Yola was estimated using the following Equation (5) [20].

$$E = LHV \times Wt \times \frac{1000}{859.85} \times \eta \quad (5)$$

Where

E= Potential power that can be generated (kW)

LHV = Lower Heating Value (kcal/kg)

Wt = Daily waste disposed of at the dumpsite(s) (tones/day)

η = overall efficiency of conversion for the WTE system = 22% [15]

859.85 = Conversion factor from kcal to kW

Economic Analysis

Two major costs are involved in waste-to-energy projects, first the capital cost, and then operating/maintenance costs. These costs were adopted from literature, freight and customs charges were then added. As stated in literature [21], the capital cost for a WTE incineration plant is \$14.5/tonne while its operational cost is \$1.5/tonne. For this study, a freight and customs duty charge of 5% was added to the capital cost bringing it to \$15.225/tonne. Factoring in maintenance time, it is assumed that the incineration plant produces at 90% of its capacity.

It was assumed that the only revenue from this project will come from the sales of electricity. For this, the current Multiyear Tariff Order of the Nigerian Electricity Regulatory Commission was used. Two economic parameters were used to determine the profitability or otherwise of the project. These are Net Present Value (NPV) and Internal Rate of Return (IRR). The NPV is calculated by taking the difference between the present values of cash inflows to the present value of cash outflows – Equation (6) [22]. The IRR is the discount rate that makes the NPV zero and it is calculated using Equation (7) [22].

$$NPV = \sum_{n=1}^{N} \frac{B - C}{(1+r)^n} \tag{6}$$

Where

B = Benefit; C = Cost; r = discount rate; n = period; N = Total periods

$$IRR = \sum_{n=1}^{N} \left(\frac{B}{(1+r)^n} \right) = \sum_{n=1}^{N} \left(\frac{c}{(1+r)^n} \right) \tag{7}$$

The following economic factors were used:

i. Monetary Policy Rate (discount rate) = 13%

ii. Cost of Unit of Electricity per kWh = USD 0.1143

RESULTS AND DISCUSSION

Technical Analysis

Quantities and compositions of MSW disposed of at dumpsites in Yola

The Waste Management Unit of the state's Ministry of Environment had not been keeping records of the quantities of waste disposed of in dumpsites until the year 2009. Therefore, records of wastes disposed of in these sites being studied before 2009 are not captured in this study. The quantities of wastes disposed of at these three dumpsites as obtained from records of the ministry of the environment are presented in Table 1.

The estimated average daily, monthly, and annual quantities of wastes disposed of in these three sites and the average composition of the MSW at each site are presented in Tables 2 and 3 respectively.

Table 1. Quantities of waste disposed of at dumpsites

Year	Site 1 (Tonnes)	Site 2 (Tonnes)	Site 3 (Tonnes)
2009	27,871	-	
2010	28,708	-	
2011	29,569	-	
2012	30,456	23,529	20,881
2013	31,370	24,470	21,612
2014	32,311	25,449	22,368
2015	33,280	26,467	23,151
2016	34,278	27,526	23,961
2017	35,307	28,627	24,800
2018	36,366	29,772	25,668
2019	37,457	30,963	26,566
2020	38,581	32,203	27,497

Table 2. Average quantities of waste disposed of at dumpsites

Dumpsite	Average Waste Disposal (Tonnes)		
	Daily	Monthly	Annual
Site 1	90.31	2,709.31	32,963
Site 2	75.80	2,274.08	27,667
Site 3	65.91	1,977.25	24,057

Table 3. Composition of solid waste

Category	%Weight Composition		
	Site 1	Site 2	Site 3
Plastics	24	28	30
Papers/Cardboards	15	10	13
Garden/Agric. Wastes	14	15	18
Food Wastes	12	12	9
Metals	1	1	1
Glass	4	3	2
Textiles	10	8	7
Inert Materials	20	23	20

Records obtained from the waste management unit of the state's Ministry of Environment show that Site 1 was opened in the year 2005 and is the oldest active dumpsite in the city. However, as has been stated earlier, records regarding the quantities of wastes disposed of at the site were not being kept until the year 2009. From the record obtained, it shows that at the end of the year 2009, 27,871 tonnes of MSW were disposed of at the site. Records obtained also showed that Sites 2 and 3 were commissioned in the same year and by the end of the year, about 23,529 and 20,881 tonnes of MSW respectively were disposed of at the sites. The data obtained showed a steady increase in the quantities of wastes accepted at the dumpsites from their inception till date, it can be deduced that this increase is due to the steady rise in the population of the city. By the end of the year 2020, the yearly average waste acceptance for Sites 1, 2, and 3 were found to be 32,963 tonnes, 27,6668 tonnes, and 24,056 tonnes respectively. While the total amount of waste accepted into each of the sites for the period of their existence is 395,559 tonnes, 249,011 tonnes, and 216,509 tonnes respectively.

In all three sites, it was found that plastics had the highest composition by weight, this is not unsurprising given the high usage of plastics in the day-to-day lives of the people in Yola and extension – Nigeria, this is corroborated by studies done in the same city by other researchers [23]. The next category of waste that was found to be prominent in the MSW generated in Yola after plastics is inert materials. Given that Yola lies in the semi-arid zone of Nigeria, it is expected to be characterised by dry weather and occasional sand storms, therefore, its MSW composition having high inert materials (sand and stones) content can be considered normal. For food waste, the values obtained are low compared to studies undertaken in other parts of the world, particularly countries with more developed economies. Researchers have postulated that the quantity of food waste in MSW is usually a reflection of the economy of that location [24], therefore, it is normal that the food waste in Yola ranges between just 9 – 12%.

Proximate Analysis, Calorific Value, and Potential Power Generation Capacity

The results of the proximate analysis performed on the MSW samples collected from the dumpsites in Yola are presented in Table 4.

Table 4. Proximate analysis of solid waste samples

Parameter	Site 1	Site 2	Site 3
Moisture Content (%)	23.00	26.00	23.67
Volatile Matter Content (%)	37.23	36.00	37.50
Ash Content (%)	34.27	31.50	30.33
Fixed Carbon Content (%)	5.50	6.50	8.50

As can be seen from the data presented in Table 4, the results of the proximate analyses for the three sites are close with the widest standard deviation being 2.02. This is because the composition of the MSW for the three sites are quite similar and this similarity in the composition is because of the following obvious reasons as regards the population that generates these wastes that are disposed of at the dumpsites: same climate; similar socio-economic characteristics; similar spending habit and similar culture.

It has been found that when the moisture content of MSW is less than 45%, its volatile matter content is around 40% and the fixed carbon content is less than 15%, it is suitable for energy recovery via incineration [25]. This means that the result of the proximate analysis conducted shows that the MSW disposed of in the dumpsites in Yola are suitable for energy recovery using incineration.

The calorific values (lower heating value) of the solid waste disposed of in each of the three dumpsites in Yola are presented in Table 5.

Table 5. Calorific values of MSW disposed of in dumpsites in Yola

Site 1 (kcal/kg)	Site 2 (kcal/kg)	Site 3 (kcal/kg)
4,044.30	4,136.10	4,407.48
878.92	1,003.71	959.12
1,537.50	1,464.00	1,545.50

The power and electricity that can be generated from the incineration of the MSW disposed of in dumpsites in Yola are presented in Table 6.

Table 6. Power and electricity generation potentials of the dumpsites in Yola

Dumpsite	Power (kW)	Electricity (kWh/day)	Electricity (kWh/ tonne)	Annual Electricity (kWh)
Site 1	1,480.01	35,520.18	393.31	12,964,866.85
Site 2	1,182.83	28,387.98	374.51	10,361,613.21
Site 3	1,085.76	26,058.21	395.36	9,511,246.01

The calorific value for the three sites was found to range between 1,464 kcal/kg (6,125.376 kJ/kg) to 1,545.5 kcal/kg (6,466.372 kJ/kg). This meets the minimum requirements for the recovery of energy from MSW by thermochemical means – 6 MJ/kg [26]. A comparison of the calorific value of the MSW generated in Yola to those of MSW generated in other state capitals in the northeast region of Nigeria as found in literature [18], [27–29] shows that that of Yola is higher than all but one (See Fig. 1).

As can be seen from Figure 1, the calorific value of the MSW generated in the region varies just slightly except for Gombe. It can be speculated that the similarity in the calorific value is because the economy, culture, and climate of the states in the region are largely similar therefore their consumption pattern and consequently waste composition and generation capacity are largely similar. The reason for the large variation in the LHV of the MSW of Gombe can however not be speculated.

It was also found that each of the sites could generate a minimum of 26,058.21 kWh of electricity each day. Cumulatively, the three sites have the potential of generating

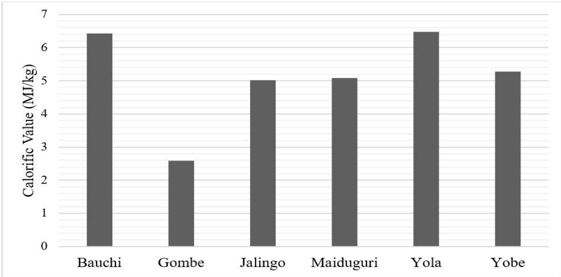

Figure 1. Comparison of Calorific Values of MSW in State Capitals of northeast Nigeria.

89,966.37 kWh of electricity daily and 32,837,726.07 kWh of electricity yearly. Using the average household size of Yola to be 7 persons [30], and the annual per capita electricity consumption of the region to be 48 kWh [31], it can be estimated that the potential amount of electricity that can be recovered from the three sites by thermochemical means can power 38,586, 30,838 and 28,307 households respectively in an ideal case assuming no losses occur.

Economic Analysis

The Net Present Value (NPV) and Internal Rate of Return (IRR) for the generation of electricity by incineration of MSW for ten years were estimated and the results obtained are presented in Table 7.

Table 7. Economic parameters for electricity generation via incineration

SITE	Capital Cost (US $)	Operational Cost (US $)	Revenue from Electricity Sales (US $)	NPV (US $)	IRR (%)
Site 1	*501,861.68*	*49,444.50*	*1,333,695.85*	*6,466,798.83*	*256*
Site 2	*421,230.08*	*41,500.50*	*1,065,899.15*	*5,137,406.41*	*243*
Site 3	*366,261.58*	*36,084.89*	*978,421.88*	*4,747,088.36*	*257*

The economic analysis shows that the estimated capital cost for energy recovery from the incineration of the MSW disposed of in the three dumpsites studied is USD 501,861.68, USD 421,230.08, and USD 366,261.58 respectively.

For potential revenue from the sales of electricity generated from incineration of MSW, if the electricity is sold at the current tariff rate charged by Yola Electricity Distribution Company (YEDC) – Ξ 46.88 (0.1143 USD) per kWh, then an annual gross revenue flow of USD 3,378,016.88 for the three sites is attainable. Factoring in the operational costs, the net annual revenue for the three sites becomes USD 3,250,987. Comparing the unit price of electricity obtained in this study to those of other studies in the country: USD 0.017/kWh in Lagos and USD 0.04/kWh in Nsukka [32]; USD 0.163/kWh in Kano [15], it can be seen that though the tariff rate for Yola is a bit higher because of the increase in electricity tariff rate in the country, the venture is still profitable. To further adjudge its profitability, its NPV and IRR were estimated. It was found that the NPV for the three sites are USD 6,466,798.83; USD 5,137,406.41 and USD 4,747,088.36 respectively. Since the NPV for all three sites is positive, and their respective IRR for 10 years are 256%, 243%, and 257% then it can be said that the economics of recovery of energy from the wastes disposed of in dumpsites in Yola looks good.

CONCLUSION

Techno-economic analysis of energy recovery from municipal solid waste in Yola metropolis was undertaken in this research, incineration was chosen as the preferred WTE technology based on the composition and qualities of the MSW generated in the city.

At the end of this study, the following tentative conclusions were reached based on technical and economic facts unravelled, also, these findings are novel in respect to energy recovery from the MSW generated in the study location –Yola.

i. The quantity and composition of MSW are key to determining if the MSW generated in any particular location is suitable for energy recovery. The study found that the quantity and composition of MSW disposed of at dumpsites in Yola are suitable for energy generation.

ii. Even though other researchers had determined that the MSW generated in Yola is suitable for energy recovery, none had quantified the energy that can be recovered, this research fills that void and has found that on an annual basis, about 32,837,726.07 kWh of electricity can be recovered from the waste disposed of in the city's dumpsites.

iii. None of the studies undertaken in the city has been able to state the most suitable waste to energy technology for the city, this research fills that void as it found out from an economic perspective and based on the composition of the waste generated in the city that incineration of MSW is the viable WTE technology for Yola.

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CONFLICT OF INTEREST

Authors approve that to the best of their knowledge, there is not any conflict of interest or common interest with an institution/organization or a person that may affect the review process of the paper.

AUTHOR CONTRIBUTION

All the work in this study were performed equally by the authors.

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