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Techno-Economic Assessment of Municipal Solid Waste as Fuel for Electricity Generation in Awka City

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Abstract – **This study investigated the Municipal Solid Waste (MSW) at Ring Road, Dump Site, Agu-Awka, Awka South L.G.A. of Anambra State, Nigeria as a potential source of energy for use in electricity generation in Awka Municipality. Samples of wastes randomly collected from the dump site, combined with data obtained from the Anambra State Solid Waste Management Authority (ASWAMA) were analyzed using bomb calorimeter. Results obtained show that the solid wastes at the dumpsite has an average calorific value of 26.675 MJ/kg, with average water content of 15.4%; on the basis of about 300 tonnes of MSW/day capacity incineration plan, about 1.58 GWh of electricity energy could be generated from the wastes and with gasification plan, about 0.75 GWh could be generated. Net Present Value (NPV) and Levelized Cost of Electricity (LCOE) financial indicators were employed to determine which thermal technique would be the best for a short-term or long term project option for MSW-to-electrical energy generation in the said Municipality with regards to break even and cost. Results showed that the levelized cost of electricity generation in the MSW incineration plant is higher in comparison with gasification plant. Results from the NPV analysis show that using gasification (Scenario C) would be the best for short-term project, having shortest break-even period of 6 years at 6% rate; while Incinerating all the wastes as fuel (Scenario A) would be the best for long-term project, yielding higher revenue after 10 years, especially at 6% rate. More so, scenario A had the least levelized cost of energy followed by scenario C while scenario B (using all except metal and glass with incineration) had the highest. These results could help in making economic decisions on which method of energy recovery to be utilized under given obtainable conditions.**

Keywords – **Municipal Solid Waste, Electricity Generation, Calorific Value, Net Present Value, Levelized Cost of Electricity.**

I. INTRODUCTION

Anambra state is situated in the south-eastern part of Nigeria. In 2011, its population was estimated at 4,805,600 with a density of 992.1 people/ km^2. Its capital city, Awka, concentrates about 3.5% of this population. Awka also concentrates most of the state's economic resources as most of the business transactions (services, industries, and commerce) take place in the city. Presently, most of the municipal solid waste (MSW) generated in Nigerian cities, including Awka, are dumped into borough pits while some are disposed along road sides, causing threat to health of the citizens. MSW comprises of combined domestic, commercial and industrial waste generated in a given municipality or locality (Fobil and et al, 2005; Kothari et al., 2010). Waste generation rates are affected by socio-economic development, degree of industrialization, and climate. In advanced nations of the world, MSW are also used as fuel in generating electricity for local consumption. In Nigeria, electricity is generated mostly at the central power stations using fossil fuel or by hydro means (Fadare, 2010). However, the available local infrastructure for electricity generation is insufficient and is only available in the urban areas and suffers from frequent interruptions and breakdowns. Only a small percentage of the population benefits from the national grid leading to massive and outrageous use of petrol and diesel generators by the citizenry. It was reported that due to acute and interrupted power supply in the country, about 60 million Nigerians own generators for electricity and spend a staggering N1.56 trillion to fuel them annually (Aboyade, 2004; Sanusi, 2010). As at the time of writing this report, the price of electricity consumption in Nigeria was N34.3 ($ 0.1) per kWh.

Design of a process for the management of MSW and the resultant economic evaluation and development of a viable business plan require good knowledge of the properties of MSW. The two main properties of MSW are the quantity and quality (physico-chemical characteristics) of the waste (Gary, 2010). It is also necessary to determine the rate at which wastes are generated at various refuse points and the quantity generated in an area in order to establish sufficiency or otherwise of sustaining a WTE plant in the area. In view of the aforesaid shortfalls in electricity generation in Nigeria, this research presents MSW, which for long has been overlooked, as another source of energy generation in Awka City, Anambra State based on its comparative economic evaluation. The latent energy present in the organic fraction of MSW can be recovered for gainful utilization (conversion to electrical energy) through adoption of suitable waste processing and treatment technologies.

II. Materials and Methods

Data used in the study were obtained mainly from the Anambra State Waste Management Agency (ASWAMA) on waste generation rate in Awka Municipality and its evacuation rate at Ring Road final dumpsite, Agu-Awka and the percentage composition of the MSW for the base period was estimated by random sampling of the waste collected at the dumpsite. Calorific values of the waste components were obtained by bomb calorimeter experiment. Equations (12) and (13) as presented by Catarina (2014) were applied in evaluating the potential energy from the MSW. Meanwhile, the municipal solid waste-to-energy thermal conversion pathways considered are discussed below.

2.1. *Incineration*

Combustion or incineration consists of burning the whole mass of waste in an incinerator. It is the process of direct burning of wastes in the presence of excess air (oxygen) at temperatures of about 800^0C and above, liberating heat energy, inert gases and ash (Gary, 2010). The heat is then used to boil water in a boiler, which can be used for driving steam turbines to generate electricity. Incineration of MSW can drastically reduce the volume of MSW by up to 80% to 90% and its weight by 75% (Tanigaki et al, 2012). There are various types of incinerators. All involve direct combustion of residual waste in the presence of oxygen to produce energy. Any non-combustible materials (e.g. metals, glass, stones) remain as a solid, known as Incinerator Bottom Ash (IBA) that always contains a small amount of residual carbon (Catarina, 2014). Energy from waste incinerators can be of variable sizes – the smallest operating plant in the UK treats about 25,000 tons per annum and the largest about 600,000 tons per annum (Catarina, 2014). They tend to have efficiencies in the range 18% to 27% when generating electricity only. The size of the facility is dependent on a number of factors including: cost, waste catchment area, distance from wider waste sources and site constraints. An incineration plant flow diagram is shown in Figure 1.

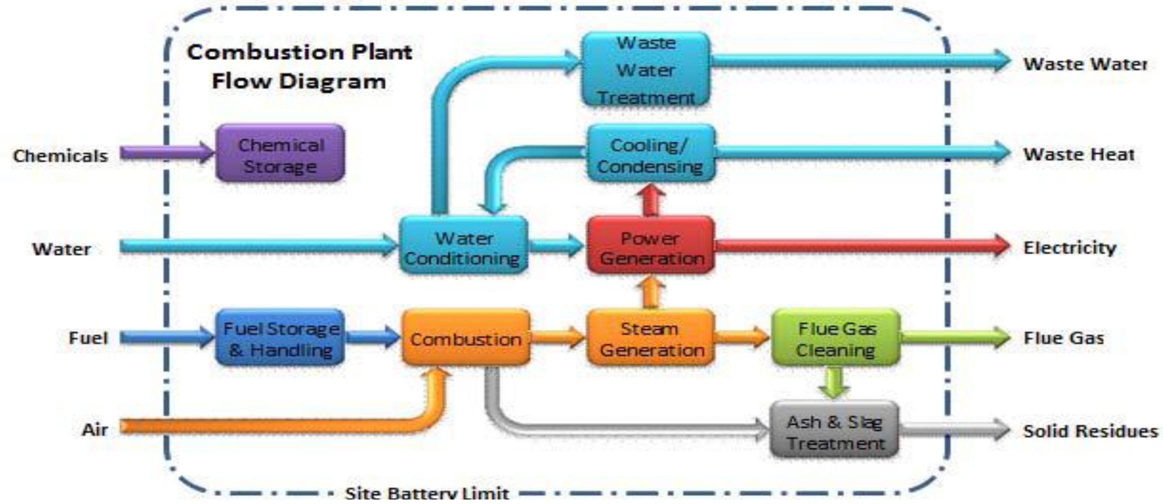

Fig. 1. Incineration plant flow diagram (Otto Simon Ltd) (Catarina, 2014).

2.2 *Gasification*

Gasification involves thermal decomposition of organic matter at high temperatures in presence of limited amounts of air/oxygen, producing mainly a mixture of combustible and non-combustible gas vis: carbon Monoxide, Hydrogen and Carbon Dioxide. The process, depicted in Figure 2, consists of heating the feed material in a vessel with partial addition of oxygen or air. Water might or might not be added.

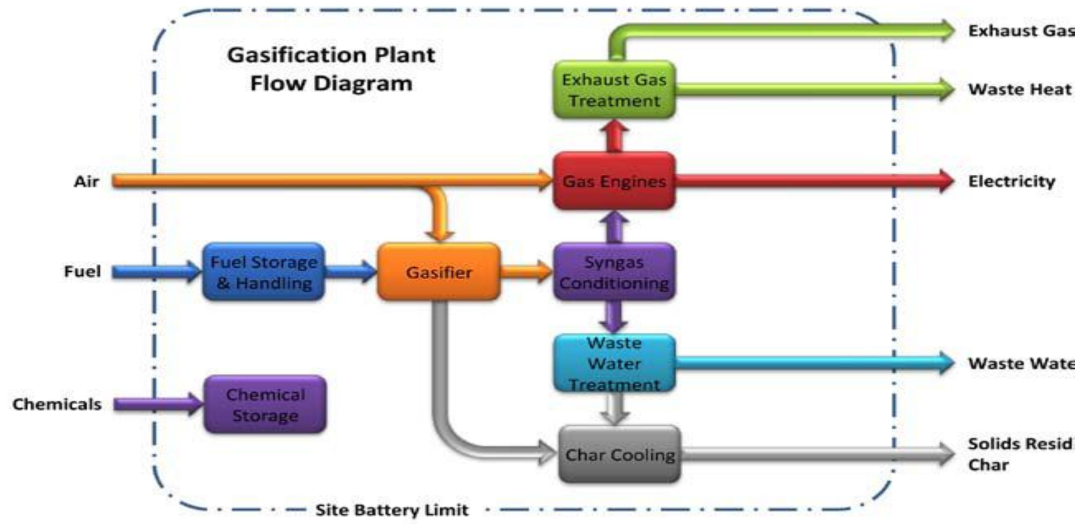

Fig. 2. Gasification plant flow diagram (Otto Simon Ltd) (Catarina, 2014).

According to Mazhar, (2013), some basic chemical reactions in the gasification process were:

$$C + O_2 \longrightarrow CO_2;\ +393 \text{ kJ/mol} \quad (1)$$

$$C + 1/2O_2 \longrightarrow CO;\ +110 \text{ kJ/mol} \quad (2)$$

$$C + CO_2 \longrightarrow 2CO;\ -173 \text{ kJ/mol} \quad (3)$$

$$C + H_2O \longrightarrow CO + H_2;\ -132 \text{ kJ/mol} \quad (4)$$

$$CH_4 + H_2O \longrightarrow CO + 3H_2;\ -206 \text{ kJ/mol} \quad (5)$$

$$CH_4 + 2H_2O \longrightarrow CO_2 + 4H_2;\ -165\ \text{kJ/mol} \tag{6}$$

The combustion reactions (exothermic reactions) are controlled so as to supply sufficient heat for the predominantly syngas reactions (endothermic reactions), yielding a temperature typically between 1,450 and 3,000^o F. It also has the same disadvantage as pyrolysis.

2.3. *Economic Indicators for Revenue Generation*

Net present value (NPV), internal rate of return (IRR) and levelized cost of electricity (LCOE) with payback period were used as economic indicators in the scenario analysis and involved an estimation of the potential energy from the available MSW through various thermal technologies, including the revenue it could generate through the sale of electricity. Also considered in the three different scenarios were the capital investment costs, operating costs and maintenance costs involved in the waste management as postulated by Smedberg (2009). The investment cost can be estimated from of the cost of number of metric tons per year or day of the plant, thus:

$$I = 2.3507 \times C^{0.7753} \tag{7}$$

Where I is the investment cost in million dollars and C is the plant capacity.

The operating and maintenance costs consist of: fixed operating costs, variable operating costs and maintenance costs. The fixed operating cost includes cost of administration and salaries and can be estimated at 2 percent of the total investment; the variable operating cost refers to the sum of cost of chemicals for flue gas cleaning system, cost of water and handling of waste water and cost of residue disposal. The overall variable operating costs as given by Farzad and Haghi, (2015) is estimated at US$17 per metric ton of waste incinerated. The annual maintenance costs are estimated at 1 percent of the investment for the civil works plus 2.5 percent of the investment for the machinery. (Smedberg, 2009) The operating and maintenance cost can be estimated using the following formula:

$$A = 0.0744 \times C^{0.8594} \tag{8}$$

Where A is the annual operating and maintenance cost in million dollars per year and C is the plant capacity.

2.3.1 *Net Present Value, NPV*

This is an indicator of how much value an investment or project adds to the firm, and while taking inflation and returns into account, compares the present value of money today to the present value of money in the future. In financial theory, if there is a choice between two mutually exclusive alternatives, the one yielding the higher NPV should be selected (Boyle, 2004). NPV can be calculated thus:

$$NPV = I_o + \frac{I_1}{1+r} + \frac{I_2}{(1+r)^2} + \dots + \frac{I_n}{(1+r)^n} \tag{9}$$

Where: I = income amount for a specific year; 0, 1, n = number of years (I_0 is negative for investment costs); r = discount rate. Discount rates of 6%-15% for economic evaluation of renewable energy projects using the financial indicators are recommended.

2.3.2 *Levelized Cost of Electricity, LCOE*

This is a measure of lifetime costs divided by energy production. It calculates present value of the total cost of building and operating a power plant over an assumed lifetime. It allows the comparison of different technologies (e.g., wind, solar, natural gas) of unequal life spans, project size, different capital cost, risk, return, and capacities. It is critical to making an informed decision to proceed with development of a facility, community or commercial-scale project. Smedberg (2009) presented the LCOE as:

$$\text{LCOE} = \frac{\sum_{t=1}^{n} \frac{I_t + F_t + E_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \quad (10)$$

Where I_t is investment cost in year t, M_t is operation and maintenance cost in year t, F_t is fuel cost in year t, E_t is electricity generated in year t, r is discount rate and n is plant life.The equivalent energy of a system can be defined mathematically as:

$$\text{Equivalent Energy} = \text{Balance Energy (CV)} \times \text{Total Waste Quantity (W)} \times \text{Conv. Factor} \quad (11)$$

$$\text{Total available energy} = \text{Equivalent energy} \times \text{efficiency} \quad (12)$$

The calorific value was calculated, thus:

$$\text{Energy content} = \frac{E\Delta T - 2.3L - V}{g} \text{ (KJ/Kg)} \quad (13)$$

WhereE = energy equivalent of the calorimeter, ΔT = temperature rise, L = length of burnt wire, V = titration volume, g = weight of sample.

III. Results and Discussion

Waste collection in Awka Municipality and its disposal at the Agu-Awka final dumpsite, Awka South L.G.A. involved three major categories of ASWAMA vehicles: compactor, chain-up and Truck. Wastes generated in various parts of Awka were collected on daily basis by waste disposal vehicles and sent to the dumpsite. Category of vehicles and number of delivery trips made in a day were recorded by ASWAMA personnel stationed at the site.

Table 1. Average Waste Generated at Ring-Road Dumpsite, Awka (Ton/Yr).

S/N	Equipment	Waste Capacity (Kg)	Total Number of Trips	Average Waste Quantity (Kg)	Average Wastes Quantity (Ton)
1	Innoson Compactor	10,330	3585.75	37,040,797.5	37,040.6
2	Iveco Compactor	13,500	771	10,408,500	10,408.5
3	Benz Compactor	13,000	740.5	9,626,500	9,626.5
4	MAN Compactor	12,300	41	504,300	504.3
5	Innoson Chain up	1,476	1,855	2,737,980	2,738.0
6	911 Truck	8,000	433.5	3,468,000	3,468.0
	TOTAL			63,786,077.5	63,785.9

3.1 *Composition of Awka MSW*

A portion of the waste collected as sample and separated according to the nature of the constituting materials, categorized and weighed. The percentage composition of the waste were determined and recorded in Table 2.

Table 2. Awka MSW Average Percentage Composition.

Composition	Quantity of Wastes (%)
Food and organic wastes	48.5
Plastics & Nylon	10.0
Textiles	5.5
Leather and Rubber	3.0
Wood	12.0
Paper	13.5
Metals	6.5
Glass	1.0

Table 2 shows clearly that Awka MSW contains more quantity of food and organic wastes (48.5%) than other materials, followed by paper (13.5%), wood (12.0%), plastics and nylon (10.0%), and so on.

3.2 *Calorific Value and Energy Recovery from Awka MSW*

The calorific values of the waste components obtained from bomb calorimeter experiment for Awka MSW are shown in Table 3.

Table 3. Calorific values of Awka MSW.

Sample	Calorific Value (KJ/kg)
Mixed MSW	29,213
Paper	28,089
Leather & Rubber	30,786
Wood	30,174
Plastic & Nylon	32,368
Textile	31,775
Food & Organic material	4,323
Average	26.675

From Table 3, it can be seen that Awka MSW consists of materials with high calorific values: Plastics and Nylon has the highest value of 32,368 KJ/kg, followed by textile materials with a value of 31,775 KJ /kg; Food and Organic materials has the least calorific value (4,323 KJ/kg). The values were used to obtain the potential energy from the waste using the following three scenarios.

Scenario A: Using all MSW as Fuel with Incineration

The average value of energy released as contained in Table 3 showed that the value obtained was about 26.675 MJ/Kg. This was the energy contained in MSW in dry basis. In this case, the energy of 1kg MSW is equivalent to energy of 1.15 kg of net MSW. This is because an average moisture content of 15.4% was taken out during the bomb calorimetric experiment and the moisture of 0.15 kg required 1.0142 MJ/Kg to dry MSW. This energy was obtained from 26.675MJ/Kg. The balance of 25.66 MJ/Kg is the energy that one would recover per kg of dry MSW from the MSW energy conversion. For the case study, the total waste generated was about 63,786 tons of waste per year. This is equivalent to energy of: 455 GWh.

Scenario B: Using all except Metal and Glass with Incineration

Table 4. Values of Awka MSW for scenario B.

Sample	Calorific Value (KJ/kg)	Waste Quantity (W)
Paper	28,089	8,611.11
Leather & Rubber	30,786	1,913.58
Wood	30,174	7,654.32
Plastic & Nylon	32,368	6,378.6
Textile	31,775	3,508.23
Food & Organic material	4,323	30,936.21
	Ave: 26.253	Total: 59,002.05

Table 4 showed that the average obtainable value of energy released was about 26.3 MJ/Kg. This was the energy contained in MSW in dry basis. In this case, the energy of 1kg MSW is equivalent to energy of 1.17 kg of net MSW. This is because an average moisture of 16.9% was taken out during bomb calorimetric experiment and the moisture of 0.17 kg required 1.0318 MJ/Kg to dry MSW. This energy was obtained from 26.3MJ/Kg. The balance of 25.27 MJ/Kg is the energy that one would recover per kg of dry MSW from the MSW energy conversion. For the case study, the total waste generated in this scenario was about 59,002 tons of waste per year. This quantity, using eqn (11), gives an equivalent to energy of 415 GWh.

Scenario C: Using Gasification

Table 5. Values of Awka MSW for scenario C.

Sample	Calorific Value (KJ/kg)	Waste Quantity (W)
Paper	28,089	8,611.11
Wood	30,174	7,654.32
Plastic & Nylon	32,368	6,378.6
Textile	31,775	3,508.23
	Ave: 30.6	Total: 26.152.26

Table 5 showed that the average value of energy released was about 30.6 MJ/Kg.This was the energy contained in MSW in dry basis. In this case, the energy of 1kg MSW is equivalent to energy of 1.04 kg of net MSW. During the bomb calorimetric experiment, an average moisture of 3.7% was taken out from the waste, and a moisture of 0.04 kg required 0.9172MJ/Kg to dry MSW. The average energy value obtained by this consideration is 30.6 MJ/Kg and the energy recovered per kg of dry MSW from the MSW energy conversion is 29.68MJ/Kg. The total waste generated in this scenario was about 26,152 tons of waste per year, which applying eqn. (11) gives an equivalent to energy of 216 GWh.

From the foregoing analyses, the calorific value and quantity of wastes involved in each of the three scenarios showed that values of energy from scenario A yielded the highest obtainable energy, followed by scenario B while scenario C had the least. This implies that, based on energy content and availability of sufficient quantity of required the waste components in Awka MSW, incineration technology would yield better result in converting the MSW to electrical energy than using gasification technology.

3.3 *Economic Evaluation of Awka MSW Using Indicators*

3.3.1 *Net Present Value (NPV): Scenario A analysis*

Discount rates of 6%, 8.5% and 13% were used for economic evaluation according to the recommendation of Boyle, (2004). Microsoft Excel was used in computing the NPV for the chosen values of interest rates. The NPV for each of the scenarios are presented in Table 6-8 and depicted in Figure 3-6.

Table 6. NPV for Scenario A at Different Rates.

Year	$\frac{I_n}{(1+r)^n}$ **at 6%**	**NPV**	$\frac{I_n}{(1+r)^n}$ **at 8.5%**	**NPV**	$\frac{I_n}{(1+r)^n}$ **at 13%**	**NPV**
0	-1.3E+10	-13230980000	-1.3E+10	-13230980000	-1.3E+10	-13230980000
1	2.15E+09	-11079702075	2.1E+09	-11129270691	2.02E+09	-11212967080
2	2.03E+09	-9050194599	1.94E+09	-9192211420	1.79E+09	-9427114938
3	1.91E+09	-7135564905	1.79E+09	-7406903336	1.58E+09	-7846714812
.	.	.	.	.	.	.
.	.	.	.	.	.	.
20	7.11E+08	12924507613	4.46E+08	8348783165	1.98E+08	2787944575

The NPV for scenario A is presented in Figure 3.

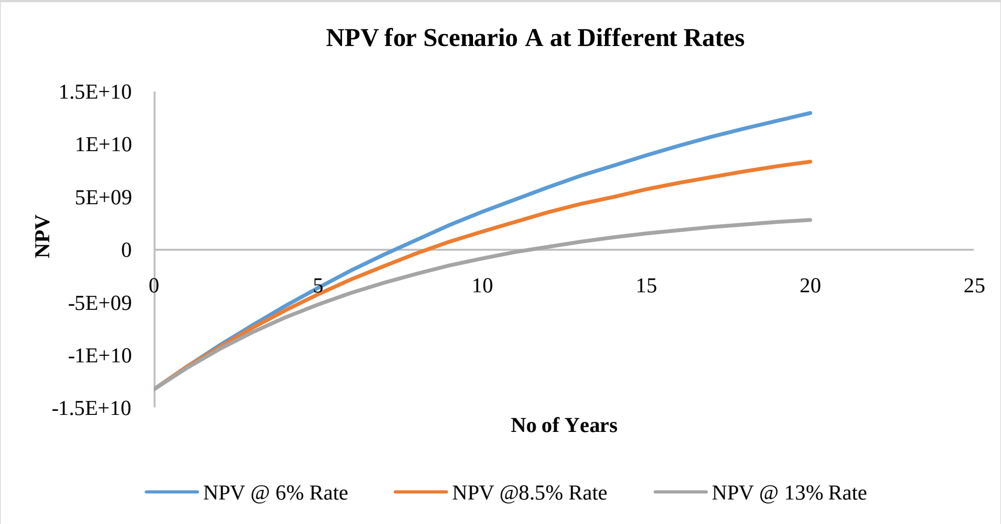

Fig. 3. NPV against the No of Years using all waste (MMSW) as fuel at different rates.

From Figure 3, it could be observed that the NPV became positive after 8 years at 6% discount rate, after 9 years at 8.5% rate and after 12 years at 13% rate. Generally, scenario A suggests to be viable for all discount rates.

Scenario B:

Table 7. NPV for Scenario B at Different Rates

Year	$\frac{I_n}{(1+r)^n}$ at 6%	*NPV*	$\frac{I_n}{(1+r)^n}$ at 8.5%	*NPV*	$\frac{I_n}{(1+r)^n}$ at 13%	*NPV*
0	-1.4E+10	-14270471230	-1.4E+10	-14270471230	-1.4E+10	-14270471230
1	4.98E+08	-13772403669	4.87E+08	-13783879880	4.67E+08	-13803257411
2	4.7E+08	-13302528611	4.48E+08	-13335408589	4.13E+08	-13389793855
3	4.43E+08	-12859250254	4.13E+08	-12922070994	3.66E+08	-13023896903
.	.	.	.	.	.	.
.	.	.	.	.	.	.
20	1.65E+08	-8214907799	1.03E+08	-9274287385	45816853	-10561742289

The NPV for scenario B as obtained in Table 7 was presented in Figure 4.

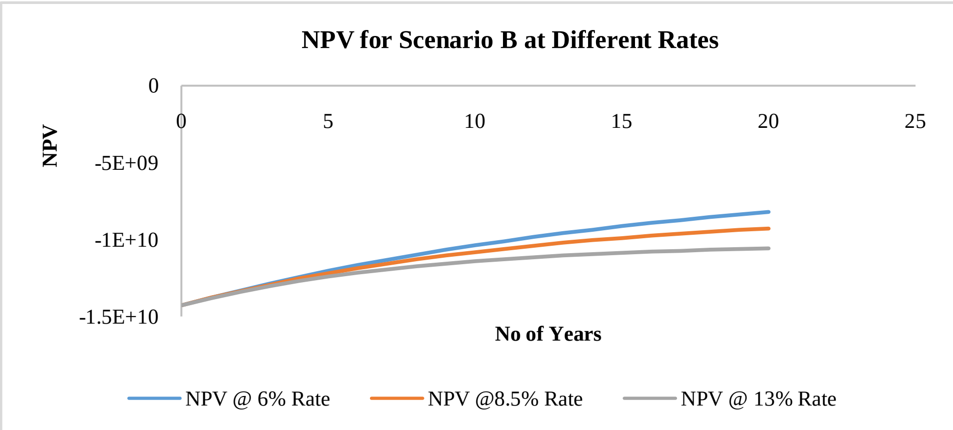

Fig. 4. NPV against the No of Years using all waste except metal and glass as fuel at different rates.

Figure 4 shows that the NPV for this scenario is negative at all rates up to 20 years (the end of the plant life for the study). Therefore, this scenario suggests being unviable.

Scenario C:

Table 8. NPV for Scenario C at Different Rates.

Year	$\frac{I_n}{(1+r)^n}$ @ 6%	NPV	$\frac{I_n}{(1+r)^n}$ @ 8.5%	NPV	$\frac{I_n}{(1+r)^n}$ @ 13%	NPV
0	-5.5E+09	-5477728105	-5.5E+09	-5477728105	-5.5E+09	-5477728105
1	1.13E+09	-4351411223	1.1E+09	-4377363225	1.06E+09	-4421183065
2	1.06E+09	-3288848127	1.01E+09	-3363202045	9.35E+08	-3486187455
3	1E+09	-2286430112	9.35E+08	-2428491280	8.27E+08	-2658757711
.	.	.	.	.	.	.
.	.	.	.	.	.	.
20	3.72E+08	8216163753	2.34E+08	5820510624	1.04E+08	2909093968

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The NPV for scenario C as obtained in Table 8 is presented in Figure 5.

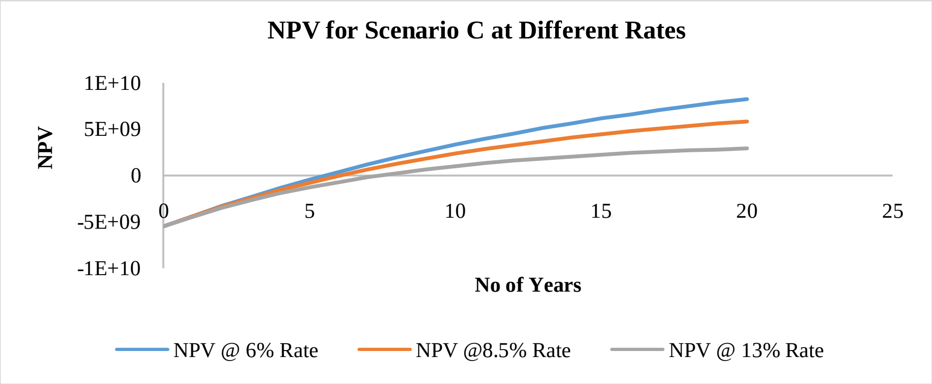

Fig. 5. NPV against the no of years using all waste except metal, glass, leather & rubber as fuel at different rates.

The NPV became positive after 6 years at 6% discount rate, after 7 years at 8.5% rate and after 8 years at 13% rate as shown in Figure 5. This implies that this scenario suggests to be viable at all rates.

The combination of the NPV for the three scenarios is shown in Figure 6.

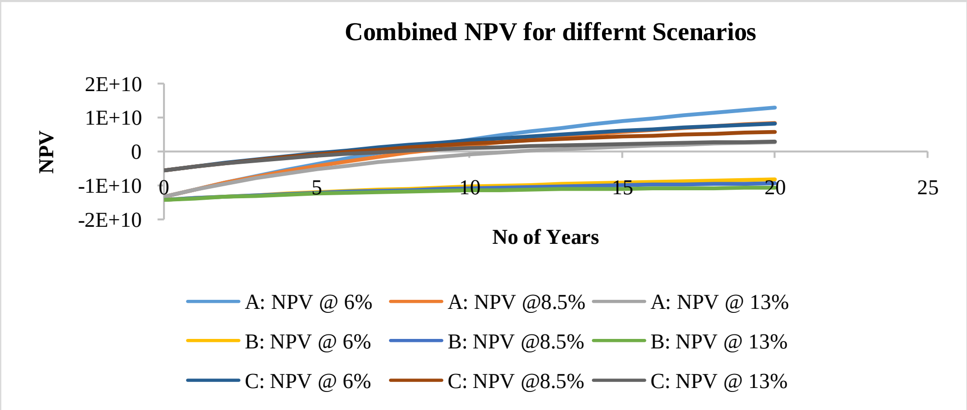

Fig. 6. NPV against the no of years for different Scenarios and rates.

From Figure 6, it could be seen that if NPV was used as the instrument for decision making, scenario C came out the best followed by scenario A. Scenario B was shown to be the worst case which should not be embarked on.

However, it was also shown from the figure that in as much as scenario C would start to yield earlier (pay back sooner) than scenario A, the later would yield considerably higher revenue at 6% discount rate after 10 years than the former. It can, therefore be concluded that scenario C would be the best for short-term project while scenario A would be the best for long-term project, especially at 6% discount rate.

3.3.2 *Levelized Cost of Energy (LCOE)*

Efficiency was assumed to be 25% of all energy produced for each electricity calculation. The selling price per unit of energy was considered to be N34.3 per kWh electricity (energy selling price per kWh by EEDC at the time of the report). These were applied in the scenario analysis in order to reflect sensitivity of the parameters described. Exchange rate used was ₦360 for $1.

The summary of the obtained values of LCOE for the various scenarios at different rates are shown in Table 9.

Table 9. LCOE. for the three Scenarios at Different Rates.

Rate (%)	L.C.O.E. (₦/KWh)		
	Scenario A	Scenario B	Scenario C
6	13.58	9.57	17.55
8.5	15.09	26.92	19.50
13	17.94	32.02	23.19

Table 9 and Figure 7 showed that scenario B had the least levelized cost at 6% rate followed by scenario A while scenario C had the highest. However, levelized cost for scenario B increased drastically at 8.5% rate and became the highest cost up to 13% rate. Scenario A had the least levelized cost at 8.5% and 13% rate followed by scenario C. Generally, scenario A had the least levelized cost of energy followed by scenario C while scenario B had the highest.

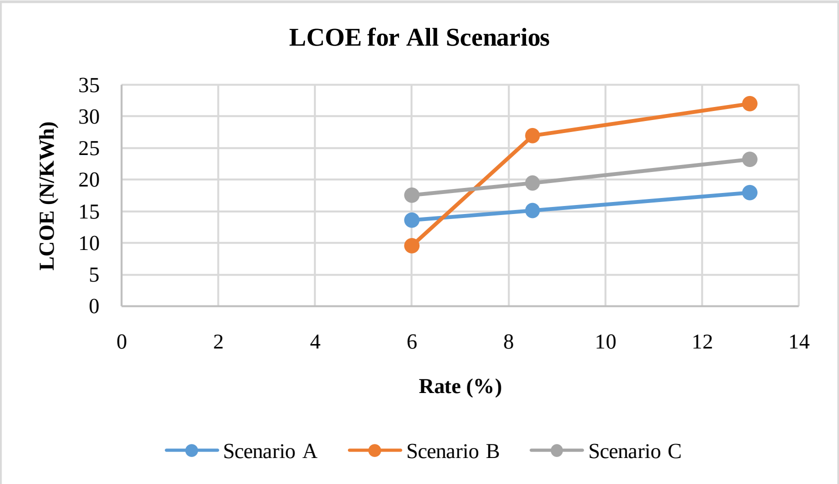

Fig. 7. LCOE for the Three Scenarios at Different Rates.

It can, therefore be concluded that the levelized cost of electricity generation in a MSW incineration plant is higher in comparison with gasification plant.

IV. Conclusion

Measurement of waste generation, its composition, characteristics and availability is important in waste management plans and decision making in establishment of WTE system. The paper has presented a report on quantity and quality of MSW generated in Awka, its components, sufficiency and suitability for energy recovery through thermal technological approach. Results from the analysis show that for every 1 kg of dry municipal solid waste from the Agu-Awka final dumpsite, about 26.7 MJ/kg of thermal energy could be recovered; that Awka MSW contains a big portion of biodegradable materials, suggesting that incineration methodology should be utilized; and for MSW with presence of large recyclable waste materials, gasification method with material recovery should be employed.

Furthermore, financial indicators were applied to determine the best option for short term and long term projects with regards to break even and cost. The NPV result show that scenario C (using gasification) would be the best for short-term project, having shortest break-even period of 6 years at 6% rate; while scenario A (using Incineration with all wastes) would be the best for long-term project, yielding higher revenue after 10 years, especially at 6% rate. More so, scenario A had the least levelized cost of energy followed by scenario C while scenario B had the highest. These results could help in making decisions on which method of energy recovery to be utilized under given obtainable conditions.

Finally, the following recommendations are made:

a) The Anambra State Government should strongly consider introducing "waste to energy" as a way of curbing the menace of waste management and simultaneously solving the energy needs of the State, using the findings from this work.

b) The study covered only Ring-road dump site, Awka. Therefore, more research could be made to cover the whole of Anambra state.

c) A different method can be used to determine the obtainable energy from each thermal technology option using existing models with respect to Awka.

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