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Evaluation of the Feasibility of Biogas-to-Electricity Plant in Maiduguri, Borno State, Nigeria

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Abstract: *There are concerns over inadequate supply of electricity to the local populace of Nigeria. Constantly increasing population has led to a wider gap between supply and demand of energy, leading to the privatisation of the power sector. Fluctuating fossil fuel prices has further increased the need to assess the available renewable energy (RE) resources. Municipal solid waste (MSW) is generally accepted to be a RE resource with wide availability, however, it has not been harnessed in Nigeria. This work will present an economic evaluation of the feasibility of investing in biogas-to-electricity projects that can process MSW generated in Maiduguri and its environments, thereby improving the supply of electricity within the city. The assessment will be carried out for energy generation by a biochemical process (Anaerobic Digestion) based on Primary and secondary data. It will also incorporate all the plants' output (digestate, recyclables, electricity and heat) as co-products which can be marketable, but heat was assumed to be used in-house. Results obtained indicates the investment would be feasible on wholesale and retail electricity distribution basis. However, trading directly to end users will pay back the investment cost of the project faster at 2 years and 361 days, at an NPV of $423,944,603.13 than having to distribute the electricity generated at wholesale prices to electricity suppliers which would pay back the investment after 3 years and 91 days. Thus, the project will help in increasing the amount of power available in the country, by 0.59%, which is an addition. Hence, the BTE project will have a positive effect on the power sector, thereby contributing to the improvement of the economy of the nation.*

Key words: *Biogas, Electricity, Anaerobic digester, Municipal solid waste*

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INTRODUCTION

The success of a biogas-to-electricity (BTE) project is dependent on the need of the local populace, since no profit will be made if there is no market for the BTE plant, resulting in a loss of the investor's capital. Nigeria is one of the major victims of shortage in global energy amongst other sub-Saharan African countries. This shortage has led to a significant overdependence of households on traditional energy source, like forest-wood and the charcoal derived from it for its primary energy consumption. A likely reason for this energy shortage is a lack of access to modern energy supply, with only about 46% of households having access to electricity (Dassapa 2011, Sambo 2009). Figures from The World Bank (2013) shows a 2 percent increase in the percentage of households without access to electricity from the year 2010 to 2013 due to an increase in population. The subject of electricity generation, distribution and transmission has been a major issue in Nigeria and has been the centre of previous research over the years (Akinbulire *et al.* 2008, Mohammed *et al.* 2013, Ogujor and Orobor 2010, Oseni 2011 and Sambo 2009) due to the inadequacy of supply to the citizens of the nation. This has resulted in self-generation of electricity through the use of small personal generators that have low efficiencies and high CO_2 emissions.

This is very expensive to generate. Furthermore, it is harmful to the environment as a result of the high CO_2 emissions from the machines utilised for self-generation.

Options of RE sources that can be utilised for decentralized power generation are wind energy systems, solar photovoltaic, biomass (agro residues, waste streams) gasifiers, small-hydro systems and so on (Buragohain, Mahanta and Moholkar 2010). Biomass based energy is distributed more uniformly, widely available and has a more consistent 'source-stream' putting it ahead of the other RE sources in Nigeria (Buragohain, Mahanta and Moholkar 2010). The use of biogas, produced from the processing of municipal solid waste as a renewable and sustainable energy source, could be the solution to the recurrent energy challenges of the country. Biogas is a gas composed of methane, carbon dioxide and other constituents; it is produced through the anaerobic digestion of biomass (including waste). Since the country has more waste generation capacity than it has the ability to handle, this could also be a feasible approach to power generation, as well as waste management (International Energy Agency 2014).

This work argues that the use of biogas produced from anaerobic digestion of municipal solid waste (MSW) streams is an economically feasible alternative for electricity production in Maiduguri, Borno state. The most important issues and the key objective of this work are:

- To estimate the amount of MSW generated and collected which will be used to determine the potential biogas yield, total electrical, digestate and recyclables output (revenue generating output).
- To perform a comparative cash flow analysis of wholesale and retail electricity distribution alternatives to determine their economic feasibility and competitiveness.

METHODOLOGY

The procedures that will be used in actualising the objectives of this study are involves collection of primary data from the waste generated within the location. Also, a variety of secondary data collected from literatures both qualitative and quantitative, and used to generate the required figures for the economic model to be carried out successfully. Location specific data will be obtained from various sources and collated.

Average per capita waste generation will be obtained from taking the average of different locations in within the study area. These locations represent the academic, commercial, industrial and residential areas, this is because waste generation varies significantly, thus, will yield errors if the average is not taken.

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Table 1: Important Data Utilised in the Research

S/N	DATA	USE OF DATA	SOURCE
1	Population	To assess the amount of waste generated	National Population Commission (2006)
2	Population Growth Rate	To assess the quantity of waste that can be generated over a number of years	UNFPA Nigeria (2014)
3	Waste Generation per person	To estimate how much waste can be generated by a person per day	Babatunde *et al.* (2013)
4	MSW Properties	General properties of waste generated in Borno state such as organic fraction of waste, carbon-nitrogen ratio and biodegradability of waste generated	Abubakar *et al.* (2013)
5	Waste Collection	To estimate how much waste can be made available for processing	Ogwueleka (2009)
6	Price of Electricity, Fees Payable, taxes and incentives, Licences	To estimate revenue that can be generated from sale of electricity, and power regulations and incentives offered	National Electricity Regulatory Commission (2010, 2012 and 2013) and KPMG (2013)
7	Energy Recovery Potential	To calculate the energy recoverable from the biochemical conversion of waste to energy	MUDGI (2013:15)
8	Plant costs	To estimate the costs of building municipal solid waste to energy plant	EIA (2013)

Population and per capita waste generation were used to calculate the total waste generated per day; this was converted to waste generated per year.

$$Total\ Waste\ Generated\ per\ day (Tonnes/day) = Population\ (hd) \times Average\ per\ capita\ Waste\ Generation\ (kg/hd/day) \quad (1)$$

This was according to calculations made by the Anderson centre, and GMU (2001). Future generated waste projections were made using the population growth rate of the state. The percentage quantity of total generated waste that can be collected was assumed to be 70% (Mattocks,1984). The MUDGI biochemical conversion model was modified according to the location specific data and used to calculate the biogas yield, net power generation and energy recovery potential of the biogas plant. Using MUDIG (2013:15) energy recovery potential as shown below;

Total Waste Quantity: W (tonnes)

Total Organic/ Volatile Solids: VS (50%)

$$Organic\ biodegradable\ fraction (66\%\ of\ VS) = 0.33 \times W \quad (2)$$

Typical Digestion Efficiency (60%)

$$Typical\ Biogas\ Yield\ (m^3) = 0.80m^3/kg\ of\ VS\ destroyed \quad (3)$$

$$0.80 \times 0.60 \times 0.33 \times W \times 1000 = 158.4 \times W \quad (4)$$

Calorific Value of biogas = 5000kcal/m³ (typical)

$$Energy\ Recovery\ Potential(kWh) = B \times 5000/860 = 921 \times W \quad (5)$$

$$Power\ Generation\ Potential(kW) = 1339.53 \times W/24 = 38.4 \times W \quad (6)$$

Typical Conversion Efficiency (30%)

$$\mathbf{Net\ Power\ Generation\ Potential(KW) = 11.5 \times W} \quad (7)$$

$$Potential\ Energy\ Income\ (\$) = Net\ Energy\ Generated\ (kWh) \times Price/kWh \quad (8)$$

Percentage plant consumption (15%) and energy loss due to down time (10%) was subtracted from total energy generated in order to get the net energy generation. The capital cost and the operation and maintenance (O&M) cost of the proposed plant was calculated based on estimates of municipal solid waste power plant costs established by EIA (2013). The cost was given as 8,312 ($/kW) and 392.82 ($/kW-year) for capital and O&M costs respectively. These figures were given for plants with nominal capacity of 50 MW. This formed the basis for the cost estimation for this study.

A discounted cash flow for economic analysis will be constructed for a ten-year MSW to electricity generation project. Ten years was selected because the licences for power projects are only valid for ten years in which it can be renewed. The variables required for the project analysis are capital investment, operation and maintenance costs, cash flows, present values (PV), net present value (NPV), internal rate of return (IRR), payback period (PP) and benefit-cost ratio (BCR) and sensitivity analysis.

RESULTS AND DISCUSSION

The waste generated per year was calculated using the amount of waste collected through a period of three months within the study area. Only 70% of total waste generated is collected, thus yielding a total waste generation of 1,142,313.87 Tonnes/year of MSW in the first year and 1,543,370.87 Tonnes/year of MSW in the tenth year. Also, the amount of recyclable waste saleable was calculated to be 50% of the inorganic waste collected after pre-treatment and is shown in Table 2.

These results were used to calculate the amounts of all required outputs to be generated as stated in the methods section. These outputs include the biogas yield, electrical energy generated, digestate output after digestion and the amount of saleable recyclables gathered. The amounts generated as shown in Table 2 was used to calculate the income generating potential of the BTE project.

Table 2: Results Obtained for Revenue Generating Outputs

Year	Population	Total Waste Collected (Ton/year)	Organic Fraction of Waste Available for Digestion (Ton/year)	Biogas Yield (M^3/Year)	Solid Digestate Output (Ton/Year)	Amount of Saleable Recyclables (Ton/Year)	Net Energy Generated (kWh)
1	5,198,716.00	1,142,313.87	712,461.16	164,151,050.9 5	320,607.5 2	175,345.18	219,026,875.5 3
2	5,375,472.34	1,181,152.53	736,684.84	169,732,186.6	331,508.1	181,306.91	226,473,789.3

				8	8		0
3	5,558,238.40	1,221,311.72	761,732.12	175,503,081.03	342,779.46	187,471.35	234,173,898.13
4	5,747,218.51	1,262,836.32	787,631.01	181,470,185.79	354,433.96	193,845.38	242,135,810.67
5	5,942,623.94	1,305,772.76	814,410.47	187,640,172.10	366,484.71	200,436.12	250,368,428.23
6	6,144,673.15	1,350,169.03	842,100.43	194,019,937.96	378,945.19	207,250.95	258,880,954.79
7	6,353,592.04	1,396,074.78	870,731.84	200,616,615.85	391,829.33	214,297.48	267,682,907.26
8	6,569,614.17	1,443,541.32	900,336.72	207,437,580.78	405,151.52	221,583.59	276,784,126.10
9	6,792,981.05	1,492,621.73	930,948.17	214,490,458.53	418,926.68	229,117.43	286,194,786.39
10	7,023,942.41	1,543,370.87	962,600.41	221,783,134.12	433,170.18	236,907.43	295,925,409.13

Cost Estimates

For the plants, the capital cost for the tenth year was used for the purpose of the analysis as this was the point with the highest energy generation. It was calculated using the capital cost criteria stated in the methods section, and is given as $367,353,475.36. Both of the project alternatives have the same capital cost as they generate the same amount of electricity. The total capital investment comprises of the capital cost, and applicable licence fees required for each of the project alternatives to be evaluated. For project alternative one, the licences for generation, transmission, distribution, systems operations and trading are included in the capital investment. While the project alternative two only takes into cognisance the licence fees for generation and wholesale distribution.

Table 3: Total Capital Investment

	Alternative one	**Alternative two**
License Category	($)	($)
Generation	30,916.20	46,374.30
Transmission	306,107.99	N/A*
System operations	306,107.99	N/A
Distribution	81,107.99	20,610.80
Trading	81,107.99	N/A
Capital cost	367,353,475.36	367,353,475.36
TOTAL CAPITAL INVESTMENT	**368,158,823.52**	**367,420,460.46**

**Not Applicable*

The operating cost was also calculated according to the criteria stated in the methods section of this study. The two projects alternatives also have the same operating costs but different operating fees as shown in Table 4.

Table 4: Total Operating Costs for the each of the two project Alternatives

Year	Alternative One			Alternative Two		
	Operating cost ($)	Operating Fee ($)	**Total ($)**	Operating cost ($)	Operating Fee ($)	**TOTAL ($)**
1	10,913,005.74	2,036,949.94	12,949,955.68	10,913,005.74	427,102.41	11,340,108.15
2	11,284,047.93	2,106,206.24	13,390,254.17	11,284,047.93	441,623.89	11,725,671.82
3	11,667,705.56	2,177,817.25	13,845,522.81	11,667,705.56	456,639.10	12,124,344.66
4	12,064,407.55	2,251,863.04	14,316,270.59	12,064,407.55	472,164.83	12,536,572.38
5	12,474,597.41	2,328,426.38	14,803,023.79	12,474,597.41	488,218.44	12,962,815.85
6	12,898,733.72	2,407,592.88	15,306,326.60	12,898,733.72	504,817.86	13,403,551.58
7	13,337,290.67	2,489,451.04	15,826,741.71	13,337,290.67	521,981.67	13,859,272.34
8	13,790,758.55	2,574,092.37	16,364,850.92	13,790,758.55	539,729.05	14,330,487.60
9	14,259,644.34	2,661,611.51	16,921,255.85	14,259,644.34	558,079.83	14,817,724.17
10	14,744,472.25	2,752,106.30	17,496,578.55	14,744,472.25	577,054.55	15,321,526.80

Comparison of Project Alternatives

In utilising the converted biogas, two project alternatives were analysed. Project alternative one details a total investment in the project, from generation of electricity to trading directly to the end users. Retail prices were used to calculate the income from electricity and kept constant over the ten year licences' validity period. Project alternative two details investment in just generation and distribution to electricity suppliers, wholesale prices were used to calculate the income from electricity, these were also assumed to be constant over the ten-year validity of the licences. Table 5 below shows the criteria for which the profit indicators used for the economic analysis of the project's viability will be acceptable for any particular project alternative. Outside of these criteria, the project will not make any profit and will therefore fail.

Table 5: Acceptability Criteria of Profit Indicators

Economic Profit Indicator	**Criteria for Acceptability**
NPV ($)	NPV > 0
DISCOUNT RATE (%)	Discount Rate < IRR
CBR	CBR >1

Table 6 shows the results of the profit indicators used in this project, obtained from the discounted cash flow analysis for the two project alternatives. The NPV of alternative one was $423,944,603.13, which was higher than zero, indicating that the project has a high profit potential. To strengthen this result, the IRR was 42%, indicating that the project could be profitable. The BCR was obtained to be 1.78 which is greater than 1; hence for every $1 invested, the wholesale electricity distribution project option will deliver $1.78. Therefore, the project could recover its costs in about two years and 361 days, and still make further profits as high as $0.78 for every dollar spent.

The NPV of alternative two was $367,083,352.63, which was also greater than zero, but less than that of alternative one, thus indicating profitability less than that of alternative one. The IRR was about 3.56% less than that of alternative one, meaning that despite its apparent potential for profitability when distributed wholesale, would yield less profit than when the electricity is distributed on a retail basis. Also, the BCR was less than alternative one by $0.8 and the costs would only be recovered after 3years and 91 days.

Table 6: Economic Profit Indicator Results from Discounted Cash Flow analysis

Economic Profit Indicator	Alternative one	Alternative two
NPV ($)	423,944,603.13	367,083,352.63
IRR (%)	42.00	38.44
BCR	1.78	1.70

As can be seen from Table 6 above, installing biogas plant will yield profits whether the energy generated is sold on a retail or whole sale basis. Hence the project alternative having the highest potential to generate profit will be chosen by the investors.

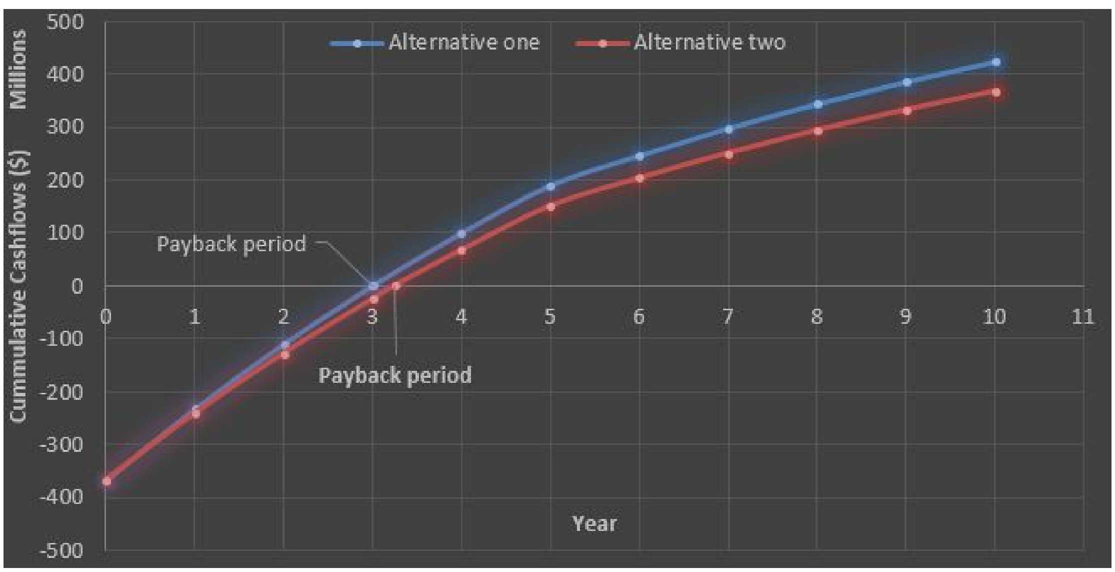

Figure 1: Cumulative Cash Flow of Project Alternatives

Figure 1 compares the cumulative cash flows of the two project alternatives being evaluated. As can be seen, there was a marked difference between selling as a retail energy provider than selling as a wholesale energy provider. Trading directly to end users will pay back the investment cost of the project faster at 2 years and 361 days, at an NPV of $423,944,603.13 than having to distribute the electricity generated at wholesale prices to electricity suppliers which would pay back the investment after 3 years and 91 days.

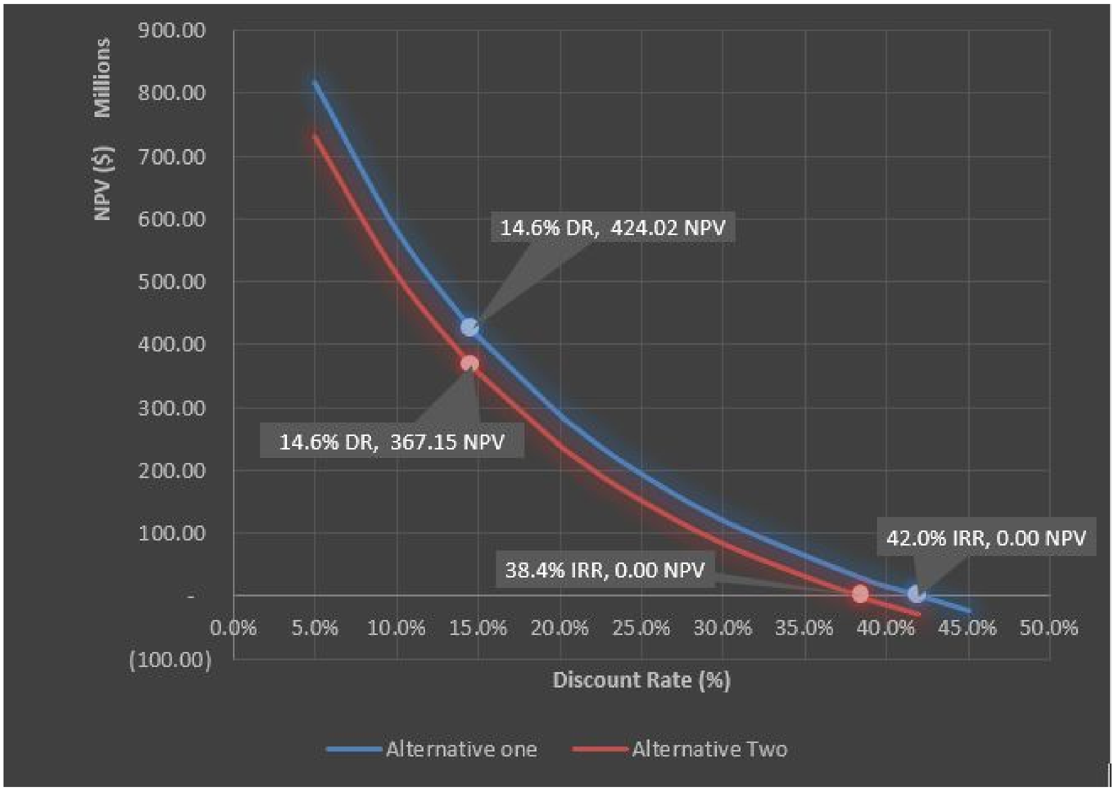

Figure 2: Relationship between the NPV and IRR for the Two Project Alternatives

As can be seen from Figure 2, the NPV becomes 0 at 42% discount rate for alternative one, and 38.4% for alternative two. This further confirms the profitability of Retail distribution over Wholesale. Therefore, the cash flow analysis of BTE plants shows economic viability of the project when all outputs (Digestate, Electricity, and Recyclables) are able to generate revenue.

CONCLUSION

From the discounted cash flow model adopted in this research, results obtained indicated that investing in Nigeria, and selling all of the plant's output (electricity, digestate, and recyclables) at current market prices, with a discount rate of 14.60%, will yield an economically viable investment. The results obtained and presented from the economic analysis of BTE plants in Nigeria, reveals that the argument posed in the introduction section of this work, which states that "the use of biogas produced from anaerobic digestion of municipal solid waste (MSW) streams is an economically feasible alternative for electricity production in Nigeria" is true and can be accepted. However, this argument can only be fully accepted if all plant outputs and benefits such as waste processing, reduction of landfill tax, reduction in carbon emission, digestate, electricity, and recyclables are inputted into the revenue generating stream.

Competition in the electricity market by new entrants in generation and retail supply will help in reducing the price of electricity, and also allow consumers to choose their suppliers, thus improving their confidence and reliability in the energy sector. This will also reduce the amount of self-generation of electricity in the state, thereby reducing cost, noise pollution and CO_2 emissions into the atmosphere.

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