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# Techno-Economic Assessment of Electricity Generation from Municipal Solid Waste (MSW) in Benin City

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**ABSTRACT**

Nigeria, with its large population, faces the twin challenge of proper waste disposal and generation of adequate electrical power. One commonly explored solution is the use of waste to energy facilities which converts waste to electrical power, effectively killing two birds with one stone. While this method of waste control is common in the western world, it has hardly been employed in Nigeria and Benin metropolis has no waste to energy facility. The aim of this work is to determine the technical and economic implications of establishing and running a waste to energy plant in Benin metropolis. To carry out a techno-economic analysis, it was necessary to determine the size and technical properties of the plant needed. The size of the facility was estimated based on the amount of waste generated in the city. The technical properties of the plant, like its method of operation and efficiency, were determined from existing data. The amount of electricity which could be generated was determined from the energy content of the waste. Samples of the main constituents of MSW in Benin City were taken to the lab to determine their calorific values and moisture contents using *ASTM D5468-02* and *ASTM D3173* standards. The overall calorific value of MSW in Benin was then calculated, from which the amount of electricity to be generated was deduced. The economic analysis was based on the calculation of a breakeven selling price (BESP) below which the venture would be unprofitable. The BESP was calculated for a variety of scenarios using the Excel spreadsheet package. The results of the test revealed that MSW in Benin metropolis has a calorific value of 2.16MWh/tonne of MSW. This would produce a grid output of 0.5MWh/tonne of MSW, or 100GWh of electricity per year. The Breakeven Selling Price (BESP) was calculated to reach a minimum of $11/MWh or ₦3,465/MWh (using $1 to ₦315 exchange rate). However, the more likely scenario in Nigeria yielded a BESP of $95/MWh or ₦29,925/MWh.

## 1. Introduction

Waste is any substance which is discarded after primary use or which is worthless, defective and of no use [1]. In other words, they are unwanted or unusable materials. As long as man exists, waste will be generated; it is inevitable, and the overpopulation of urban centres means that waste collection and disposal are vital if we are to live in a clean environment. However, while the developed countries have an organized and efficient waste management system, the situation is a little less pleasant in Nigeria. For years, the proper collection and disposal of waste, particularly solid waste, has been an enormous problem [2]. In Benin metropolis, it isn't uncommon to see huge heaps of rubbish piled on the streets and in market places and only very recently has there been a slight improvement in waste collection. Even so, the method of disposal remains far from being effective as most of the approved dumpsites are overflowing to the brim. A possible solution to the problem of waste management in the city and country is conversion of waste to energy.

The concept of waste to energy is hardly a novel idea. For decades, waste has been used to generate power in several forms through various means. This method of waste management has the twin advantage of getting rid of huge amounts of solid waste while at the same time providing very valuable power. Despite the appeal of this method of waste disposal, it has remained largely unused in Nigeria and Benin metropolis has no waste to energy facility.

This report describes the techno-economic implications of generating electricity from municipal solid waste generated within Benin metropolis. The objective was to determine the amount of solid waste generated the amount of electricity this could generate and the economic ramifications of such an undertaking.

## 2. Methodology

The quantity of waste that could be generated per day was determined. This was done using the population of Benin City as at 2015, the projected population growth rate of 2.78% as stipulated in [3] and the waste generation rate of 0.5kg/person/day as determined in [4]. This showed that around 670 tonnes of solid waste is generated daily within the city. Allowing for some shortfall, the plant chosen was a single-furnace grate combustion facility with the capacity of treating 25 tonnes/hr (600 tonnes/day), with 90% availability (8,000 hours of operation per year), i.e. 200,000 tonnes/year. This plant was chosen because of its high availability, simplicity of operation, low personnel requirement and the fact that it is the most proven technology for WTE plants [5]. The process schematic of MSW to electricity via mass burn (incineration) is shown in Fig 1.

The amount of electricity that would be generated from the municipal solid waste (MSW) was determined using the energy content of the waste and the operating parameters of the chosen facility. The key components of MSW as determined in [4], were taken to the laboratory for determination of their individual moisture contents and calorific values. The tests were done following *ASTM D3173* and *ASTM D5468-02* standards respectively. Following the steps set out in [6], the energy content of each of the key components was obtained by multiplying individual dry weight (weight after drying) by their calorific values. The total energy content, obtained as the sum of the individual energy contents, was then divided by the total wet weight (weight before drying) to obtain the average calorific value of MSW in Benin. Operating conditions of the proposed facility were set based on plants currently in operation as seen in [5] and [7], making adjustments to allow for the average temperature conditions of Benin (saturation temperature of the condenser was set at 50℃ to allow adequate heat rejection). The plant chosen has no sorting compartment; all the waste is combusted together. The high temperatures in the boiler and the vibration of the grate ensure that proper burning occurs. Afterwards, incombustible materials are sorted out of the bottom ash. Boiler pressure was set at 40 bar, condenser pressure at 0.1233 bar, superheat temperature at 400℃ and isentropic efficiencies of turbine and compressor at 87%. With a thermal efficiency of 30.3%, the plant would be able to generate, after losses and self-consumption, 0.5MWh/tonne of MSW for the grid. This amounts to 100GWh of electricity produced for sale every year. The life of the facility was set at 20 years, the average lifespan of similar facilities before any major refurbishing is needed [5].

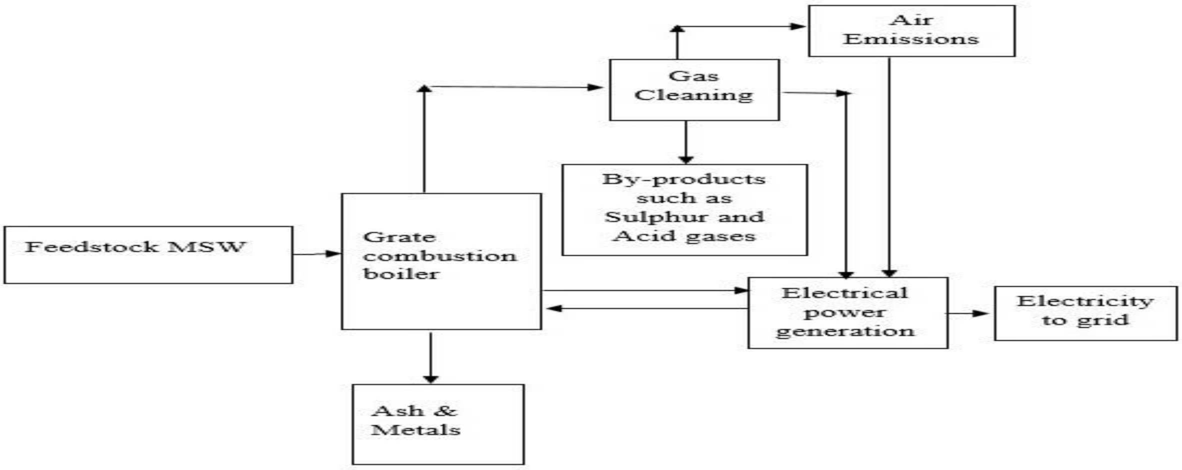


Fig 1: Process schematic of MSW to Electricity via Mass Burn [8]

## 3. Results and Discussion

The results obtained from the tests and calculations are shown in Table 1.

Table 1: Energy content of MSW

| Component | % composition | Wet weight(kg) | % moisture content | Dry weight(kg) | Calorific value (kJ/kg) | Energy content (kJ) |
|---|---|---|---|---|---|---|
| Food | 45 | 301455.9 | 70 | 90436.77 | 11609 | 1049880463 |
| Plastics | 15 | 100485.3 | 2 | 98475.59 | 17015 | 1675562232 |
| Textiles | 4 | 26796.08 | 10 | 24116.47 | 18408 | 443936016.6 |
| Metals | 5 | 33495.1 | 1.8 | 32892.19 | 0 | 0 |
| Glass | 5 | 33495.1 | 2.5 | 32657.72 | 0 | 0 |
| Paper | 10 | 66990.2 | 6 | 62970.79 | 12282 | 773407218.2 |
| Wood | 10 | 66990.2 | 60 | 26796.08 | 18625 | 499076990 |
| Rubber | 6 | 40194.12 | 2 | 39390.24 | 19560 | 770473047.5 |
| Total | 100 | 669902 | | | | 5212335967 |

The average calorific value of MSW in Benin City was determined to be 2.16MWh/tonne of MSW.

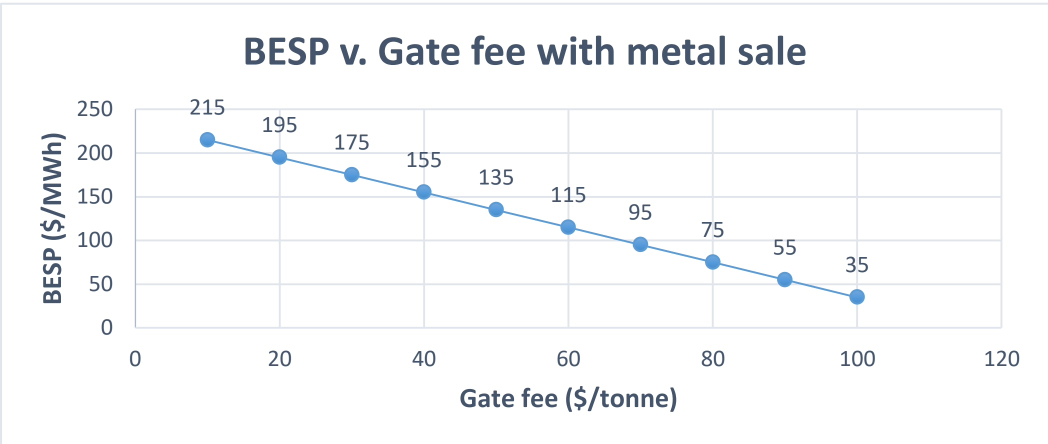


Fig. 2: BESP v. Gate fee with metal sale

The aim of the economic analysis was to determine the minimum conditions required for the venture to break even at the end of its useful life. These conditions were calculated for several scenarios and its economic impact compared with the existing alternatives.
Selling the electricity generated above the breakeven selling price (BESP) would mean the venture makes a profit at the end of its useful life; selling below means a loss. The BESP was calculated for the following scenarios: gate fee ranging from $10 - $100 without carbon credits or metal sale, with carbon credits only, with metal sale only and with carbon credits and metal sale. The results are shown in Fig. 2 and 3.

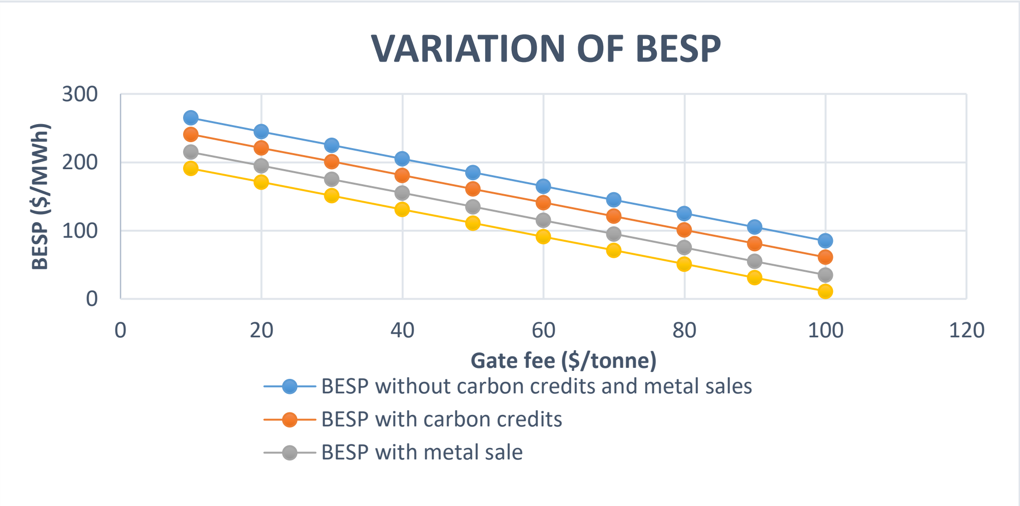


Fig. 3: Variation of BESP

The total cost of the project was estimated at $570,000,000 over a span of 20 years ($130,000,000 installation cost and annual operating cost of $22,000,000). The sources of revenue investigated include sale of electricity, collection of gate fee from waste collectors, sale of metals for recycling and collection of carbon credits. The breakeven price of electricity was determined for a wide range of scenarios. The lowest possible price for electricity was $11/MWh or ₦3,465/MWh (using $1 to ₦315 exchange rate). This price was obtained from the scenario of $100/tonne gate fee, receipt of carbon credits and sale of recyclable metals. However, the more likely scenario is one that does not involve carbon credits due to the difficulty experienced in trying to qualify for carbon credits (stringent requirements and long scrutiny processes) as noted by [5]. This limitation places the minimum possible electricity price at $35/MWh or ₦11,025/MWh with a gate fee of $100/tonne (₦31,500/tonne). This amount is considerably lower than the Benin average of ₦31,270/MWh (BEDC, 2017). However, the gate fee is relatively high. Fixing the gate fee at $70/tonne (₦22,050/tonne) ensures the waste collectors can continue to make a profit and fixes the BESP at $95/MWh or ₦29,925/MWh. This is a reasonable price and ensures that the venture breaks even at the end of its life. Selling above this price makes this venture profitable.

The results compare favorably with related studies. In a similar study done in Lagos [9], the BESP was ₦4,554/MWh with a gate fee of ₦23,800/MWh. The relatively low BESP can be attributed in part to the huge volume of MSW generated in Lagos. For all the scenarios evaluated in [10], the venture wasn't economically feasible mostly due to the relatively low gate fees charged (₦7,088/tonne). This highlights the importance of the gate fee charge to the success of the entire project.

## 4. Conclusion

This study has shown that the type and quantity of solid waste generated within the metropolis can suitably justify setting up a 600 tonne-a-day waste-to-energy processing plant. It has also shown that it will add a tremendous amount of power (100GWh) to the national grid. In addition, the breakeven selling price of ₦29,925/MWh is below the current selling price of electricity in Benin, ensuring that it is ultimately a cheaper alternative.

In terms of investment prospects, the high start-up costs required are a disadvantage. This, in addition to the length of time required for the venture to become profitable, may severely limit private investment. The more likely investors would be the government or a consortium of high-end investors. However, the economic appeal of the investment can be increased if the selling price of the electricity is increased and/or a co-generation plant is attached to harness the heat generated. Steps could also be taken to qualify for payment of carbon credits.

Further studies should be done to determine the impact of seasons on the amount and type of solid waste generated. The environmental impact assessment of the effect of electricity generation from MSW using direct combustion technique in Benin City should be investigated as well as the possibility of using other waste to energy techniques besides direct combustion.

## 5. Conflict of Interest

There is no conflict of interest associated with this work.

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