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Waste to Energy Potential Assessment: CASE STUDY for Ndola (March 2023)

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Abstract:-

- ***Aims:***

To determine the Viability of electricity generation from Municipal Solid Waste (MSW) in Ndola-Zambia.

- ***Place and Duration of Study:***

Department of mechanical Engineering (University of Zambia) in Lusaka Zambia and the City of Ndola between 2019 and 2022.

- ***Methodology:***

The demographic characteristic of the study was drawn from Ndola with respondents from Ndola city council, independent Waste pickers, Informal waste pickers and selected housing units across the city compromising of High cost , medium cost and Low cost.

To answer to the objectives of the study, the researcher employed a survey approach with simple random sampling method where qualitative as well as quantitative survey questionnaires were used to gather data, and entered into Statistical Package for Social Sciences (SPSS), then tabulated and analyzed using Excel and presented in percentages, frequencies, cross tabulation and correlation.

The Waste to Energy (WtE) opportunities in Ndola were carried out in the context of simulating two scenarios: Biomethanation and Incineration. The Intergovernmental Panel for Climate Change (IPCC) default model was presented to estimate emission of methane from municipal solid waste at kaloko landfill site Ndola, Zambia.

- ***Results:***

Findings revealed that the estimated Net Annual methane emission potential from solid waste landfills was 22.09 (Gg/yr.) in the year 2015, giving a net power Generation Potential of 7.57MW.The maximum methane production rate by the IPCC default model was calculated to be 32.2(Gg/yr.) and was observed during the year 2035, giving a Net Power Generation Potential of 11.07MW. The power generation potential for Ndola was estimated at 21MW in the year 2015 resulting in Energy Generation Potential of 0.52GWh from incineration.

The Maximum Power generation potential was estimated in the year 2035 giving a Net Power Generation Potential from Incineration of 7.87MW.The Energy Generation potential was found to be 0.75GWh in the year 2035 at an efficiency of 25 percent.

- ***Conclusion:***

Biomethanation can be used as the most suitable technology in Ndola due to availability of degradable organic waste stream (134.13Gg/yr.), high efficiency (25% to 30%); lowest annual capital ($0.1–0.14/ton) and operational cost. Maintenance of methane emissions has a direct impact on national energy security and mitigating potential climate change. It can be assumed that the increased volume of generated methane, from increased solid waste in this landfill, is sufficient enough to be considered for new standard landfill site construction with methane capturing facilities.

Keywords:- *Bio-Methanation, Gasification, Landfill, Gasification IPCC Default Model.*

I. INTRODUCTION

Municipal Solid Waste (MSW) generation has been escalated at a global scale (Farooq et al., 2021; Asase, 2009; Bello et al., 2016). According to the World Bank (2018), the global annual MSW generation was 2.01 billion tons in the year 2018, up from 1.3 billion tons in the year 2012. It is expected that the global annual MSW generation rate will increase up to 2.59 billion tons by 2030 and 3.40 billion tons by the year 2050 (Kaza et al., 2018; Mayer et al., 2019). Growing Waste Generation is related to numerous environmental problems such as Greenhouse gas emissions, air pollution and water pollution.

This large increase in MSW generation is attributed to different factors including economic growth, population expansion, industrial development, urbanization, and rural to urban migration, etc. (Kaza et al., 2018; Agbelie et al., 2015). Waste generated in big quantities, and lack of appropriate waste management system, are two of the most critical issues facing the world today. (Labib et al., 2019). About 70 percent of MSW still ends up on landfills or uncontrolled dumpsites, which often contaminate surface water, ground water or soil and emit greenhouse gases (Mavropoulos et al., 2012). Today, the waste of about three billion people is still disposed of in an uncontrolled manner (UN, 2015). It has been emphasized by many studies that multiple public health, safety and environmental issues derived from inappropriate or ill waste management have soared Greenhouse Gases (GHG) emissions and decrease the quality of life, promote water and soil contamination (Scarlat et al., 2015; Bogner et al., 2003). Until now, the largest fraction of municipal solid waste generated is still landfilled. In developing countries landfilling and dumping represents the only feasible option for final waste disposal (Munawar and Fellner, 2017). However, landfilling and dumping of waste in many countries is still associated with severe negative impacts on the environment.

In most developed and developing countries with an increasing population, prosperity and urbanization, it remains a major challenge for municipalities to collect, recycle, treat and dispose off increasing quantities of solid waste and wastewater (Mayer et al., 2019; Bogner et al., 2003).

According to ECA, (2009), about half of the waste generated in Africa is left uncollected, and it is left in urban dumping landscape. According to World Bank, (2012), over the last two decades, Zambia has made significant socio-economic progress. This rapid and sustained growth, coupled with increasing population and urbanization, has soared waste generation and energy demand (ZEMA, 2011).

As a result Lusaka City in Zambia generates about 1,000 tons of solid waste daily. About 300 tons of the waste is disposed of at the designated dumpsites and treated in a sustainable environmental manner (UN-Habitat, 2010). Zambia has witnessed an increase in dumping of waste, unsustainable treatment methods, un-managed burning and uncontrolled burying of waste with adverse health and environmental implications in the past decade. This resulted in the outbreak of waterborne diseases in Zambia in previous years. (Sabo et al., 2020).

Alongside the proliferated dilemma of MSW generation and its sustainable management, global energy demand has also increased (Farooq et al., 2021). It has been widely admitted that the power generation sector and transportation sector are considered the top most energy-intensive sectors around the world. Most of the energy needs in these sectors are fulfilled by expensive fossil fuels (Asamoah et al., 2020; Kamausuor et al., 2014; Ofori, 2016). According to Ofori (2016), the generation of energy from waste also enhances sustainable waste management by avoiding the emission of methane, which is typical with landfilling.

Economic development and related increase in global energy demand, has created pressure on the supply of energy resources and waste management (Beyene et al., 2018).

Waste to Energy (WtE) technologies have been recognized to convert MSW into useful energy and minimize the problems related to Waste Management and Energy Shortage (Farooq et al., 2021). Waste to energy conversion is an ecologically and economically attractive practice which is rapidly growing associated with energy demand, waste disposal, and environmental monitoring (Beyene et al., 2018).

II. MATERIALS AND METHODS

- *Population of the Study*

The study population comprised staff and management employees of Ndola City Council (NCC), independent collectors and Residential housing units depicting High income, low income and medium income areas. Therefore, the target population of the study was 118 individuals comprising of seven individuals from NCC Management, 28 individuals working at the landfill site known as crew members, and 83 independent collectors and 110 housing units from Kansenshi, Pamozi and Twapia

- *Determination of Sampling Size*

Ndola District is divided into constituencies and each constituency into wards. Stratified sampling design was used in order to spread the sample over geographic sub areas and population sub groups.

A total of 90 households from different wards in Ndola were selected. The wards were picked randomly as 40 houses for high cost ward being Kansenshi ward and Kanini ward, 25 houses for Middle income cost being Pamozi and low income cost being 25 house hold being Twapia Ward. (Central Statistical Office Zambia 2016).

- *Determination of Moisture Content*

The samples were prepared at the research site and in duplicate by weighing 1kg and 0.5kg of the domestic solid waste in a petri dish. The dish was placed in a Sterling Hot Air oven at 1100C for one hour after which it was placed in the desiccator to cool and then re-weighed. The procedure was repeated until a constant average weight was recorded. Moisture content of the sample was then calculated as

$$\%\ \text{moisture} = \frac{loss\ in\ weight\ *100}{weight\ of\ sample} \qquad (1)$$

- *Methods for Estimating Methane Production from Landfills*

The default method was used to estimate the methane emissions from landfill site. Among the available methods, the simplest one for the estimation of methane emissions from landfills is based on mass balance approach, i.e. the default methodology. This method was being used in the revised IPCC (1995) guidelines as the default methodology for estimating methane emissions from solid waste disposal sites. A number of empirical constants, like methane correction factor, DOC, dissimilated organic fraction converted into LFG, have been considered while developing the default methodology and accordingly the emissions are calculated. Though IPCC has claimed that the default methodology provides reasonable annual estimate of actual emissions and this has been widely used in the situations where detailed data is not available, but it may not provide realistic estimate because it is assumed that all potential methane is released during the same year the waste is disposed off,

$$Methane\ emissions\left(\frac{Gg}{yr}\right) = \left(MSWT * MSWF * MCF * DOC * DOCF * F * \frac{16}{12} - R\right) * (1 - OX) \quad (2)$$

Where:

- ECH4 is Methane emission from landfills
- MSWT is Total MSW generated (Gg/yr).
- MSWF is Percentage of urban waste actually land filled; in this paper MSW equals the quantity of urban waste sent to landfills, so MSWF = 70 per cent. The remaining 30 per cent is assumed to be lost due to recycling, waste burning at source as well as at disposal site, waste thrown into the drains and waste not reaching the landfills due to inefficient solid waste management system
- MCF = methane correction factor (fraction) = Three default values ranging from 1.0 to 0.4 are included, depending on the site management and with 0.6 as general default value Source: IPCC,2006
- DOC = degradable organic carbon (fraction) (kg C/ kg SW) = Content of degradable organic carbon in the waste, recommended to be 15% by IPCC.
- DOCF: fraction DOC dissimilated = Percentage of actually decomposed DOC in the waste (recommended to be 77% by IPCC)
- F = fraction of CH4 in landfill gas (IPCC default is 0.5) 16/12 = conversion of C to CH4 R = recovered CH4 (Gg/yr)
- OX = oxidation factor (fraction – IPCC default is 0).

The method assumes that all the potential CH4 emissions are released during the same year the waste is disposed off. The method is simple and emission calculations require only input of a limited set of parameters, for which the IPCC Guidelines provide default values, where country-specific quantities and data are not available.

- *Heat to Power Generation Potential Calculation by Biomethanation Process*

The biomethanation process is preferred for organic waste stream with moisture content to allow for microbial activity. The typical conversion efficiency for this process is taken as 30% (Churney et al., 1989). The values for the total landfill gas (LFG) generation are taken for IPCC default model. The power recovery (PRP) and net power generation potential (NPRP) is given by (Eqs. (3) and (4)). The values for the LFG generation were taken from IPCC default model.

$$PRP = \frac{\left(\text{Total Methane Generation}\left(\frac{M}{day}\right)^{3} * \text{NCV} * 365.25\right)}{0.042 * 1000 * 24} \quad (3)$$

$$NPRP = \frac{\left(\text{Total Methane Generation}\left(\frac{M}{day}\right)^{3} * \text{NCV} * \eta * 365.25\right)}{1000} \quad (4)$$

Where NCV is the Net Calorific Value of LFG and lies in the range 0.194-0.242 kW/m3 and η is the efficiency for the bio-chemical process.0.242KW/m3 was Chosen for this study. (Chakraborty et al., 2013).

- *Power Recovery Potential using Incineration*

In order to evaluate the Waste to Energy potential from municipal solid waste using Incineration WOIMA model was used to calculate the LHV at a moisture content of 26 percent. The input parameters to the WOIMA model include the Moisture content of MSW, Geographical location of the landfill site, the percentage composition of MSW (Organic Waste, Paper waste, Plastic waste, Metal waste). In this study, the Waste to Energy potential from incineration was obtained by the equation below, equation is the expression used to calculate an estimate of the electric power that can be obtained by incineration. The percentage of incineration efficiency varies between 25 to 30 per cent according to literature (Ouda et al., 2013). In this study, a 25 percent efficiency was used and Dry Waste without moisture content was considered.

The calculation of energy recovery potential using incineration route was obtained using the following equations:

$$\text{ERP}\left(\frac{GWh}{day}\right) = \frac{\left(DryWaste\left(\frac{tons}{day}\right) * LHVofwaste\left(\frac{kWh}{kg}\right)\right)}{1000} \quad (5)$$

$$PGP(MW) = \left(\frac{Drywaste\left(\frac{kg}{s}\right) * LHVofwaste\frac{KW}{kg}}{1000}\right) \quad (6)$$

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$$Net\ Power\ Generation\ Potential(MW) = \eta * \text{PGP} \quad (7)$$

> *Levelized Cost of Energy Determination*

In this study LCOE was utilized in the selection of a suitable technology for Ndola. The LCOE is a vigorous method that helps with technology selection and decision support for electricity projects and expanding electricity portfolios. This method involved sound analysis of the following technologies anaerobic digestion and incineration. According to Nordi (2015), the main components of the Levelized cost calculation include, the development cost of a project which includes achieving planning permission and compliance with regulatory requirements.

- The capital cost of bringing a plant to operation.
- On-going fixed and variable costs of operating a renewable generator and keeping it available for generation.
- Fuel costs or gate fees and related technical assumptions such as fuel efficiency.
- Availability: defined as the maximum potential time that a generation plant is available to produce electricity annually. The factor will vary depending on how the plant is operated and the amount of downtime required for maintenance. For example, the expected availability of a gasification plant is 99 percent, allowing for maintenance downtime and parts replacement.
- Load factor: defined as the ratio of average annual output to its total potential output if a plant was to operate at full capacity over its lifetime.
- Pre-development, construction and operational time periods.

III. RESULTS AND DISCUSSIONS

> *Determination of Waste Characterization*

The MSW for Ndola include 37% Food Waste 14 % paper and Plastic % 34 Yard waste and 15 % other Waste. The Yard and Food Waste are taken as the organic content suitable for Biomethanation process with the moisture content of 25%.

The characteristics of waste collected in Ndola, as identified in the study, comprises of organic waste (food and kitchen waste and green waste), Paper/Glass which are recyclable materials (paper, Garden (leaves, branches), and other Waste (cardboard, glass, bottles, jars and tin cans, debris waste, electrical appliances)

The Chart below indicated Ndola's Waste Composition

Fig 1 Ndola Waste Composition

The Study showed that biodegradable waste was very high in Ndola waste stream coming up at 71% while Paper and plastic was at 14 percent. The finding is in line with many studies that found a large proportion of biodegradable and recyclable waste in Africa (Agbelie, 2015; Edema, 2012). The results generally reflected results from past studies on the

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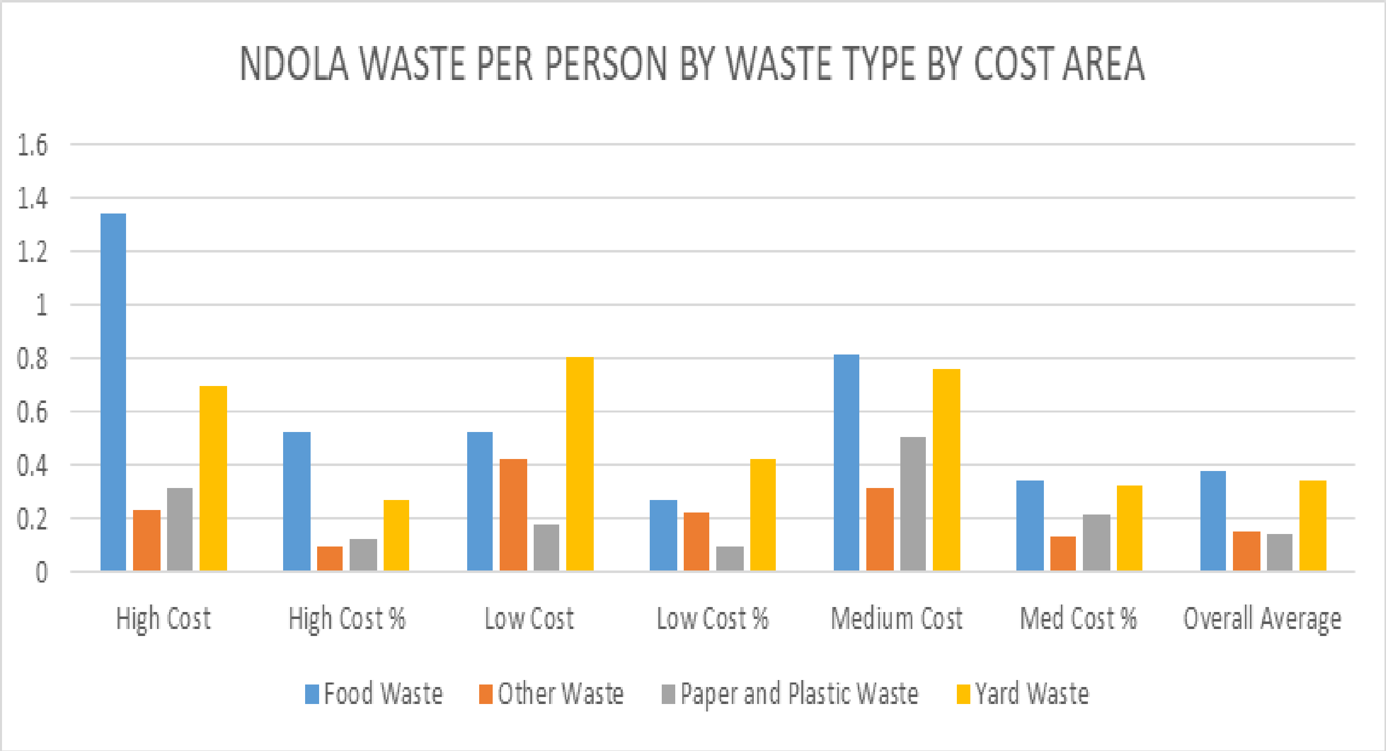

Fig 2 NDOLA Waste Per Person by Waste Type by Cost Area

Characteristics of waste in Ndola and in Zambia in general (Edema et al, 2012; Mudenda et al., 2018; Sambo et al, 2020), biodegradable waste, including food and other organic materials, have been identified to constitute the largest portion of the total MSW in Zambia.

The figure above indicates Ndola's Waste Characterization high cost, medium cost and low cost areas

➢ *Disposal Methods Used in NDOLA*

In the study the respondents were asked to indicate on how is Waste disposed of in Ndola by choosing from six disposal methods namely Burning, recycling, disposed of in landfill, left at any place of convenience and compositing.

The results show, 63.7 per cent of the respondents strongly agree with disposing waste in Landfill Site as waste disposal method in Ndola. From the point of view of respondents, the majority of waste disposed in landfill site was organic waste. Respondent also agreed that 15 percent of the waste is Recycled and 9 percent of the waste is disposed by burning. 10 percent of the respondents confirmed that 10 percent of the waste in disposed by leaving it at any place of convenience, respondents indicated that 3% of the waste is disposed by composting.

Table 1 Annual Methane and Power Recovery Potential

Year	Annual Methane Generation Gg/yr	Power Recovery Potential (MW)
2015	22.09	7.57
2016	22.5	7.71
2017	22.9	7.86
2018	23.3	8.01
2019	23.8	8.16
2020	24.28	8.32
2021	24.74	8.47
2022	25.21	8.64
2023	25.69	8.80
2024	26.18	8.87
2025	26.67	9.14
2026	27.18	9.31
2027	27.69	9.49
2028	27.22	9.67
2029	28.76	9.85
2030	29.3	10.04
2031	29.87	10.23
2032	30.43	10.42
2033	31.01	10.63
2034	31.6	10.82
2035	32.2	11.03

The Chart below shows the waste disposal methods used in Ndola in accordance with the finding

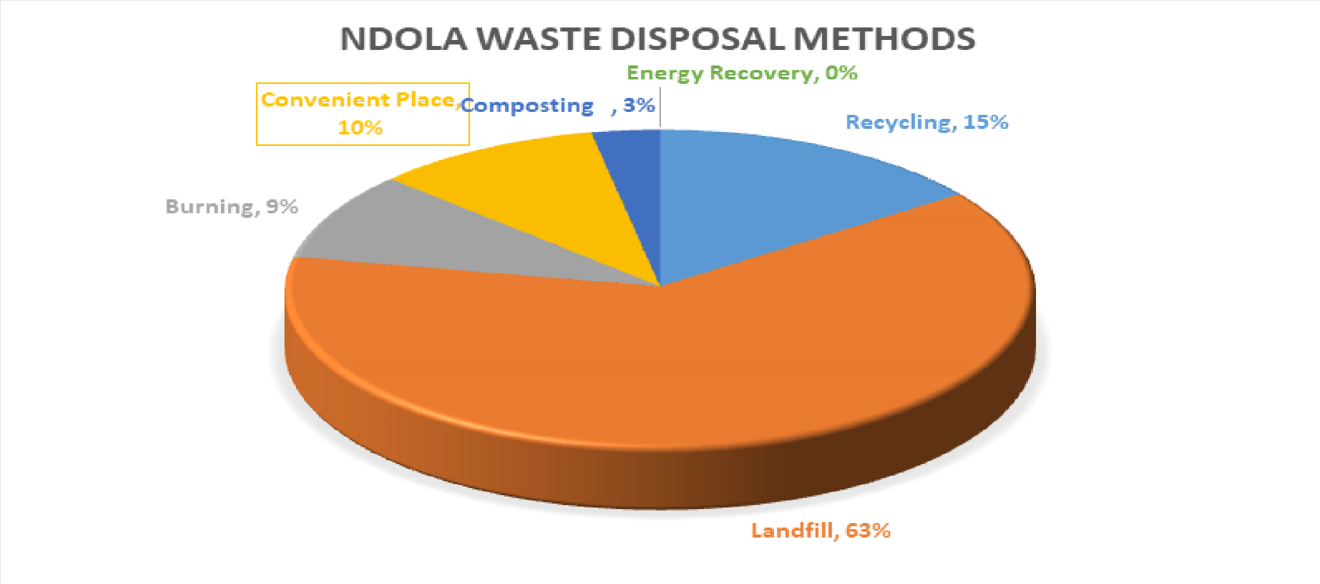

Fig 3 Ndola Waste Disposal Methods

Out of 130 house hold contacted for waste separation 10 of them failed to have the waste separated even though the households were interviewed. In High income Areas the majority of the Waste was food waste accounting for 1.34kg per person compromising nshima (Maize meal), rice and vegetables and the second was yard waste being 0.69 accounting for mainly leaves and branches and Thirdly Paper and Plastic accounting for 0.3kg of waste. Other waste was coming last at 0.23kg per person comprising mainly cardboard, glass etc.

In the Middle income Areas the majority of waste Food waste accounting for 0.8kg per person followed by Yard waste being 0.79kg per person and thirdly paper and plastic waste accounting for 0.49kg per person followed by other waste accounting for 0.3kg per person.

In low Income Areas the Predominance waste was Yard Waste accounting for 0.8kg per person, followed by food waste accounting for 0.51 kg per person. The third part of waste in Ndola low income area was other waste accounting for 0.42 kg and lastly paper and plastic standing at 0.17kg per person.

The overall average waste generated per person in Ndola was found to be 0.64kg per person in High income areas, followed by 0.59kg per person for Middle income areas and lastly 0.48 kg per person in Low income areas. The waste generated per person in Ndola was found to be therefore 0.57kg per person in this study.

➢ *Estimating Methane Production Potential from Landfills*

For the estimation of Methane production from Ndola landfill site, user specified input are used in the LandGEM Modem. Biomethanation for this study is applied and takes the organic content of waste as input to the LandGEM model.

The potential methane emission from MSW disposed at the Ndola landfill, from the year 2015 to the year 2035, as computed by the default methodology taking the values of methane correction factor as 0.6, fraction of DOC in MSW taken as 0.15, fraction of DOC which actually degrades as 0.77, fraction of carbon released as methane as 0.5, conversion ratio as 16/12, potential methane generation rate as 0.08 and realized methane generation rate per unit of waste as 0.05. The methane emission for different population ranges from 22.1Gg in the year 2015 to 32Gg in the year 2035 as demonstrated in Table 1.

Based on values generated in line with the volume of generated methane form MSW in Ndola landfill, taking into account the population increase, the current study assumed that it was appropriate to install methane capturing facilities. Values clearly demonstrated an increase in methane production from the year 2015 to the year 2035. The assumption made in the default methodology was that the potential methane is emitted in the same years from the year 2015 to the year 2035 for which the solid wastes were deposited yearly. Because of the high methane content, Landfill Gas (LFG) fugitive emissions were a major threat to the environment (Lizik et al., 2013; Jung et al., 2011.

The current study assumed that, the percentage of MSW sent to landfills was 70 percent based on the LandGEM default Method. The remaining 30 percent was assumed to be lost due to recycling, waste burning at source as well as at disposal site, waste thrown into the drains and waste not reaching the landfills due to inappropriate solid waste management system.

Table 2 Power Generation and Energy Recovery Potential

Year	Power Generation Potential (MW)	Energy Recovery Potential (GWH)
2015	21.56	0.51
2016	21.97	0.52
2017	22.39	0.54
2018	22.81	0.55
2019	23.25	0.56
2020	23.69	0.57
2021	24.14	0.58
2022	24.59	0.59
2023	25.06	0.60
2024	25.54	0.61
2025	26.03	0.624
2026	26.52	0.637
2027	27.03	0.649
2028	27.54	0.661
2029	28.06	0.674
2030	28.59	0.686
2031	29.14	0.699
2032	29.69	0.713
2033	30.26	0.726
2034	30.83	0.740
2035	31.42	0.754

The Table 2 above summarizes the annual methane generation potential in Giga gram per year. The Table is also indicative of the Power recovery potential in MW from Biomethanation.

➢ *Methane and Power Recovery Potential from Municipal Solid Waste using Biomethanation*

The results for Power Generation potential from biomethanation process for the period from 2015 to 2035 is shown in Table 1. The Minimum total Methane production from Landfill is estimated to be 39308.2618 M3/yr. in the year 2015 giving a Net Power Generation Potential of 7.57MW and the Maximum Methane Generation Potential was estimated to be 57275.9727M3/yr. in the year 2015 giving a Net Power Generation Potential of 11.03MW.

The results of equations for power recovery are indicative of potential for Power recovery Potential and Net Power recovery potential from Ndola MSW disposal from Landfill. There was an increase in MSW generated due to increase in population as indicated in Table 1. The increase in MSW resulted in the increase in Power Recovery Potential from 7.57MW in 2015 to 11MW in 2035 as indicated in Table 1.

The actual Power Recovery Potential and Net Power Recovery Potential from Biomethanation was computed using equation 3 and 4. PRP is the Power Recovery Potential and NPRP is the Net Power Recovery Potential.

The biomethanation process is preferred for organic waste stream with moisture content to allow for microbial activity. The typical conversion efficiency for this process is taken as 30% [Gotmare et. al., 2011]. The values for the total land fill gas (LFG) generation are taken from IPCC default method.

The NCV is the Net Calorific Value of LFG and lies in the range 0.194-0.242 kW/m3 and ɳ is the efficiency for the bio-chemical process.

➢ *Power Generation Potential by Incineration*

The results for Power Generation potential from Incineration process for the period from 2015 to 2035 is shown in Table 1. The results are indicative of a systematic increase in Net Power Generation Potential and energy Generation Potential due to the continuous increase in Waste Generation as indicated in Table 1 below. The dry matter content was considered by removing the 25% moisture content from the Waste.

The Power Generation Potential increased from 21.56MW in 2015 to 31.14MW in 2035. Conversely the Net Power Generation Potential increased from 21.56MW in the year 2015 to 31.42MW in the year 2035.The Energy Recovery Potential also increased from 0.518 GWh in the year 2015 to 0.75 GWh in the year 2035.

The Table 1 below summarizes Power Generation potential and Energy recovery potential from Incineration.

➢ *LCOE calculations*

The cost analysis used in this study to compare WTE technologies was obtained through levelized Cost of Energy of the Two Scenarios namely Biomethanation and Incineration were considered.

The Incineration process is the most widely used waste to energy technology in the world incorporating both Heat recovery and Electricity Generation. The Incineration process has a high capital and investment cost compared to Biomethanation. The higher efficiency allow for daily through put and labor skill requirements of incineration plants makes it more favorable use in most countries. The levelized Cost of electricity for incineration was found to be $0.015/kwh and the levelized cost of electricity for Biomethanation was found to be at $0.00755/kWh.

Biomethanation process has the lowest Annual Investment cost of $138, 000, 000 for 100MW capacity plant and operational and Maintenance cost (Variable and Fixed) of 20 percent of Investment cost. Biomethanation process is likely to offer ideal economical solution for problems associated with Waste Management in the City of Ndola. It is also important to note that the majority of the waste ends up in landfill sites offering a favorable generation of Methane as a source of energy. This is the effective technology with organic waste standing at 71%, moisture content at 25% key ingredient for Biomethanation process.

IV. DISCUSSION OF FINDINGS

This study indicated a variation of Waste disposal methods used in Ndola from Recycling 15% disposed at any place of convenience 10 % burning 10%, landfilling 63%, and composting 3% .The study showed a high incline towards landfilling as a disposal methods which makes Biomethanation a more favorable WtE method to be applied.

The Study showed a high activity of waste pickers that are mainly picking recyclable waste. The 15% recyclable waste has high energy content substrate. This abundant presence of plastic and paper in developing countries waste stream, has raised concern about recycling and circular economy, noticing an important participation of waste pickers in this particular industry (WIEGO, 2016)

The same recyclable materials are what is needed for Incineration plant. This makes Incineration deprived of key input as they are picked by waste pickers

The MSW studied in this study depicted waste composition of Organic Content 71% paper and plastic 14 % and other waste 15%. The study also found moisture content of 25%. The high organic content and high moisture content provides important feedstocks for Biomethanation.

The High organic content of MSW depicted in this study further favors Biomethanation process for WtE.

This study underscored that waste management is the privilege field of people with low educational back ground in Ndola standing at 87.4% who have not attained grade 12 certificate. The Study underscored high content of Waste burned 10 percent and Waste disposed at any place of convenience 3%. This is due to lack of infrastructure, proper transportation, and Waste management practice in the city of Ndola. The current study is supported by a study which stated that the lack of infrastructure for collection, transportation, treatment and final disposal of waste, management planning, financial resources, know-how and public attitude reduces the chances of improvement in Waste management. (Srivastava et al; 2015).

The current study established an increase in methane emission from 22.1Gg/yr. in the year 2015 to 31.6Gg/yr. in the year 2035 due to population increase resulting from urbanization as demonstrated in table 1. This has a potential to harness and to overcome energy downturn in Zambia, particularly in Ndola.

The finding of this Study was in line with (Chander Kumar Singh 2018) who stated that Economic development drives the population to move to cities where basic infrastructure and amenities are available. This diversion of the population subsequently leads to changes in the overall lifestyle and living standards and thereby increases the per capita generation of MSW. We found that the higher the population density, the more MSW was generated. The power Generated from Biomethanation increase from 7.57MW in the year 2015 to 11.02MW in the year 2035

Municipal Solid Waste (MSW) in Ndola contains organic as well as inorganic matter as evidenced in fig 1. The potential of energy recovery through incineration route is quite appreciable according to findings, many studies around the world have valued incineration as ambitious technology in reducing waste volume as well as reduction of land field spaces in urban areas by producing energy (Avinash A. Patil and Kulkarni; 2015; Solano; 2002).

The current Study found an increase in Power Generation Potential from 21.56MW in the year 2015 to 31.42MW in the year 2035. The study considered an incineration efficiency of 25% which resulted in the Net Power Generation potential of 5.49MW in the year 2015 and 7.85MW in the year 2035. The increase was due to the increase in Waste Generation Rate resulting from Population Growth at a rate of 1.9 percent per annum. Although incineration is viable with regard to mentioned studies, an incineration plant involves heavy investments and high operating costs (Ouda et al; 2015) and is deprived of high energy content feedstock due to the law of waste pickers.

The most Suitable Technology was also evaluated on the basis of, Levelized cost of energy, availability of Degradable organic waste Stream, higher efficiency, lowest annual capital and operational cost.

The levelized cost of energy for incineration was found to be $0.015/kwh. The investment and operational and maintenance test for incineration was found to be higher than for biomethanation. The levelized Cost of energy for Biomethanation was found to $0.00755/kWh.

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REFERENCES

[1]. Ahsan Farooq, Piyanon Haputta, et al., 2021;A Framework for the Selection of Suitable Waste to Energy Technologies for a Sustainable Municipal Solid Waste Management System 2021

[2]. Kaza, S., Yao, L., Bhad-Tata, P., and Woerden, F. V. (2018). What a Waste 2.0: A Global Snapshot of Solid Waste 2050. Washington, DC: The World Bank. doi: 10.1596/978-1-4648-1329-0

[3]. Lemaire X, Bawakyillenuo S, and Agbelie: Waste to Energy: African Cities can Transform their energy Landscape 2015 May 18

[4]. A. Mavropoulos, D. Wilson, C. Velis, J. Cooper and B. Appelqvist, "Globalization and Waste Management. Phase 1: Concepts and Facts," International Solid Waste Association, Wien, 2012.

[5]. United Nations, Department of Economic and Social Affairs, Population Division, "Probabilistic Population Projections based on the World Population Prospects: The 2015 Revision," United Nations, New York, 2015.

[6]. Scarlat et al., 2015; Bogner et al., 2003:Evaluation of energy potential of Municipal Solid Waste from African urban areas,2015

[7]. Munawar and Fellner: Landfilling in Tropical Climates – Measures for Better Design and Operation,2017

[8]. Bogner, J., M. Abdelrafie Ahmed, C. Diaz, A. Faaij, Q. Gao, S. Hashimoto, K. Mareckova, R. Pipatti, T. Zhang, Waste Management, In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

[9]. Zambia Environmental Management Agency 2011. The Enviro-Line. Longman, Lusaka

[10]. joy sambo , mazuba muchindu , sikopo nyamb1 , taro yamauchi Sustainable Solid Department of Social Work and Sociology, School of Humanities and Social Sciences, University of Zambia, Zambia 3 Research Institute for Humanity and Nature, Japan: Waste Management: An Assessment of Solid Waste Treatment in Lusaka, Zambia

[11]. Zuo, J.; Zhao, Z.Y. Green building research–current status and future agenda: A review. Renew. Sustain. Energy Rev. 2014, 30, 271–281

[12]. World Health Organisation. Guidelines for Drinking-Water Quality, 3rd ed.; WHO Libr. Cat. Data: Geneva, Switzerland, 2004 World Bank.

[13]. World Bank (2017). Municipal Solid Waste (MSW) PPPs. Washington DC: World Bank Group. https://ppp.worldbank. Org/public-private-partnership/sector/solid-waste

[14]. Srivastava, V.; Ismail, S.A.; Singh, P.; Singh, R.P. Urban solid waste management in the developing world with emphasis on India: Challenges and opportunities. Rev. Environ. Sci. Bio-Technol. 2015, 14, 317–337.

[15]. Soltani, A., Sadiq, R., and Hewage, K. (2016). Selecting sustainable waste-to- energy technologies for municipal solid waste treatment: a game theory approach for group decision-making. J. Clean. Prod. 113, 388–399. doi: 10.1016/j.jclepro.2015.12.041

[16]. Ouda, O. K. M., Raza, S. A., Nizami, A. S., Rehan, M., Al-Waked, R., and Korres, N. E. (2016). Waste to energy potential: a case study of Saudi Arabia. Renew. Sustain. Energy Rev. 61, 328–340. doi: 10.1016/j.rser.2016.04.005

[17]. Ofori-Boateng, C., Lee, K.T. and Mensah, M. (2013), "The prospects of electricity generation from municipal solid waste (MSW) in Ghana: a better waste management option", Fuel Processing Technology, Vol. 110, pp. 94-102.

[18]. Moya, D., Aldás, C., López, G., and Kaparaju, P. (2017b). Municipal solid waste as a valuable renewable energy resource: a worldwide opportunity of energy recovery by using waste-to-energy technologies. Energy Proc. 134, 286–295. doi: 10.1016/j.egypro.2017.09.618

[19]. Nordi GH (2015) Technical-economic evaluation of WTE (waste-to-energy) plants based on steam Power cycles. Santo Andre: Federal University of ABC

[20]. Kumar, S.; Gaikwad, S.A.; Shekdar, A.V.; Kshirsagar, P.S.; Singh, R.N. Estimation method for national methane emission from solid waste landfills. Atmos. Environ. 2004, 38, 3481–3487