

# COMPARATIVE STUDY OF WASTE TO ENERGY CONVERSION PROCESSES (ANAEROBIC DIGESTION AND LANDFILL GAS TO ENERGY) USING LIFE CYCLE ASSESSMENT TECHNIQUE

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## ABSTRACT

Waste-to-energy Conversion processes are considered as one of the key waste treatment technologies due to their energy and heat recovery efficiencies from the waste. A number of research studies were carried out to understand the potential environmental loads from such processes. This study aimed at analysing Waste to Energy Conversion Processes (Anaerobic Digestion and Landfill Gas to Energy) through life cycle assessment model. The processes were studied using GaBi software (Version 9.1.2.68) based on input-output materials flow. The software was used to analyse the environmental burden by the selected impact categories namely acidification, eutrophication, global warming, abiotic depletion, human toxicity and odour potentials. It was revealed that Landfill gas to energy process has higher impact on all the impact categories. Among the two processes, Anaerobic Digestion was found to be comparatively more favourable to environment than Landfill gas to energy. It is recommended that further study be carried out on the economic feasibility of the two processes.

**Keywords:** *Waste to Energy; Environmental assessment; Anaerobic Digestion; landfill Gas -to-energy*

## 1 INTRODUCTION

High levels of greenhouse gas (GHG) emissions mainly due to fossil fuel consumption, poised threat to the world as a result of global warming. Industrial and economic development is mainly responsible for the continuous increase in GHG emissions [1]. The world Bank, in 2017, reported that, the global solid waste generation was estimated at about 2.01 billion tonnes, with projected increase to about 3.40 billion tonnes by the year 2050 [2]. For environmental sustainability, alternative means of energy generation and sustainable waste management will replace global dependence on the use of fossil fuels for power demands. In most developing countries, the existing infrastructural facilities for waste management and energy supply are inadequate to keep pace with the rate of waste generation and energy demand [3]. According to [4], effective management, utilization and conversion of MSW to useful energy (WTE) have the potential to cut down carbon emission footprint and could be a means of providing a sustainable and environmentally friendly solution to bridging the gap between energy and the environment. Waste to energy (WTE) processes are therefore, regarded as a viable and promising solution for effective management of the staggering amount of waste generated as well as energy generation [5]. The WTE technologies have been greatly modernised and prioritised in many countries especially in the developed nations with Significant progress on their applications as waste management options and methods for producing cleaner energy. In 2012, the United States of America generates 14.5 million MWh of electricity from 84 WTE facilities [6]. However, the adoption of the WTE technologies in Nigeria, for effective utilization and

conversion of MSW to useful energy is low. [3] reported that, while waste to energy technologies have been developed to a considerable extent in most countries around the world, Nigeria is yet to develop her potential in this regards due to lack of concrete scientific information that could encourage the development of such technology. WTE can occur through a number of processes such as incineration, gasification, pyrolysis, anaerobic digestion, and landfill gas recovery. However, similar to conventional energy generation from fossil fuels, WTE also lead to GHG emissions and other environmental impacts, such as Eutrophication, Human toxicity, Abiotic Depletion Potential, Acidification Potential, and so on. Therefore, it is imperative to study the environmental impacts of WTE technologies to estimate their potential to create a sustainable environment [5]. Life Cycle Assessment (LCA) is a tool for quantifying the environmental performance of products taking into account the complete life cycle, starting from the production of raw materials to the final disposal of the products, including material recycling if needed [7]. It is beneficial for the decision-makers for the selection of the most sustainable WTE process and identifying potential factors for improvements [8]. Quite a lot of researches have adopted the application of Life Cycle Assessment (LCA) to compare the environmental impacts of different WTE options. Their outcomes have been used to identify the WTE conversion processes(s) which are relatively suitable in terms of environmental performance. Thushari *et al.* [9] assessed the environmental impacts of the different waste management systems (landfilling, recycling, composting, and incineration) using LCA base on ISO 14040 and 14,044 standards. The LCA results found landfilling to be the dominant source of greenhouse gas (GHG) burdens, while waste recycling was found to result in the reduction of GHG. Mayer, Bhandari and Gäth [10] carried out a Critical analysis of 195 and 68 peer-reviewed studies on environmental life cycle assessment (LCA) of waste-to-energy (WTE) technologies in European and Asian regions respectively. The authors found out that, a majority of the analyzed studies were marked by several shortcomings and showed poor compliance with the ISO 14040 and ISO 14044. Their results also showed that 55 studies did not present a functional unit and 45% of all reviewed studies did not present a life cycle inventory. Tong *et al.* [11] conducted an LCA to determine the extent to which the proposed integration of AD and gasification is environmentally friendly and sustainable by comparing it with direct incineration and other AD strategies (AD followed by compost or incineration). LCA results showed that compared to incineration, AD scenarios exported more electricity and achieved significant improvement in all the impact categories except for eutrophication (Eutro) and photochemical ozone creation (POC), while the poorer performance of AD in Eutro and POC was caused by high NO<sub>x</sub> and CO emissions from the biogas engine. In Nigeria, several studies were reported on the energy potentials of MSW to produce energy. However, studies on LCA and environmental impacts of WTE technologies were found to be minimal in the literature [12, 13]. Esae *et al.* [14] carried out a critical review and an in-depth analysis to assess the socio-environmental and economic benefits of energy generation from MSW in Nigeria using secondary data. The authors reported that anaerobic digestion (AD) and combined heat and power (CHP) are the most suitable in Nigeria where the emissions of GHGs are rapidly increasing due to over-dependency on fossil fuel. Ayodele *et al.* [3] carried out an LCA to compare environmental benefits of different waste to energy treatment plants {landfill gas to energy, hybrid of incineration and anaerobic digestion and hybrid of incineration and landfill gas to energy} with landfilling for electricity generation in each of the twelve selected cities of Nigeria, in order to determine the option that best fit the locations in an environmentally sustainable manner. Their results revealed that, hybrid of Incineration/Anaerobic Digestion is potentially viable compared to other methods in terms of Global warming potential (GWP), while Landfilling Gas to Energy technology is the best in terms of carcinogenic reduction potential. Ogundipe and Jimoh [15] have used a life cycle assessment (LCA) methodology to determine a municipal solid waste (MSW) management strategy for Minna, Niger State, Nigeria. The authors used SimaPro 7.2 educational software to model three scenarios as alternatives to the current waste management system in Minna. Their research results showed that scenario 1(Recycling/Composting/Landfilling) had a greatest reduction in global warming, carcinogen, ecotoxicity and acidification potentials and therefore found to be the best and most favourable alternative in Minna city. Despite the few previous work on WTE in Nigeria, none of them have conducted life cycle/environmental impact of WTE conversion processes in Kano. This paper, therefore, analyse the environmental performance of two selected WTE processes (Anaerobic Digestion and Landfill Gas to

Energy) for energy generation in Kano metropolis through Life cycle assessment of their environmental impact categories for sustainable environment.

## 2 MATERIALS AND METHODS

### 2.1 Study Area

The research area, Kano metropolis, is the capital of Kano State. Koko *et al.* [16] reported that, it is located between latitudes 11°51' and 12°08' North of the Equator and longitudes 8°25' and 8°39' East of Great Meridian at an average altitude of approximately 472 m above sea level. It comprises eight local governments with a projected population of more than 3 million, as at 2011 [17].

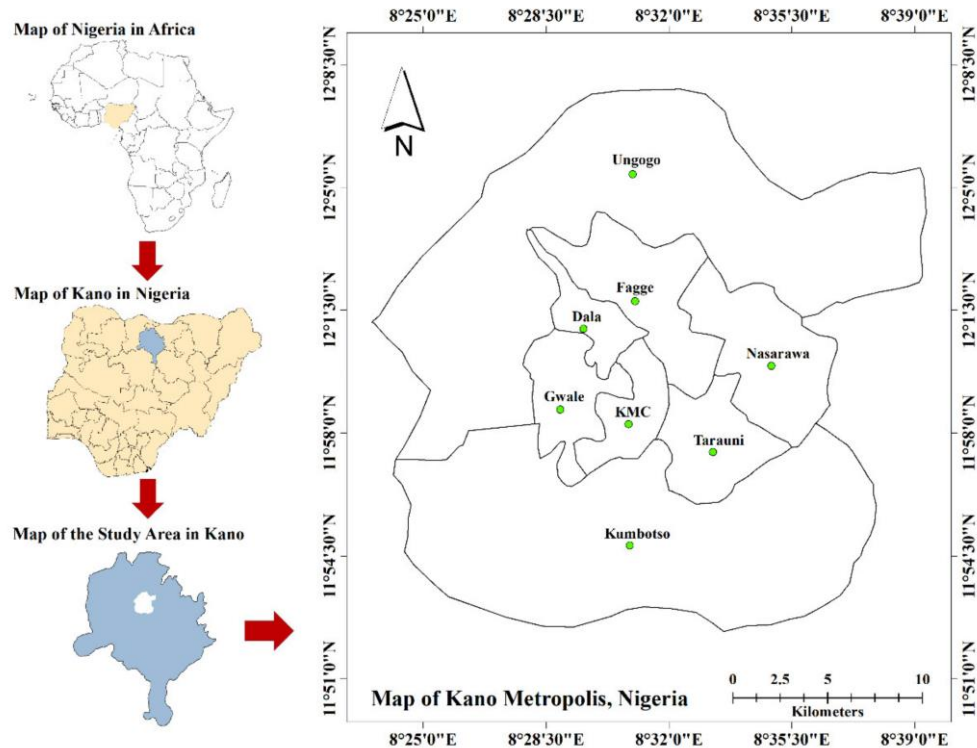


Figure 1. The study area (Kano Metropolis, Nigeria)

### 2.2 Determination of environmental impacts of the WTE processes through Life Cycle Assessment model.

The LCA model of the WTE conversion processes was developed using GaBi Education software (Version 9.2.68), by considering the four core LCA principles (goal and scope definition, inventory analysis, impact assessment, and improvement assessment). The Centre for Environmental Studies (CML 2001 - Jan. 2016) method has been applied to analyse the environmental burdens from the various processes by different impact categories (i.e. acidification, eutrophication, global warming, abiotic depletion, human toxicity and odour potentials).

#### 2.2.1 Goal and scope

The study developed an LCA model and compare two WTE Processes (i.e. Landfill gas to energy and Anaerobic) that may be implemented in Kano metropolis. The Gabi database was used to obtain the environmental loads. the functional unit (reference flow) will be considered as a tonne of MSW. System boundaries: The respective masses of the waste components of MSW will be considered as the input materials, while slag or solid residue, emission to the air and electricity generation are considered as the output of the LCA models.

2.2.2 Assumptions to be used in the LCA model

The following assumptions were made: All environmental impacts generated from the production of a product prior to becoming a waste were neglected, therefore the life cycle of the MSW begin after it has been discarded. This is called Zero Burden assumption. The waste collection and transportation will be the same and therefore omitted from the LCA. All the WTE plants are located at the outskirts of Kano city at an equal distance from the transfer station. Hence, emission as a result of waste transportation for each process will be the same and neglected [18]. Energy and emission during construction of the waste to energy handling facilities will be neglected. The environmental impact analyses for all the waste to energy processes will be carried out over a period of 20 years (2020–2040).

2.2.3 Lifecycle Inventory Analysis

This is conducted by collecting inventory data (i.e. input and output flow, such as material needed and released, emission, and energy consumed and produced) from the waste characterization study of Kano metropolis, journals, manual books, articles, GaBi Education software database and other references related to this study. Databases in the software was studied and filtered for relevancy and subsequent addition to the inventory.

2.2.4 Life cycle impact assessment

This was also done Impact assessment in Gabi Education software through the input of the inventory data. The impact categories for the study were selected from CML 2001 which encompassed of acidification, eutrophication, global warming, abiotic depletion, human toxicity and odour potentials. These categories were chosen base on the fact that many related studies have discussed them, as they had significant effects on the environment and humans.

3 RESULTS AND DISCUSSIONS

Environmental impact assessment of the LCA model was presented in characterization and normalization methods. The characterization results represent the contribution of the potential environmental burdens through different impact categories. Inventory of the characterization gave the idea not only on the specific polluting substances that is responsible, but also the process phases for the environmental burdens. Figure 1 shows the system boundary for the LCA model. Results are presented in the different impact categories of the LCA model.

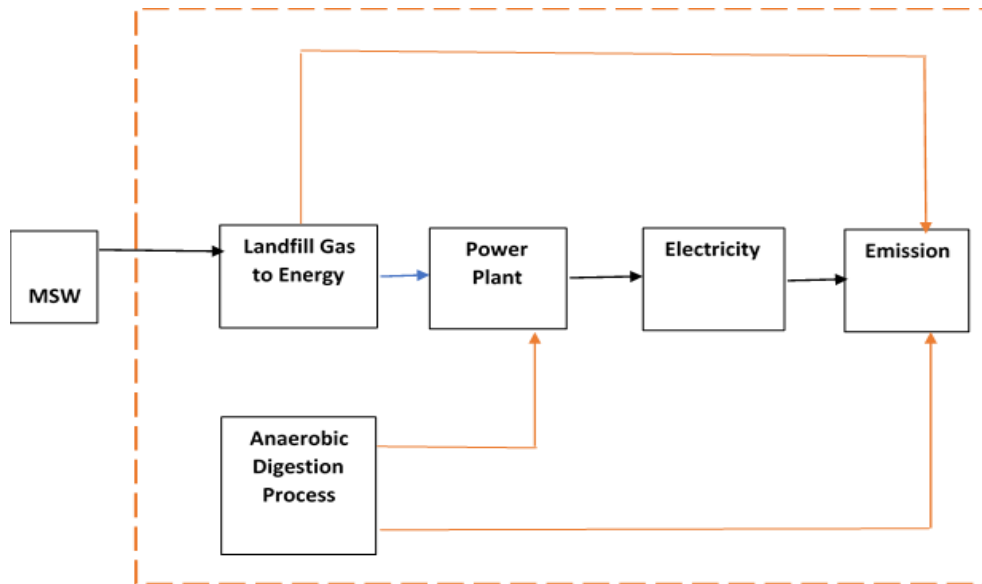


Figure 2. System boundary for the Waste to Energy Conversion processes

Table 1. Life Cycle Inventory (LCI) Data for the WTE processes

	Anaerobic	LFGTE
Input/output Flows		
Diesel (kg)	-	2.5 (*)
Electricity (MJ)	3.6 (¥)	3.6 (¥)
Natural gas ((kg)	-	-
Textiles ((kg)	-	1.9kg (α)
Paper ((kg)	-	1.0kg (α)
Wood ((kg)	-	0.5kg (α)
Rubber ((kg)	-	0.6kg (α)
Food Wastes ((kg)	3.9 (α)	3.9kg (α)
Air Emissions		
Carbon dioxide, fossil ((kg)	0.2 (β)	30.00 (β)
Nitrogen oxides ((kg)	0.57 (β)	15.00 (β)
Sulphur dioxide ((kg)	0.009 (β)	-
Sulphur oxides ((kg)	-	-
Dioxins ((kg)	-	-
Other emissions to air ((kg)	-	-
Methane (VOC) ((kg)	-	5.00 (β)
Carbon dioxide (Land use change) ((kg)	-	20.00 (β)
Carbon monoxide ((kg)	-	277.79(β)
Carbon monoxide, from soil or biomass stock ((kg)	-	92.60 (β)

Note: ¥Estimated; \* Literature; αMeasured; βCalculated

Table 2. Impact categories for Anaerobic Digestion process

Life Cycle Anaerobic Digestion	
Environmental quantities, CML 2001 - Jan. 2016	
Acidification Potential (AP) [kg SO2 eq.]	0.30
Eutrophication Potential (EP) [kg Phosphate eq.]	0.07
Global Warming Potential (GWP 100 years) [kg CO2 eq.]	0.20
Human Toxicity Potential (HTP inf.) [kg DCB eq.]	0.69
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	0.02
Odour Potential [kg H2S eq.]	0.01

Table 3. Impact categories for Landfill Gas to Energy process

Life Cycle Landfill Gas to Energy	
Environmental quantities, CML 2001 - Jan. 2016	
Global Warming Incl Land Use Change (LUC)	
Acidification Potential (AP) [kg SO2 eq.]	7.50
Eutrophication Potential (EP) [kg Phosphate eq.]	1.95
Global Warming Potential (GWP 100 years) [kg CO2 eq.]	170.00
Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO2 eq.]	170.00
Human Toxicity Potential (HTP inf.) [kg DCB eq.]	18.00
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	10.50

Table 4. Comparison of the environmental impact categories for the WTE Processes

Impact Categories	Anaerobic Digestion	LFGTE
AP [kg SO2 eq]	0.3	<b>7.5</b>
EP [kg PO4 eq.]	0.07	<b>1.95</b>
ADP [MJ]		
HTP [kg 1,4-DB eq]	0.69	<b>18</b>
GWP 100 [kg CO2 eq]	0.2	<b>170</b>
PCOP [kg C2H4]	0.02	<b>10.5</b>
Odour Potential [kg H2S eq.]	0.01	

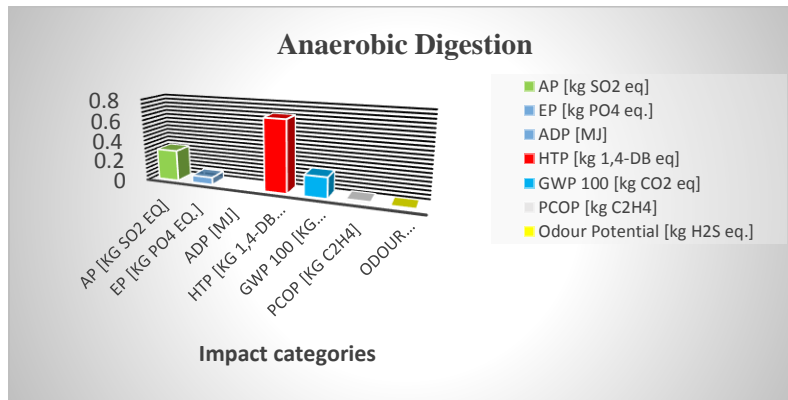


Figure 2. Environmental Impact Categories of Anaerobic Digestion Process

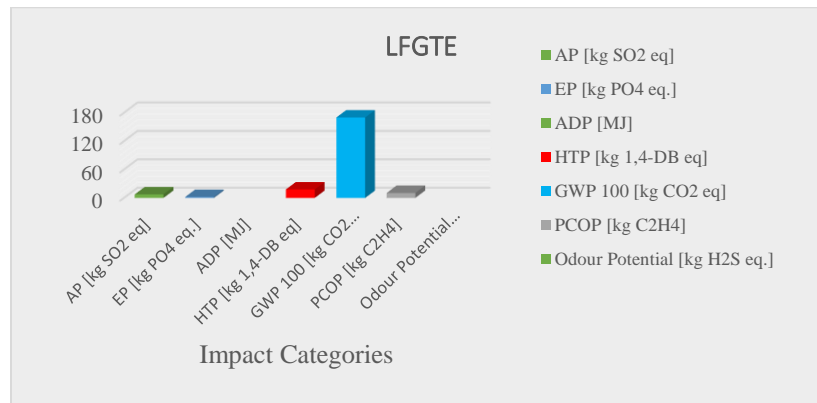


Figure 3. Environmental Impact Categories of LFGTE Process

The environmental impact assessment of each of the WTE process was performed based on CML 2016 methodology and then expressed as Global Warming Potential (GWP), Acidification Potential (AP), Abiotic Depletion Potential (ADP), Photochemical Oxidation Potential (PCOP), Human Toxicity Potential (HTP) and Odour Potential. The results of the impact categories for the considered WTE processes are shown in Tables 2 and 3. Table 4 shows the values illustrated in bold font representing the highest environmental impact levels, while the italic font demonstrates the lowest level of environmental impacts for each impact category. From Figures 2 and 3, LFGTE has the higher environmental impact in EP (1.95 kg PO4 eq.), GWP (170 kg CO2 eq.), AP (7.5 kg SO2 eq.), HTP (18kg 1,4-DB eq.), and PCOP (10.5 C2H4 kg eq)). The Anaerobic Digestion has the least environmental impact in all the selected categories. This tallied with a similar research carried out by Nubi *et al.* [19] where it was concluded that the environmental impacts and energy balance of AD was preferable for Lagos and Abuja having the least environmental impact for all the impact categories.

#### 4 CONCLUSIONS

A comparative analysis of waste-to-energy processes (Anaerobic Digestion and Landfill Gas to Energy) for electricity generation in Kano metropolis, Nigeria have been carried out. It was concluded that Anaerobic Digestion has the lowest environmental impacts for Kano metropolis based on all the impact categories selected and therefore more favourable for the environment. It is therefore recommended that further study be carried out to determine the economic feasibility of the Waste to Energy conversion processes.

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