



EVALUATION OF SAFETY CHALLENGES AND ENVIRONMENTAL BENEFITS IN WASTE TO ENERGY TECHNOLOGIES IN LAGOS, NIGERIA

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Abstract

This study examined the safety challenges and environmental benefits of waste to energy (WTE) technologies in Lagos, Nigeria aimed at; identifying the specific Waste-to-Energy technologies currently implemented in Lagos, Nigeria. Identifying the main safety challenges connected to the implementation of Waste-to-Energy technologies in Lagos, Nigeria and Investigating the environmental benefits in operating Waste-to-Energy technologies in Lagos, Nigeria. A cross-sectional research design technique was used while questionnaire was used for data collection. Purposive sampling technique was used to sample 384 respondents from the waste-to-energy firms in Lagos. Quantitative data were analysed using descriptive statistics (Percentage, Mean and standard deviations). The results of descriptive analysis showed that Incineration and anaerobic digestion system with mean values of 0.60 and 0.54 respectively were the only two Waste-to-Energy technologies implemented in Lagos. Weak regulation oversights, exposure to toxic emissions and inadequate staff training on safety are three topmost safety challenges facing waste-to-energy system in Lagos, (mean scores 0.59, 0.58 and 0.56 respectively) while Reduction in landfill overflow, Reduction in illegal and open dumping of waste, cleaner environment and Cleaner energy production are benefits of waste-to-energy system (mean score of 0.64, 0.64, 0.63 and 0.63 respectively).). it was concluded that WTE system is a double-benefit system because it provides energy as well as reduces environmental pollution from waste. It was recommended that other states in Nigerian should adopt WTE systems

Keywords:

Safety Challenges, Environmental Benefits, Waste-To-Energy (WTE) Technologies, Lagos, Nigeria.

1.0 Introduction

Waste, at its core, is defined as any substance or object discarded after primary use, or which is superfluous, defective, or of no further use to the owner (Institute for Environmental Research

and Education Team, 2025). It encompasses materials produced through human or industrial activity, as well as unwanted byproducts, residues, or materials that no longer serve their intended purpose, ultimately ending up in landfills, incinerators, or, ideally, undergoing recycling or recovery processes. Recovery is one aspect of sustainable waste management that is based on the well-known hierarchy of “prevention” “reuse”, “recycling”, “recovery” and “disposal”. Landfills, while often the most convenient solution, can leach harmful contaminants into the soil and groundwater. Incineration, while reducing volume, can release air pollutants (Siddiqua *et al.*, 2022). Ferdoush *et al.* (2024) noted that waste generation is a significant environmental challenge that is rapidly increasing globally.

The rapid growth of urbanization and industrialization has led to an unprecedented increase in global waste generation, posing significant environmental and public health challenges (Voukkali *et al.*, 2023). The traditional waste disposal methods, such as open dumping, contribute to soil and water pollution, greenhouse gas emissions, and the depletion of valuable land resources (Al-Wabel *et al.*, 2022). As the global population is anticipated to increase in the coming decades, there is a projected surge in waste generation at an unprecedented pace. In recent years, the acceleration of urbanization, industrialization, and economic growth has led to an intensified pace of waste generation (Abdulfatah 2023). Urbanization, which is a natural consequence of rapid population growth, is not a problem in itself, however it leads to several environmental problems such as damages to public spaces and wetlands, air and water pollution and solid waste generation as a result of random and unplanned growth (Ikizoğlu & Koçak, 2020). Municipal Solid Waste (MSW) among various waste types has emerged as the most substantial contributor (Islam, 2016). Samarasiri *et al.* (2017) opined that, MSW includes waste originating from residential, institutional, and industrial sources and comprises a vast array of substances, including food and vegetable waste, paper, plastics, metals, glass, textiles, wood, grass, leaves, and various organic and inorganic substances. Kumarasiri and Dissanayake, (2021) stated that the amount of waste generated globally is truly astounding, with the World Bank estimating an annual production of almost 1.3 billion tons of MSW, and this figure is predicted to rise to 2.2 billion tons by 2025 and further escalate to 2.59 billion tons per year by 2030. By 2050, it is predicted that the annual MSW generation will reach a staggering 3.4 billion tons, presenting a formidable environmental challenge (Sharma & Jain, 2020).

Waste-to-Energy (WTE) refers to the recovery of heat and power from waste, and in particular non-recyclable waste (Zhang *et al.*, 2015). Traditionally, renewable energy has referred to resources that are replaceable or inexhaustible in nature, such as hydro, solar, and wind energy, as well as bioenergy. Waste-to-Energy (WTE) conversion technologies have emerged as a sustainable solution to address global waste management challenges while simultaneously generating renewable energy. Turning waste biomass into energy is a sustainable replacement for fossil fuels while addressing waste management problems (Thakur *et al.*, 2025). Thermochemical conversion processes, such as pyrolysis, gasification, and hydrothermal liquefaction, as well as biochemical conversion processes such as fermentation and anaerobic digestion, can generate sustainable biofuels, biogas, biochar, and syngas from biomass (Jha *et al.*, 2022). The digestion produces biogas and digestate. Biogas can be used as fuel for power generator. Digestate can be composted for use as a soil conditioner or dewatered and used as a low calorific value refuse-derived fuel. For both thermochemical and biochemical processes, constant and stable efficiency parameters such as temperature, pH, residence time, and biomass feedstock composition are critical to the efficiency of the technologies (Afshar & Mofatteh, 2024).

Waste-to-Energy (WTE) technologies consist of any waste treatment process that creates energy in the form of electricity or heat from several types of waste: from the semi-solid (e.g., thickened sludge from effluent treatment plants) to liquid (e.g., domestic sewage) waste (UNFCCC, 2023).

The following are the types of Waste to Energies technologies: Pyrolysis, Gasification, Plasma Gasification, Anaerobic Digestion, Mechanical Recycling, Chemical Recycling and Composting. Minimizing the environmental impacts of waste management is key to sustainable use of the ecological environment. The WTE market is growing at an unprecedented rate, with reports showing growth from \$19 billion in 2012 to at least \$29.2 billion by 2022 (Iyamu *et al.*, 2017). Embracing decarbonization technologies in the energy sector is very important to curtail CO₂ emissions and move toward a low-carbon future (Debnath *et al.*, 2023). Among various sources of clean energy, Waste to Energy (WTE) is recognized as a renewable energy source that efficiently converts discarded Municipal Solid Waste (MSW) into electricity and heating steam, making it a more sustainable alternative to landfilling with reduced land requirements and solid waste volume (Hu *et al.*, 2018). Abdulfatah (2023) noted that proper handling of MSW poses a significant challenge for a developing nation like Nigeria. The current most known WTE technologies are; Incineration, which is direct combustion of municipal solid waste (MSW) and/or refuse-derived fuel between 750 and 1100°C in the presence of oxygen that produces steam for electricity and/or heat generation in a boiler or steam turbine (Reddy, 2016). It can generate heat or electricity, or combined heat and power.

Also, gasification, a partial oxidation of waste (e.g., wood waste, agricultural residues, sewage sludge, and plastic waste) between 800°C and 1200°C in the presence of a controlled amount of oxygen that produces synthetic gas for further combustion or conversion to chemical feedstock (Chavan *et al.*, 2022). While, pyrolysis is the thermal degradation of waste (e.g., wood waste, agricultural residues, sewage sludge, and plastic waste) between 300°C and 1300°C in the absence of oxygen, that produces liquid fuel for further combustion or conversion to chemical feedstock (Dalmini *et al.*, 2019). Another type is anaerobic digestion, which is a biodegradation of (readily degradable) organic wastes in the absence of oxygen by anaerobic microorganisms. Waste input can be separated from organic fraction of MSW, food waste, animal/human excreta, or liquids and sludges (Kumarasiri & Dissanayake, 2021). Waste to Energy Industry has a well-defined specific set of safety issues relating to combustion, steam pressure, turbines, generators and power distribution, which are well understood and well controlled with techniques and standards in place. However, the introduction of Gasification Waste to Energy technology, presents a whole new series of safety issues similar in operations to what is obtainable in chemical process plants (Taiwo & Mbamalu, 2025). On this backdrop, this study assessed the safety challenges and environmental benefits of Waste-to-Energy technologies implementation in Lagos, Nigeria.

In Lagos, 13,000 to 15,000 tonnes of Municipal Solid Waste (MSW) are generated on a daily basis (Mendez, 2025). According to Dawodu *et al.* (2022) and Mendez (2025), about 40 per cent of the MSW is gathered, out of which approximately 13 per cent is recycled. According to Balogun (2017), the highest ratio of the waste produced in Lagos is either dumped or burnt in open landfills. Chavan *et al.*, (2022) expressed that the burning and dumping of waste in open landfills pose air pollution hazards and other serious health issues. Harmful gases such as dioxins, PM_{2.5}, CO₂, Heavy metals, etc., are emitted during the burning of waste in open land, which may lead to serious respiratory conditions and eventually cause early mortality. According to Khan *et al.* (2022), Waste-to-Energy technologies are solutions for reducing the disposal of waste through landfill, as well as generating electricity and reducing emissions of greenhouse gases (GHGs) produced from waste burning. As noted by Dawodu *et al.* (2022) and Abdulfatah (2023), several challenges are associated with Waste-to-Energy technologies, which include: safety concerns, regulatory issues, and challenges of resistance from the host community of facilities. Personnel of Waste to Energy technologies may be exposed to certain biohazards, toxicants and sharp objects.

Mock (2024) identified that sustainable waste-to-Bio products Engineering Centre laboratory staff were exposed to the following safety issues: unlabeled solutions, uncapped sharps, unlabeled

gas tanks and unsafe fume hood conditions. Incinerators are seen as one of the reasonable solutions to the problem of waste management, however, there is a range of pollutants released by incinerators which constitute ill-health. Maring *et al.* (2023) identified major air pollutants from operating incinerators as fine airborne particulates (2.5 µm diameter and smaller), toxic metals, and organic chemicals. Inhaling airborne particulates over a long period of time is linked to cardiovascular and respiratory issues (Schraufnagel, 2020). Meanwhile, exposure to toxic metals from the combustion of waste, most especially plastic wastes, over the long term has been associated with immune system damage, reproductive concerns, and cancer (Cachon *et al.*, 2023). Metal fume fever usually presents with malaise, fever, chills, arthralgias, and myalgias 4 - 8 hours after exposure to metal fumes, usually through melting of metallic waste (Modupeola & Popoola, 2024; Kravets *et al.*, 2025).

In the aspect of the host community of Waste-to-Energy (WTE) technologies facilities, odour and noise hazards are prevalent, having an adverse effect on the quality of life of the people living in the community (Phan *et al.*, 2021). Another potential hazard to the people's environment of the WTE technologies facilities is a chemical spill, which may, in the long run, have a negative impact on the ecosystem nearby. According to Mrozik *et al.* (2021), improper or careless processing and disposal of spent batteries leads to contamination of the soil, water and air. The toxicity of the battery material for example is a direct threat to organisms on various trophic levels as well as a direct threat to human. The Waste-to-Energy technologies in normal operation have the same characteristic threats and safety risks as regular process systems and there is the potential of a top event should the hazards lose containment. Some advanced countries where the Waste-to-Energy technologies is in practice have witnessed some accidents and seen some major emergency situations and operational disasters in the process systems that call for concern (Elsdon & Pal, 2011).

During normal operations for a regular WTE technologies process system, the by-products that are formed are either contained in the process system, or released into the environment. This is dependent on the design adopted and consideration of the safety and health implications in handling of the process by-products formed, which predominantly are liquids and gases; whether safe or not, as they could be very toxic in nature. The regulatory provisions and operational specifications, that guide and direct operators on how to handle the by-products from Waste-to-Energy technologies activities is also very important (Bishoge, *et al.*, 2019).

Based on the aforementioned challenges associated with Waste-to-Energy technologies deduced from various studies and more that are not mentioned, it brings to mind a significant concern about the adoption of Waste-to-Energy technologies as a viable solution and best practice in our modern-day waste management systems. This study was designed to evaluate the safety and environmental challenges in Waste-to-Energy technologies in a major urban city in Nigeria, with abundance of waste generated daily; to actually discover how favourable (and viable) or not, the solution presents. Thus, this study on assessing the safety challenges and environmental benefits of Waste-to-Energy technologies implementation in Lagos, Nigeria, provided the necessary answer to the big question of Waste-to-Energy technologies being of great advantage or disadvantage to health and safety. The study presented also an opportunity to evaluate the possibilities in managing the new Waste-to-Energy technologies in a growing African commercial city.

2.0 Methodology

2.1 Research Design

Cross-sectional research design was adopted in this study. this design was adopted because it involves using quantitative survey to obtain opinion of a large number of participants by using a which increases the likelihood that the findings can be applied to a larger population (Dawadi *et al.*, 2021).

2.2 Study Area

The study was conducted in Lagos State. Lagos is situated on the Atlantic coastline of South-Western Nigeria, between latitudes 6°15'N and 6°41'N and longitudes 2°42'E and 4°14'E on the West Coast of Africa, as seen in Figure 3.1. At around 3,577.0 square kilometers (sq. km), or 0.4 percent of the nation's total size, it is the smallest state in Nigeria (Oyeyemi *et al.*, 2025). Lagos is comprised of twenty Local Government Areas (LGAs), sixteen of which are classified as extremely dense metropolitan regions (Uduku *et al.*, 2021). Lagos, which is a bustling port city with around 220.6 square kilometers of water bodies, mangrove swamps, and wetlands, is situated on a large peninsula and island and is additionally known to as Greater Lagos or the Lagos Metropolitan Area. The country's largest city and most significant economic hub, Lagos and its neighboring metropolis are home to the nation's main seaports (Oni *et al.*, 2024). Lagos is responsible for more than ninety per cent of Nigeria's commercial flow and ten per cent of the country's Gross Domestic Product (GDP). With 65 per cent of Nigeria's industrial sector based in the city, it has the sixth biggest economy in Africa. According to Auwalu and Bello (2023), Lagos is home to a dense and extensive network of towns and urban areas connected by several road networks. Lagos City's haphazard and uncontrolled urbanization and the insufficient and decaying infrastructure are characteristics of the city's rapidly expanding population

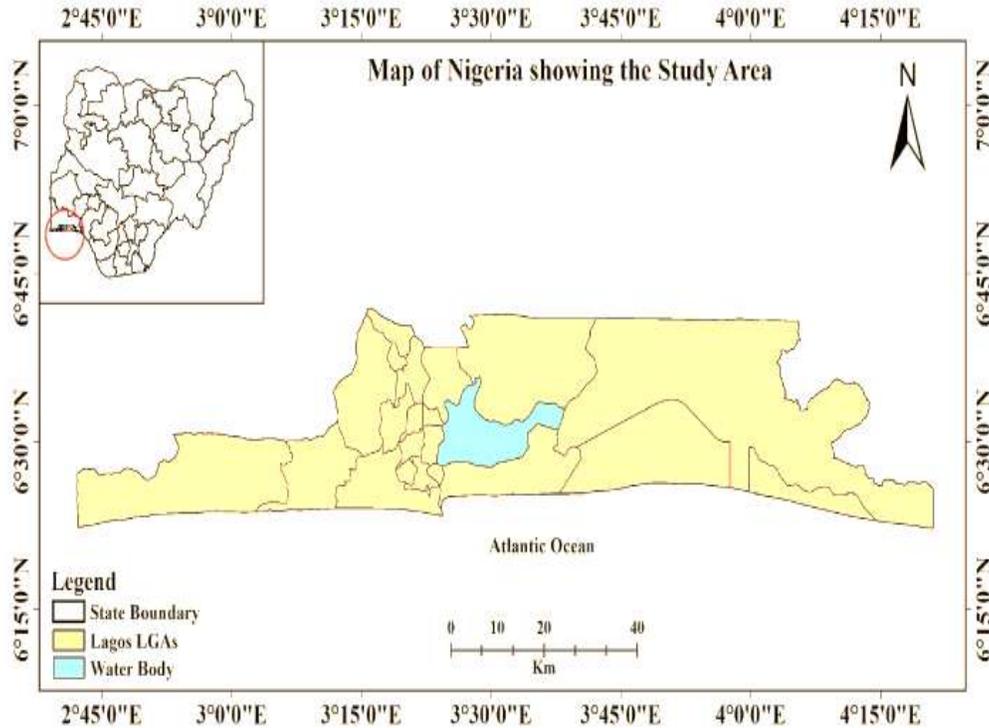


Figure 3.1: Showing the Map of Lagos state the study area [*Source:* Koko and Bello (2023)].

2.3 Population of the Study

The study population comprises all staff members of all the Waste-to-Energy technology companies in Lagos, Nigeria.

2.4 Samples and Sampling Techniques

The study utilized non-probability sampling technique specifically the purposive sampling techniques to sample four companies in the waste-energy business in Lagos state namely - Oando Clean Energy, Emakemtos Global Service, Nigeria Limited, Safi Renewable Energy, and Africa Waste Energy Limited. The selection was based on consent and proximity of the firms to the researcher. To achieve a representative sample, the sample size was calculated. A sample of 384 staff was drawn from the four (4) Waste-to-Energy technology companies using the Cochran’s formula for an infinite sample size calculation. This sample size determination formula is used when the actual study population is unknown but the research can assume a proportion or percentage of the required respondents from the population

$$n_0 = \frac{z^2 p(1-p)}{e^2} \tag{3.1}$$

Where,

n_0 is calculated sample size (based on infinite population) = 384, z is z -value based on 95% confidence level = 1.96, p is predictable percentage of the population = 0.5 (since it is unknown) and e is the required margin of error = $\pm 5\%$ or 0.05.

The calculated sample size of 384 was divided into equal proportions for equal representation among the staff of the four (4) Waste-to-Energy technology companies in Lagos state. Consequently, each of the Waste-to-Energy technology companies has ninety-six (96) participants to complete the Google forms, based on convenience and snowball sampling techniques. Meanwhile, two (2) key components were purposively selected from the four (4) Waste-to-Energy technology companies in Lagos state to complete the interview.

2.5 Nature and Sources of Data

Primary data was used in this study. The major data used in this study was gathered through questionnaire administered to sampled workers in Waste-to-Energy technology companies in a Google Form.

2.6 Method and Instrument for Data Collection

Quantitative data were gathered using the questionnaire in a Google form designed to provide answers to the research questions. The Google form is made up of twenty-seven (27) questions and four (4) different sections (A to D). Section A of the Google form was designed to capture the socio-demographic characteristics of respondents and consists of four (4) variables: sex, age group, educational level, and company. Section B was designed to identify the specific Waste-to-Energy technologies currently implemented in Lagos and consists of seven (7) distinct multiple-choice questions. Section C of the Google Form was designed to assess the main safety challenges connected to the implementation of Waste-to-Energy technologies in Lagos and comprises seven (7) different multiple-choice questions. Section D of the Google Form was designed to examine the environmental benefits derived from the implementation of Waste-to-Energy technologies in Lagos and includes ten (10) different multiple-choice questions. Click the following Google form link for a copy: <https://forms.gle/1HDHjB9TVXTWYZ7DA>. Copy of Google form link was embedded in an introductory and participants consent brief note. The brief note was then dispatched to the WhatsApp numbers of the staff of the four (4) Waste-to-Energy technologies companies. A total of 340 responses were recorded from the Google form compared to the expected sample of 384, which indicates an 88.5% completion rate (as shown in Table 3.1). Meanwhile, a total of eight (8) participants were interviewed, which indicates a 100% completion rate.

Table 2.1 Survey completion rate (Google form).

Company	Expected sample	Gathered Responses	Completion rate (%)
Oando Clean Energy	96	86	89.5%
Emakentos Global Service Nigeria Limited	96	82	85.4%
Safi Renewable Energy	96	87	90.6%
Africa Waste Energy Limited	96	85	88.5%
Total	384	340	88.5%

2.7. Methods of Data Analysis

The data collected through the survey questionnaire was sorted and recorded using the Statistical Package for Social Science (SPSS), version 24. Descriptive statistical analysis was thereafter conducted to provide answers to the study research questions. Frequency, percentage, mean, standard minimum & maximum values and ranks were the descriptive statistical analytics tools used in the study.

3.0 Results and Discussions

3.1 The specific Waste-to-Energy (WTE) technologies currently implemented in Lagos.

Table 3.1 to Table 3.5 shows the responses of the sampled respondents on the specific Waste-to-Energy technologies currently implemented in Lagos. It demonstrates that the majority of the respondents, 205(60.1%) and 183 (53.7%) identified incineration and Anaerobic digestion as the categories of Waste-to-Energy technologies presently being used in Nigeria. The majority of the respondents, 239(70.2%) and 197(57.8%) agreed that Municipal solid waste/household waste and Agriculture waste respectively the generated waste mostly explored in Waste-to-Energy developments in Lagos, Nigeria. The majority of the respondents, 199 (58.5%) identified electricity as the most frequently generated energy from waste in Nigeria. The majority of the respondents, 200 (58.8%) opined that the present status of the government support for Waste-to-Energy technologies in Nigeria is Moderate support. The highest distribution of the respondents, 228 (67.1%) and 205 (60.3%) identified that Private companies and State governments respectively were the furthestmost involved stakeholders in the Nigeria Waste-to-Energy enterprise.

Table 3.5 shows the descriptive statistic and ranks of the identified Waste-to-Energy technologies being implemented in Lagos. It demonstrates that the means of Incineration system and anaerobic digestion system (0.60 and 0.54) were the only two types of implemented Waste-to-Energy technologies above the benchmark 0.5 and ranked first and second respectively. Consequently, Incineration system and anaerobic digestion system are the specific Waste-to-Energy technologies currently being implemented in Lagos, Nigeria. The first objective centered on the specific Waste-to-Energy technologies currently implemented in Lagos revealed that incineration and anaerobic digestion are the current Waste-to-Energy technologies currently implemented in Lagos, Nigeria. These results aligned with the finding of this study Mayer *et al.* (2019) discovered incineration as main waste-to-energy system implemented in Europe. Dastjerdi *et al.* (2022) also revealed that anaerobic digestion is a major waste-to-energy technique used and implementation in Australia

Table 3.1 Showing Responses on Categories of Waste-To-Energy Technologies Currently Implemented in Lagos. [Number of valid responses = 340(100%)].

Variables	Frequency (F)	Percentage (%)
Which categories of Waste-to-Energy Technologies are you presently aware of being used in Lagos, Nigeria?		
Anaerobic digestion	183	53.7
Gasification	128	37.3
Incineration	204	60.1
Pyrolysis	96	27.8
Landfill gas recovery	89	26.0
None of the above	32	9.4

Table 3.2 Showing responses on specific generated waste mostly explored in Waste-to-Energy developments currently implemented in Lagos. [Number of valid responses = 340(100%)].

Variables	Frequency (F)	Percentage (%)
Which of the following generated waste are mostly explored in Waste-to-Energy developments in Lagos, Nigeria?		
Agricultural waste	197	57.8
Municipal solid waste/household waste	239	70.2
Industrial waste	125	36.8
E-waste	59	17.4
Sewage/sludge	73	21.5
Not sure	47	13.8

Table 3.3 Showing Responses on form of Energy Most Frequently Generated from Waste in Lagos. [Number of valid responses = 340(100%)].

Variables	Frequency (F)	Percentage (%)
What form of energy is most frequently generated from waste in Lagos, Nigeria?		
Heat	29	8.5
Electricity	199	58.5
Biogas	75	22.0
Synthetic fuels	15	4.4
I'm not sure	27	7.9

Table 3.4 Showing Responses on the Status of Government Support for Waste-To-Energy Technologies in Lagos, Nigeria. [Number of valid responses = 340(100%)].

Variables	Frequency (F)	Percentage (%)
What is the present status of government support for Waste-to-Energy technologies in Lagos, Nigeria?		
Strong and active support	27	7.9
Moderate support	200	58.8
Minimal support	75	22.0
No support	15	4.4
I don't know	27	7.9

Table 3.5 Showing Responses on Stakeholders are Furthermost involved in Waste-to-Energy Enterprises in Lagos. [Number of valid responses = 340(100%)].

Variables	Frequency (F)	Percentage (%)
Which stakeholders are furthermost involved in Waste-to-Energy enterprises in Lagos, Nigeria?		
Federal government	190	55.9
State governments	205	60.3
Private companies	228	67.1
International organizations	138	40.6

Academic institutions	114	33.5
Local communities	85	25.0

Table 3.6 Descriptive Statistic and Ranks of the Identified Waste-to-Energy Technologies Implemented in Lagos.

Type of Technology	Mean	S. D	Minimum	Maximum	Ranks
Incineration	0.60	0.49	0	1	1 st
Anaerobic digestion	0.54	0.50	0	1	2 nd
Gasification	0.37	0.48	0	1	3 rd
Pyrolysis	0.28	0.45	0	1	4 th
Landfill gas recovery	0.26	0.44	0	1	5 th
None of the above	0.09	0.29	0	1	6 th

Note: S. D – Standard Deviation. Coding; 1- Identified Implemented, 0 – not identified, Benchmark – 0.5.

3.2 The Main Safety Challenges Connected to the Implementation of Waste-to-Energy Technologies in Lagos.

Table 3.7 to Table 3.14 shows the responses on main safety challenges connected to the implementation of Waste-to-Energy technologies in Lagos. It demonstrates that the majority of the respondents, 209 (61.5%) and 197 (57.9%) recognized Fire and explosion hazards and Exposure to toxic emissions as the main safety risks regularly connected with Waste-to-Energy facilities in Lagos, Nigeria. The majority of the respondents, 191 (56.2%) and 184 (54.1%) identified Inadequate staff training and Poor facility maintenance respectively are the roots causes of safety incidents in Waste-to-Energy plants in Lagos, Nigeria. The majority of the respondents, 139 (40.9%) considered Waste collector as the workers at most risk of injury in Waste-to-Energy operations. The highest distribution of the respondents, 120 (35.3%) opined that present safety regulations for Waste-to-Energy technologies in Lagos, Nigeria is slightly effective. The majority of the respondents, 225 (66.2%) and 183 (53.8%) identified Use of protective equipment (PPE) and Emergency response plans respectively as safety measures routinely implemented at the Waste-to-Energy facilities in Lagos, Nigeria. The highest distribution of the respondents, 199 (58.5%) and 188 (55.3%) identified Weak regulatory oversight and Lack of funding for safety infrastructure as challenges that is hampering the enforcement of safety standards in Lagos, Nigeria Waste-to-Energy projects. Majority of the respondents, 133 (39.1%) identified the Government regulatory agencies as the body primarily responsible for ensuring safety in Waste-to-Energy projects.

Table 3.15 shows the descriptive statistic and ranks of the recognized safety challenges in Waste-to-Energy technology facilities in Lagos. It demonstrates that improper use of Personal Protective Equipment (PPE) and fire & explosion hazards have the highest means (0.66 and 0.62), which are above benchmark 0.5 and were ranked first and second. Also, the means of weak regulation oversights, exposure to toxic emissions, inadequate staff training on safety, lack of funding for safety infrastructure, lack of proper emergence response plans and poor facility maintenance (0.59, 0.58, 0.56, 0.55 and 0.54) were slightly above the benchmark 0.5 and ranked third to seventh. While, means of Inadequate waste handling and lack of safety protocols, 0.50 (twice) were equal with the benchmark 0.5 and ranked eighth and ninth. Therefore, the following are the recognized core safety concerns of implementing Waste-to-Energy technologies in Lagos; improper use of Personal Protective Equipment (PPE) and fire & explosion hazards, weak

regulation oversights, exposure to toxic emissions, inadequate staff training on safety, lack of funding for safety infrastructure, lack of proper emergence response plans and poor facility maintenance, Inadequate waste handling and lack of safety protocols in that order. These results aligned with the finding of this study, Mrozik *et al.* (2021), a potential hazard in WTE technologies facilities is a chemical spill, which may, in the long run, have a negative impact on the ecosystem nearby. According to improper or careless processing and disposal of used batteries leads to health contamination of the soil, water and air (Khan *et al.*, 2022). Meanwhile, Phan *et al.* (2021) identified and noise hazards, having an adverse effect on the quality of life of the people living in the community. Chavan *et al.* (2022) highlighted that fire is associated with open dumping of organic waste,

3.8 Showing the Responses on Main Safety Challenges Connected to the Implementation of Waste-to-Energy Technologies in Lagos.

Variables	Frequency (F)	Percentage (%)
Which of the following safety risks are regularly connected with Waste-to-Energy (WTE) facilities in Lagos, Nigeria?		
Fire and explosion hazards	209	61.5
Equipment malfunction	162	47.6
Exposure to toxic emissions	197	57.9
Inadequate waste handling	171	50.3
Chemical spills	113	33.2
I am not aware of any risks	40	11.8

Table 3.9 Showing the Responses on the Root Causes of Safety Incidents in WTE Plants in Lagos.

Variables	Frequency (F)	Percentage (%)
What are the root causes of safety incidents in WTE plants in Lagos, Nigeria?		
Poor facility maintenance	184	54.1
Lack of safety protocols	170	50.0
Inadequate staff training	191	56.2
Equipment failure	159	46.8
Overloading of systems	103	30.3
Not sure	44	12.9

Table 3.10 Showing the responses on workers who are most at risk of injury in WTE operations in Lagos.

Variables	Frequency (F)	Percentage (%)
Which workers are most at risk of injury in WTE operations in Lagos, Nigeria?		
Waste collectors	139	40.9
Maintenance workers	85	25.0
Plant technicians	61	17.9
Supervisors	13	3.8
Nearby residents	25	7.4
None of the above	17	5.0

Table 3.11 Showing the responses on the Effectiveness of the Present Safety Regulations for Waste-to-Energy Technologies in Lagos.

Variables	Frequency (F)	Percentage (%)
How effective are the present safety regulations for WTE technologies in Lagos, Nigeria?		
Very effective	13	3.8
Moderately effective	87	25.6
Slightly effective	120	35.3
Not effective at all	86	25.3
I am not familiar with the regulations	34	10.0

Table 3.12 Showing the responses on Safety Measures Routinely Implemented at WTE facilities in Lagos, Nigeria.

Variables	Frequency (F)	Percentage (%)
What safety measures are routinely implemented at WTE facilities in Lagos, Nigeria?		
Use of protective equipment (PPE)	225	66.2
Emergency response plans	183	53.8
Safety training for workers	168	49.4
Regular safety audits	97	28.5
Hazard signage and labelling	135	39.7
None of the above	27	7.9

Table 3.13 Showing the Responses on Challenges that Hamper the Enforcement of Safety Standards in Waste-to-Energy technologies in Lagos, Nigeria.

Variables	Frequency (F)	Percentage (%)
What challenges hamper the enforcement of safety standards in Lagos, Nigeria WTE projects?		
Weak regulatory oversight	199	58.5
Lack of funding for safety infrastructure	188	55.3
Limited technical knowledge	168	49.4
Corruption	143	42.1
Low prioritization of worker safety	119	35.0
Negligence	94	27.6

Table 3.14 Showing the Responses on Agents Primarily Responsible for Ensuring Safety in Waste-to-Energy Projects in Lagos.

Variables	Frequency (F)	Percentage (%)
Who is Primarily Responsible for Ensuring Safety in Waste-to-Energy Projects in Lagos, Nigeria?		
Government regulatory agencies	133	39.1
Plant management	93	27.3
Environmental health and safety officers	58	17.1
Workers themselves	27	7.9
Community safety groups	11	3.2
I don't know	18	5.3

Table 3.15 Descriptive Statistic and Ranks of the Recognized Safety Challenges in Waste-to-Energy Technology Facilities in Lagos.

Safety Challenges	Mean	S. D	Minimum	Maximum	Ranks
Improper use of Personal Protective Equipment (PPE).	0.66	0.47	0	1	1 st
Fire and explosion hazards.	0.62	0.49	0	1	2 nd
Weak regulatory oversights.	0.59	0.49	0	1	3 rd
Exposure to toxic emission.	0.58	0.49	0	1	4 th
Inadequate staff training on safety.	0.56	0.50	0	1	5 th
Lack of funding for safety infrastructure.	0.55	0.50	0	1	6 th
Lack of proper emergency response plans.	0.54	0.50	0	1	7 th
Poor facility maintenance	0.54	0.50	0	1	7 th
Inadequate waste handling	0.50	0.50	0	1	8 th
Lack of safety protocols	0.50	0.50	0	1	9 th
Limited technical knowledge	0.49	0.50	0	1	10 th
Safety training for workers	0.49	0.50	0	1	11 th
Equipment malfunction	0.48	0.50	0	1	12 th
Equipment failure	0.47	0.50	0	1	13 ^h
Corruption	0.42	0.49	0	1	14 th

Note: S. D – Standard Deviation. Coding; 1- Identified safety challenges, 0 – not identified, Benchmark – 0.5.

3.3 The Environmental Benefits Derived from the Implementation of Waste-to-Energy Technologies in Lagos.

Table 3.17 to Table 3.24 Showing the environmental benefits derived from the implementation of Waste-to-Energy technologies in Lagos. It demonstrates that the majority of the respondents, 234 (68.8%) and 219 (64.4%) identified Open dumping of waste and Landfill overflow as environmental issues that Waste-to-Energy technologies help reduced in Lagos. The majority of the respondents, 203 (59.7%) and 164 (48.8%) identified Methane (CH₄) and Particulate matter as the category of emissions which are reduced through Waste-to-Energy implementation compared to waste burning. The majority of the respondents, 214 (63.0%) and 191 (56.2%) recognised Cleaner surroundings and Reduction in illegal dumping as the positive environmental impacts observed in areas with Waste-to-Energy technologies facilities in Lagos. The highest distribution of the respondents, 141 (41.5%) opined that Waste-to-Energy technologies are moderately effective in reducing Lagos’s reliance on landfill sites. The majority of the respondents, 214 (62.9%) and 189 (55.6%) recognised Electricity generation and Reduction in fossil fuel use as the forms of renewable energy that benefits Waste-to-Energy technologies offer the environment. The majority of the respondents, 218 (64.1%) and 167 (49.1%) identified Organic or biodegradable waste and Plastic waste as waste that when used for Waste-to-Energy can contribute to environmental sustainability. The highest distribution of respondents, 142 (41.8%) opined that Waste-to-Energy technologies play a moderate role in the accomplishment of Nigeria’s environmental sustainability goals. The majority of the respondents, 215 (63.2%) and 196 (57.7%) identified Cleaner energy production and Reduction of landfill usage as the environmental benefits of Waste-to-Energy technologies that should be prioritized in study area.\

Table 3.25 shows the descriptive statistic and ranks of the environmental benefits in operating Waste-to-Energy technologies in Lagos. It demonstrates that means of Reduction in landfill overflow, Reduction in illegal and open dumping of waste, cleaner environment and Cleaner energy production, 0.64 and 0.63 (three times) were above the benchmark 0.5 and ranked first

and second. The means of Reduction in toxic gases, Reduction in Greenhouse gases (GHGs), Reduced air pollution and Improved air quality (0.58, 0.57, 0.54 and 0.51) were slightly above the benchmark 0.5. Based on the above analysis, the following are the environment benefits of operating Waste-to-Energy technologies in Lagos; Reduction in landfill overflow, Reduction in illegal and open dumping of waste, cleaner environment and Cleaner energy production, Reduction in toxic gases, Reduction in Greenhouse gases (GHGs), Reduced air pollution and Improved air quality in that order.

Analysis of the this objective which focused on environmental benefit of operating waste-to-energy system revealed the following environmental benefits of operating Waste-to-Energy technologies in Lagos: Reduction in landfill overflow, Reduction in illegal and open dumping of waste, cleaner environment and Cleaner energy production, Reduction in toxic gases, Reduction in Greenhouse gases (GHGs), Reduced air pollution and Improved air quality in that order. In agreement with the findings of this study, Umar *et al.* (2024); Zhang *et al.* (2024) found that WTE helps to reduce methane emissions, Sharma *et al.* (2024) found WTE technologies help reduce waste disposal issues, Okuh *et al.* (2023) found that WTE technologies promote sustainability through cleaner energy production.

Table 3.17 Showing the Environmental Issues Waste-to-Energy technologies can help reduce in Lagos, Nigeria. [Number of valid responses = 340(100%)].

Variables	Frequency (F)	Percentage (%)
Which of the following environmental issues can Waste-to-Energy technologies help reduce in Lagos, Nigeria?		
Air pollution	183	53.8
Landfill overflow	219	64.4
Open dumping of waste	234	68.8
Groundwater contamination	165	48.5
Deforestation	97	28.5
I don't know	34	10.0

Table 3.18 Showing the Categories of Emissions that are reduced through WTE Implementation in Lagos, Nigeria. [Number of valid responses = 340(100%)].

Variables	Frequency (F)	Percentage (%)
What categories of emissions are reduced through WTE implementation in Lagos, Nigeria, in comparison to open waste burning?		
Carbon dioxide (CO ₂)	145	42.7
Methane (CH ₄)	203	59.7
Nitrous oxide (N ₂ O)	106	31.2
Sulphur dioxide (SO ₂)	123	36.2
Particulate matter	164	48.8
Not sure	55	16.2

Table 3.18 Showing the Positive Environmental Impacts Observed in Areas with WTE facilities in Lagos. [Number of valid responses = 340(100%)].

Variables	Frequency (F)	Percentage (%)
Which positive environmental impacts have been observed in areas with WTE facilities in Lagos, Nigeria?		

Improved air quality	173	50.9
Cleaner surroundings	214	63.0
Reduction in illegal dumping	191	56.2
Less use of fossil fuels	120	35.3
Reduced pest and disease outbreaks	105	30.9
No noticeable impact	44	12.9

Table 3.19 Showing the Effectiveness of Waste-to-Energy Technologies in Reducing Lagos, Nigeria’s reliance on landfill sites. [Number of valid responses = 340(100%)].

Variables	Frequency (F)	Percentage (%)
How effective are Waste-to-Energy technologies in reducing Lagos, Nigeria’s reliance on landfill sites?		
Very effective	87	25.6
Moderately effective	141	41.5
Slightly effective	62	18.2
Not effective	24	7.0
Not sure	26	7.6

Table 3.20 Showing the Forms of Renewable Energy Benefits WTE Technologies in Lagos, Nigeria Offer to the Environment. [Number of valid responses = 340(100%)].

Variables	Frequency (F)	Percentage (%)
What forms of renewable energy benefits do WTE technologies in Lagos, Nigeria offer to the environment?		
Electricity generation	214	62.9
Reduction in fossil fuel use	189	55.6
Production of biogas	133	39.1
Energy recovery from waste	162	47.7
Heat generation	83	24.4
I don’t know	35	10.3

Table 3.21 Showing the Waste Sorts Which Contribute Most to Environmental Sustainability When Used in WTE in Lagos, Nigeria. [Number of valid responses = 340(100%)].

Variables	Frequency (F)	Percentage (%)
Which waste sorts, when used in WTE in Lagos, Nigeria, contribute most to environmental sustainability?		
Organic or biodegradable waste	218	64.1
Plastic waste	167	49.1
Agricultural waste	146	43.0
Paper waste	113	33.2
Sewage sludge	77	22.6
Not sure	38	11.2

Table 3.22 Showing the Role WTE Play in Accomplishing Lagos, Nigeria’s Environmental Sustainability Goals. [Number of valid responses = 340(100%)].

Variables	Frequency (F)	Percentage (%)
What role does WTE play in accomplishing Lagos, Nigeria’s		

environmental sustainability goals?		
Major role	105	30.9
Moderate role	142	41.8
Minor role	51	15.0
No role	20	5.9
I'm not aware of such goals	22	6.5

Table 3.23 Showing the Environmental Benefits Derived from the Implementation of Waste-to-Energy Technologies in Lagos, Nigeria. [Number of valid responses = 340(100%)].

Variables	Frequency (F)	Percentage (%)
Which environmental benefits of WTE technologies do you think should be prioritized in Lagos, Nigeria?		
Cleaner energy production	215	63.2
Reduction of landfill usage	196	57.7
Lower greenhouse gas emissions	175	52.1
Improved urban sanitation	153	45.0
Protection of water bodies	134	39.4
Reduction in illegal waste burning	119	35.0

Table 3.24 Descriptive Statistic and Ranks of the Environmental Benefits in Operating Waste-to-Energy Technologies in Lagos.

Variables of Environmental benefits	Mean	S. D	Minimum	Maximum	Ranks
Reduction in landfill overflow	0.64	0.47	0	1	1 st
Reduction in illegal and open dumping of waste	0.63	0.47	0	1	2 nd
Cleaner environment	0.63	0.47	0	1	2 nd
Cleaner energy production.	0.63	0.47	0	1	2 nd
Reduction in toxic gases	0.58	0.49	0	1	3 rd
Reduction in Greenhouse gases (GHGs)	0.57	0.49	0	1	4 th
Reduced air pollution	0.54	0.49	0	1	5 th
Improved air quality	0.51	0.50	0	1	6 th
Lessened ground water contamination	0.49	0.50	0	1	7 th
Reduction in pest and disease outbreaks	0.31	0.50	0	1	8 th
Lesser use of fossil fuels	0.35	0.50	0	1	8 th

S. D – Standard Deviation. Coding; 1- Identified environmental benefits, 0 – not identified, Benchmark – 0.5.

4.0 Conclusions

The study identified the Waste-to-Energy technologies currently implemented in Lagos, Nigeria as Incineration and Anaerobic Digestion, utilizing majorly, Municipal Solid Waste and Agricultural Waste and the major energy demanded was for electricity. The main safety challenges recognized are fire/ explosion hazard, exposure to toxic emissions and possible chemical spills. The environmental benefits in operating Waste-to-Energy technologies in Lagos, Nigeria include: Reduction in landfill overflow, Reduction in illegal and open dumping of waste, cleaner environment and Cleaner energy production, Reduction in toxic gases, Reduction in Greenhouse gases (GHGs), Reduced air pollution and Improved Air Quality. The use of Waste-to-Energy technologies from the study is clearly in favour of human health, socio-economic

advancement and benefit to the environment. With health and safety in consideration, Waste-to-Energy technologies as implemented (incineration and anaerobic digestion), help waste management business models to establish and thrive on the concept of sustainable development. The innovation and sustainable waste management alternative, however requires the development of specific regulatory guidelines and frameworks in addressing safety and environmental issues associated to Waste-to-Energy technologies. To guarantee the effective and efficient deployment of the sustainable waste management techniques, the regulatory authorities must be strengthened with adequate resources, equipment and sufficient man power; as the existing policies and staff strength are lacking. Thus, the resources needed for the operations and management of Waste-to-Energy technologies must be made available and sufficient; for effective monitoring and compliance, with statutory regulatory provisions.

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