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A Research On The Technical And Financial Feasibility Of Waste Incineration Technology In Ghana

Case Study: A Modular Waste Incineration Plant In Tema

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ABSTRACT:

This research study examines the technical and financial feasibility of waste incineration technology as a solution to Ghana's growing waste management problems. The study provides an overview of the waste management situation in Ghana, highlighting the challenges associated with current waste disposal methods. The study reviews waste incineration technology, discussing its advantages, limitations, and potential application in Ghana. The study also explores the financial viability of waste incineration, analysing the costs and benefits of implementing this technology in Ghana.

The study provides an overview of the financial aspects of waste incineration, including capital costs, operating expenses, and revenue potential. The study reviews the economic benefits and challenges associated with waste incineration and analyses the cost of setting up a waste incineration facility and potential revenues from energy production by applying a case study that takes into consideration all the factors that influence the successful construction and running of an energy facility in Ghana.

The study also provides an overview of waste incineration technology, including its principles, processes, and equipment. The study also examines the factors that can affect the technical feasibility of waste incineration, such as the composition of waste, the type of incinerator used, and the operational conditions.

The study concludes with recommendations for policymakers, waste management authorities, and investors interested in exploring waste incineration as a potential solution to Ghana's waste management challenges. Overall, this research study provides important insights into the technical and financial feasibility of waste incineration technology in Ghana, offering a valuable resource for those seeking to improve waste management practices in the country.

KEYWORDS: (waste-to-energy, waste, incineration, energy, renewable, municipal solid waste management).

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1. Introduction

Solid waste management has become a major discussion concerning global climate change and greenhouse gas emissions. Solid waste can be generated in mostly all working environments and based on its source can be classified into domestic/household, industrial, agricultural, or construction waste [1]. Industrial and construction waste is rising because of the boom in these sectors. However, this type of waste is highly regulated due to how toxic it can be to the environment. Agricultural waste is mostly organic and the least toxic. It is often reused as manure for other agricultural purposes. Domestic or municipal solid waste makes up the greater part of all waste generated and our lifestyle and consumption influence this. Municipal solid waste has a varied composition which makes its management difficult in areas where waste sorting is not advanced. Most developing countries struggle with managing municipal solid waste and Ghana is no exception.

An enormous quantity of solid waste is produced daily in Ghana because of the rise in urbanization, which continues to exert pressure on the waste management system. The system has resource deficiency and a weakened institutional capacity to match the growing urban population [1]. Also, regulations concerning waste disposal are not properly enforced. The result is a porous waste collection and disposal system which often leaves Accra, the capital, and some other bigger cities in filth. Especially in areas where commercial activities take place such as markets and public transport terminals.

The Greater Accra Region has risen to 5.4 million in the past decade which is about a 34 percent increase [2]. The rapid population growth is fuelled by urban migration in search of better opportunities. Lack of proper land use urban planning in Accra hinders effective sanitation and waste management practices. The inadequate road networks in slums make it difficult for waste collection vehicles to reach those parts of the city [3]. The amount of municipal solid waste generated to approximately 900 thousand tons a year. About 75 percent of this waste is collected and disposed on landfills, and 5% percent is recycled, the remainder is often left on the streets some clogged in drainages which results in flooding whenever there is heavy rainfall. The waste collected by authorized waste collection companies is disposed of at landfill sites allocated for these purposes, the landfills are not treated frequently, and the waste is seldom burnt in the open-air causing air pollution and odour. This situation leads to the spread of diseases like cholera and malaria. This form of waste management is not appropriate and alternative clean and sustainable means must be considered.

However, in recent times there have been some changes in the waste management system which has led to privatizing collection and disposal of waste in all major cities across the country. This policy has proven to be more efficient and has significantly increased the efficiency of waste collection. The challenge now lies with the disposal of collected waste. This makes it necessary for more effective and sustainable waste management methods like waste incineration to be explored to also help address the power challenges this country has.

1.1. Statement Of Research Problem

Efficient municipal solid waste management remains a challenge in Ghana due to a combination of factors ranging from financing to policy implementation gaps. Additionally, for the past decade, Ghana has faced energy challenges due to the increase in demand and the inability of the energy sector to meet this increasing demand. Some experts have attributed the situation to over-dependence on hydro and fossil-fuelled power sources, with higher costs of production and emissions.

Waste-to-energy (incineration) is one of the major sources of energy for most developed countries around the world and it is time developing countries like Ghana adopt this technology to facilitate the effective usage of municipal solid waste in generating clean energy this will also help in addressing the current waste management issues. A limitation to Waste-to-energy (incineration) technology development in Ghana has been the unavailability of accurate data on waste generation and composition and collection.

Also, the lack of waste sorting attitude and facilities raises concerns when considering waste incineration technology.

1.2. Research Objectives

The target of the research is to analyse the composition and thermal efficiencies of municipal solid waste generated in Ghana to determine the potential energy quantity that can be generated from this waste. Also, the research will help ascertain which waste incineration technologies will best fit the form of municipal solid waste generated in Ghana and the profitability of such a project using an existing technology by a Finnish-based company in a case study. The case study involves a pilot project in Tema, a municipality in the Greater Accra Region of Ghana. The study is geared towards answering the following research questions.

Are Ghana's waste composition and thermal properties suitable for waste-to-energy technology (incineration)?

How can waste sorting and collection be improved and what will be the effect on waste incineration Technology?

How profitable will a waste incineration plant be considering all the necessary factors?

The findings of this research will give the government and the private sector the necessary information and data for effective waste management. It will further prove the technical and financial feasibility of waste incineration technology. The study will also provide the current waste generation and composition data and information needed by stakeholders to assess the viability of other waste-to-energy technologies in Ghana. The findings of this study will assess the profitability of a waste incineration project in Ghana.

Some studies have been conducted concerning waste management in Ghana. However, most of these studies do not emphasize the waste-to-energy capabilities of the waste composition in the country. These studies aim to demonstrate waste as a burden rather than as a potential energy resource when carefully managed as this has become easier with the rapid improvement in technologies around the world. This study focuses on highlighting the energy potentials from municipal solid waste, the factors to be considered for a successful setup of a waste-to-energy facility and discussing the benefits of setting up such a facility.

1.3. Policy Significance

The finding from this study will trigger some policy changes in areas of solid waste management and power generation to create the essence of revolving policies on sanitation and waste management to enhance the feasibility of waste incineration technologies and provide the needed grounds for introducing this technology to the country. These policies could include tax incentives, energy purchasing agreement benefits, and effective waste sorting and collection. Generally, when findings from this study prove waste incineration as being feasible in both financial and technical terms, it could be used as a bargaining tool to convince the government to lay down policies aimed at providing some guarantees to investors who will want to build waste incineration facilities and to protect their investments as well.

1.4. Structure Of The Thesis

Chapter One gives the background of the study and highlights the purpose of the research in terms of viewing municipal solid waste as an energy resource. It is further followed by chapter two which gives an intensive literature review on the various waste-to-energy technologies and their performance in terms of the energy potential of the type of waste used. Also, factors to consider when setting up a waste incineration facility. Chapter three elaborates on the research methodology, discussing the research process. The fourth chapter covers the current municipal solid waste management situation in Ghana and the current waste generation and composition data. The fifth chapter tackles the case study and finds a solution to the situation in the fourth chapter. It also analyses the financial aspect of such a project. The sixth chapter discusses the findings and concludes the study.

2. LITERATURE REVIEW

2.1. Key Concepts For Municipal Solid Waste Management

This concept refers to the collection, transfer, treatment, recycling, resource recovery, and disposal of solid waste. Municipal solid waste usually composes of waste from households, and non-hazardous solid waste from industrial, commercial, and institutional establishments, markets, and street sweepings [4]. The system is aimed at protecting public health and ensuring environmental sustainability through a reduction in greenhouse gas emissions. It also ensures efficient usage and conversion of valuable materials, hence creating avenues for employment and revenue generation for the sector.

Waste management presents complex technical and policy challenges coupled with economic, administrative, and social challenges that need to be carefully handled for an efficient system [4]. The waste management system comprises municipalities, waste collection companies, and waste handling companies, which include landfills, recycling, waste-to-energy, and waste recovery companies. Government policies and agencies create the system and provide supervision and assessment. Waste management systems across the globe have some similarities but most importantly are tailored to fit the demand of that country. Global environmental policies also influence waste handling policies in various countries. Most developed economies are drawing towards a much cleaner and more sustainable form of waste handling.

2.2. Scope Of Municipal Solid Waste Management

Municipal solid waste management is aimed at establishing sustainably based on reduce, reuse, and recycle principles (3R principle) [5]. There is a wide range of existing Municipal solid waste management strategies coupled with innovations to achieve the required results. Municipal solid waste management systems are designed based on the budget, composition, and waste quantities generated and what is expected to be derived from the waste component. An efficient waste collection system is the first step to a proper waste management system. The whole idea is to ensure the streets and homes are free of rubbish or waste materials. Therefore, gathering, collection, and transportation of waste to the processing point is vital to the overall effectiveness of the system and this aspect of municipal solid waste management cannot be compromised. However, what is done to the waste collected is dependent on the country's policy on waste disposal. The easiest route is landfilling but advanced systems apply the 3R principle more effectively. Reusable and recyclable materials are separated, and the rest are reduced as much as possible.

2.3. Planning And Management

Planning is an essential stage in the entire process, and it must be done right to prevent the total failure of the waste management system. This involves strategic planning based on the environment and stakeholders involved, legal and regulatory framework is also required during this stage to give a clear view of what needs to be done and how it should be done. Also, public participation, financial management, and institutional arrangements are very key to developing an efficient waste management system. During the planning stages is when the entire waste management system is designed with consultation of both public and private partners. A proper waste management plan specifies onsite waste managers, establishes goals and objectives, determines waste forms and quantity, and sets targets for controlling the volumes of waste in landfills. It should also describe recycling or reuse methods. Identifying the waste transportation models, pre-treatment and segregation is also vital, and the progress must be monitored. Future details should entail material use and handling processes, improve communication and training to encourage participation from everyone effectively, and describe the sequencing and methods for deconstruction projects. Finally, there should be means for project review [6].

2.3.1. Waste Generation

Waste is generated when materials are no longer of use and disposed of [7]. Municipal solid waste is mostly obtained from domestic public activities and is mainly food waste or other combustible materials that are out of use such as plastics, paper, and fabrics. Municipal solid waste management covers waste characterization by researching waste sources, rates, and composition. information obtained assists in planning the effectiveness of waste collection systems and arrangements. Municipal solid waste management generation is influenced by several factors. These factors include population, demographics, and the economic outlook of communities. Global waste generation has experienced a significant increase in the past decade due to changes in lifestyle and obviously, population growth. The latest figure for 2021 is a staggering 2.01 billion tons with the average daily waste generation per person at 0.74 kilograms but ranging from 0.11 to 4,54 kilograms which is enormous. Developed countries with high populations contribute to 34 percent of the total global waste generation even though they represent just 16 percent of the world's population [8].

Projections for 2050 show that waste generation numbers could reach 3.4 billion tons surpassing twice the increase in population during that same period. Contribution from developed countries is also expected to increase by 3%. These figures are not encouraging hence, public education on the need to reuse and recycling of products and materials is essential. This will help minimize the quantities of waste generated.

The waste composition also varies across income levels.

The East Asia and Pacific region generate most of the global waste currently at 23 percent, and the Middle East and North Africa region produce on minimum levels, at 6 percent. However, the fastest-growing regions are Sub-Saharan Africa, South Asia, the Middle East, and North Africa, and waste generation is expected to double or triple by 2050[8].

2.3.2. Waste Handling

This is the main process in municipal solid waste management. This involves waste collection, waste transfer, waste treatment, and waste disposal. Waste collection is the core activity of waste management companies, either private or public, and is the first stage of the waste handling process. This is after planning done in the initial stages is implemented. the success or failure of the waste management system partly depends on the efficiency of the waste handling process. Waste treatment before disposal is essential in preventing environmental pollution and these processes are characterized by landfill management. The waste type being handled determines the methods suitable to enhance the possibility of reuse or recycling of materials from waste pile [9].

2.3.3. Waste As Fuel

Municipal solid waste can be seen in two ways, either as just trash fit for landfills or as raw material for power generation. Over the years municipal solid waste has seen relevance in the energy sector. Initially, the lack of proper sorting of household waste at the generation stages was a limitation to harnessing the energy potential in both combustible and organic waste. In the area of waste incineration, improved combustion technologies and advanced preparation of waste materials have limited the effect of sorting on the energy generation process. These combustible waste materials are pre-treated and fed to the incineration plant to produce energy in the form of heat or electricity. The viability of municipal solid waste as fuel depends on the average calorific value of the waste. Hence, for combustible waste to be profitable as fuel for incineration, it must have a high calorific value which translates to low moisture content. Solid waste has different composites, and the calorific value is determined by the average value of its entire composition.

Organic waste for Biogas production still requires some level of sorting even though the process integrates separation. Organic waste composition in a pile of waste for biogas production should be at least 80 percent to make the process more efficient. Methane obtained from biogas is either directly combusted for energy generation, and district heating or cleaned to make it fit as fuel for vehicles with gas engines.

The idea of landfilling is significantly reducing especially in developed countries because of massive investments in waste incineration and biogas production facilities. Countries like Denmark and Sweden convert almost all their municipal solid waste to energy and recycle what is fit for other purposes. A decrease in landfills contributes to reducing greenhouse gas emissions and environmental pollution.

2.3.4. Waste-to-Energy

Waste-to-energy is the term used for the processes involved in generating energy in the form of electricity or heat from primary waste combustible and incombustible waste. Waste-to-energy conversion methods are classified under Thermo-chemical, Bio-chemical, and chemical conversion. Thermo-chemical conversion comprises combustion (incineration), Gasification, pyrolysis, and liquefaction. Biochemical conversion comprises Anaerobic digestion, fermentation, and Microbial fuel cells whiles trans-esterification is classified under chemical conversion. Incineration is the fastest-growing waste-to-energy technology. It is proven to be an effective and efficient waste management solution and has been successfully implemented in most developed countries around the world. Waste incineration offers many advantages over other waste handling methods in waste management. This has helped accelerate its implementation on all continents and even in developing countries. Waste-to-energy offers a more effective way of reducing waste volumes to ensure a reduction in dependence on landfills. Waste incineration facilities are clean and can be situated close to urban areas, therefore, reducing the need for long-distance transportation of waste to landfills. Waste Incineration is also more environmentally friendly as compared to landfilling and most importantly provides energy for electricity and heating and consequently helps reduce the reliance on fossil fuels. The incineration process also produces bottom ash which can be used for construction works as aggregates.

Globally, there are over 1200 waste incineration plants in operation across more than 40 countries and many more are being built in other countries that seek the efficient and environmentally friendly usage of solid waste. About 1000 of the 1200 waste-to-energy facilities in operation do not pre-treat their waste before combustion due to more advanced technologies. The heat from the combusted waste is channelled to a boiler to produce steam which can be used for electricity production and/or hot water production for district heating. Combined heat and power (CHP) are the most common system, as it permits a more efficient usage of the heat energy generated.

Municipal solid waste incineration facilities have the disadvantage of high initial capital investment and operation costs, therefore posing a challenge for developing countries that may have an interest in establishing this type of energy facility for improving waste handling [9].

2.3.6. Waste to Electricity Technologies

Current technologies make it possible to generate high volumes of electric energy through direct heat power or internal combustion engines powered with fuels generated from waste products. Technologies such as waste incineration, anaerobic digestion, and gasification plants have become efficient methods of energy generation to supplement other energy sources. Energy generation from waste is made possible by making use of various technologies, any of these technologies have specific traits and their feasibility can be high or less depending on several parameters. These include the waste composition, energy content, the desired final energy form, the thermodynamic and chemical conditions in which the technology can work best, and the overall energy efficiency. The conversion processes can be classified into thermochemical and biochemical. Thermochemical processes involve high temperatures (combustion and gasification) and require dry matter as the most suitable feedstock. On the other hand, biochemical processes involve moderate temperatures (anaerobic digestion and fermentation) and utilize microfacial processes to convert waste and are restricted to biodegradable waste such as food and yard waste. The wet matter from the biogenic fraction of municipal solid waste and agriculture waste is the most suitable feedstock for biochemical conversion technologies. Also, some technologies are not so popular such as microbial fuel cells which produces electricity by oxidizing biodegradable organic matter in the presence of either bacteria or enzyme, esterification, Landfill with gas capture, hydrothermal carbonization (HTC), and Dendro liquid energy (DLE). hydrothermal carbonization and Dendro liquid energy are immerging technologies with high potential. The former is the chemical acceleration of natural geothermal processes using an acid catalyst. It is an efficient process that copies the natural process of coal generation using a combination of heat and pressure to chemically transform bio-waste into a carbon-dense material with similar or better properties as fossil fuel. The latter is a recent German innovation in the biological treatment of waste and presents high potential in the waste-to-energy field. The process produces 4 to 8 percent inert waste that is suitable as aggregate for construction.

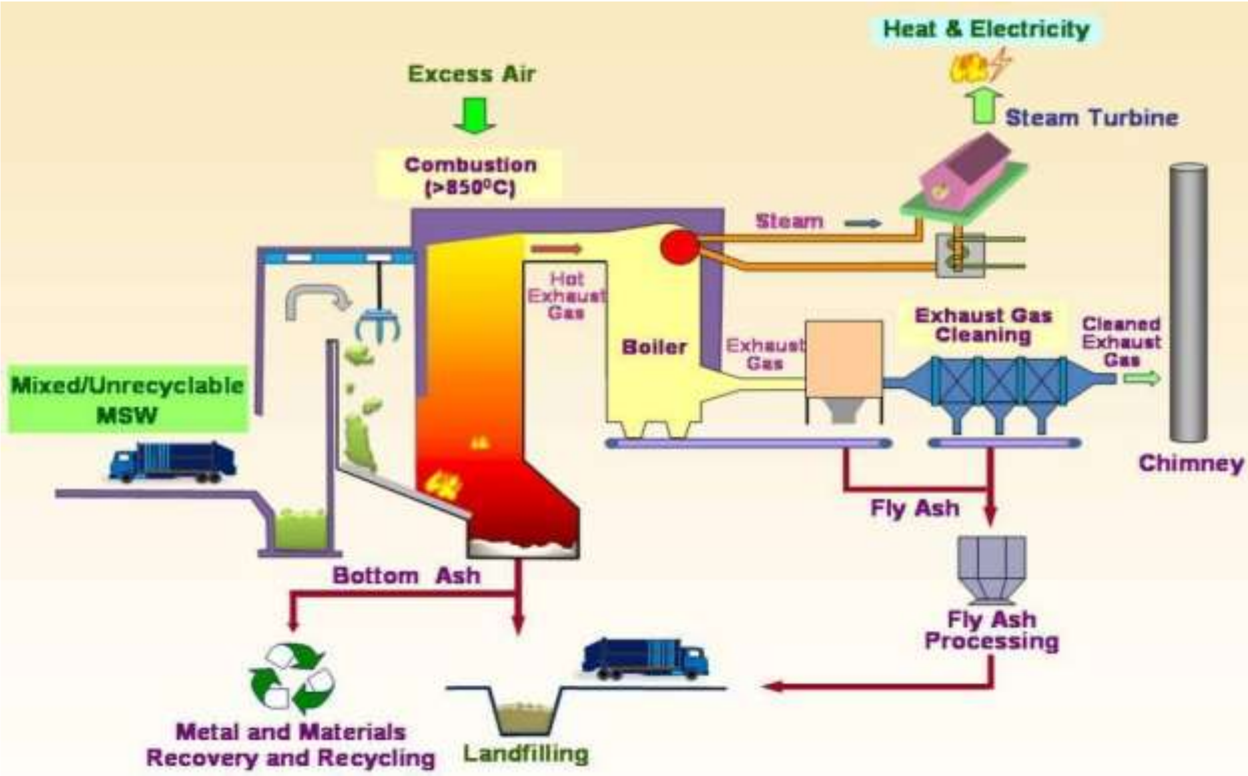
2.4. Waste Incineration Processes

Waste incineration technology involves the combustion of solid waste products under very high but controlled temperatures to generate high-pressure steam. The generated steam is channelled to drive a steam turbine coupled to a generator to generate electricity. The excess heat from the steam is used for district heating. The incineration process involves the burning of municipal solid waste in a furnace with temperatures ranging from 800 degrees Celsius to 1000 degrees Celsius and this makes it possible to generate superheated steam.

Waste incineration facilities are fed with combustible waste from mostly domestic sources. The waste may be sorted or not sorted. The waste composition may include wood, plastics, paper rubber, etc. These waste materials have high carbon content, high calorific value, and lower moisture content and making them combustible. Waste fed to the furnace is pre-treated either by pre-heating or sorting depending on the incineration facility or the type of furnace being used. The heat generated from the combusted waste is channelled to the boiler to produce high-pressure steam which drives a turbine and the turbine drives a generator coupled to the turbine through a gearbox. This process generates electricity that goes to the grid or directly powers a facility as illustrated in “Fig. 1”.

The waste incineration process produces flue gases and boiler ashes that require treatment. Flue gas is composed of carbon dioxide (CO2) and water vapor as well as nitrogen and excess oxygen residue from the intake of combustion air. There is a possibility of containing pollutants such as particulate matter, carbon monoxide, nitrogen oxides, Sulphur oxides, and mercury. These gases are cleaned by passing them through a series of processes and adding chemicals like lime to make sure only carbon dioxide and water vapor go out of the stack. Bottom ashes from incinerated materials are collected, sorted to removed metals, partly burnt materials, and treated before being disposed of, they can also be used for construction purposes [10].

New technologies, innovation, and global regulation have made Waste-to-energy a clean and a better alternative for municipal solid waste management. However, the general concerns regarding air and noise pollution are still a setback for this technology. For these reasons, most waste incineration facilities are set up on the outskirts of town. Even though the incineration of municipal solid waste does not eliminate the waste materials, it significantly reduces the volumes of waste sent to landfills. That is a reduction of approximately 75 percent by weight and 90 percent by volume [11].



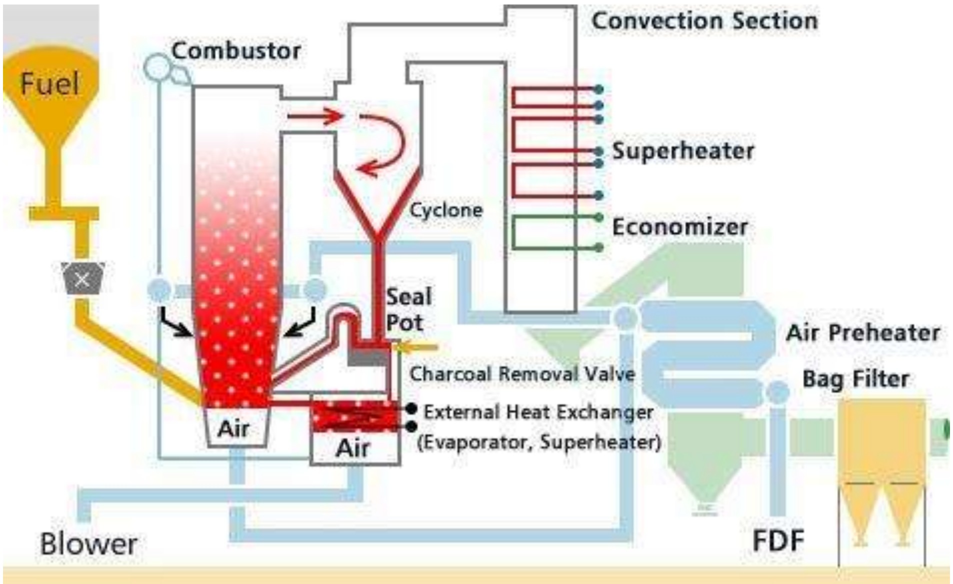
"Fig. 1." Waste-to-Energy Incineration Process [11].

2.5. Waste Incineration Furnace Technologies

Municipal solid waste incineration plants have similar features namely, the tipping hall, feed hopper, boiler, bottom ash bunker, super-heater, economizer, scrubber, flue gas treatment system, chimney, and furnace. However, the latter makes the difference in every incineration facility. In other to obtain the highest possible temperatures from incineration, furnace technology has been constantly improved. Some of these new and improved technologies make it possible to combust unsorted waste and still obtain the optimum temperatures. The type of furnace selected for a waste incineration facility depends on the type and composition of waste. It is also dependent on the waste pre-treatment process if there will be any. There are multiple incineration furnace technologies but the most popular are moving and fixed grate, rotary kiln, and fluidized bed. The furnace helps in waste volume reduction, and the rest of the process ensures the recovery of energy, the destruction, capture, and concentration of hazardous substances,

2.5.1. Fluidized Bed Furnace

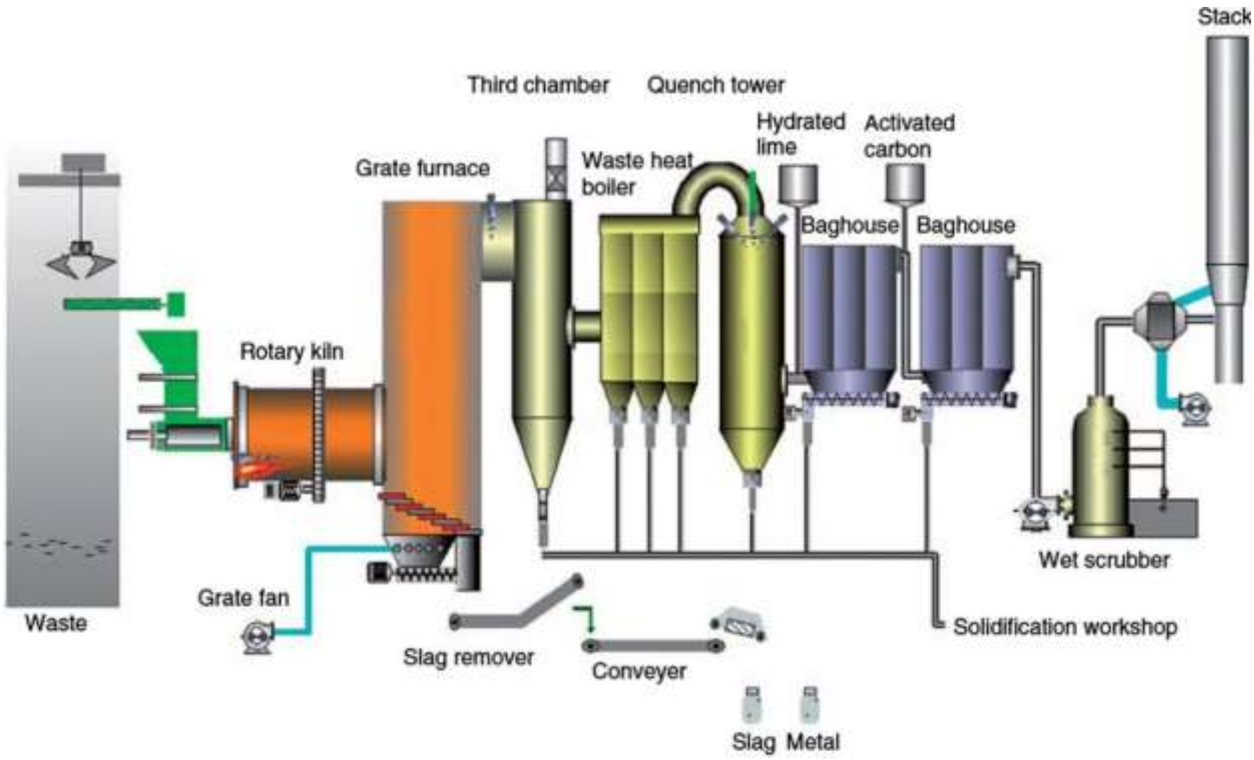
The fluidized bed furnace is of two main types, the Circulating Fluidized Bed (CFB) and the Bubbling Fluidized Bed (BFB). The principles of operation of both technologies are the same. In both furnaces, fuel particles are suspended in a hot, bubbling, or circulating fluidity bed of ash and sand or limestone through which jets of air are blown to provide the oxygen required for combustion. This results in fast and intimate mixing of gas and solids to promote rapid heat transfer and chemical reactions within the bed. Fluidized bed furnaces have great combustion techniques [12]. The technology also has high thermal efficiency and high flexibility in terms of fuel input. It also has low NOx and SOx production. However, this technology, as shown in “Fig. 2”, has the downside of demanding some form of pre-treatment of waste before its fed into the furnace.



"Fig. 2." A Fluidized Bed Furnace [12].

2.5.2. Rotary Kiln Furnace

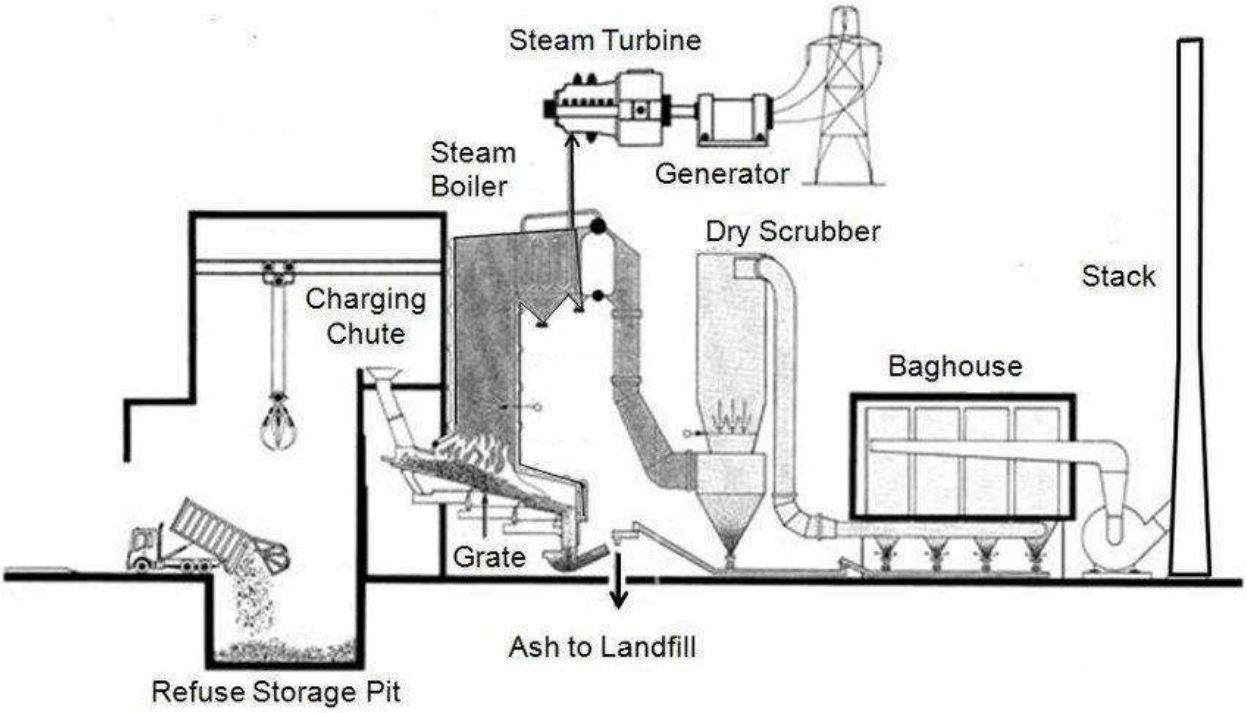
The rotary kiln furnace is a refractory lined rotating cylinder in which the waste is combusted. The kiln is a slightly inclined cylindrical vessel from the horizontal which is made to rotate slowly about its longitudinal axis. The kiln often has a diameter of 1 to 5 meters and a length of 8 to 20 meters. This means it has a capacity of up to 2.4 tons per day. The feedstock is fed into the upper end of the cylinder and is moved gradually downwards to the lower end as the kiln rotates to stir and mix the feedstock. The hot gases to commence the combustion is generated either in an external furnace or by a flame inside the kiln projected from a burner pipe which is fuelled with oil, gas, or pulverized petroleum coke [12]. The rotary kiln furnace, illustrated in "Fig. 3", has the best excess air ratio and can be used in combination with a moveable grate furnace where the moveable grate will serve as the ignition part and the rotary kiln will be the burning chamber. This combination is very efficient as it minimizes the volume of unburnt materials from the slag.



"Fig. 3." A Rotary Kiln Furnace [12].

2.5.3. Moving Grate Furnace

The moving grate furnace is the most suitable for the mass burning of solid waste. The waste materials are fed onto a grate which moves through the furnace. The systematic movement of the grate through the furnace ensures that fed-in waste materials are dried and combusted at very high temperatures of 850 to 950 degrees Celsius and above with sufficient air supply. The non-combustible part of waste exits the grate as slag or bottom ash through the ash chute to the base ash collector. This technology is the most widely used because it has been well-tested and has met technical requirements and demands. Moving grate furnaces can achieve efficiencies of up to 85% and can have a capacity of around 1200 tons of waste per day [13]. The design is the most suitable for areas where there is unsorted waste. The moving grate requires little maintenance compared to other incineration technologies, but the capital cost is relatively high. The technology is illustrated below in “Fig. 4”.



“Fig. 4.” A Moving Grate Furnace [12].

2.6. Factors That Affect the Successful Setup Of A Waste Incineration Facility

Both developed and developing countries are gradually embracing waste-to-energy technology and there has been an increasing number of incineration plants being built across all the continents but most, especially in Europe. This is a result of the difficulties arising in finding landfill sites in densely populated areas and other environmental concerns. However, in establishing a successful waste incineration facility, various factors need to be considered. These factors assist in planning and building the facility by bringing to bear certain issues which may critically affect the project. These general factors are considered in detail during the feasibility study.

2.6.1. Geographical Location

The geographical location of an incineration facility is very important in other to prevent or minimize the negative effect on public health and the environment. The location of a waste incineration facility must be selected with consideration of both economic and environmental issues. All potential environmental issues can be highlighted through an environmental assessment. A properly constructed and well-managed incineration plant has a similar environmental impact, potential public nuisance, transport networks, and other infrastructural needs as a medium to a heavy industrial setting. For this reason, the location of an incineration plant should be in areas preserved for medium or heavy industrial facilities. An ideal waste incineration plant should be located close to the potential energy consumers and the waste source to minimize the movement of waste trucks across long distances to the facility to deliver waste.

Air quality and noise levels are important factors that need to be well controlled to meet the set regulations. Hence, it is necessary to site the incineration facility in an open area where the bad smell from waste and noise operation of the facility will not be a burden to other neighbours. For these reasons, incineration plants must not be sited in stip valleys or areas prone to smog. Much of the noise from an incineration plant comes from the flue gas fans and the ventilators for cooling which operate throughout the day. Transportation of waste to the plant and handling waste materials inside the facility is capable of noise pollution. Therefore, a waste incineration facility should be at least 3 to 5 kilometres away from residential areas to reduce the impact of noise pollution and nuisance caused by the bad smell.

It is important to evaluate locations for waste incineration facilities. The process considers several locations and selects the most suitable site with the waste generation area, traffic, and transport, air quality, noise impact, proximity to energy distribution networks, utilities, and landfill.

Municipal solid waste incineration plants normally generate surplus energy in a form of heat and this energy is utilized in most countries for district heating. However, countries in South Sahara Africa, and the Middle East have averagely high temperatures and they will need the energy for cooling. This is now possible by absorption chilling technologies. Hence, it is important to build this cooling technology.

“Fig. 5.” A Modern Waste Incineration Plant (Image by WIOMA corporation).

close to the facility to prevent heat losses from transporting hot water over long distances. “Fig. 5” is a 3D design of a modern waste incineration plant with a pond for cooling. Absorption chillers operate with hot water around 130 to 160 degrees Celsius.

The excess heat can also be used for hot water production in food processing and other industrial facilities that make use of the heat. The incineration facility setup should also make space for a well-controlled landfill for burnt waste residue treatment. These residues are normally aggregates for road construction after treatment [14].

2.6.2. Political Factors

The success of every major project in a country depends on how politically sound and stable the country is. Projects that require the involvement of foreign investors are also motivated by policies that support the project in the form of incentives and a conducive environment to permit the smooth establishment and running of the project.

Waste-to-energy projects are impactful projects and can have a significant effect on a country's waste management and energy system. Projects of this nature thrive on government policies concerning these sectors. The feasibility of a waste incineration project in any country is relative to the type of municipal solid waste management system in operation and the government's willingness to alter this system, if not suitable, to support the project. This makes it difficult to initiate projects of this nature in developing countries because there are many lapses in their waste management system and the government is often required to review the policies in these sectors, which seems like a huge engagement. Waste-to-energy projects are more successful in countries that have them aligned with the government's policies and goals [37].

Also, waste-to-energy projects are feasible when the energy sector of the country is well structured and the consumer of the energy to be generated is clearly defined. The energy generated may be sold to a single consumer if the is a need or transmitted to the national grid. The consumer may be a utility company with an existing distribution network for power, district heating, or cooling. Government policies in the energy sector highly influence the success of any energy project. This is because the energy sector is normally owned and controlled by the government in many countries. These policies define the feed-in-tariffs and incentives for power producers. Waste-to-energy projects require high capital cost, are a complicated source of fuel, and contributes to the success of the waste management system. For these reasons, the feed-in tariff for such power projects is usually higher than for other forms of energy. This is to ensure the profitability of such projects and attract more investors in that area. However, incentives in the form of feed-in tariffs and taxes for special projects are dependent on government policies and goals. Some countries do have special incentives for renewable energy projects, but others do have. In countries where waste-to-energy facilities do not exist, such incentives may also not exist, and it will take the government's goodwill and vision to make new policies to support such projects.

Most developing countries may not have the luxury of establishing a nationalized Waste-to-energy facility considering its high initial investment and operating, and maintenance costs. But the government can create a supportive environment for investors, both local and foreign, to initiate this growing technology. A supportive environment that entails positive legislation, an efficient waste management system, a good feed-in tariff, incentives, and government involvement in ensuring that licenses required for these projects are acquired with less stress. Waste-to-energy facilities can also be established easily by the government’s partnership with private waste management companies if there are any. With this partnership, the plant could be operated by waste management companies or a government-owned power-producing company. The former experiences few problems regarding the supply of ‘fuel’ or disposal of residue and problems related to the selling and distribution of energy are averted.

2.6.3. Economic Factors

Waste incineration facilities are capital-intensive and dependent on reliable waste generation for their operational stability. They also have high operating and maintenance costs and due to that, the net treatment cost per metric ton of waste incinerated is high compared to regular landfilling. These factors may be discouraging to an investor who is only interested in the financial figures but these facilities have benefits that go beyond monetary value. They contribute greatly to the waste management system and reduce landfilling. Waste incineration projects require commitment from local authorities and government agencies through subsidies and incentives to make them profitable. Waste incineration plants can generate funds from tipping fees, general levies, public subsidies, sales of power produced, and residues from burnt waste when treated. Considerations should be made thoroughly on the ability and willingness of the public to pay tipping fees and the amount to be charged based on the type of waste. When this is properly streamlined, it can generate a considerable amount of funds for the facility [15].

In ensuring the survival of an incineration plant, there should be a 15 to 20 years stability plan which encompasses prices for consumables, spare parts, residue disposal, and sale of energy. Also, tipping fees must be competitive to ensure the ability and willingness to pay. Consistency in the waste generation stream and proper waste collection and sorting mechanism is also relevant in determining the net treatment cost over a longer period.

The investment cost of a waste incineration plant relies on variable factors including the plant incineration capacity and the lower heat value. Relatively, plants with low capacity tend to be more costly per metric tonne in investment cost than those with high capacity. Also, the investment cost is dependent on the type of energy production, either direct power production or combined heat and power production. Flue gas treatment is an important aspect of incineration technology and the required emission levels determine the cost of equipment which consequently affect the investment cost of the facility. The capacity of the plant also determines the number of incineration lines needed.

The operation and maintenance cost of an incineration facility varies with the capacity and the region where it is located. However, the general operation and maintenance cost comprises administrative cost and salaries, which are fixed operating costs, and a couple of variable costs which includes, chemicals for the flue gas scrubbing system, electricity cost (if the facility has a steam turbine and generator installed, electricity is produced for the grid or used by the facility), water including wastewater handling, residue disposal, machinery (spare parts) and building structure maintenance cost.

The fixed operating costs heavily depend on the number of employees, the percentage of skilled and unskilled workers, engineers, and the local wage structure. The variable operating cost to a certain extent depends on the selected flue gas cleaning system. The most significant item of the variable cost is the cost of chemicals for flue gas cleaning [8]. Regarding normal practices, the annual maintenance costs are believed to be 1 percent of the investment cost for civil works and 2.5 percent of the investment cost for machinery and spare parts. However, this estimation may vary depending on the conditions and regional location of the facility.

A significant element in financing a waste incineration project is the sale of energy. In extreme cases, the revenue from energy sales can account for about 90 percent of the total revenue. This is however possible with waste having a lower calorific value in the range of 9 to 13 MJ/kg which confirms that the power production capability of a facility depends on the lower heat value (net calorific value) of the waste feedstock. In planning energy production and sale, the specific energy demand must be highly considered. If the heat energy is meant to generate electricity only, arrangements should also be made on how to dispose of the residual heat from the used steam. In most cases, this excess energy is used for district heating or cooling to make sure no energy goes to waste.

If the production and sale of processed steam is an important part of the energy business, this revenue must be determined by an agreed sales agreement. The price per metric ton of steam supplied depends on the pressure and temperature of the steam. It is also important to note that the main function of an incineration plant is the treatment of waste to reduce its volume and render it harmless.

Gate or tipping fees are commonly used for large industrial customers, and waste collection companies who pay a fee for waste delivered directly to the incineration facility. There is a possibility of inconsistent waste delivery to the facility, and this may prevent the plant from contently operating at full capacity which will in turn affect energy sale revenue. Customers may seek alternative, less expensive, waste treatment through landfilling, or they illegally dump or burn waste. Controls must be in place to ensure that sufficient volumes are delivered to the facility to cover capital and operating costs. Local waste management authorities must commit to delivering an acceptable minimum quantity of waste to the incineration facility as per the agreement [16].

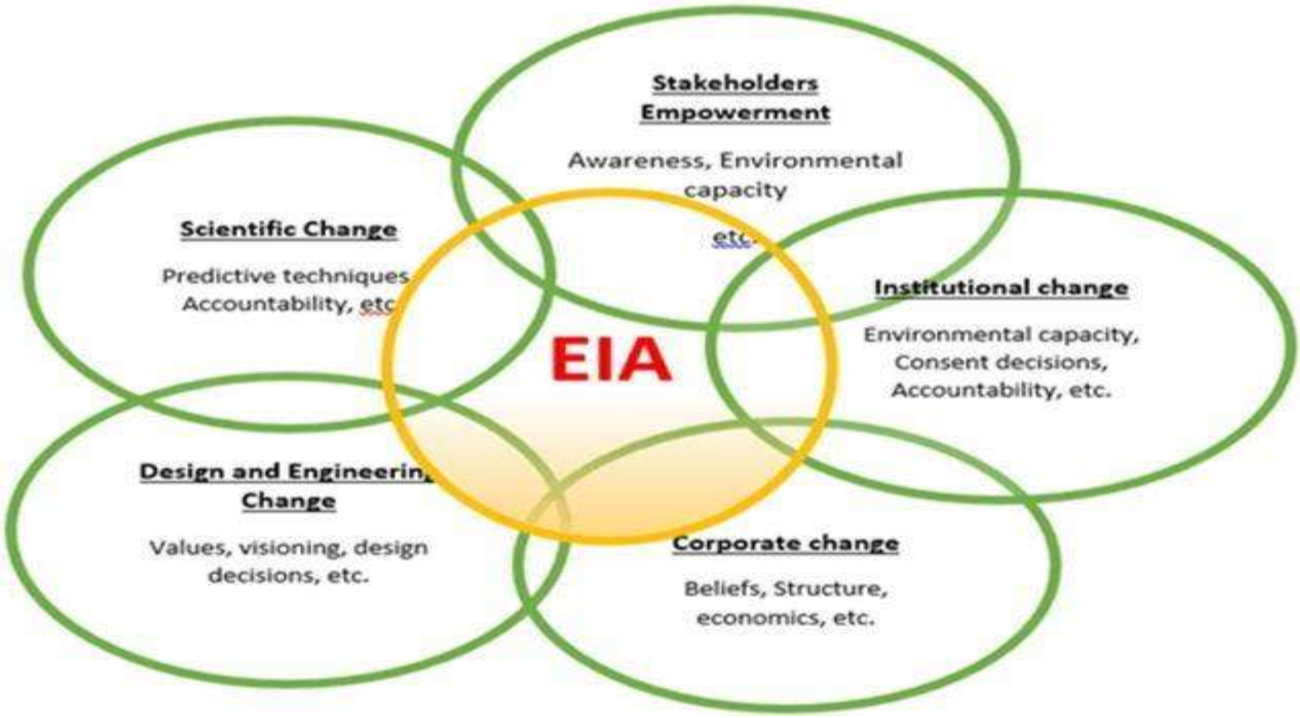
Electricity and heat energy generated by a waste incineration facility contribute to the energy production capacity of the country. Energy can be sold to a local power supplier or a private customer. A stable demand for power will guarantee revenue generation for the plant and ensure that all financial obligations are met. Public subsidies in various forms from the local government or environmental protection organizations can be beneficial. Government grants, low-interest loans, and or tax exemptions are some factors that encourage investors to invest in waste incineration projects. For a country to attract foreign investment, the economic standing of the country is vital. Inflation and the strength of its local currency determine the long-term value of the investment.

2.6.4. Legal Factors

Waste management strategies can be implemented with the support and directive of a legal framework. Legislations must entail a series of ordinances and regulations designed to manage solid waste, including procedures and methodologies for monitoring, and enforcing the regulations There are general legislations such as landfill directives, waste framework directives, waste incineration directives, control measures for biological treatment, and landfill ban on organic waste. In some countries, there are clear guidelines on which waste-to-energy technologies to implement under the Best Available Technology (BAT) framework which stipulates the level of technological efficiency is acceptable, and the cost associated with it must be reasonable for performance. Considerations regarding the legal framework of the country on waste management are essential for the success of such projects. These laws must support and protect investors who decide to invest in waste-to-energy projects. The level of independence and transparency of a country’s judiciary must also be factored in when deciding to invest. Laws on land acquisition, business registration, and taxes. According to a World Bank publication in June 2015, countries with good legal frameworks attract more foreign investment and a ranking by U.S News put the United Kingdom and Germany at the top in this category.

2.6.5. Environmental Factors

Waste incineration is an effective way to protect the environment by efficiently converting solid waste into a useful form of energy and consequently making it harmless after going through the process. The incineration process must be carefully monitored to ensure that there are no environmental concerns raised. These concerns are often associated with the flue gases from combustion released into the environment [17]. However, flue gas treatment of incineration plants has quickly evolved over these few years with highly improved standards and requirements from international environmental regulatory bodies. Flue gas treatment facilities of incineration plants are of such importance, and this is evident in the setup of incineration facilities. about one-third of the perimeter of most facilities consists of flue gas treatment equipment and provisions are made for more additions when needed to meet the requirement of the international regulatory bodies. To ensure that waste incineration facilities do not negatively affect the environment, an Environmental Impact Assessment (EIA) is done for every major project. This assessment points out the negative aspects of the project concerning the region of location and the mitigation plan for these concerns. The Environmental Impact Assessment helps assess issues related to noise, odour, chemical usage, wastewater discharge, and emissions. The locals usually take part in these processes by expressing their sentiments concerning the project as shown by a chart in "Fig. 6". The Environmental Impact Assessment processes and regulations vary by country but have the same objectives all around the globe where it is performed. Waste incineration facility Environmental Impact Assessment must be done in accordance with requirements laid down in the world bank operational directive 4.01 [18].



"Fig. 6." Environmental Impact Assessment Chart [18].

2.7. Benefits Of Setting Up A Waste Incineration Facility

Waste incineration facilities have enormous benefits to the environment and economy of a country. Technology is considered the best means of utilizing solid waste which has been difficult to manage by most countries due to the high increase in urbanization and scarcity of suitable locations for landfills creating environmental concerns when not properly operated. The overdependence on fossil fuels as the main global energy source is threatening climate change and the discovery of other clean sources of energy will be a positive contribution toward the attainment of totally clean energy dependence in the next few decades.

2.7.1. Job Creation

The Waste-to-energy industry is a fast-growing industry, and it is contributing effectively to the economy of countries that adopt this technology. Aside from the large revenues generated through gate tipping fees and sales of energy, the industry has also made a significant impact in the creation of jobs directly or indirectly. Jobs are created from the construction phase of the facilities to the operation phase. The operation of an incineration facility requires mechanical engineers, automation engineers, IT specialists, electrical engineers, and sales and administrative staff. The Waste-to-energy industry in the US employs approximately 5320 people. This number includes workers at the 85 facilities and off-site employees of the various national and regional organizations that own and operated Waste-to-energy facilities. Also, this includes local government personnel in charge of plant oversight and maintenance. In addition, 8600 jobs are created indirectly forming a total of around 14000 jobs just in the US [19].

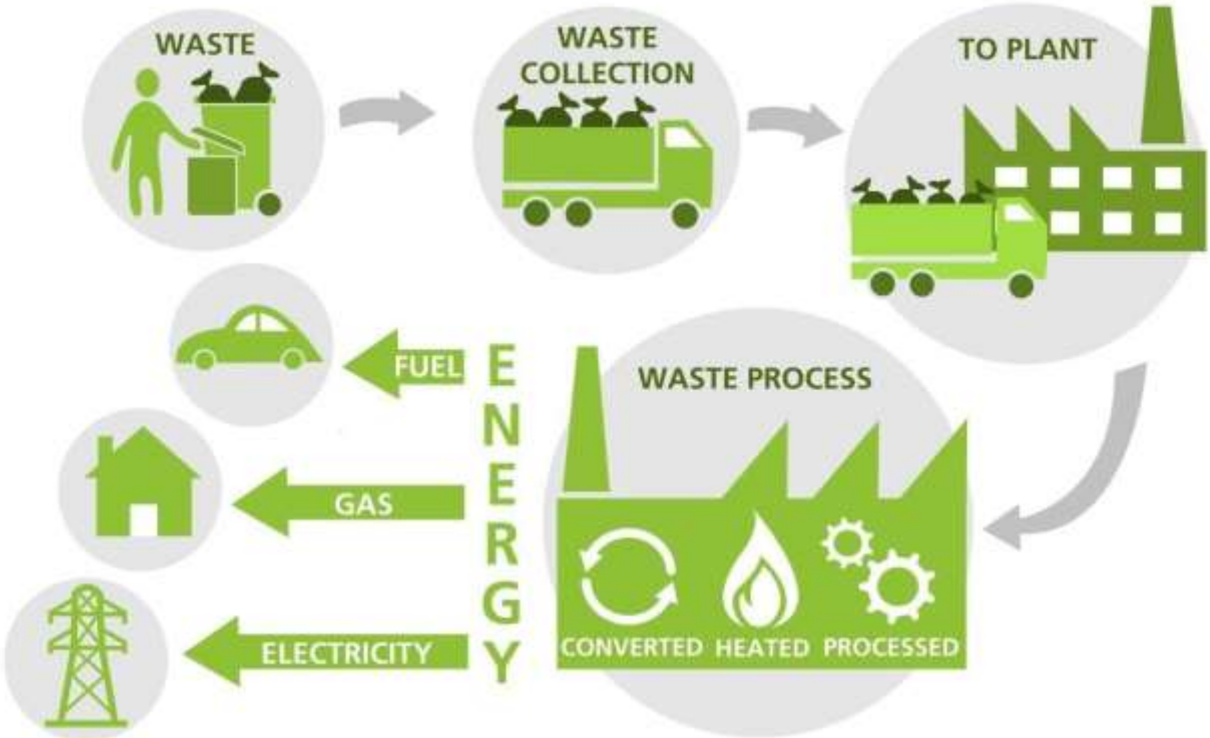
Ethiopia has Africa's first major waste incineration facility which commenced operation in 2017. The facility has a capacity of 350,000 tons of waste annually and employs 100 skilled and unskilled personnel. It has also created thousands of jobs with the newly established waste collection system [20].

It is argued that recycling creates more jobs as compared to waste incineration. However, recycling is limited to only certain types of waste and incineration takes care of what cannot be recycled. It is estimated that waste incineration facilities across Europe create around 56000 direct and indirect well-paid jobs with great working conditions and benefits [21][22].

2.7.2. Contribution To Municipal Solid Waste Management System

The main purpose of waste incineration is to reduce the solid mass of the waste by 80 to 85 percent and the volume by 95 to 96 percent depending on the waste mix and make it safe for disposal. The technology does not substitute landfills, but it significantly reduces the necessary volume for disposal. "Fig. 7" shows the waste-to-energy process from waste disposal, collection, incineration, and energy conversion. Countries with good waste management systems and good landfill operations still need alternatives to reduce the volume and number of landfills. This is particularly due to the increasing urbanization which significantly increases the volumes of waste generated and the difficulty in obtaining land at good locations for landfilling coupled with emissions from landfills. This challenge triggered the need to find means of reducing the dependency on landfills. Waste incineration was purposely initiated to assist in waste management and later on improved to utilize the energy generated from its combustion process. Countries like Sweden and Denmark have benefited immensely from energy production from waste incineration over the past few decades and it has also drastically reduced the percentage of waste sent to landfills. Sweden sends only 4 percent of its household waste to landfills. In Sweden, regulations for producers of packages and tires were introduced in the early 1990s [23]. landfill taxes were also introduced in January 2000. between 2002 and 2005 a law banning the combustion of landfill waste come was put into action [24]. Sweden still operates below its capacity to incinerate all the waste generated with its 20 waste incineration facilities, However, about 22 more facilities are either being planned or constructed to support this course [24]. The Swedish people generally support waste incineration as a form of sustainable energy and raise concerns regarding raises in taxes on such facilities [25].

Denmark imports waste from neighbouring countries to fuel the numerous incineration plants in the country and as a result, the country can provide 20 percent of its district heating from these incineration facilities. Waste incineration can solve the problems facing developing countries in their waste management sectors. The technology is expensive, but it surely pays off by reducing landfilling and providing a clean source of energy to supplement the country’s energy needs [26].



“Fig. 7.” Waste-to-Energy Process [26].

2.7.3. Economic Benefits

Waste-to-energy facilities have several economic benefits ranging from job creation, and revenue generation to cost saving in land acquisition for landfills and landfills operating costs. The technology put waste that could be kept in landfills to good use and help generate revenue from the energy produced. The generated revenue is enough to run the facility and pay back the investment made with time.

In the USA, the waste-to-energy industry is huge, and it employs about 5,350 workers [27]. this comprises all personnel across 85 facilities nationwide and offsite workers across the value chain ranging from technicians, engineers, and local government employers. the industries in this sector contribute around $460 million in salaries and benefits annually and about 429 million to other employees through business with other industries.

2.7.4 Environmental Benefits

Protecting the ecosystem is a matter of global interest due to the risk it poses even though some countries are contributing more to support the goal than others. This has led to the implementation of several regulations in every sector whose activities directly or indirectly affect the environment. Greenhouse gas emissions have over the years been a major worry for the globe and this is because of the rapid changes being experienced in our climate presently [29]. The is great fear as to what may transpire in the few decades ahead of us and the fate of our future generations if uncontrolled emission of harmful gases is allowed to continue. Most of the developed countries with major industries are the biggest contributors to emissions due to the use of fossil fuels in power generation, transport, and industrial activities. The use of fossil fuels for the generation of power and other industrial processes is a great concern. Our environment is also being polluted with dangerous gases from fossil fuels and uncontrolled landfills in underdeveloped and developing countries. Municipal solid waste is another threat to the environment. Trillions of tons of waste are transported to landfills annually. Most developed countries manage to recycle some part of their waste is sent to landfills. However, not all these waste materials are recyclable hence leaving a huge portion in landfills.

Waste-to-energy technologies have immensely contributed to ensuring a clean environment by assisting in the efficient management of solid waste and reducing volumes of waste transported to landfills. Waste incineration facilities are designed to effectively reduce the mass and volume of solid waste drastically and render it safe and useful for construction works. Countries that have utilized this technology have been able to manage their municipal solid waste more efficiently and reduced the percentage of waste in landfills significantly. The result is a cleaner environment with minimum risk of diseases from poor hygiene. In limiting the dependency on landfills, the emission of harmful gases like methane is also reduced. Methane gas emissions are more than 20 times the potency of carbon dioxide gas emissions and are considered a dangerous contributor to climate change. It is reported that the global energy production from Waste-to-energy facilities is equivalent to millions of barrels of oil annually.

Arguments surrounding emissions from flue gas in waste incineration plants have been opposed to the development of flue gas treatment in these facilities. Harmful gases from the combustion processes are channelled through a series of filters and chemicals are added to absorb these gases and allow only water vapor through the stack or chimney. Therefore, there is no pollution at all to the environment [30].

2.8. Waste-to-Energy In Developing Countries

Municipal solid waste management is a concern to many of the world's largest urban areas. As populations increase the quantities of waste generated increase as well. This increases the burden of waste management authorities and is even tougher due to the relative decrease in space for disposal. It has created a challenge for municipalities and a need to put a high proportion of the waste generated into other relevant use than just disposing of them in landfills. As waste management authorities pursue how to run clean and safe landfills around the peripherals of their cities, the task becomes more severe since siting and preparation of landfills requires the acquisition of large land area, which is expensive, as well as ensuring a good daily operation of the site in other to minimize potential negative environmental impacts [12].

Most underdeveloped and developing countries have failed in ensuring effective solid waste management practices, from the collection, and transportation to the disposal of waste. Most countries are challenged with depleted waste management systems and inefficient practices through improper waste disposal in drainages as well as public places [31]. The rampant growth in the level of urbanization in most underdeveloped and developing countries is expected to continue in the future and the threat it poses is that there are no sufficient infrastructural provisions and effective land use plans to match up with the demands of the urban growth rate, especially in the slums and impoverished areas. The inability of these countries to meet the basic solid waste management requirements has affected their realization of making good use of waste through modern waste-to-energy technologies which are being utilized by developed countries around the world. Waste-to-energy and recycling have made it possible for most developed countries to reduce their dependency on landfills drastically. These countries achieved that by first attaining the basic waste management principles of effective sorting of waste, collection, transportation, and proper management of landfills [33].

These principles are necessary because they contribute to an effective and sustainable supply of waste to these waste-energy facilities when they are established, and they also ensure the availability of recyclable waste materials. These facilities absorb a high percentage of waste generated but not all and consequently landfills are still needed. Hence, there is a need to ensure the proper development and maintenance of basic waste management principles.

Most underdeveloped and developing countries around the world are struggling with municipal solid waste management and these concerns keep increasing as the urban population continues to grow. The Inability to ensure that waste generated is properly collected transported and disposed of is because of poor planning and policy implementation from the early stages. Systems and facilities are not managed as they should and above all, public education is compromised. The latter has caused more harm because the literacy level of the citizens is low, and a great deal of awareness needs to be created to inform the least educated of the need to adhere to sorting and proper disposal of waste the sort out waste and dispose of waste. There is a challenge when most residents live below the poverty line and struggle to afford three square meals a day.

The current level of waste management in these countries will make it difficult for an effective operation of a waste-to-energy facility. The effect of solid waste sorting on waste incineration processes is indeed limited due to technological advancement. However, the waste collection systems in these countries are questionable as a result of a failure in the effective implementation of sanitation policies if there are any.

3. RESEARCH METHODOLOGY

This chapter elaborates upon the study structure and data collection methods for the study. The study is quantitative research, and it is aimed at determining the technical and financial feasibility of a waste incineration plant in Ghana by analysing the waste data obtained for a selected area in Ghana to serve as a pilot project. The research focus is on deriving detailed information on the waste collection and composition data of Ghana and analysing the feasibility of the derived waste composition to determine whether it meets the standard figures for the successful establishment of an incineration facility. Data gathered from the study gives a clear picture of the trend of waste generation, collection, and composition in the country currently and provides good information on which further research can be done. The study also provides information for potential investors who may be interested in establishing a waste incineration plant in Ghana, upon which further feasibility study could be done. Comprehensive data on waste generation, collection, and composition are not readily available even though municipal, and metropolitan assemblies are tasked to collect and keep these data. However, after a few contacts, I obtain the relevant data required to make the study successful.

3.1. The Research Design

The research data collecting strategy was clear and definite as the relevant information was gathered through consultation with the authorities in charge of data on waste management in the country, and more importantly the region of focus. Some information was also obtained from previous studies done by other scholars on similar topics, and current data published by the statistical service of the country. Emails were sent out to some waste management companies for information on the waste management structure and policies which they responded. The Accra metropolitan assembly and the Ghana statistical services websites were also important sources of information for this study. Information gathered from various sources was compared and assessed to ensure its validity. Some data were a few years old and some were current, but the trend was the same with just a little deviation at some points. Fortunately, solid waste generation and collection figures are published annually and the change in values corresponds with growth in population and improvement in the efficiency of the waste management system. The final data from the above findings were evaluated to obtain the calorific values and further calculations were made to derive the energy potential of each waste component and the total energy potential per ton of waste incinerated. The energy values from this evaluation assisted in proposing the right incineration technology. Information on the specifications of a waste incineration technology from a modular incineration plant was used in projecting the energy production from the waste data collected concerning the composition and heat values derived from the study evaluation. The energy generation figures obtained from the supposed pilot project are compared to the standard figures and analysed. The result together with the financial estimations will result will give clear grounds to determine the feasibility of the project and any other similar projects.

3.2. Data Collection Method

Data was gathered from a literature review and direct sources through a series of official emails sent out to the municipal assembly and other relevant authorities to which the majority replied to. There was a visit to the biggest landfill in the Greater Accra region, the Tema Metropolitan assembly waste management facility, and the Zoomlion waste management facility in Accra. Zoomlion is the largest private waste management company in the country they were vital to this study. They gave some data on the quantity of waste transported to their landfills annually. Data were also obtained on the average number of trucks that deliver waste to the landfill daily. Knowing the capacity of the trucks, the volume of waste transported could also be estimated and compared to the actual data. Data from the Ghana Statistical Services and that from the Accra Metropolitan Assembly covered all the regional assemblies which also gave details on the composition of waste collected from the main city and trade zones. Some data from previous studies in this area were of great use. However, data from those studies were collected from different parts of the country and there were some variations in the final figures derived from the studies. To conclude with a more realistic outcome, findings from all the studies considered were analysed and compared to the real data gathered and some variations were expected because of the age factor. It is obvious that data on waste varies annually due to several factors of which all were considered in analysing the data obtained.

3.3. Research Quality

The quality of research is defined by the extent to which the data collection techniques and analysis will yield consistent results. The four major threats to quality and reliability are participant error, participant bias, observer error, and observer bias. The personal interactions during data collection were with the staff of stakeholder companies and institutions and their responses relied on documents made from records of their activities over a period.

The reliability of the data obtained is high and if any error is imagined, it would be from their data collection but not from this study. the objectives of this study required personal data collection and analysis from the major cities throughout the country. The municipalities and regional assemblies are charged to keep these records which are published annually. As stated previously, similar studies have been conducted in other parts of the country on the quantities and composition of solid waste generated. The result of this research is often similar, and it is noted that the waste compositions vary throughout the country and are a result of both social and economic factors. The per capita waste generation in the country is similar in most sources and the daily and annual quantities of waste generated in Accra are from both local and international sources because it is the capital city and more exposed. The result of these findings has a little amount of deviation just as it will be in even developed economies. But overall, the result from this study can be relied on in planning for a similar project in Ghana which is the purpose it is meant to serve.

3.4. Ethical Issues In Research

In every study, priority must be given to issues on ethics relating to the interviewees' comfort and willingness to contribute to the survey. Also, managing of confidential business information given to the researcher is essential. This study did not compromise on these ethical issues, as information was sorted from individuals, most specifically staff of companies and agencies in the waste management sector. Information was formally sought, and many were willing to share with the researcher. Emails were sent to some relevant agencies for data or clarification of the figures from data provided online. Some of these emails were replied and it was helpful to the study, others were not willing to give out any information and some of the emails were not replied to. These circumstances were well understood because the respondents have their complete liberty in which information, they choose to give even though I had a letter from my study supervisor. Overall, expectations were met with the information gathered, ethics of data protection were observed, and data obtained from other studies and online sources were adequately referenced.

4. FINDINGS ON WASTE MANAGEMENT AND ENERGY IN GHANA

4.1. Solid Waste Management System

Accra, the capital city of Ghana is challenged with poor sanitation due to deficiencies in municipal solid waste management resulting in waste collection laxity in some suburbs and busiest streets [34]. Accra is one of the smallest regions in the country by area but the most populated, this is partly due to the lack of decentralization of the economy resulting in the influx of citizens from across the country in search of jobs and a better standard of living. Consequently, there are several unplanned settlements in the suburbs where adequate road networks are compromised and making it difficult to collect waste using trucks as it is done in other planned communities. Many of such settlements are also heavily populated thereby generating large quantities of waste.

The metropolitan and municipal assemblies are supposed to oversee sanitation and the effective implementation of the appropriate waste management procedures in residential settlements. However, these authorities have not been much effective in delivering this mandate due to financial constraints, planning, and effective implementation of policies. lack of funding for required machinery and equipment contributes to the limitations in their operation. The result of this is the absence of waste-collecting bins at vantage points in various communities. Communities that are fortunate to have waste bins are sometimes faced with a situation where the waste containers become full and have waste overflowing because the authorities failed to empty the containers on time. This poor waste management system has forced the intervention of private waste-collecting companies. These companies operate very effectively and offer good services to their customers. They provide their customers with waste bins, and they go around with the trucks emptying these waste bins based on their community schedules. These companies charge a fee that most average households cannot afford. The private waste collection companies are unable to operate in most of the slums in Accra because there are no routes to most of the homes in these communities.

There are other big cities in the country with similar solid waste management challenges, but Accra has the worst situation because of its huge population density. These challenges are not limited to the communities only, the streets and major commercial areas of Accra have over consistently been challenged with sanitation woes. This is evident in the busiest parts of the city including, markets, shopping streets, and public transport stations [34]. Huge piles of solid waste are often spotted on the streets of these areas mentioned. Sanitation on the main streets of Accra has been contracted to a private waste management company called Zoomlion Ghana Limited. This company is tasked with cleaning the streets of the major cities in the country and other public places across the country. They discharge their duties quite effectively with thousands of employees all over the country. However, this seems not to be enough. Public education on individual waste handling is needed to address the bad habit of some Ghanaians who prefer to dump refuse irresponsibly on the streets and in drains even when waste bins are provided by the company at vantage points [4].

With the inefficient waste collection process, just about two-thirds of the total waste generated is collected. The means of disposing of this collected waste is another major challenge. In Accra, just about 55% of waste is collected and disposed of in landfills which are not environmentally friendly, and some have sanitation deficiencies caused by a lack of proper management and bad location [34]. Some of these landfills have little or no control at all and lack treatment, causing more damage to the health of communities located close to them. Waste in landfills is often burnt openly and this releases harmful gases into the atmosphere and negatively impacts the environment.

4.1.1. Solid Waste Generation

Accra, the capital of Ghana is the most populous city and generates nearly 1.3 million metric tonnes of municipal solid waste per annum of which approximately 67 percent is organic matter. The waste average waste generation per capita is estimated at around 0.5 kilograms daily making Ghana one of the highest municipal solid waste-generating countries in Africa [35]. Waste generation in Accra is estimated to have increased by three folds in the past two decades. The factors affecting this increase include rapid population growth, an increase in urbanization, and an advanced economic lifestyle [3]. The affluent communities usually generate high quantity per individual than less affluent ones. This is due to variations in purchasing power and informal recycling and reuse practiced by less affluent communities [15]. There are waste transfer centres in most districts in Accra as shown in “Fig. 8” for gathering and sorting waste before transporting it to the landfills.

“Fig. 8.” A Waste Transfer Facility In Accra (Image By Zoomlion Ghana).

Research shows that the increasing use of plastic bags and sachet water in Ghana and predominantly, in the capital is also a contributing factor. The urban population of the country is expected to double by the next decade, according to the Ghana Statistical Services, and this may double the current waste generation figures. solid waste generation is very high in the main business zones of the city including markets and public transport stations. Street hawking also generates a considerably high level of waste, but it becomes a problem when customers of these street hawkers throw plastic bags or papers for wrapping the content on the streets instead of dumping them in the waste bins located on the streets. Waste generated at market areas is mostly food waste, plastic, and paper bags and this form of waste is the most dominant in the types of waste generated in the country, very similar to household waste except for some metallic, wooden parts, and explosives.

Industrial waste is also considered in its quantities. However, these forms of waste are properly managed due to the strict regulations governing industrial activities in the country, and much of this waste in the form of heavy metallic parts and plastic parts is often bought by some industries that recycle it for their use.

4.1.2. Collection And Disposal Of Solid Waste

Being aware of the severity of indiscriminate dumping and littering with a large proportion of waste not uncollected in the Municipalities, the Assemblies engage the services of private waste collectors to increase the efficiency of waste collection in residential and commercial areas. Of the 13,000 metric tonnes of waste generated daily, only 25 percent of the quantity is collected. A figure that falls below what it can accept in any developing country percent less than the national average collection rate. This leaves behind a significant amount of waste per figure from the statistical services. Comparing the current level of waste collection to the Municipal Assembly’s target of an 80 percent collection rate, there is a significant shortfall. This trend threatens the health of the inhabitants and the is not a good look developing country. Regarding waste collection statistics, the Municipal Assembly contributes 35 percent whiles the private sector collects the remaining 55 percent. The open disposal of waste has led to scavenging activities, where recoverable waste is by the local folk and sold for recycling.

However, waste collected from these activities is minimal due to the waste composition, which is dominated by organic substances [5].

4.1.3. Recycling

Municipal solid waste in the form of plastics, papers, and metals can be found everywhere, in modern economies, and all social classes regardless of economic disparities, including Ghana. Plastics became dominant in mass commercial use after the first world war. Plastics have been a major concern in solid waste management in developing countries in Africa and around the world. Some countries still struggle to adapt to the new technologies that can ensure proper disposal and recycling of these types of waste. Plastic waste is generated in thousands of metric tonnes annually in the major cities of Ghana with most of it being disposed of in the wrong manner. Either in landfills or open combustion which releases toxic gases into the atmosphere, posing health risks, and contributing to negative climatic conditions [6]. Plastics are of infinite shape, infinite use, infinite possibilities, and infinite time. Hence, plastic waste can be disposed of by two reliable and efficient methods which are recycling and waste-to-energy technologies. Plastic wastes which are sorted such as bottles, sachet, plastic bags, and other components are suitable for recycling into different forms for reuse. Also, plastic waste which cannot be sorted from a bunch of solid waste is suitable as fuel for incineration plants to generate heat, electricity, or both. These facilities have high technological control of gases from the incineration process and ensure that the environment is not affected by these gases.

Ghana is yet to build the first major waste incineration facility in this modern age where waste-to-energy technologies are becoming one of the most efficient and profitable ways of managing municipal solid waste. However, recycling plastic and metallic waste is ongoing but on a small scale which is not convincing because it contributes almost nothing to the waste management problems of the country. Research shows that as of 2016, there were about 40 plastic manufacturing companies in Ghana producing about

26000 metric tons of assorted plastic products, and over 10000 finished plastic products are imported annually [36]. Just 2 percent of the plastic that is generated into waste was recycled. The remaining 98 percent remained on the streets or disposed of landfills waste management companies. The consequences of the former are blocking the drains, air, and water pollution, and subsequent flooding of major cities mostly caused by clogged drainages.

"Fig. 9." Zoomlion Limited Recycling Facility In Accra (Image By Zoomlion Ghana).

According to the world economy, Ghana generated approximately 840,000 tonnes of plastic waste in 2020 and approximately 9.5 percent of that was collected for recycling. There are more than 2000 waste pickers who are local folk making an impact by cleaning up beaches, drains, and other sites. This is an initiative to create employment and support the waste management system [36].

A feasibility study by the Centre for Scientific and Industrial Research in Ghana revealed that the country can generate an enormous amount from the recycling of plastic waste as shown in "Fig. 9". This can be achieved if plastic waste can go through a series of stages including collection, sorting, recycling, and resale to user agencies. There are four plastic waste companies in Ghana whose capacity can amount to 400 tons per month. However, these companies are operating far below capacity due to the unavailability of sorted plastic waste. The strategy towards attaining this goal is to create public awareness of the need to sort out waste and improve the waste disposal and collection system. [7].

4.1.4. Solid Waste Sorting

Sorting waste is the process of separating solid waste into different material classes. Waste sorting can be done manually by households and collected through curb-side collection processes or automatically separated in material recovery facilities. The latter is an expensive procedure and thus most developed countries ensure that waste sorting becomes a normal practice. One of these arrangements is by providing waste bins for collecting different types of waste. Solid waste sorting is the first step in recycling and proper waste disposal. Sorted waste becomes more useful than just ordinary trash since some may be reusable or recycled and the rest could be used for other important processes including energy production.

Most African cities including Accra are faced with terrible issues concerning their waste management systems because of the lack of domestic waste sorting resulting. This situation is mostly attributed to a lack of education and public awareness or ignorance among the average citizenries. Waste sorting is a hectic process and even developed countries with a high rate of illiteracy sometimes have setbacks dealing with this process domestically because it is self-supervised, but the rate of sorting is high and low in countries with low literacy rates and many of the citizens living below the poverty line. However, most Western countries took time to educate the public about the benefits of waste sorting and the need to sort out your waste before disposal and this education and awareness creation has become a continuous exercise even after seeing success in their efforts. The waste management authorities have provided the means to make the process easier for the public. Some countries give out plastic bowls to households for the different types of waste they produce. This makes it possible for waste to be sorted right from the homes and allocates different waste bins with illustrations indicating which type of waste should be dumped into it [7].

Ghanaians generate a huge amount of solid and food waste daily which when properly sorted can be used as fuels for incineration and anaerobic digestion plants to generate electricity and biogas to supplement the energy deficits. This will also reduce the number of landfills in the country and subsequently reduce the health issues associated with these landfills. Even though new incineration furnace technologies accommodate unsorted waste, the cost of flue gas treatment becomes higher. Sorting out solid waste also makes it easier for recyclable contents to be retrieved and sold to recycling companies.

The current situation of waste sorting in Ghana is discouraging and the worst of it is the fact that there is not a single large-scale waste-to-energy facility in the country which means that waste management authorities have nothing urging them to push the agenda of waste sorting because that is of no use in the case of landfills. However, the few solid waste recycling industries in the country are struggling because they are not able to operate at their maximum capacity certainly due to the lack of raw materials.

The adaptation of waste sorting will enable the conversion of solid waste into new resources, reducing environmental pollution and optimizing natural resource utilization. This requires waste management authorities to be responsible and familiarized with Western techniques, collective action, and goal setting, as well as maintenance, monitoring, and evaluating the progress of new projects or initiatives. The sustainability of the system evolves around stakeholder participation and consensus building among households, service providers, communities, formal and informal private sectors, and local governments. There must be a long-term plan for education and awareness creation starting from schools to churches and programs of national television informing them of the environmental and economic benefits of taking time to sort their solid waste. In other to make an impact on the youth, it will be beneficial to include waste management topics in the school curriculum of the younger pupils to teach them the necessity and methods of sorting their household waste.

4.2. Municipal Solid Waste Management Policies In Ghana

Ghana established the Environmental Sanitation Policy (ESP) in 1999 but it did not change much in the waste management situation indicating that the policy could not address certain relevant issues influencing the need for a revision in 2019. Policies such as the Millennium development goal, the growth and poverty reduction strategy, and the new partnership for African development surfaced after the formulation of the ESP [37]. These global and regional policies have their focus on different aspects of development. As a result, they needed to be streamlined and updated to fit changing conditions. Waste management in Ghana over the years has taken different dimensions. The government previously was solely responsible for solid waste management. However, this policy has been replaced by a system that ensures both the district assemblies and private companies share responsibility. This decision was triggered by the total failure of the public sector to handle the task efficiently due to the rapid increase in population and changing lifestyles. The consumption pattern of especially the growing urban middle class is increasing the complexity and composition of the waste streams in the country. An example is a shift from packaging foods with biodegradable materials like leaves and paper, to packaging foods with plastics.

The Ministry of local government and rural development in collaboration with various waste management stakeholders, such as ministries, departments and agencies, metropolitan municipal and district assemblies, private waste management companies, NGOs, and CBO's established the new environmental sanitation policy in 2010. The government involved various stakeholders in the formulation of this policy. This study revealed that a wide range of stakeholders was involved during the policy formulation at various levels in the case of the new ESP in Ghana, at the national level, the stakeholders involved included the Ministry Department and Agencies such as the

Ministry of local government and rural development and Environmental Protection Agency (EPA). The Metropolitan, Municipal, and District Assemblies (MMDAs) were involved at the regional and district level. Private waste management companies such as Zoomlion Ghana Limited (ZLG) and Liberty Waste Limited (LWL) were also among the participating stakeholders. International organizations such as United Nations Children's Fund (UNICEF) and non-governmental organizations including Plan Ghana (PG), World Vision (WV), and Action Aid (AA) were consulted in the policymaking. Also, individuals and households were involved in the policy formulation. The citizenry was involved in the process through consultations with associations such as Queen Mothers from marketplaces, yam workers associations, and landlord associations, amongst others [10].

The government, to curb the high employment rate among the youth through private sector empowerment, introduced the Ghana Youth Employment and Entrepreneur Development (GYEEDA) in collaboration with Zoomlion Ghana Limited (ZLG) in 2016. In this arrangement, Zoomlion was charged with the responsibility of providing the recruited youth into this program with the appropriate equipment and working gear to undertake the sweeping of major streets and public places in the major cities and towns across the country. The company also provides training and supervises their daily activities. The government on the other hand does the recruitment of workers, pays their allowances through Zoomlion every month, and pays the company for the management services. [11].

4.3. Stakeholders

There are some major stakeholders in the solid waste management sector of Ghana. These stakeholders were involved in the formulation of the new Environmental Sanitation Policy in 2010 when the government merged with the private sector to provide the best services and to ensure that municipal solid waste management becomes effective and efficient. Most of these stakeholders were involved in the effective implementation of the policy. It is ideal to point out these stakeholders and their respective roles in the municipal solid waste management sector of the country.

The major stakeholder in every waste management sector is the public. The general public's effective compliance with the laid down procedures on waste handling ensures the that the policies are well implemented. Part of the failure of the 2010 ESP was a result of the lack of compliance on the part of the public. Some experts blame this on the government for the inadequate education and sensitization of the public on domestic and public waste handling as it is believed that charity begins at home. Some experts claim appropriate public education combined with the provision of waste bins will encourage proper waste handling and reduce littering on the streets of the major cities in the country.

An important stakeholder is the Ministry of local government and rural development, for it oversees the needed funding for the effective implementation of the policy and monitoring of the progress of the policy. They communicate to the leaders of the government if there is a need to increase the budgeted funds for the projects and they award contracts to the private sector. Another reason why the country's waste management system is inefficient is the lack of funds from the government, hence some other stakeholders blame the ministry for being reluctant to persuade the government to increase funds allocated for this purpose in the annual national budget. In this case, others also blame the ministry for corruption and misuse of funds.

Other critical stakeholders are the metropolitan, municipal, and district assemblies. These are the operative authorities who work closely between the government and the public. The metropolitan assemblies oversee the municipal assemblies while the municipal assemblies oversee the district assemblies, and they represent the government on all levels. The district assemblies cover smaller areas and can operate more closely with the people. These assemblies represent the people, and they channel their concerns to the government [10].

The environmental protection agency is a stakeholder that needs a mention. This agency protects the interests of our environment and ensures that waste management projects are carried out in compliance with global environmental regulations and standards. However, it is argued that the agency has not done enough to ensure that landfills in Ghana are well managed. They are expected to guide the metropolitan assemblies and the private waste management companies in increasing sanity at the various landfills.

Lastly, private waste management companies are major players in the waste management sector of the country. These companies oversee the day-to-day collection of solid waste from some households that can afford their services. The most relevant of these companies are Zoomlion Ghana Limited (ZLG) and Liberty Waste Limited (LWL), Dispose of Green Limited (DGL), Jekora Ventures (JV), and J Stanley-Owusu Limited. An introduction of waste-to-energy technology in Ghana will require planning together with these solid waste management companies to provide the right quantities and composition of solid waste that will be required [36].

4.4. Government Policies

In the area of energy, the government has been forced to find expeditious solutions to prevent future energy crises resulting in overdependency on fossil-fuelled plants. There are plans to build new gas plants to be fuelled with gas from the recently completed gas project on the oil field in Takoradi. Existing fossil-powered plants are being revived and some are currently in operation. However, the government still has plans to encourage the growth of clean energy production under which Waste-to-energy falls. As a result, initiation policies and programs such as the national electrification scheme, a self-dependent electrification program, a national off-grid rural electrification program, and a renewable energy development program [38]. The 2019 renewable energy master plan is aimed at achieving the following by 2030; Increase the renewable energy mix in the national power generation from 42.5 MW in 2015 to 1363.63 MW (with grid-connected systems totalling 1094.63 MW), Reduce the use of biomass as the main fuel for thermal energy applications, Provide a renewable energy-based decentralized electrification option in 1,000 off-grid communities, Promote the involvement of the locals in the renewable energy industry [37]. Waste incineration technology is categorized as a form of renewable energy and is supported by this new energy policy. Small-scale incineration facilities can provide off-grid electricity to towns and their surrounding villages. The government is determined to increase the capacity of renewable and other sustainable sources of power in the supply mix, particularly solar, wind, hydro, and waste-to-energy. This will be made possible by focusing on implementing the provisions of the Renewable Energy Act, 2011, Act 832, which will promote waste-to-energy technologies and provide grid integration programs for renewable energy plants.

4.5. Tax Incentives

The Ghanaian government has stated its intention to achieve 1.4 GW of renewable and clean energy installed by 2030 [37]. Hence, incentives have been provided to draw investors into the sector. Aside from the substantial tax reduction on profits, renewable energy investors enjoy the highest feed-in tariffs as compared to the other sources of energy production. Feed-in tariffs range between 56 to 63 pesewas/KWh. Also, the feed-in tariff duration has been shifted from 10 to 20 years and this provides some security for the investment. Imported Machinery and components for renewable and clean energy production also enjoy tax exemptions at the ports. Ghana’s investment laws also guarantee a 100% transfer of profits, and dividends [39].

4.6. Over-Dependence On Fossil Fuels

Currently, the electricity demand of the country outweighs the supply and has compelled the electricity company of Ghana to engage in load shedding to ensure an even distribution of the power available. As of 2021, Ghana's total electricity peak load was around 3,246 MW and the installed capacity was 5,481 MW with a reliable capacity of 4,975 MW. Power production in the country is dependent on hydro and thermal power. The three major hydro dams in the country generate a total of 1,580 MW accounting for 28.9% of the total installed capacity while the thermal plants produce a total of 3,753 MW accounting for 68.4% and 144 MW from other renewable sources dominated by solar power. Renewable energy installed capacity was increased from 59 MW in 2020, about 85 MW additional capacity in a year is impressive. Ghana 2021 exported 1,734 MW of electricity to neighbouring countries. To solve the 2015 power crisis, the government hastily sign sloppy power purchasing contracts with private power producers at high tariffs. some of these contracts were taken or pay agreements and 500 MW of unused generated power is being paid for by the taxpayer. In other to undo this incompetence, the government plans to terminate some of these agreements and replace these power plants with renewable energy by 2030. The availability of the enormous amount of waste generated daily, and the increased effort to ensure effective waste management makes it more suitable for investment in waste incineration technology [40].

4.7. Waste-to-Energy Technologies

Ghana, like other developing countries, has difficulties in the effective management of its municipal solid waste and at the same time have challenges with its electricity power sufficiency and stability. A country in such a dilemma has the option to turn things around by converting most part of the huge amount of solid waste generated into a useful energy source to ensure a balance in both sectors. An introduction to a suitable

Waste-to-energy technology and an advancement in the current municipal solid waste management system will help in this course.

With the quantity and composition of waste being generated in Ghana, considering the lack of waste sorting, a moving grate incineration technology will be the most applicable technology as noted from its system of operation and specifications. This technology is capable of incinerating unsorted waste and permits high furnace temperatures due to its design. The first Waste-to-energy facility in Africa, the Reppie plant shown in "Fig. 10", was built in Addis Ababa Ethiopia in 2014. It featured a moving grate furnace specifically designed for the solid waste composition and calorific values of the waste generated in the streets of Addis Ababa. This system is designed to incinerate 1400 tons of unsorted solid waste per day, and it generates 185GWh of electricity which gives it a capacity of 25 MW [41].

Moving grate incineration furnace has high efficiency. However, every Waste-to-energy system has a calorific value cut-off point. When the average calorific value of the waste being incinerated goes below this figure, it results in very low furnace temperatures and subsequently affects the efficiency of the facility, and this is a major risk of incinerating unsorted solid waste with high moisture content. In this case, there is an option of preheating waste. The higher the moisture content of waste, the lower its calorific value, resulting in high levels of unburnt waste and consequently lower furnace temperature.

Due to the huge organic waste component of solid waste composition in Ghana, other waste-to-energy technologies could be considered specifically, anaerobic digestion. Biogas production facilities offer solutions for the effective management of biodegradable solid and liquid waste. This technology is growing significantly in most developed countries. Biodegradable waste is always highly generated in every country from consumable products and even though they do not pose much threat to the environment, they become dangerous to public health when not properly disposed of. Most marketplaces and slums in the country generate large quantities of food waste daily.

This waste may not be suitable for incineration, but it can be converted into a useful energy source by the application of the appropriate anaerobic digestion technology.

The challenge with applying anaerobic digestion technology is the low level of waste sorting. Waste sorting in developed countries is always not perfect. However, just applying the basics of separating plastic waste bins from organic waste bins creates a difference. Most often, plastic waste substances a found in biodegradable waste bins but it does not cause much of a problem because modern anaerobic digestion facilities are designed to accommodate a minor percentage of non-degradable waste. These waste substances are separated and transported to an incineration facility to be combusted.

“Fig. 10.” Construction of the Reppie Incineration Plant in Ethiopia.

4.8. Waste Generation And Composition Data

Waste generation rate and composition across Ghana are dependent on the community and the economic standards of the people in the community. The settlement hierarchy is classified according to high-income, middle-income, and low-income areas. High-income areas are mostly residential areas with good road networks and have access to reliable social amenities such as water, electricity, and security with well-demarcated houses, supermarkets, and schools. The houses are often detached single or story buildings with large compounds either paved or grassed. Middle-class income areas are normally characterized by flats or bungalows. The household is on average three people and there is access to social amenities and services. Low-income areas usually have poor social services and amenities. They are mostly with buildings ranging from single-story houses to squatting shacks. These different areas across the regions of the country have different per capita daily waste generation. The per capita daily waste generation in Ghana, illustrated in “Table 1”, is determined by finding the average of the regional data.

“Table 1.” National waste generation estimates.

National Average daily waste generation per capita	0.47 kg
Population (2022 estimate)	32,100,000
Daily waste generation (approximate)	0.47kg x 32,100,00 15,087,000 kg 15,087,000 x (0,00110231) tons 16,630.5 tons
Annual waste generation (approximate)	16,630.5 tons x 365 days **6,070,151.1** tons

4.9. National Solid Waste Composition

The solid waste composition in Ghana varies with each area, city, and region. However, in all situations, organic waste is the dominant form of waste followed by plastic waste. Current incineration technologies are efficient and suitable for waste substances with an average minimum calorific value of 7 MJ/kg [42]. It was noticed that organic matter dominates waste samples collected for various studies, but its percentage varies by region and area. Data collected from 6 regions was a study done by K. Miezah with samples collected across the regions. These data will be relevant in planning waste incineration and recycling projects. “Table 2” shows the average solid waste composition data for the Greater Accra region to represent the national average solid waste composition of which samples were collected from the Mallam waste disposal site and the study was done by Ackah Ruth.

“Table 2.” National Average Municipal Solid Waste Composition [42].

Waste Type	Paper	Plastics	Metal	Glass	Textile	Organic	miscellaneous	Inert
Percentage	8%	21%	7%	6%	7%	39%	10%	2%

4.10. Calorific Values Of Solid Waste

The capacity of waste material to sustain the combustion process with no addition of extra or supplementary fuel determines the materials’ calorific value or lower heat value. The calorific value of waste as fuel consists of several physical and chemical parameters, the most relevant of all being the moisture content of waste. The required lower calorific value of waste for an incineration process depends on the design of the furnace and fuels with low calorific value require a furnace design that allows minimal heat losses and permits waste to dry before combustion. The calorific value of waste in incineration technology is vital to the energy output of the entire process.

A study conducted in Accra the capital of Ghana, indicated that the average calorific value of the waste samples collected was around 14 MJ/kg and the moisture content was around 30%. This is due to the high percentage of organic waste which is approximately 39% of the composition of collected waste samples [43]. The table below demonstrates the heat values from different waste contents.

"Table 3." Calorific Values of Waste Component.

Waste Component	Energy Content (MJ/dry.kg) at 30% moisture content
Organic waste	9
Textile, Rubber & leather	17
Glass & Metals	0
Paper & Cardboard	16
plastics	30
Other combustibles	16

"Table 4." Estimated LHV of Waste Feedstock in MJ/kg.

Organic waste	[9*0.39] = 3.51 MJ/kg
paper	[16*0.08] = 1.2 MJ/kg
Textiles, rubber & leather	[17*0.07] = 1.19 MJ/kg
Plastics	[30*0.21] = 6.3 MJ/kg
Other combustibles	[16*0.1] = 1.6 MJ/kg
Total	**13.8** MJ/kg

"Table 3" outlines the various waste components and their relative calorific values. plastic waste holds the highest heat value and organic waste has the list heat value because of its high moisture content. Metal and glass waste are not combustible but recyclable waste and have no heat value.

The energy derived by incinerating a kilogram of waste is **13.8** Megajoules as illustrated in "Table 4". The obtained figure is higher than the minimum calorific value requirement of **7** MJ/kg and that makes the waste sample feasible for the incineration process.

"Table 5." Waste Energy Content in MWh/ton.

Organic waste	(9/3600) *1000 = 2.5 MWh/ton
Paper	(16/3600) *1000 = 4.4 MWh/ton
Textiles, rubber & leather	(17/3600) *1000 = 4.7 MWh/ton
plastics	(30/3600) *1000 = 8.3 MWh/ton
Other combustibles	(16/3600) *1000 = 4.4 MWh/ton

"Table 6." Total Energy Content in MWh/ton.

Organic waste	[2.5x0.39] = 0.98
Paper	[4.4x0.08] = 0.35
Textiles, rubber & leather	[4.7x0.07] = 0.33
plastics	[8.3x0.21] = 1.74
Other combustibles	[4.4x0.1] = 0.44
Total	**3.84** MWh/ton

"Table 7." Estimated Energy Potential from National Waste Generated.

Daily thermal energy potential from waste	3.84 MWh/ton x 16,630.5 tons **63,861.12** MWh
Annual thermal energy potential from waste	63,861.12 MWh x 365 = **23,309.3** GWh
Average Electricity conversion ratio of WTE Technology	25%
Annual electricity generation potential	23,309.3 x 0.25 = **5,827.3** GWh

5. CASE STUDY

5.1. A Pilot Waste Incineration Facility In Tema

To ascertain the technical and financial feasibility of a waste incineration facility in Ghana, a conceptual scalable plant is proposed for Tema, a major industrial and port city in the capital region. The case study will apply national data and data from the proposed area to determine its feasibility backed with estimated figures. The concept can be applied in other parts of the country. Especially, industrial zones and rural areas to generate electricity and/or produce hot water for industrial and agro-processing needs. Tema was chosen because of the high population density, the industrial zone, and the improved waste management system.

5.2. Population And Demographics

The population of the metropolitan area was estimated at around 350,000 in 2014 and the urban population is around 196,000 according to the 2021 national population census. The city is vibrant and has a youthful population and it was planned in the early 1960s to be the home to workers at the main fishing and container harbour and the heavy industrial zone.

5.3. Society

In the early days of development, the city was made up of skilled and semi-skilled workers who trooped in during the industrial era of the country. Subsequently, more people moved to the area for fishing and trade. Its society was made up of the upper and middle class who lived in affluent areas, and the lower class that trooped in later because of trade and other job opportunities. The city is divided into communities and is generally well-planned and demarcated with streets and good access roads. There has been some slum coming up lately, but they are limited to certain areas. It is a port city and has a well-balanced society with diverse cultures and tribal mix. There are also many foreigners in the city who work in these industries. The city is also popularly termed the centre of the world because the Greenwich Meridian (i.e., Longitude 0º) passes through the Metropolis, which meets the equator or latitude 0° in the Ghanaian waters of the Gulf of Guinea

5.4. Economy

Tema is a major port city and the industrial and energy hub of Ghana. It is home to the biggest port and fishing harbour in the country and many major industries. The city has the biggest industrial zone with hundreds of light and heavy industrial facilities. It is also home to the major grid infrastructure of the country and 15 power plants. The Ghana free zones were established to promote manufacturing and industrialization and it has an enclave in Tema for new industries which makes it a perfect location for any waste incineration facility. The area currently has about 190 operational factories that generated a combined 1.9 billion dollars in revenues in 2021 according to the Ghana Revenue Authority.

5.5. Waste Management System

The Tema metropolitan assembly oversees waste management through its waste management department. The city has one of the country's most efficient waste collection systems, which is attributed to the proper planning and demarcation of its neighbourhoods with good access roads which permit waste trucks to collect waste. Most households have subscribed to the services of one of the three major private waste collection firms that operate in the metropolis. However, there are still some challenges with waste disposal in the deprived areas causing sanitation and health issues. The biggest waste landfill in the metropolitan area was decommissioned because it fell below the green building standards and posed environmental and health risks for residents in the area. It has been replaced with a new 8-million-dollar landfill site according to the metropolitan assembly website.

5.6. Waste Collection Data

Waste data collection data for the Tema metropolitan assembly was obtained from the waste management department through the help of the deputy director. The department operates the landfills in the metropolis and keeps a record of waste collected by weighing waste trucks delivering waste to the dumping sites, and it is done with the help of the three waste management companies that operate in the metropolitan area namely, J Stanley Owusu Limited, Meridian Waste (Zoomlion Limited), and Asadu waste limited. The waste collection data between 2013 and 2021 is illustrated below in “Table 8” to “Table 17”. The reason for the vast variations in the annual figures was not addressed by the department.

“Table 8.” 2013 Waste Collection Data.

MONTHLY METRIC TONNAGE 2013				
NO.	MONTH	NO. DAYS	TOTAL TONNAGE	AVERAGE TONNAGE
1	JANUARY	21	15,806.71	752.70
2	FEBRUARY	24	33,337.35	1,389.06
3	MARCH	26	34,130.79	1,312.72
4	APRIL	26	32,633.25	1,255.13
5	MAY	27	34,531.56	1,278.95
6	JUNE	26	31,507.64	1,211.83
7	JULY	27	37,789.14	1,399.60
8	AUGUST	27	36,717.50	1,359.91
9	SEPTEMBER	30	36,163.19	1,205.44
10	OCTOBER	30	37,623.05	1,254.10
11	NOVEMBER	30	36,383.56	1,212.79
12	DECEMBER	31	38,837.41	1,252.82
	TOTAL	325	405,461.15	14,885.03

"Table 9." 2014 Waste Collection Data.

MONTHLY METRIC TONNAGE OF 2014				
NO.	MONTH	NO. DAYS	TOTAL TONNAGE	AVERAGE TONNAGE
1	JANUARY	21	15,806.71	752.70
2	FEBRUARY	24	33,337.35	1,389.06
3	MARCH	26	34,130.79	1,312.72
4	APRIL	26	32,633.25	1,255.13
5	MAY	27	34,531.56	1,278.95
6	JUNE	26	31,507.64	1,211.83
7	JULY	27	37,789.14	1,399.60
8	AUGUST	26	26,566.79	1,021.80
9	SEPTEMBER	26	20,889.49	803.44
10	OCTOBER	27	21,817.71	808.06
11	NOVEMBER	25	20,024.79	800.99
12	DECEMBER	27	19,496.92	722.11
	TOTAL	**308**	**328,532.14**	**1,066.66**

"Table 10." 2015 waste collection Data.

MONTHLY METRIC TONNAGE 2015				
NO.	MONTH	NO. DAYS	TOTAL TONNAGE	AVERAGE TONNAGE
1	JANUARY	27	19,277.40	713.98
2	FEBRUARY	24	24,276.14	1,011.51
3	MARCH	27	27,232.31	1,008.60
4	APRIL	26	24,910.23	958.09
5	MAY	25	27,295.80	1,091.83
6	JUNE	26	25,883.33	995.51
7	JULY	27	24,370.78	902.62
8	AUGUST	25	25,202.58	1,008.10
9	SEPTEMBER	26	24,470.17	941.16
10	OCTOBER	27	26,733.23	990.12
11	NOVEMBER	25	23,209.56	928.38
12	DECEMBER	27	26,010.10	963.34
	TOTAL		**298,871.63**	**11,513.24**

“Table 11.” 2016 waste collection Data.

MONTHLY METRIC TONNAGE 2016				
NO.	MONTH	NO. DAYS	TOTAL TONNAGE	AVERAGE TONNAGE
1	JANUARY	27	25,484.17	943.86
2	FEBRUARY	25	22,822.18	912.89
3	MARCH	27	23,126.83	856.55
4	APRIL	26	23,707.06	911.81
5	MAY	26	50,609.77	1,946.53
6	JUNE	26	23,527.79	904.92
7	JULY	26	22,520.53	866.17
8	AUGUST	27	26,144.20	968.30
9	SEPTEMBEI	26	25,093.30	965.13
10	OCTOBER	26	41,012.50	1,577.40
11	NOVEMBEF	26	25,979.14	999.20
12	DECEMBER	27	25,061.66	928.21
	TOTAL	**315**	**335,089.13**	**12,780.97**

“Table 12.” 2017 waste collection Data.

MONTHLY METRIC TONNAGE 2017				
NO.	MONTH	NO. DAYS	TOTAL TONNAGE	AVERAGE TONNAGE
1	JANUARY	26	26,397.74	1,015.30
2	FEBRUARY	24	22,973.19	957.22
3	MARCH	27	27,697.75	1,025.84
4	APRIL	25	33,040.59	1,321.62
5	MAY	27	27,383.48	1,014.20
6	JUNE	26	23,488.39	903.40
7	JULY	26	23,398.78	899.95
8	AUGUST	27	21,145.27	783.16
9	SEPTEMBER	26	30,075.56	1,156.75
10	OCTOBER	26	38,880.89	1,495.42
11	NOVEMBER	26	46,863.82	1,802.45
12	DECEMBER	31	55,225.37	1,781.46
	TOTAL	**317**	**376,570.83**	**14,156.78**

"Table 13." 2018 Waste Collection Data.

MONTHLY METRIC TONNAGE 2018				
NO.	MONTH	NO. DAYS	TOTAL TONNAGE	AVERAGE TONNAGE
1	JANUARY	27	48,130.42	1,782.61
2	FEBRUARY	24	51,773.49	2,157.23
3	MARCH	27	50,582.73	1,873.43
4	APRIL	25	36,294.44	1,451.78
5	MAY	27	27,062.63	1,002.32
6	JUNE	26	31,802.16	1,223.16
7	JULY	26	32,818.83	1,262.26
8	AUGUST	27	31,500.80	1,166.70
9	SEPTEMBER	25	34,512.82	1,380.51
10	OCTOBER	27	29,148.32	1,079.57
11	NOVEMBER	26	28,594.49	1,099.79
12	DECEMBER	26	32,566.37	1,252.55
	TOTAL	**313**	**434,787.50**	**16,731.91**

"Table 14." 2019 Waste Collection Data.

MONTHLY METRIC TONNAGE 2019				
NO.	MONTH	NO. DAYS	TOTAL TONNAGE	AVERAGE TONNAGE
1	JANUARY	31	30,291.38	977.14
2	FEBRUARY	28	27,522.01	982.93
3	MARCH	31	21,925.25	707.27
4	APRIL	30	22,739.50	757.98
5	MAY	31	18,910.61	610.02
6	JUNE	30	19,645.29	654.84
7	JULY	31	38,701.35	1,248.43
8	AUGUST	31	11,110.57	358.41
9	SEPTEMBI	30	20,375.67	679.19
10	OCTOBER	31	25,466.39	821.50
11	NOVEMBE	30	21,752.47	725.08
12	DECEMBE	31	15,095.38	486.95
	TOTAL	**365**	**273,535.87**	**9,009.73**

"Table 15." 2020 Waste Collection Data.

MONTHLY METRIC TONNAGE 2020				
NO.	MONTH	NO. DAYS	TOTAL TONNAGE	AVERAGE TONNAGE
1	JANUARY	31	18,766.88	605.38
2	FEBRUARY	29	17,448.28	601.66
3	MARCH	31	9,897.81	319.28
4	APRIL	30	8,584.98	286.17
5	MAY	31	12,309.05	397.07
6	JUNE	30	14,890.48	496.35
7	JULY	31	16,239.07	523.84
8	AUGUST	31	17,872.72	576.54
9	SEPTEMBER	30	16,530.01	551.00
10	OCTOBER	31	16,154.24	521.10
11	NOVEMBER	30	15,154.01	505.13
12	DECEMBER	31	15,057.77	485.73
	TOTAL	**366**	**178,905.30**	**5,869.27**

"Table 16." 2021 Waste Collection Data.

MONTHLY METRIC TONNAGE 2021				
NO.	MONTH	NO. DAYS	TOTAL TONNAGE	AVERAGE TONNAGE
1	JANUARY	31	16,116.78	519.90
2	FEBRUARY	28	13,633.10	486.90
3	MARCH	31	18,894.37	609.50
4	APRIL	30	18,632.24	621.07
5	MAY	31	18,221.81	587.80
6	JUNE	30	17,229.71	574.32
7	JULY	31	18,226.18	587.94
8	AUGUST	31	17,374.47	560.47
9	SEPTEMBER	30	15,967.63	532.25
10	OCTOBER	31	17,480.88	563.90
11	NOVEMBER	30	18,210.52	607.02
12	DECEMBER	31	20,050.95	646.80
	TOTAL	**365**	**210,038.64**	**575.45**

"Table 17". 2022 Waste Collection Data.

MONTHLY METRIC TONNAGE 2021				
NO.	MONTH	NO. DAYS	TOTAL TONNAGE	AVERAGE TONNAGE
1	JANUARY	31	18,603.66	600.12
2	FEBRUARY	28	15,893.38	567.62
3	MARCH	31	18,209.75	587.41
4	APRIL	30		
5	MAY	31		
6	JUNE	30		
7	JULY	31		
8	AUGUST	31		
9	SEPTEMBER	30		
10	OCTOBER	31		
11	NOVEMBER	30		
12	DECEMBER	31		
	TOTAL	**365**		

5.7. WOIMA Modular Waste-to-Energy Power Plant

The case study is built on the WIOMA modular waste incineration technology. This technology is highly efficient and has three model designs and three output options to suit every demand. It is based on grate combustion. The purpose of the combustion grate system is to incinerate different kinds of heterogeneous solid waste fuels flexibly to homogenous flue gas efficiently and with a high tolerance for inert materials like metals, glass, and sand. The fuel is dried, ignited, and combusted at the moving grate. The fuel inside the combustion chamber is conveyed and mixed by a reciprocating step grate. The grate is divided into independent hydraulic-cylinder-actuated grate zones with below-mounted ash hoppers and primary air feed [45].

The purpose of the combustion air system is to provide the correct amount of combustion air to the fuel combustion process at the grate and in the combustion, chamber optimally phased for combustion control, temperature, and flue gas emission control.

Two different types of grates are available depending on the calorific fuel value. The air-cooled grate is designed for low LHV fuels with CV at 7-17 MJ/kg. The partially water-cooled grate is designed for high LHV fuels with CV at 14-24 MJ/kg. The right grate type is selected based on the fuel CV design point and range.

The power plant is a robust medium-scale facility designed to burn up to 62,000 tons of municipal solid waste annually and has a lifespan of 30 years in the most unfavourable conditions. It is designed based on 20 and 40-footer shipping containers which ensure easy transportation and act as secured enclosures and protective housing on-site. This highly automated facility is prefabricated in Finland to ensure short construction and installation time [45].

5.7.1. Specifications

- Fuel power 10, 15, or 20 MWfuel
- Thermal efficiency ~88 % and Electrical efficiency ~25 %
- The plant produces (10/15/20 MWfuel models respectively)
- Steam 12 / 18 / 24 tons / h (400°C @ 40 bar(g)) OR
- Electricity 2.4 / 3.7 / 5.0 MWe (gross) / 2.0 / 3.2 / 4.3 MWe (net) OR
- Electricity 1.4 / 1.9 / 2.2 MWe (net) and thermal energy 6.7 / 10.0 / 13.3 MWth

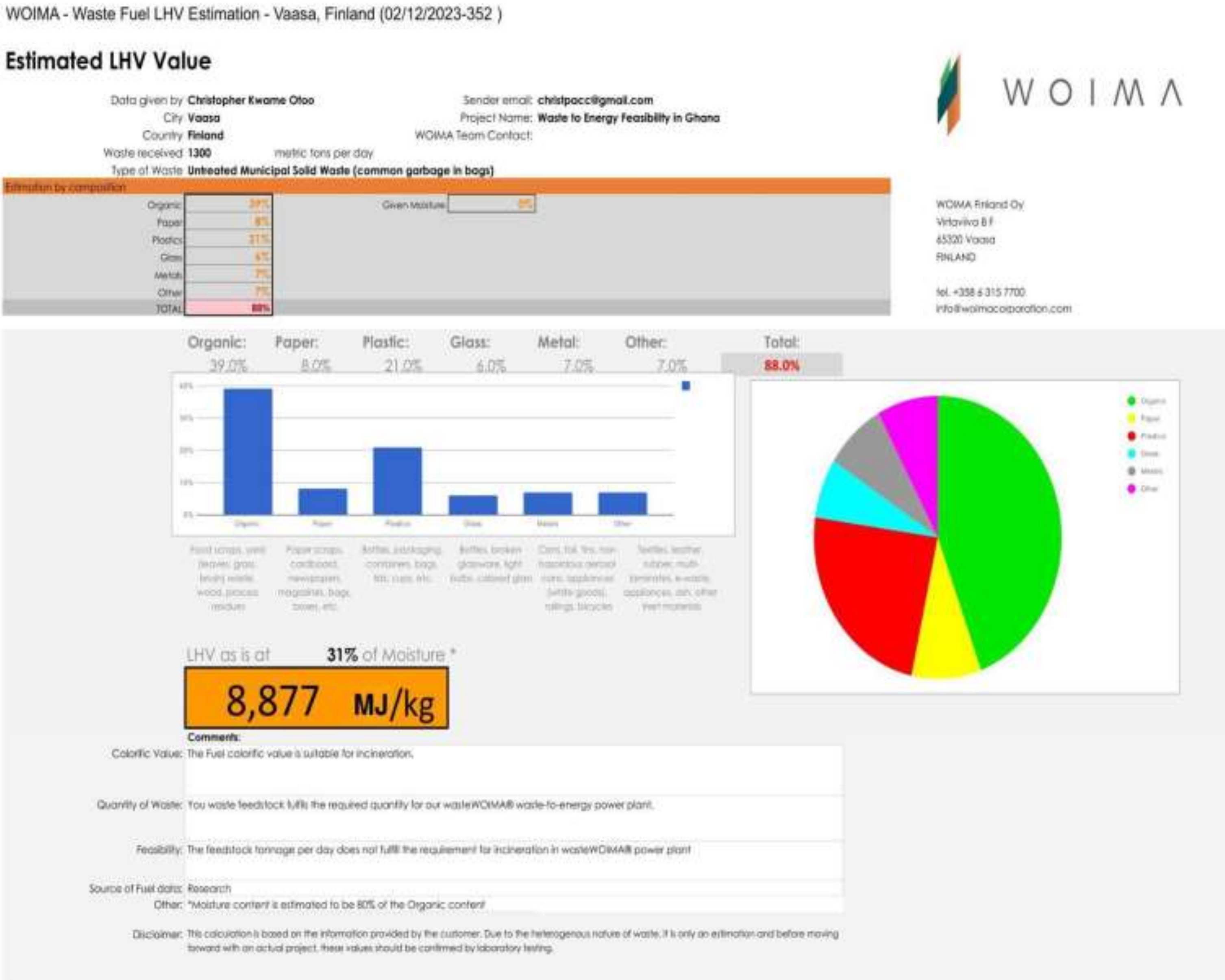
Out of 70 / 100 / 130 tons of Refuse Derived Fuel (RDF) or 90 / 130 / 170 tons of Municipal Solid Waste (MSW) per day.

The WIOMA modular waste-to-energy has three power options depending on the energy need, 10, 15, and 20 MW with approximately 88% thermal efficiency and approximately 25% electrical efficiency. Depending on the selected capacity, the output option can be 100% electricity with approximately 2.0 MW, 3.2 MW, and 4.3 MW net power. There is also an option for 100% steam with 12, 18, and 24 tons respectively at 400 degrees Celsius and 40 bar pressure. The final option is a hybrid of 1.4, 1.9, and 2.2 MW of electricity with 6.7, 10.0, and 13.3 MW of thermal energy suitable for district heating or food processing. The design illustrated in "Fig. 11" is based on prefabricated shipping container-sized modules making it easy to transport. Also, construction and installation time is reduced, has simple maintenance methods, and provides advanced automation with minimal manpower required [45]

"Fig 11." WOIMA Modular Waste Incineration Plant [45].

5.8. Technical Feasibility Of Pilot Project

The ability of waste to produce the required thermal energy for electricity or steam production through combustion determines its feasibility for the incineration technology. In the case of this pilot project, the waste incineration Technology supplier has a system for determining the technical feasibility of the project.



"Fig 12." WOIMA Feedstock LHV Estimation Result.

Waste composition data for the area is submitted and the system automatically estimates the lower heat value of waste to determine its suitability for the technology. “Fig. 12” demonstrates the result of the pilot project. Based on the average waste composition of the Tema area, the lower heat value was estimated at 8.8 MJ/kg. This makes feedstock suitable for incineration using the WOIMA technology.

“Table 18.” Estimated Energy Potential from Waste in Tema.

Average Annual Collected Waste	2841791.69 tons / 9years =**315,754.6** tons
Annual thermal energy potential from waste	3.84 MWh/ton x 315,754.6 tons **1,212,497.8** MWh
Average Electricity conversion ratio of WTE Technology	25%
Annual electricity generation potential	1,212,497.8 x 0.25 = **303,124.4** MWh

Based on the waste collection data, the average waste collection during the 9-year period is estimated at around 316,000 tons a year and applying the combined heat value of the feedstock, which is 3.84 MWh, the annual thermal energy potential is estimated as shown in “Table 18”. The estimated figures indicate that there is enough feedstock to fuel a 138 MW waste incineration plant in the Tema metropolis.

5.9. Financial Estimation Of Pilot Project

To determine the financial feasibility of the pilot project, it was subjected to project cost and profit analysis. the estimated cost of the project was sourced from WIOMA, the technology supplier, and other auxiliary costs and expenses were obtained from data on other similar projects. the cost estimations applied the current feed-in tariff for renewable energy projects in Ghana to determine the annual revenue from electricity sales. Gate fees for waste trucks are unknown and can be negotiated with the waste management companies to provide an extra source of revenue for the facility.

"Table 19." Investment And Expense Data.

PROJECT COST ESTIMATION		
TOTAL INVESTMENT COST	€25,000,000	
CAPACITY (KW)	20,000	
WASTE COMBUSTION (tons)	64,000	
GATE FEES	€0.00	
GROSS POWER GENERATION (KW)	5,000	
NET POWER GENERATION (KW)	4,300	
AVAILABILITY RATE	91%	
LOWER CAROLIFIC VALUE	8.9 MJ/kg	
ANNUAL ENERGY PRODUCTION (KWh)	34,277,880	
FIT	€0.19	
ANNUAL REVENUE	**€6,512,797.20**	
EXPENSES		
MAINTENANCE machines	2.5% of CAPEX	€625,000.00
MAINTENANCE electricals	2.5% of CAPEX	€625,000.00
MAINTENANCE civil works	2.5% of CAPEX	€625,000.00
PERSONNEL cost	0.01% of CAPEX	€250,000.00
INSURANCE cost	0.003% 0f CAPEX	€75,000.00

"Table 20." Debt Financing Calculation.

	20 YRS LOAN AT 5% INTEREST RATE			
YEAR	ANNUAL PAYMENT	PRINCIPAL	INTEREST	UNPAID BALANCE
			5%	**€ 18,750,000.00**
1	€ 1,875,000.00	€ 937,500.00	€ 937,500.00	€ 17,812,500.00
2	€ 1,827,625.00	€ 937,000.00	€ 890,625.00	€ 16,875,500.00
3	€ 1,780,775.00	€ 937,000.00	€ 843,775.00	€ 15,938,500.00
4	€ 1,733,925.00	€ 937,000.00	€ 796,925.00	€ 15,001,500.00
5	€ 1,687,075.00	€ 937,000.00	€ 750,075.00	€ 14,064,500.00
6	€ 1,640,225.00	€ 937,000.00	€ 703,225.00	€ 13,127,500.00
7	€ 1,593,375.00	€ 937,000.00	€ 656,375.00	€ 12,190,500.00
8	€ 1,546,525.00	€ 937,000.00	€ 609,525.00	€ 11,253,500.00
9	€ 1,499,675.00	€ 937,000.00	€ 562,675.00	€ 10,316,500.00
10	€ 1,452,825.00	€ 937,000.00	€ 515,825.00	€ 9,379,500.00
11	€ 1,405,975.00	€ 937,000.00	€ 468,975.00	€ 8,442,500.00
12	€ 1,359,125.00	€ 937,000.00	€ 422,125.00	€ 7,505,500.00
13	€ 1,312,275.00	€ 937,000.00	€ 375,275.00	€ 6,568,500.00
14	€ 1,265,425.00	€ 937,000.00	€ 328,425.00	€ 5,631,500.00
15	€ 1,218,575.00	€ 937,000.00	€ 281,575.00	€ 4,694,500.00
16	€ 1,171,725.00	€ 937,000.00	€ 234,725.00	€ 3,757,500.00
17	€ 1,124,875.00	€ 937,000.00	€ 187,875.00	€ 2,820,500.00
18	€ 1,078,025.00	€ 937,000.00	€ 141,025.00	€ 1,883,500.00
19	€ 1,031,175.00	€ 937,000.00	€ 94,175.00	€ 946,500.00
20	€ 946,500.00	€ 946,500.00	€ -	€ -
TOTAL	**€ 28,550,700.00**		**€ 9,800,700.05**	

Just like many energy projects, the estimations considered debt financing of 75 percent with a 5 percent annual interest and a 20-year repayment period. "Table 20" shows the debt finance figures which include the total interest payment and the total cost of financing the project. These figures are further included in the revenue and cash flow estimations presented in "Table 21" which shows figures for the first 5 years only.

"Table 21." Revenue And Cash Flow Estimation.

	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5
Capacity and Type of Project (KW)	4,300	4,300	4,300	4,300	4,300
Total Investment cost (EUR)	**€25,000,000.00**	**€25,000,000.00**	**€25,000,000.00**	**€25,000,000.00**	**€25,000,000.00**
FIT(EUR)	€ 0.19	€ 0.19	€ 0.19	€ 0.19	€ 0.19
Equity percentage	25%	25%	25%	25%	25%
Debt Financing percentage	75%	75%	75%	75%	75%
Interest Rate	5%	5%	5%	5%	5%
Loan Repayment period	20 YRS				
Equity Financing (EUR)	€ 6,250,000.00	€ 5,250,000.00	€ 5,250,000.00	€ 5,250,000.00	€5,250,000.00
Debt Financing (EUR)	€ 18,750,000.00	€ 15,750,000.00	€ 15,750,000.00	€ 15,750,000.00	€ 15,750,000.00
Depreciation Straight line	€ 500,000.00	€ 420,000.00	€ 420,000.00	€ 420,000.00	€ 420,000.00
Corporate Tax	8%	8%	8%	8%	8%
life span of waste incineration plant	30 YRS				
Revenues	€6,512,797.20	€6,512,797.20	€6,512,797.20	€6,512,797.20	€6,512,797.20
-Operating Expenses	€625,000.00	€525,000.00	€525,000.00	€525,000.00	€525,000.00
-Depreciation	€ 500,000.00	€500,000.00	€500,000.00	€500,000.00	€500,000.00
operating income EBIT	€5,387,797.20	€5,487,797.20	€5,487,797.20	€5,487,797.20	€5,487,797.20
-Interest expenses	€ 937,500.00	€ 890,625.00	€ 843,775.00	€ 796,925.00	€ 750,075.00
EBT	€ 4,450,297.20	€ 4,597,172.20	€ 4,644,022.20	€ 4,690,872.20	€ 4,737,722.20
-Taxes	€ 356,023.78	€ 367,773.78	€ 371,521.78	€ 375,269.78	€ 379,017.78
net income	**€ 4,094,273.42**	**€ 4,229,398.42**	**€ 4,272,500.42**	**€ 4,315,602.42**	**€ 4,358,704.42**
Cash Flow					
EBIT	€ 5,387,797.20	€ 5,487,797.20	€ 5,487,797.20	€ 5,487,797.20	€ 5,487,797.20
- Taxes	€ 356,023.78	€ 367,773.78	€ 371,521.78	€ 375,269.78	€ 379,017.78
+ Depreciation	€ 500,000.00	€ 500,000.00	€ 500,000.00	€ 500,000.00	€ 500,000.00
d. Cash Flow available before debt service and dividend payment	€ 5,531,773.42	€ 5,620,023.42	€ 5,616,275.42	€ 5,612,527.42	€5,608,779.42
e. Less Interest expenses	€ 937,500.00	€ 890,625.00	€ 843,775.00	€ 796,925.00	€ 750,075.00
f. Less Principal repayment	€ 937,500.00	€ 937,500.00	€ 937,500.00	€ 937,500.00	€ 937,500.00
Cash flow to equity	**€ 3,656,773.42**	**€ 3,791,898.42**	**€ 3,835,000.42**	**€ 3,878,102.42**	**€ 3,921,204.42**
Debt Service Cover Ratio	2.95	3.07	3.15	3.24	3.32

The revenue and cash flow estimation are from year 1 to year 20 even though the WIOMA power plant has a lifespan of 30 years. However, the project is proven profitable with a positive cash flow to equity throughout the 20-year period. the Net Present Value (NPV) of the project is estimated at over 27 million euros, exceeding the total initial investment cost. The internal rate of return is at 15 percent which is good for an energy project and 147 percent return on investment. Figures obtained from the cost analysis prove the financial feasibility of the pilot project.

"Table 22." Project Financial Feasibility Estimation.

TOTAL CASH FLOW	**€ 83,107,824.48**
TOTAL COST OF INVESTMENT	**€ 34,800,700.00**
NET PRESENT VALUE (NPV)	**€25,888,713.61**
INTERNAL RATE OF RETURN (IRR)	**15%**
RETURN ON INVESTMENT (ROI)	**138.8%**

6. SUMMARY, CONCLUSION, AND RECOMMENDATION

6.1. Summary

The average waste composition across Ghana is dominated by organic substances with a relatively low calorific value due to the high moisture content. However, this does not change the suitability of the feedstock for waste incineration. The estimated Lower Heat Value for waste feedstock is 13.8MJ/kg which is higher than the minimum requirement of 7MJ/kg and the estimated average thermal energy contained in a waste feedstock is 3.8MWh per ton. The WIOMA system estimated Lower Heat Value at 8.8 MJ/kg and despite a variation of 5 MJ/kg, the feedstock is suitable for their incineration technology. The variation is perceived to be because their system is more accurate, or it is designed to suit their incineration technology. The waste collection figures obtained from the Tema metropolitan area indicate the availability of waste as feedstock with adequate energy content capable of fuelling any waste incineration facility. The financial estimates for the pilot project confirm the viability of the project any other waste incineration project across the country is likely to be financially feasible due to the relatively high feed-in tariff.

6.2. Conclusion

Ghana is yet to have its first waste incineration facility and with the solid waste data and analysis presented in this research, it is evident that a waste incineration facility is feasible. The estimated figures for the pilot project affirm the technical and financial feasibility of any similar project. The socio-economic factors and government policies of the country concerning renewable energy encourage investment in this sector. Also, the municipal solid waste management challenges faced by the country coupled with the desire to increase installed capacity for renewable energy drastically by 2030, makes it reasonable to invest in waste incineration projects. This will reduce the dependency on landfills and improve the waste management system of the country.

6.3. Research Limitations

The main limitation of this research is inflation, which means prices quoted in the study may not be accurate when the study is published. The past year has seen prices of goods and services rise at a record high. Data gathered for this study were obtained directly from the authorities in charge. Waste generation and composition data were obtained from the statistical service and some other stakeholders. Another limitation is the fact that a study of this nature demands an on-field survey across the country to provide more accurate information. Due to cost and limited time frame, the study was conducted based on analysing data from these authorized sources to give the best result. However, the information provided is accurate enough to determine the feasibility of waste incineration in Ghana.

6.4. Recommendations

This study is backed by data obtained by the researcher and data from other studies done in this area. However, it is recommended that a proper feasibility study be done locally before any decision is made on building a waste incineration facility in Ghana. It is also recommended that waste samples are tested in the Laboratory to verify energy content values as part of the feasibility study.

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