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ENERGY RECOVERY POSSIBILITIES FROM MUNICIPAL SOLID WASTE, IN LAGOS, SOUTHWEST NIGERIA

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ABSTRACT

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Energy Recovery Possibilities from Municipal Solid Waste in Lagos, Southwest Nigeria.

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This Thesis analyses the problems faced by the Lagos State Government, in coping with an increase in Municipal Solid Waste (MSW) management and because of population growth and an increase in standard of living of Lagos State residence. The objective is to estimate the capacity of energy recovery and material recovery in a more sustainable and environmentally friendly 'waste to energy' models.

Scenario 1, analysed the present unsustainable 'waste to landfill' management practice, 72% of total MSW is landfilled and less than 5% is recovered via energy and material. Scenario 2 produced 2.23Mt/a of (Refuse Derived Fuel RDF) and 0.09Mt/a of Tire Derived Fuel (TDF) for energy recovery in the Cement kiln from MSW. Also, 0.67Mt/a of Biofertilizer was produced in Scenario 2. Scenario 3 produced an estimated amount of Biogas from 1.61 Mt/a of biodegradable waste and a potential huge amount of Biofertilizer from biowaste.

Due to advanced waste treatment option employed in Scenario 2 and 3, waste to landfill reduced from over 72% of total MSW in Scenario 1 to 8% in Scenario 2 and 3. The overall goal of this thesis is to reduce the amount of waste to landfill, through different mechanical (Incineration) and biological (Composting, Anaerobic digestion) waste treatment options.

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Abbreviations

WTE	Waste to energy
MSW	Municipal solid waste
BAT	Best available technology
LAWMA	Lagos State Waste Management Authority
CH_4	Methane
CO_2	Carbon dioxide
GDP	Gross domestic product
CO_2e	Carbon dioxide equivalent
GWP	Global warming potential
TDF	Tire derive fuel
RDF	Refuse derived fuel
NCV	Net calorific value

SRF	Solid recovered fuel
MBT	Mechanical and biological treatment
MSWM	Municipal solid waste management

1 INTRODUCTION

Nigeria has an estimated population of 182 million people with annual growth rate of 3.5 (National population commission of Nigeria, 2016), and a land size of 924,000 km2. Also, the biggest economy in Africa with a GDP of $546.628 billion and an annual growth in GDP of 6.3% (World Bank, 2014).

The population of Nigeria has grown from 160 million in 2010 to 177 million in 2014 (World bank, 2016) and the Gross Domestic Product (GDP) also grow within the same period from USD367.128 Billion in 2010 to USD546.682 Billion in 2014 (World Bank, 2016). Population and economic growth are the major indices for huge consumption of resources and are also the prelude to increasing in rate of waste generation.

The present waste management system could not cope with the present challenges, because of completely absent in waste treatment options such as Incineration of waste to energy, efficient materials recovery, and Biogas and Biofertilizer from biodegradable waste, which would have reduced the amount of waste sent to landfill. However, the system resolved to the present waste management structure ‘Waste to landfill’ which is not environmentally friendly, coupled with health risk caused by air and water pollution to the people living within proximity to the dump site.

The management of waste in Nigeria is a three levels approach, consisting of the federal, the state and the local government council. The federal ministry of environment has an oversight responsibility of environmental protection, preservation of natural resources, waste management and environmental laws at federal level, as well as the state ministry and at the local councils.

The Lagos State generates 13,000 tonnes per day (4.74 Mt/a) of MSW in 2014, based on LAWMA (Lagos State Waste Managament Authority) estimates and 80% of the total waste are recyclables. This can be attributed to the rapid urbanization and economic activities in Lagos and based on estimate 44% of total MSW are Biodegradables. (Oresanya et al. 2014). which are landfilled, to produce landfill gas, in the State.

Lagos State and the rest of the country still experiences shortages in electrical power supply which is a limiting factor in realizing its economy and social potential among great cities in the world such as Tokyo, Shanghai, New York etc. Hence, the need to cost effectively channel the growing waste toward energy and material recovery with the aid technology, research, and development became neccessary. This thesis provides the platform which estimates the power capacity of MSW in Lagos State in a mutual benefiting outcome in both waste management and power generation, known as waste to energy. (Branchini et al. 2015).

This thesis will analyse waste treatment options, to produce renewable energy and bio product, such as fertilizer. Using three scenarios (Baseline, Second and Third Scenario). The scenarios will show different outcome, using the same input. Finally, best possible outcome, with the least amount of global warming potential is recommended

Most incineration plants, in waste to energy system uses a grate firing system and fluidized bed system, gasification etc. as BAT (Best Available Technology) in WTE (Waste to Energy) sector, these technologies will be best suited for WTE conversion in Lagos.

1.2 Study Area

Nigeria is divided into six geopolitical zones, Northeast, Northwest, Northcentral, South-south, Southeast and Southwest. Lagos State is one of the six States in Southwest geopolitical zone, of Nigeria.

Lagos state, has an estimated population of 17 million residences (United nations, 2014). The state is the 7th largest economy in Africa, with GDP in 2014, pegged at 90 billion dollars (LASGIDI, 2014), and 150 billion in 2016, (Central bank of Nigeria, 2016) Lagos state, has a land mass of 3,557 Km2.

Lagos state first oil field will start operation in 2018, the economy will even be bigger than it is presently. With all the positive economic indices of Lagos, coupled with associated increase in annual waste generation, a robust and sustainable waste management is required to improve the existing ‘waste to landfill’ structure.

1.3 Research Objectives

In 2014, the population of Lagos state was 17 million inhabitants and World bank has projected the population to reach 25 million by 2030 at growth rate of 8.5% according to United Nations, therefore, the need to design an efficient waste management system is very necessary and urgent. This thesis will determine the composition of MSW in Lagos

Therefore, the thesis will estimate potential power capacity from Biogas, Refuse Derived Fuel (RDF) from volatile waste, Tire Derived Fuel (TDF) from scrap tires, Biofertilizer from composting, using different waste treatment options in Lagos State.

This thesis will create three different waste to energy Scenarios with the same input mass of Municipal Solid Waste (MSW) but different output as recovered energy.

The objective of Waste characterisation to this thesis project, is to determine the overall Lagos State waste composition in percentage.

Determining the composition of MSW in Lagos State. by using the following procedures;

1. Ascertain the waste disposed composition, with respect to their material categories, from residential, commercial, institution and industrial waste sectors.
2. Ascertain the composition of defined material categories, originating from residential, commercial, institution and industrial sectors within the state authority, for this Thesis and further analyses.

2 OVERVIEWS OF MSW MANAGEMENT IN GENERAL

The generation of waste due to human activities, is dated back to prehistoric times, when waste materials were considered as an item with low value or useless commodity. As at the time, waste generation did not pose threat to human existence, due to small world's population and vast area of land for waste disposal. However, as human population increase and the convergence of people in town and cities began, the resultant waste also grew exponentially because of life style and increase in standard of living. The incremental increase in waste generation is not only due to increase in population, it is also because of growth in human consumption and materials acquisition across the globe. As seen in affluence state and as currently occurring in developing countries across the world, such as Nigeria. (Karagiannidis et al. 2012)

The concept of waste at first glance is understood by everyone, but a careful examination of the term "waste" is relative and sometimes it can be misunderstood, due to it relativity. The understanding of waste is relative in two mail regards, firstly, an item is in the state of waste, when it loses it primary value or function as a result of use. However, what is considered waste as result of loss of primary function or value, could serves as raw material in it secondary state, as seen in nature, the death of an animal or plant, serves as food for insects. Similarly, the age of technology has shown that human waste can be used to generate energy, in waste to energy conversion process, in which this final thesis will attempt to analysed and estimate the energy potential of waste.

Waste may lose it primary function to whom generated it, but may gain it secondary function for a secondary user, who set the function and value of the waste. The notion of waste is also dependant on the state of technological advancement and location of generation, for instance horse manure can be consider as a waste in the city but can also be consider a fertilizer in the rural areas. (Bontoux, Leone et al. 1997).

Based on European directive (Directive 2008/98/EC), waste is defined, as any substance or object which the holder disposes or intend to dispose in accordance with national law enforced, for instance radioactive waste, wastewater, MSW. The Directive also lays down some basic waste management principles: it demands that waste be managed without risk to human health, an abuse to the environment and especially without risk to water, air, soil, plants or animals, without causing a nuisance through noise or odors and without adversely affecting the green areas or places of special interest.

2.1 Classification of waste (RDF and SRF)

Wastes can be classified into different classes, based on their unique characteristics and as incineration became more popular, the need to differentiate and standardized the classes of wastes became more relevant.

Since the last three decades, making fuels from waste has been a well-known waste management choice, for energy recovery methods. High percentage of waste streams which require more energy and resources to be recycled, which maaybe difficult to adequately sort, may contain high energy content which can be an important feature for energy recovery (Geert et al. 2015).

Most importantly the choice of energy recovery option is only adequate in an environment where the market exists, such as European Union and the United State, most recently in developing countries. this enforces the need for waste producing companies to meet the fuel requirements of their customers, such as waste to energy company. universal language or code is necessary to achieve the trading objective.

The difficulty of a common language for waste fuel is further compounded, because most calorific waste are still called refuse-derived fuel (RDF) on daily bases. There is no consensus on the meaning of RDF, because the characteristics and quality are not similar in the waste market and mostly the compositional quality of waste and the environmental features are not adequately known.

This portray an environmental risk for waste fuel producers and combustion operator of these fuels, because, specific and sometime hazardous components may pose danger to human health and equipment. This environmental impact may not be accepted by the public and capable authorities (Geert et al. 2015).

While an RDF may have low chlorine content and good calorific value, customers can never be sure of its composition because it is not measured and analysed in an adequate and agreed procedure. To make term waste derived fuel easier, the European Union made standards known as CEN/TC 343 for 'solid recovered fuel' (SRF).

Solid Recovered Fuel (SRF) produced from waste freed from hazardous characteristics, in compliance with European standard EN 15359. Ideally, the standard is not mandatory, the main agreed condition is that a producer write the details of SRF and it should be classify it contents, by specifying its net calorific value and the amount of chlorine and mercury content of the fuel. The obligatory condition includes the detailed content of heavy metals stated in the Industrial Emissions Directive and a declaration of agreement should be issued (Geert et al. 2015).

Although, this standardised condition implies that, there is an accord on the true meaning of SRF, it is also meaningful to note that EN15359 standards does not require any quality level agreement. The essential quality of SRF is therefore defined by the customer, indicating the SRF quality and can vary from customer to customer.

SRF will be an important fuel for the future, but more must be done to ensure waste derived fuel is of SRF quality, to create confidence in the market (Geert et al. 2015).

Note: EN 15359 is a standard for waste incineration only, other methods requiring fuel cleaned before conversion may not requires any sulphur or chlorine limitation.

Table 1: Classification of Waste by Fuel

Fuel	Characteristics
Mass fired combustion	No source separation and No pre-treatment of waste
SRF (Solid recovered fuel) EN 15359 is a standard for incineration only	
RDF (Refused derived fuel) combustion	Mechanically separated from mixed waste
REF (Recovered fuel) combustion	Mechanically refined from separated waste

2.2 Municipal solid waste

Any kind of waste generated because of human activities in a geographical location, can be refer to as solid waste. Consumption habits and economic growth, as led to MSW (municipal solid waste), which are simply waste generated from various segments of human activities or sector in a specific municipality, waste could originate from commercial sector, educational sector, health sector, households, and public places. (Agbesola et al. 2013)

The definition of MSW varies from society to society, it largely depended on the waste management options available to a municipality. In EU countries, MSW is define in relation to data collections, data are annually collected and compared to generate waste information for municipality, Municipal waste is defined as waste mainly produced by household, offices and public institutions, therefore, waste collected on behave of municipal, is known as MSW (Municipal Solid Waste) (Branchini et al. 2015)

2.3 Municipal solid waste management

Figure 1, Illustrate municipal solid waste management system, in the simplest form, to a more advanced level in MSW management. The solid waste management system in Fig. 1a illustrate a system limited to simple source separation of some recyclable waste, to landfilling of the remaining waste. The more advanced waste management system is shown in Fig. 1b equipped with waste treatment option, which recover the recyclable materials and produce energy. Only the unrecovered materials through material and energy recovery system are landfilled. The knowledge of Figure 1b, will be used to create WTE (Waste to Energy) scenarios in the later part of this thesis.

The use of transfer station, in Integrated waste management facility (IWMF) is to collect waste from different area of the municipality, the transfer station can achieve economic of scale in the whole of waste management chain, more than optima use of the road network in the city, which are often prone to heavy traffic and congestion. (Karagiannidis et al. 2012)

IWMF is often use for treatment and final disposal of waste, to achieve cost efficiency and economic of scale in a densely-populated area such as Lagos, Nigeria.

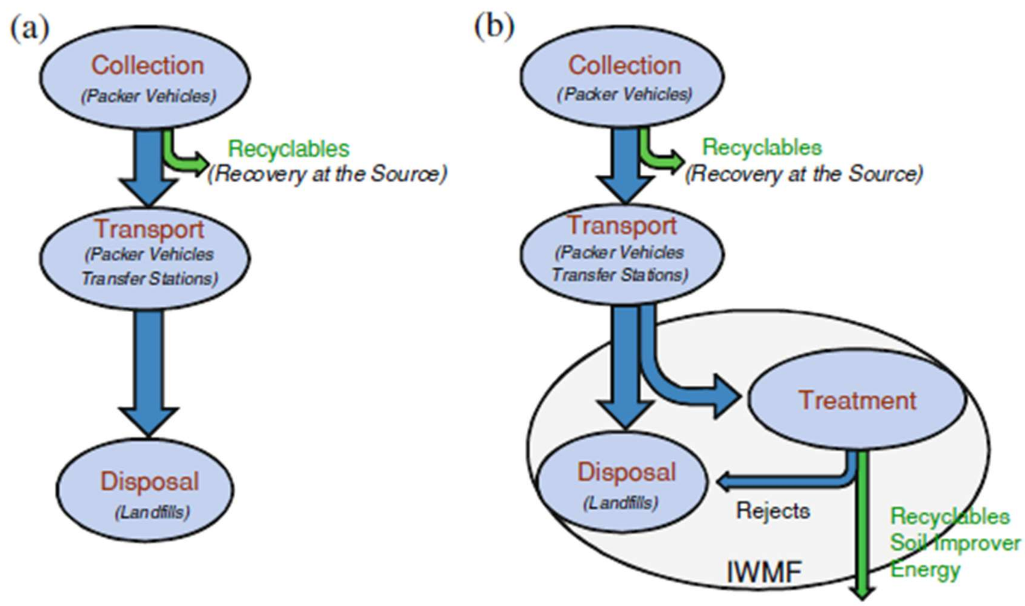

Figure 1: Evolution of the MSW management system from an initial to a more advanced stage

Source:(Karagiannidis et al. 2012) ‘’Waste to Energy, Green Energy and Technology’’)

2.4 Relationship between waste management and Energy production

Energy production and MSW (Municipal Solid Waste) generation are interdependent on one another in relation to waste to energy conversion process, in every phase of life cycle of waste and energy production, as shown in Table 2. (Niessen et al. 2010)

MSW	Energy production
Waste materials can be used as fuels • Incineration (combustion) of waste • Biogas production with the anaerobic digestion of biodegradable waste • Biogas combustion for heating of buildings or processes • Biogas conversion to electricity • Biogas utilization as transport fuel (cars, buses)	Landfill gas collection and recovery • Like waste materials can be used as fuel.
Waste management requires energy • Electricity for pre-treatment • Heat for drying or heating of materials • Waste-heat can be utilized for waste treatment in some cases	Energy production produces solid waste for waste management • Ash • Flue gas treatment residues
Waste producers • Households • Industry • Agriculture	Waste utilizers • Industry • Agriculture

Table 2: Relationship between waste management and Energy production (Niessen et al. 2010)

3 OPTIONS FOR MUNICIPAL WASTE MANAGEMENT TREATMENT

Higher percent of waste generated within Lagos residence, some business and industrial areas, such as households, market places, beverage industries and hotels are organic. Households produce high quantity of organic waste, consisting of processed and raw kitchen waste. Higher share of organic waste is mostly found in low income region 40-85 percent compared to high income region, with low share of organic waste 20-50 percent (Pudasaini et al. 2014).

The high percentage of biodegradable contents present in solid waste, leads to high moisture content and high waste density. The choice of waste treatment options is most influenced by these physical characteristics. Climatic condition also has great influence on waste treatments options, such as high wet and high heat seasons.

Lagos State has a tropical climate. The summers are much rainier than the winters in the State. The Köppen-Geiger climate classified Lagos as tropical savanna climate. The average temperature in Lagos is 27.0 °C. The average annual rainfall is 1693 mm. (Climate-data, 2017). There are different options and technologies which are mostly used in developed cities and developing cities for effective waste management, which are analysed below.

3.1 Mechanical treatment

Mechanical sorting or treatment systems, contain many smaller unit processes that are placed in a series, to produce a treatment (sorting) chain, every smaller treatment unit process of a mechanical sorting system, usually performs a set of functions which enable the preceding step easier. The main reason of a Mechanical Treatment (MT) is to increase value to the waste management operations. To make a MT attain it design objective, its function and merits must be clearly stated at the beginning of the design. The merits are usually achieved by producing useable recyclable materials for recycling purpose and to improve the performance of further unit process (Anttila et al. 2013).

Mechanical treatment (MT) unit can produce waste stream with added value, for example, by producing high valued biodegradable waste for biological treatment (Composting and Anaerobic digestion) or SRF (Solid Recovered Fuel) as a fuel for waste to energy (WTE). Hence, it should be noted that an MT unit produces rejects with some degree of organic material as residues, in addition to the recovered materials. The MT unit is an essential element in combined solid waste management systems, it functions are applicable both upstream and downstream of waste management system. (Anttila et al. 2013)

Mechanical treatment functions are subdivided into three segments: reduction, separation and compaction.

3.1.2 Reduction

The reason for size reduction technique is to reduce the size of the waste particles into smaller ones, so that the waste structure can look the. Presently there are different ways to reduce waste size via mechanical treatment techniques. The commonest types are hammer mills, impact crushers, shredders, cascade mills and jaw crushers. (Anttila et al. 2013)

3.1.3 Separation

The separation procedure is mostly done with magnetic separators, screens, eddy current separator, and air classifiers. Mostly, two or more streams are achieved as consequence of functions of the separation techniques. The efficiency of recovery and the cleanliness of the of the output waste stream are the most important function of a mechanical treatment is in the separation techniques. (Anttila et al. 2013)

Screen:

Screens can separate waste streams of a specific size, the function of screening technique is based on size of opening on the screening surface, which allow a size of waste particle to flow through the moving screen. There are different kind of screening technologies today (Anttila et al. 2013).

Air classifier separator:

The functions of air classifier are depended on air flow, which blow away the lighter waste fractions from the waste stream, therefore allowing heavier particles, such as wet biodegradable materials, stones, and metals, to fall off from different platform in the system. The most popularly used air classifier technology in mechanical waste treatment system, are the rotation air classifier and zigzag air classifiers. (Anttila et al. 2013)

Magnetic separators:

A magnetic separator can separate ferrous metals, these metals are picked up by magnetic systems, equipped in overhead conveyor. This mechanical waste treatment technology need waste material to undergo size reduction technique through shredding, to efficiently separate ferrous metals from waste stream.

Eddy current separation techniques:

Metals that cannot be separated by magnetic means, are separated using Eddy current separation technology, such as copper and aluminium by electromagnetic field.

3.1.4 Compacting

Compaction provides an important benefit of mechanical treatment, in a waste management system, because it helps to reduces the need for a storage place and the cost of transportation, by increasing transportations payload for recyclable materials. Compaction is also essential for energy recovery benefit by increasing the wastes energy density. It mostly includes both solid resistance and extrusion moulding technology.

When the walls of compacting units, press the waste particles to form a moulded bulk, to increase the bulk density of the waste, the bulks are then wrapped for ease of loading, transportation, unloading and storage processes. Compaction that is associated with SRF process is mostly achieved by using pallet presser (Anttila et al. 2013).

3.2 Biological treatment

3.2.1 Anaerobic Digestion

Biogas production in an anaerobic digester of organic fraction of MSW (Municipal Solid Waste), is a promising choice in developing countries and cities, around the world. It provides clean and versatile energy and excellent choice as waste management option, with a very high energy potential. (Karagiannidis et al. 2012)

Organic waste is a compound of organic material, resulting from dead organism, such as plant and animal and their waste. The sources of organic waste for Anaerobic digestion are, manure, food waste and plant. Anaerobic digestion is a chain of biological process, that used anaerobic bacteria to breakdown organic compound into methane (biogas) and carbon dioxide, the process takes place in the absence of free oxygen.

Anaerobic digestion process is subdivided into four main stages, for simplicity of understanding. Hydrolysis, Acidification, acidogenesis and methanogenesis. During hydrolysis, the fermentative bacteria breakdown insoluble complex organic cellulose into soluble substance, such as fatty acid and sugar. (Monnet et al. 2003) Acidification: In second stage the monomers are transformed into alcohols and volatile fatty acids by acidification bacteria. Hydrogen and carbon dioxide are released.

In the third stage, acetogenic bacteria, also called acid former convert the product from the first stage to simple organic acid, carbon dioxide and hydrogen. The acids are: propionic acid, acetic acid, butyric acid, and ethanol. In the last stage, methane is form during methanogenesis by bacterial call methane former. Methane is formed in two distinct process, firstly by means of sharp division of two acetic acids, to produce methane and carbon dioxide, or by reduction of carbon dioxide with hydrogen. (Karagiannidis et al. 2012)

The figure 2 below shows the reaction flow of anaerobic digestion of organic fraction of municipal solid waste.

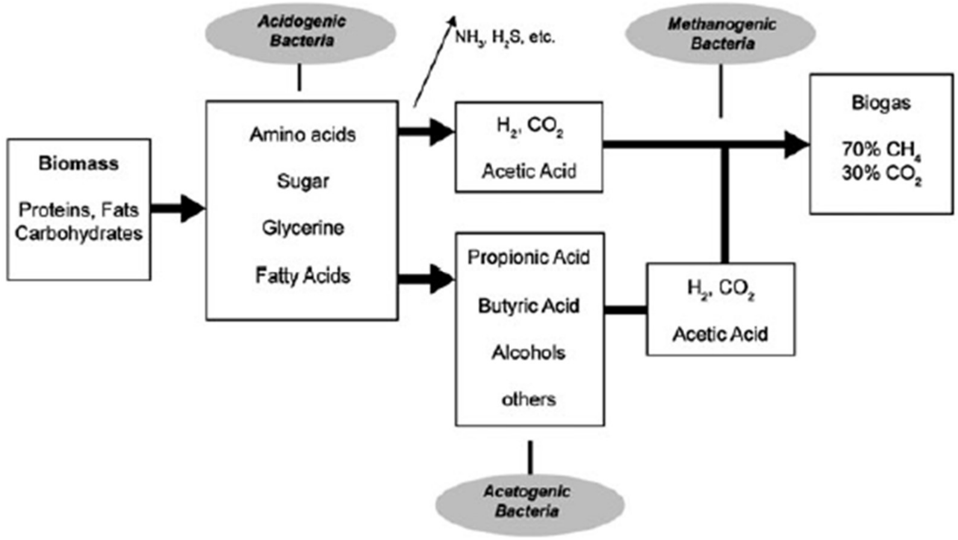

Figure 2: Reaction chain of anaerobic digestion process (Monnet et al. 2003)

In developing countries AD (Anaerobic Digestion) also has social and societal influence, especially in the villages, because the autonomous supply of fuel for cooking can be partly attained. The usual and often time wasting and tiring collection of biomass can be omitted, which would have positive impact on the immediate environment, but most importantly, have a positive influence on domestic work and cooking. Since, in most cases women carry out these activities, AD may also contribute to improve domestic conditions of women in rural areas.

Typical fuel for Anaerobic Digestion

1. Food waste (Kitchen and restaurant waste)
2. Abattoir waste (Animal waste)
3. Sewage slug and agricultural material (Garden)

Outputs are:

1. Biomethane for gas grid, with the required gas scrubbing and injection technologies.
2. Biogas, which can be used to generate electricity and heat – CHP is the norm for such plants, with digestate as an alternative option.

3. Digestate - material which can be used as a green fertiliser or soil conditioner on agricultural land to replace chemical fertilisers, although, even with the right quality there is also the risk of toxic materials (heavy metals) or pathogens.

3.2.2 Composting

Composting is an ancient technology, that is practiced today, from small to large scale practice. Composting is a controlled decomposition, the natural transformation of organic substance into biologically stable humus substance, that makes quality soil nutrient. Compost is easier to manage than other organic materials and manure, it stores well and it is odour free.

Composting take place under the activities of microorganisms, naturally found in soil. On normal condition microorganism, nematodes, earthworms and soil insects, do most of the initial mechanical breakdown of organic material into small particles. Once the most favourable physical conditions are met, the soil bacteria, fungi, protozoa and actinomycetes appropriate the organic material and composting process is initiated. The composting organisms function well at a warm temperature between 10 – 45 Degree Celsius). (Cooperband et al. 2002)

Fertilizer can also be produced from composting and through Anaerobic digestion, which supply lots of plant essential nutrients, namely Nitrogen (N), Phosphorous (P) and Potassium (K). The primary function of fertilizers is to increase crop yield but they also cause some health and environmental hazards. Due to this anomaly, human preference shift to food grown crops without chemical fertilizer.

In recent years, due to research and innovation in crop production becomes more advanced, biofertilizer has become biological nutrient fixation in the soil, for organic food production. Biofertilizers are low cost, renewable source of soil nutrient for organic food production. It gains it acceptance among the low income and medium size farmers due to it low cost. In addition, their application improves soil structure. (Bhattacharjee, Dey et al. 2014)

3.3 Incineration (Waste to Energy plant)

The existence of waste incineration plant started at the beginning of nineteen century in Europe, as a method to reducing the amount of waste to landfill and reduce waste impact on the human and environment. The development of WTE (waste to energy) technology continue to improve and it increase the benefit of efficient energy generation. WTE technology, is employed to generate heat and electricity in many developed countries, instead of conventional fossil fuel (Branchini et al. 2015).

Presently different kind WTE technologies is in existence, such as waste to energy plant (Incineration), anaerobic digestion, and gasification, however, mass burn incineration (Direct combustion technology) is still the highly dominant technology in WTE conversion system.

Direct incineration of waste on moving grate, which produce superheated steam as an input into the steam turbine in a cycle, known as Hirn cycle. The characteristics of combusting MSW (municipal solid waste), such as LHV (lower heating value) is the determinant factor, which determine the quality of the recovered energy (Branchini et al. 2015).

Basic schematic WTE plant shows four processes and common plant sections

1. Waste delivery and storage area (Bunker)
2. Furnace is the combustion of waste area
3. Energy recovery and conversion area
4. Pollution cleaning and control area.

Bunker section: Trucks, are usually used to transport and store waste into the bunker, usually after the visual control and weight are determined. Keeping the delivery area closed can be an important method to prevent the associated smell, noise, and air pollution problems. The bunker is usually a place that is leakproof and equipped with concrete bed, where the waste is gathered and mixed using cranes equipped with grapples. The blending of the waste helps attain a balanced heat value, size, structure, composition, etc (Branchini et al. 2015).

Furnace section: In basic term, waste combustion is the combustion of combustible materials comprised in the waste. Waste can be classified as an heterogenous substance, which contain higher percentage of organic material, metals moisture content and minerals containing mainly of organic materials, minerals, metals, and water. Combustion process releases heat energy in the form of energy recovery or recovered energy. Incineration takes place when the required temperature is reached and the right amount of oxygen, which then ignites the combustion process.

The incineration process occurs in the gas phase can take several seconds and simultaneously heat energy is released at a point where calorific value and oxygen supply is enough. This can lead to thermal reaction chain, which does not require another kind of fuel, because the process is self-supporting by the reaction chain (Branchini et al. 2015).

The main phases of the waste incineration process are:

1. Degassing and drying
2. Pyrolysis and gasification
3. Oxidation

Boilers (Energy recovery section): WTE plants has a boiler which are the energy recovery section of waste to energy plant, the boilers are water tube boilers, and mostly have four passes: three of the passes are arranged vertically, which are known as radiation passes and one convective pass. Boilers are usually integrated into the furnace, where heat energy is recovered. The recovered heat energy can also be used to drive a turbine which then convert mechanical energy into electrical energy (Branchini et al. 2015)..

The basic features of energy recovery section of WTE plant

1. Economizer
2. Evaporator and
3. Super-heater

When designing, and constructing of a combustion chamber for incineration of waste, the most important feature to take into consideration is the risk of corrosion, commonly known as corrosion problems.

Waste to energy (WTE) plants have greatly improved in technology, efficiency and are more excellent when compared older incinerators, with less emission control system.

However, the variation in calorific value of MSW and its slightly high content of chlorine add to a highly corrosive atmosphere, that decrease the life span of heat exchanger tubes, the combustion chamber, the water walls of the first passage, and the superheaters are the boiler components most affected by corrosion (Branchini et al. 2015).

Most crucial factor effecting corrosiveness inside of WTE boilers are:

1. Temperature of metal surface
2. Gas temperature
3. Temperature fluctuation
4. Characteristics of molten salt deposits.

The detailed corrosive factors inside boiler of WTE incinerator and the cost incurred as a result of corrosion, are outside the scope of this Thesis. (Branchini et al. 2015)

Typical input (Fuels) to an incinerator:

1. MSW (Municipal Solid Waste)
2. C&I (Commercial & Industrial Waste)
3. RDF (Refuse derived fuel)

Outputs from an Incinerator

1. Electricity and Heat: in some cases, electricity and heat, both are both generated simultaneously from a CHP (Combined Heat and Power) plant, and in some cases only heat or only electricity depending on the needs. For instance, in CHP plant are used to provide municipal heating and at the same time generate electricity, e.g. Kotka CHP plant.
2. Bottom ash: This is the residual substance of a combustion process and the quantity of bottom ash depends on the nature (moisture content, metals) of MSW (Municipal Solid waste). Ash can be used road as bed material in the construction road
3. Fly ash: this can pollute the environment and can be controlled with the aid of pollution control device, e.g. cyclone.

Types of Incinerator

3.3.2 Mechanical Grate Incinerator

Mechanical grate incinerators were primarily design and developed for coal incineration in power plant, but since 1930, there use for MSW incineration has increased. Moving grates help to transport the fuel from the feeder through the combustion chamber to ash discharging section of the incinerator. Complete combustion is aided by a means of a moving staircase grates, which enable fuel to fall from one staircase to the next. Several arrangement of the grates are possible, such as reciprocating grates which provides turning motion for the fuel, the overflying movement of the fuel are necessary for a complete combustion of all the combustible materials in the combustion chamber (Buekens et al. 2012).

Applications:

The primary design of mechanical grate incineration is for combustion of calibrated coal, because calibration enable the complete combustion of all particles, at the end of combustion process. However, MSW (municipal solid waste) is also not homogeneous just like calibrated coal.

The different in the uniformity of MSW are corrected by feed that has been homogenised, with the aid of specific grate action, which drained the MSW in the pit. Several choices are presently available for co-firing municipal waste and other fuel, such oil and plastics, sometimes sewage sludge (Buekens et al. 2012).

Merits of mechanical grate incinerator:

The performance of mechanical grate incineration has been measured severally, in many developed societies. The performance measured can best comparative advantage as compared to other alternatives (such as fluidized bed incineration) tested over more than a century.

Demerits are:

It can only burn wastes that are supported by grates, grate incinerators do not support liquid and waste powders.

Least suitable for municipal waste with very low or very high HHV (High heating Value), unless the mixture of both, Fluidised bed units are more suitable in this respect.

3.3.3 Fluidized Bed Incinerators

Circulating bed incinerators was developed in earlier Europe and America, before the rest of the world. Circulating fluid bed units are mostly common because stability of combustion process can easily be achieved by simple addition of cheap coal, instead of using costly fossil fuel. The combustion process of fluidized bed incineration of waste, is erratically burns by means of bubbling bed and sandy materials and temperature range of 750-900 degrees Celsius.

Combustion of materials takes place above the bubbling bed, sometimes called freeboard zone. The zone enables a well mixture of waste, so that reduction and oxidation agents can mix and burn out completely. Secondary air provides the swirl required for proper mix of volatile materials. thermal flywheel is provided by fluidised bed material to effectively respond to short-term fluctuations in feed rates and quality. (Buekens et al. 2012)

Applications

Fluidized bed technology was first introduced for gasification of coal in 1920s, also for cracking of gas oil into gasoline, in catalytic process in the United State, during world war II by Massachusetts Institute of Technology. fluidised bed incineration is also applicable for drying of polymer powders and roasting of sulphide. Incineration of wastewater is the common and the most notable application of fluidised bed technology. Gasification, and pyrolysis of classified refuse have been widely developed in Japan, Scandinavia, and Finland. (Buekens et al. 2012)

Merits of Fluidized Bed Incinerators:

Fluidized bed incinerators are relatively simple to construct, operate, maintain and can be automated. In fluidized bed incinerators moving parts are absent, at elevated temperatures, high heat generation and bed-to-wall heat transfer rates are achieved because of high-quality of gas to solids contact. Complete combustion can be achieved at a temperature range of between 750–850 degrees Celsius and a low excess air of 15–35%. Therefore, the amount of generated flue gas and NOx are comparably small (Buekens et al. 2012).

Demerits:

When the combustion temperature rises above the softening point, at this point the most severe operating defect occurs, which cause rapid melting of particle and solidification of bed parts and sometimes bed materials. When this defect occurs, the most notable solution is to remove the solidified materials or parts by hammering (Buekens et al. 2012).

3.3.4 Cement (Rotary Incinerators) Kiln as a Hazardous Waste Management Option

Many developing countries rarely owned hazardous waste treatment technologies such as incinerator for the treatment of hazardous waste such as PCB, expired pesticides, and other hazardous waste. Cement kilns for solving hazardous waste management option is gathering increasing interest in most developing countries. The cement industry is an extremely energy consuming sector.

Reusing the hazardous waste as replacement for raw materials and fuel during the cement production process provides an energy and material recovery which could be taken as great benefit of win–win condition. This Thesis discusses the key aspects in hazardous waste, management by cement kilns. As it relates to the management of scrap tires or TDF (Tire Derived Fuel). (Karagiannidis et al. 2012)

Characteristics of Cement Kiln as a Hazardous Waste Management Option:

The characteristics of the cement kiln as an efficient method for hazardous waste management option can be listed as follows:

1. High thermal capacity
2. Alkaline environment
3. High temperature and long residence time
4. Minimum amount of waste generated

Benefits of using Cement Kilns as hazardous waste management option:

The benefits of using cement kiln in management of solid and hazardous waste can be listed as follows:

1. High temperature and Long residence time, to produce cement clinker, the temperature of the kiln must reach 1500°C and the combustible gas temperature must reach 1700oC. These kiln and gas temperature must have residence time of 6 to 10 seconds, plus the very high turbulence in the kiln, to ensure the obliterate even the most stable organic compounds.
2. Conservation of non-renewable resources
3. Energy recovery
4. Reduction in waste transportation fee and risk
5. Reduction in cement production costs
6. Facilities already exist.
7. Reduction in amount of waste generated at the end of the chain.

4 MUNICIPAL SOLID WASTE MANAGEMENT IN LAGOS

Municipal solid waste management in Lagos state, at present, will be pictured using data and results from the 2016 waste characterisation study in Lagos State, Nigeria.

4.1 History

The management of solid waste in Nigeria first come into light in 1970s, with the emergence of oil boom, which gave raise to industrialisation and urbanisation to Lagos, Kaduna and Port Harcourt, the major cities where crude oil refineries are located. The resultant high volume of waste was becoming much difficult to manage by the local government council in Lagos State and the poor state of waste management system in Lagos was visible to the rest of the world. In 1977 the city of Lagos hosted FESTAC 77, the world press classified Lagos as the 'dirtiest capital city in the world', and consequently the birth of West African first waste management system was commissioned in April 1977, called Lagos State Refuse Disposal Board (LSRDB) under Edict 9 of 1977 in Nigeria. Managed by Powell Duffen Pollution Control Consultants of Canada.

In 1981, the name was changed to Lagos State Waste Disposal Board (LSWDB) due to added responsibilities of commercial-industrial waste collection and disposal to the board, which also includes drain clearing and disposal of scraped vehicles.

In December 1981, the name was finally changed to Lagos State Waste Management Authority (LAWMA), under edict 55, which made the authority to be responsible for collection and disposal of household, commercial/Market and industrial waste throughout the state and provision of commercial waste service in the state. Such as Domestic/household, Medical, Hazardous, and Special waste (sewage sludge etc.)

4.2 The impact of waste management system in Lagos State

Providing social services for the people of Lagos state, through job creation, health and safety advocacy, enlightenment campaign in primary and secondary schools across the state, on the necessity and impact of a functioning waste management system to Lagos State. LAWMA providing healthy and clean environment, for the residence, through household, commercial and industrial municipal waste management services, to the residence, which keep the city of Lagos clean and healthy.

4.3 Definition of waste streams

Waste characterisation study conducted by LAWMA in 2016 during the data collection process for this thesis, the study identified different waste sectors, by their unique characteristics that make them a sample mean, which represent the total waste stream, as define below.

1. **Residential waste**, is collected by both PSP (Public Sector Participation) and LAWMA operatives, from the households across the state. This waste is primarily collected using trucks such as Double and Single Trucks, Trailer Trucks and Open Back Trucks and Mammoth Compactors.
2. **Commercial and Institutional waste**, schools, market, parks, and government institutions mainly generate this. This waste is collected in variety of vehicles, include those mentioned above.
3. **Industrial waste,** generated through industrial activity, which includes waste generated during mining, manufacturing process, packaging, and disposal.

Industrial waste is the material disposal from the production of specific consumer products.

In the study, Industrial, commercial, and Institutional waste is combined, because the collection method is such that, these wastes are collected by the same PSP/LAWMA operatives and the waste compositions for these category of waste is the same for all areas. Therefore, in the statistical analysis of sampled and sorted data to derive the title of Industrial Commercial and Institutional (ICI) wastes the Waste characterisation study. LAWMA pre-divided Lagos state into five subsectors using similarities in population density and economic characteristics of the sampling area. This was the basis for picking waste samples used for the study.

Note that, waste from the Transfer Station at Simpson Street and Agege are not included in this study, because waste from those TLS (Transfer Loading Station) are usually lumped sum into one big trailer, for transportation to the dump sites and income subsector cannot be identify. Therefore, it does not satisfy the sampling requirement of the study. Sample area and the corresponding Local Council Development Area are listed in the Table 3, below.

Table 3:waste sector divided into average income level categories and their corresponding Local Government Area (LGA).

AREA CATEGORISATION	SECTOR	LGA	SPECIFIC LOCATION
High Density, Low income	HDLI	Ajeromi, Ebute-Meta	Ajeromi, Otto
Low Density, High income	LDHI	Ikoyi, Obalende, Iru Victoria Island	Ikoyi, lekki, VI
Medium Density, High Income	MDHI	Ikeja, Kosofe, Oshode Isolo	Ikeja GRA, Ogudu GRA, Ajao Estate
Medium Density, Low income	MDLI	Alomosho, Lagos Mainland	Alimosho, Ebute Meta
Low Density, Low Income	LDLI	Imota, Ikorodu North, Epe	Imota, Isin, Agbowa, Epe

The study does not include the following waste stream:

1. Medical waste
2. Hazardous waste
3. Pollution control waste

5 MATERIALS AND METHODS

5.1 Waste characterisation

This section present the summary of the date collection methods and calculation procedures used in waste characterisation study. The sampling plan was conducted in accordance with industrial standards for conducting waste characterisation studies and the America Society for Testing and Material (ASTM) standard D5231 for sample size. (2016, Lagos Sate Waste Characterisation Study).

PSP Collected Waste

To determine the waste composition from the different waste sectors, which were mainly delivered by PSP collectors, were collected at the four active landfill sites in Lagos State. before the exercise, dump site specific data was collected from the Managers of the each of four landfill sites to determine the mixture of the sectors and subsectors that are brought to each of the dump sites. This was achieved through a questionnaire survey administered before the field exercise. **Appendix A** shows the results of the questionnaire survey for Olushosun landfill site. From the survey result, the sampling plan for the selection of trucks at each landfill was constructed see in **Appendix B.**

It should be noted that, based on the experience on the first day of the sampling and sorting exercise, it was discovered the PSP waste collectors do not distinguish between residential and commercial buildings when collecting wastes and LAWMA collected wastes are mostly those brought from the Transfer Loading State (TLS). This shows up in the ratio of wastes disposed by LAWMA, compared with those brought by PSP collectors as shown in the result of the questionnaire survey in **Appendix A.**

These finding also resulted in an amendment to the sampling exercise, where Residential wastes, brought in by PSP collectors, were sampled and in the same case, Residential wastes combined with the ICI wastes stream which led to sample allocation within the subsectors being adjusted as earlier discussed

The sampling procedures were carried out on four landfill sites in Lagos State, as shown in Table 4 below, for a period of two weeks. Sampling operation were conducted on two landfill sites simultaneously per week as shown in Table 5 below. The wastes were hand-sorted and physically characterised, at the end of the procedures total of 286 waste samples were collected from the four landfill sites.

The waste compositions are determined by study parameters, the number and allocation of samples, the landfill sites where the sampling operation were carried out and requirement for selecting waste samples, these includes:

1. Physical waste characterisation and
2. Waste composition

Table 4: Participating Facilities

Landfill facility	Location	LGA	GPS Coordinates	Waste disposal (tonnes per day)
Olusosun	Ojota	Ojota	Easting 0729293, Northing 0564225	2965
Solous II	Osheri-Idimu	Alimosho	Eating 0527897, Northing 0725651	1266
Epe	Afero village	Epe	Easting 0603577, Northing 0725778	443
Ewu-Elepe	Ikorodu	Igbogbo-Bayeku	Easting 0729289, Northing 0564235	728
TOTAL				5402

Table 5: Total Number of Samples Collected at each Landfill Site

Waste Sector	Number of Samples taken from each Landfill				Total
	Epe	Solous II	Olushosun	Ewu-Elepe	
Collected residential waste	42	62	82	70	256
Collected industrial waste	1	1	0	16	18
Collected commercial waste	9	2	0	0	11
Collected institutional waste	1	0	0	0	1
Total					**286**

5.1.1 Physical Waste Characterisation

Waste sampling at the landfill site was carried out over a period of twelve (12) sampling days, for eight working hours per day. All the sampled waste was collected from the PSP trucks. No sample was collected from LAWMA trucks, as their waste are mostly from the TLS (Transfer Loading Station), which does not representatives of sampling factor, as earlier explained. The samples collected were hand sorted and physically characterised. A sum of 286 samples, which comprises of 256 residential wastes, 18 industrial wastes, 11 commercial wastes and 1 institutional wastes, were categorised.

5.1.2 Data Collection Procedures

Field personnel were responsible for the selection of samples arriving from PSP trucks to the dump sites. The trucks were tipped in an already prepared location with the dump site and samples were collected in random from the portion of each pile. The samples comprised of about 90Kg of waste, were then sorted in 10 material class/composition: Paper, Beverage container, Plastics, Glasses, Metals, Organics, C & D (Construction and Demolition), Inorganics and Textiles. Classes were further classified into 87 materials, as stated below.

PAPER: Boxboard, Compostable paper, high grade office paper, magazines/catalogues, mixed paper, News print, other paper, Uncoated OCC/kraft.

BEVERGE CONTAINERS: Milk and juice cartons, Water bottles

PLASTICS: Other PET containers, PET bottle/jars, HDPE bottles/jars clear, HDPE bottles/jars coloured, Other HDPE containers, Other bottles/jars, Other containers, Expanded polystyrene (EPS), Commercial & Industrial Film, groceries Bags, LDPE, Other film, Other rigid plastic products, Composite plastics, Trash bags

GLASS: Flat glass, other glass, Recyclable glass

METAL: Aluminium beverage containers, Ferrous containers (in cans), HVAC ducting, other aluminium, other ferrous, other metal, other non-ferrous containers

ORGANICS: Bottom fines and dirt, Diapers, Food scraps waste, other organics, Yard waste compostable, Yard waste woody

CONSTRUCTION & DEMOLITION: Bricks, Ceramics/Porcelain, Clean & other aggregates, clean dimensional lumber, clean engineered wood, clean unpainted gypsum board, concrete, others painted gypsum board, painted wood,pPlastic C & D materials, reinforced concrete, rock & other aggregates, roofing, treated wood, wood pallets.

INORGANICS: Computer equipment peripherals, Computer monitors, Electronic equipment, Fluorescent bulb, Fluorescent bulky items, Lead-acid batteries, other household batteries, Television sets, Tires, White good-not refrigerated, White good-refrigerated.

TEXTILES: Carpet, carpet padding, Clothing, Other textiles

OTHERS: Factory dust, Iron, Stainless steel, other industrial waste, Latex paint, Mercury containing items, Oil paint, Other automotive fluid, Plant/organism/pest control/growth, Sewage solids, Sharp & infectious waste, Used oil filters

After the samples were hand-sorted, each material was weighed and the corresponding information to each material class was recorded.

5.2 Scenarios

In order to estimate the energy potential of MSW (Municipal Solid Waste) in Lagos State Nigeria, three scenarios were created (Baseline scenario, Scenario 2, and Scenario 3). To achieve the objectives of this thesis, all the data are collected on the site, during the 2016 Waste characteristic study by Lagos State Waste Management Authority (LAWMA).

In table 6, is a methodology design showing three scenarios, to present the various waste to energy treatment options, associated with each scenario. Waste composition results, obtained from waste characterisation exercise is used to determine the values of each waste streams for all the scenarios.

Table 6: Showing three Different Scenarios and Associated Waste Treatment Options.

	Scenario 1	**Scenario 2**	**Scenario 3**
MSW to Landfill	X		
Landfill gas collection			
Biogas from AD	-	-	X
Mechanical treatment			
Separating recyclables		X	X
Other reject incl. organic to landfilling Mt/a		X	X
Organic fraction (Composting)		X	
RDF production		X	X
TDF for Cement Kiln	X	X	X

5.3 Baseline scenario (Scenario 1)

Baseline scenario (Scenario 1), as illustrated in figure 3, shows the status of present waste management practice in Lagos State. The only waste to energy option available in this scenario is the conversion of scrap tire into TDF (Tire Derived Fuel). The tires are manually collected on the landfill sites and shredding also takes place on the landfills for ease of transportation to the cement kiln. The values of recovered energy are presented in the result section (Chapter 6).

All the collected wastes from the points of generation (Residencial, Commercial and Industrial waste), are sent to the landfills (Olusosun, Epe, Ewu-Elepe and Solous) through PSP and LAWMA trucks. Resource personnel (scavengers) employed to separate the recyclables such as metals, glasses, plastics for onward transportation to the factories for recycle purposes. However, it is highly impossible for human to handpicked tons of recyclables from mixed wastes, because of low efficiency and speed of operation but the efficiency of total handpicked recyclable materials can be assumed to be 12% of the total recyclables on the landfills. The estimated mass in percentages of Municipal Waste compositions are presented in Chapter 6 (results section).

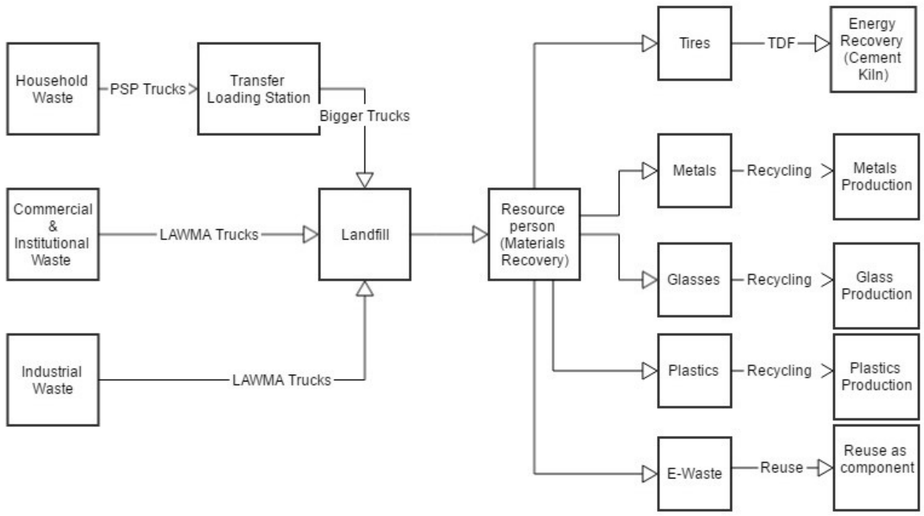

Figure 3: Schematic Diagram of Baseline Scenario, showing waste flow from points of generation to different waste treatment options.

In 2014, Lagos State generated 13000 tons per day of Municipal Solid Waste (MSW), which is equivalent to 4.75 megatons per year and Lagos state has population of 17 million, according to World Bank estimate in 2015.

Waste generated per person per year can be calculated by dividing generated wastes per year by the total population for that given year, as shown in equation 1.

Therefore,

$$\boldsymbol{Waste\ generated\ per\ person\ per\ year} = \frac{\mathbf{4.75 * \ 1,000,000,000}\ \boldsymbol{kg/a}}{\mathbf{17\ 000\ 000}}$$

$$= \mathbf{280}\,\frac{\boldsymbol{kg}}{\boldsymbol{person,a}} \qquad \mathbf{1}$$

Waste generated per person is a function of affluence, which also varies from country to country and from region to region.

The values of other wastes streams (metals, plastics, paper, organic, textiles, e-waste etc) is obtained by multiplying the percentages (%) of waste characteristics result in section 6.0, with total annual waste generated.

The net power generation potential in this Scenario 1 for TDF to kiln can be determined by application of equation 3 and the combustion characteristics of TDF in table 7 and Mass of scrap tire in table 15 (Result secton).

Table 7: Combustion characteristics of TDF. (Pipilikaki et al. 2005) ‘’Cement & Concrete Composites 27 (2005) 843–847’’)

Typical Analysis of TDF	
Analysis	TDF
Volatile (%)	72
Ash (%)	7
Carbon (%)	84
Hydrogen (%)	5
Sulfur (%)	2
Nitrogen (%)	1.75
Net calorific value (MJ/kg)	31.40

In scenario 1 (Baseline scenario) is assumed that 0.84% of scrap tires (converted into TDF) can be recovered from total MSW

Mass 0,04 Mt/a * 1 000 000 = 40 000 t/a

Net calorific value(NCV) = 31.40MJ/kg *(Pipilikaki et al. 2005)*

Thermal efficiency of direct firing = 76% (*EURECA 2013 – Energy Efficient Measures in Cement Production*)

$$Power\ generation\ potential\ (MJ/a)_{TDF} = NCV \times W \times 1000 \quad 2$$

$$Net\ power\ generation\ potential (MJ/a)_{TDF} = \eta \times NCV \times W \times 1000 \quad 3$$

Where W[t/a] is mass of waste, NCV[MJ/kg] is Net calorific value and η *is the thermal efficiency of the kiln.*

5.4 Scenario 2

Scenario 2: shows the estimated wastes stream from the output of mechanical treatments system. This process produced RDF for energy recovery, organic waste, for composting as farmland fertilizer and other rejects which also contained some amount of organic waste, are sent to landfill, the entire scenario reduced the amount of waste to landfill (Dump site).

Scrap tires are separately collected, and shredded into TDF for energy recovery, in the cement kiln, as described in Scenario I. Figure 4 shows schematic diagram in scenario 2. Metals and glasses are recovered, as material recovery

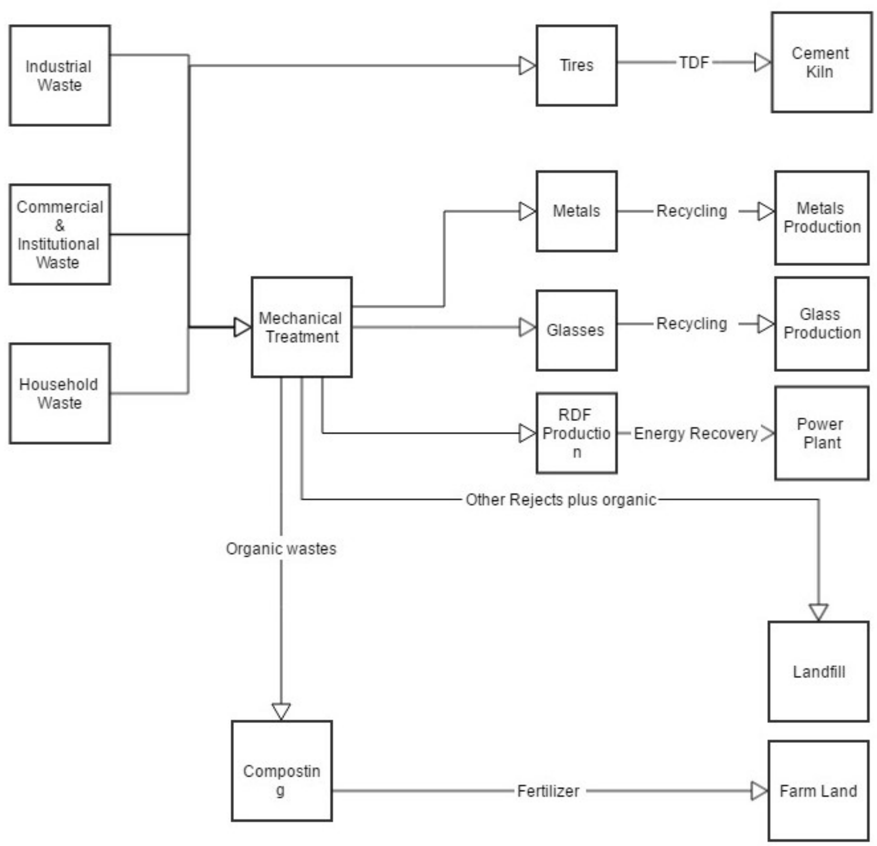

Figure 4: Mechanical Separation, Organic Rejects for Compost, RDF and TDF Production for Energy Recovery

Mass balance can be described as the overall mass flow in a waste stream into the output waste stream, while material balance in this thesis, refer to the component of input waste stream, such as Paper, Metals, Textiles, Plastics, Beverage container, etc. to output waste stream in the production of RDF. (Agbesola et al. 2013, Nasrullah et al. 2015)

In scenario 2, it can be assumed that 4.75 megatons of MSW was also generated, per year but the compositions are based on the output of MBT, as shown in Table 8.

It can be estimated that 0.84% of scrap tires are source separated from total MSW (Municipal Solid Waste) generated. The percentage of Metals and Glasses is 1.5% with an assumed recovery rate of 90% and metal is 1.3 with assumed recovery rate of 75%. High calorific RDF is generated which accounts for 48.16% of the total output waste streams. 34% of Organic waste, with assumed recovery rate of 78% (NTECUS et al. 2010), composting via mechanical and biological treatment plant, and other rejects is 14.2% which also contain some organic contents to landfill. A shown in Table 8 below and the corresponding mass in megatons are shown in table 9.

Table 8: Mechanical and Biological Treatment in Scenario 2, Output of Total Waste Stream by Assumed Percentage for Metals, Glasses, and Organic Materials. Which Represent Material Balance of Scenario 2. (INTECUS et al. 2010) ‘’ Waste Management and Environmental-

MSW 100%	
Separately Collected	
Tires	0.84%
Mechanical Treatment	
Metals	1.5 % *of total MSW (assumed recovery rate of metals 90%).*
Glasses	1.3 % *of total MSW (assumed recovery rate of metals 75%).*
High Calorific RDF	48.16% *NTECUS et al. 2010*
Biological Treatment	
Composting for fertilizer	34% *of total MSW (assumed recovery rate of glasses 78%).*
Other Rejects incl. organic	14.2% *NTECUS et al. 2010*

Mechanical and Biological Treatment

Mechanical and biological treatment (MBT) plant is used to produce refuse derived fuel (RDF) out of MSW. The table 9 below shows the estimated share of output stream in megatons per year via mechanical treatment plant, based on material balance in scenario 2.

Table 9: MBT Output in Scenario 2 in Megatons per year, Based on Material Balance in Table 8

The output of mechanical treatment in Scenario 2 from Table 8		
Composition	**%**	**Mt/a**
Tires (TDF)	0.84	0.04
Metals	1.5	0.07
Glasses	1.3	0.06
RDF	48.16	2.29
Organic for composting	34	1.61
Other rejects inc organic contents to landfill	14.2	0.67
Total	100	4.75

Net power generation potential of RDF

In a research on Lagos MSW, conducted by (Amber et al. 2012) concluded based on experiment that; The Net Calorific Value (NCV) for Refuse Derived Fuel (RDF) analyzed without pre-treatmentn or drying is 11.38MJ/kg while for oven dry MSW (Municipal Solid Waste) at 85 degree Celsius has a calorific value of 17.23 MJ/kg. Equation 5 can be used to determine the Net power generated potential using RDF of mass 2.29Mt/a as fuel to power electric generator of 27% efficiency, in Lagos State.

Also, according to (Rabiu, Osibote et al. 2016), the NCV of the RDF was found to have the same average as the unpelletized MSW at 19 MJ/k. This indicates that the starch has no effect on the NCV of the waste; however the range of the NCV from the pelletized samples was somewhat narrower ranging from 16.8 to approximately 20 MJ/kg.

Table 10: Energy content of MSW (Asian journal of engineering, sciences & technology, vol. 2, issue 2, 2012)

Composition of MSW	Energy content net calorific value (MJ/kg)	Moisture content %
Organics waste	11.59	
Paper	10.14	
Plastics	14.89	
Polyester	46.5	
extiles	9.27	
RDF (dry)	17.23	49.90%

Mass (W) of 2.29Mt/a = 2,290,000t/a

NCV = (0.51*17.23) – (2.4*0.499) = 7.60 MJ/kg

Efficiency of 27%

$$Power\ generation\ potentia\ of\ RDF = NCV \times W \times 1000 \quad (4)$$

$$Net\ power\ generation\ potential(MJ/a)_{RDF} = \eta \times NCV \times W \times 1000 \quad (5)$$

Where W[t/a] is mass of waste, NCV[MJ/kg] is Net calorific value and η is the conversion efficiency of generating plant.

Net TDF power potential for Scenario 2

The net TDF power generation for rotary kiln can be determined by application of equation 3 on the combustion characteristics of TDF in table 7 and Mass of scrap tire in table 9.

Mass = 0.04 Mt/a = 40,000t/a

Net calorific value (NCV) = 31.40MJ/kg *(Pipilikaki et al. 2005)*

Thermal efficiency of direct firing = 76% (*EURECA 2013 – Energy Efficient Measures in Cement Production*)

Composting Potential in Scenario 2

Composting potential can be calculated based on estimate by finding the ratio between the waste input of composting in tons per year and expected compost output in tons per year, see table 11 below. The mass of organic fraction through mechanical sorting system in Table 9 is 1.61 megatons per year.

Table 11: Key data of compost operation for the analysed composting plants. (Sinnathamby, Vijayapala, et al. 2016) "FACTORS AFFECTING SUSTAINABILITY OF MUNICIPAL SOLID WASTE COMPOSTING PROJECTS IN SRI LANKA." About the 1st International Conference in Technology Man)

Composting plant	Year funded	Waste collected (t/d)	Waste input composting (t/d)	Expected compost (t/d)	Potential reduction of waste disposal	Reference
Balangoda urban council BUC	2008	15	>10	4	80%	Sinnathamby, Vijayapala, et al. 2016

5.5 Scenario 3

Scenario 3, organic waste for Anaerobic Digestion, and Scrap tires for TDF (Tire Derived Fuel) are source separated. Other rejects, which also includes some mixture of organic waste are sent to landfill and scrap tires are shredded for energy recovery in Cement Kiln. Mechanical treatment is also used in this scenario, to separates different waste streams, such as metals and glasses, which are recycled as material recovery. The RDF is used to generate electricity as energy recovery from waste and other rejects which also includes same percentage of organic materials are landfilled. Schematic diagram of scenario 3, is shown in figure 5 below.

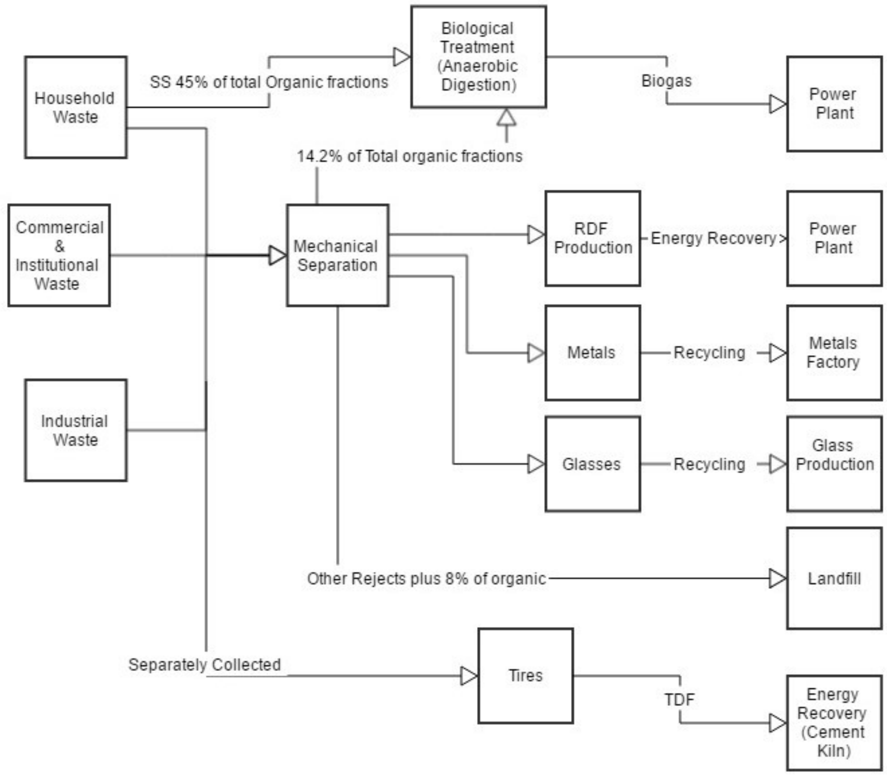

Figure 5:Scenario 3: Biological treatment of source separated Organic to Biogas, thermal treatment of Scrap Tires (TDF), Mechanical Treatment of Waste and Production of RDF

The anaerobic digestion (AD) process takes place in mainly oxygen free natural environment. The industrial AD process, that is recommended by this thesis to Lagos State Waste Management, take place in a specially design digester tank, which is a part of biogas plant.

Biogas is methane rich gas, which can be used as renewable fuel by direct combustion, to generate renewable electricity and can also be upgraded to biomethane, for car engine. Digestate is sludge-like, by-product of AD process that remain after the decomposition of organic waste, rich in plant macro and micro nutrients, which can be used as fertilizer to increase yield of agriculture products. (Al Seadi et al. 2013)

This thesis also decided that 14.2% of total organic content recovered via mechanical treatment can also be used for AD.

Table 12: Material Balance for Scenario 3, Estimating 45% Source Separated Organic Waste for AD, while the Remaining 55% is Obtained via Mechanical Separation. This is a representation of Material Balance of Scenario 3. (INTECUS et al. 2010)

MSW 100%	
Source Separated	
Tires (Source separated)	0.84%
Organic (Source separated) for Anaerobic Digestion (AD)	19.8 *of total MSW (assumed 45% of total organic waste is recovered through source separation)*
Mechanical Treatment	
Metals	1.5 *% of total MSW (assumed recovery rate of metals 90%).*
Glasses	1.3 *% of total MSW (assumed recovery rate of glasses 75%).*
High Calorific RDF	48.16%
Biological Treatment	
Organic material Mechanical separated for Anaerobic Digestion (AD).	14.2%
Other Rejects including organic	14.2%

Table 13: Mechanical and Biological Output, based on Table 12, which Shows the Percentage Output of Each Material Component.

Mechanical and Biological Output in Scenario 3 from Table 12			
Composition	**%**	**Mt/a**	
SS organic waste for Anaerobic Digestion	19.8	0.94	*For energy recovery*
Tires (TDF)	0.84	0.04	*For energy recovery*
Metals	1.5	0.07	*For material recovery*
Glasses	1.3	0.06	*For material recovery*
RDF	48.16	2.29	*For energy recovery*
Organic material for Anaerobic Digestion	14.2	0.67	*For energy recovery*
Other rejects inc organic contents to landfill	14.2	0.67	*To landfill*
Total	100	4.75	

Based on Lagos State waste characterisation study in 2016, the share of organic waste out of the total waste stream is 44%. see Figure 6 of chapter 6. It can be assumed that in 10 years, if the legislation become more environmentally friendly and the citizen become more aware of the need to protect their immediate environment, which in turn forced the legislator to make and enforce a more sustainable waste management practice, then Lagos state could achieve s 45% (19.8% of total MSW) source separated of total organic fraction for Anaerobic Digestion. Since, 100% organic waste recovery through source separation is not yet possible, because even in Finland with more advanced waste management system only 45% of total organic fraction is recovered presently via source separation. While it may take Lagos State another 20 or more years, with the present slow implementation of waste management's policies and lack of clear waste management goal as presently obtainable in EU countries.

The remaining 55% of total organic waste, can be assume to be recovered through mechanical sorting system, in which 14.2% of pure of total organic fraction is recovered for Anaerobic Digestion (AD), and 14.2% of other rejects which also includes some small percentage of organic contents to be landfilled, as shown in Table 13, above. Therefore, the combined mass of 0.94Mt/a and 0.67Mt/a are sent to Anaerobic Digester.

Biogas Potential from Anaerobic digestion

Mass of Biowaste = 1.61Mt/a = 1,610,000t/a = 1,610,000,000kg/a
TS (% of FM) = 60% *(Kranert et al. 2010)*
VS (% of TS) = 65 *(Kranert et al. 2010)*
Biogas Potential = 0.4 m^3/kg VS) *(Kranert et al. 2010)*
Share of methane in biogas = 60% *(Kranert et al. 2010)*

Therefore, equation 6 below can be used to determine Lagos State's Biogas potential from biowaste and the corresponding values of TS total solid (dry mass), FM fresh mass, and VS volatile (organic mass), in table 14 below.

$$Methane\left(\frac{m^3}{a}\right) = Mass\ of\ Biowaste\left(\frac{kg}{a}\right) \times TS(\%) \times VS(\%\ of\ TS) \times Biogas\ potential \times Share\ of\ methane\ in\ biogas \qquad 6$$

Methane contains 10 kWh/m3 (36 MJ/m3) *(46 Forestry Commission 2013)*

Methane energy content (MJ/a) = Methane (m3) * 36 MJ/m^3

Table 14: Biogas yields and composition of selected substrates. (Kranert et al. 2010, ‘’Waste analyses of the laboratory of solid waste management. Institute of Sanitary Engineering, Water Quality, and Solid Waste Management, ‘‘Unpublished)

Substance	TS (%FM)	VS (%TS)	Biogas (m^3/kg VS)	Methane (% by Vol.)
MSW				
Bio-waste	30-65	45-70	0.15-0.6	58-65
Market waste	35-60	75-90	0.4-0.6	60-65
Grass	9-13	80-90	0.2-0.7	50-56

TS total solid (dry mass), FM fresh mass, VS volatile (organic mass)

6 RESULTS AND DISCUSSIONS

6.1 Result from Waste Characterisation

Waste composition results by percentages in pie chat, show in figure 6 below, include result from physical sampling, waste sorting and weighing, that where conducted at each of the four dump sites. The goal of the study waste to physically characterised 250 samples with sample size of 90 kg in total as earlier shown in table 4 above 286 wastes were sampled and hand-sorted at four dump sites, from wastes originating within Lagos state. Commercial (include industrial and institutional) waste and residential waste derived from the waste characterisation exercise are included, in the waste characterisation result shown on pie chat by percentages in figure 6 below.

Figure 6: Waste Characteristic Results, Showing total waste composition by percentage

As stated earlier, Lagos State generated 13,000 tonnes per day of MSW per day, which is equivalent to 4.75 megatons per year. In which Organic wastes are 2.02Mt/a, Papers are 0.63 Mt/a, Plastics are 1.09 Mt/a, Construction and Demolition wastes are 0.05 Mt/a, Metals are 0.08 Mt/a, Glasses are 0.08 Mt/a, Tires are 0.04 Mt/a, E-wastes are 0.05 Mt/a and Textiles are 0.56 Mt/a. The total waste results in scenario 1 are the corresponding values of waste characterisation results shown in table 15 below.

Table 15: The estimated waste composition in Megatons per year the actual collected mass amounts are unknown

Waste Composition	**Mt/a**
Paper	0.63
Beverage Containers	0.07
Plastics	1.09
Glasses	0.08
Metal	0.08
Organics	2.07
Construction and Demolition	0.05
Textiles	0.56
Tires	0.04
E-Waste	0.05
Inert Waste	0.04
Total	**4.75**

6.2 Results analysis

Table 16: Showing Results for The Three Scenarios

	Scenario 1		Scenario 2		Scenario 3	
	Mass [Mt/a]	Energy [TJ/a]	Mass [Mt/a]	Energy [TJ/a]	Mass [Mt/a]	Energy [TJ/a]
MSW to Landfill [Mt/a]	3.41	-	0.38		0.38	
Biogas from AD [MJ/a]		-		-	1.61	151
Mechanical treatment		N		Y		Y
Recyclables [Mt/a]	0.42	-	0.13		0.13	
Organic fraction (Composting) Mt/a		-	0.64			
RDF production [MJ/a]		-	2.29	4699	2.29	4699
TDF for Cement Kiln [MJ/a]	0.04	955	0.04	955	0.04	955

N; Yes, N; No

6.2.1 Recovered recyclables

Estimated values of recyclables. The actual collected mass amounts are unknown

In scenario 1, 4.75Mt/a of total waste generated in Lagos state, were sent to landfill, out of which the landfilled waste contains: 1.3 Mt/a metal, glass, plastic and tires. Some of these wastes are collected manually from landfill sites for recycle purposes (i.e metals, glasses, plastics, and e-waste). The landfilled wastes contain: 1.3 Mt/a metal, glass, plastic and tires. Most likely the scavengers are not able to collect 100% of metal, glass, plastic and tires.

Therefore, 0.42 Mt/a of recyclables with 12% (see figure 7) assumed handpicking rate, are collected and sent to the factories for recycle purposes, within 10 Km radius of Olushosun landfill. But in Scenario 2 and 3 lesser amounts of recyclables were recovered via mechanical sorting system, which are not very efficient because their assumed recovery rate was 90% for metals and 75% for glassed. Although plastics and E-waste which formed part of total recyclables (1.3Mt/a) in Scenario 1 are not recovered as materials but as energy in Scenario 2 and 3.

The E-waste, are also manually collected on the landfill, as shown in scenario 1(Baseline scenario). The collected electronics components are further manually separated, into resistors, capacitors, ICs etc. and are sold to Alaba International and Ladipo market in Lagos, by the collectors These markets are sources of cheap and used electronics components, for Nigerian electronics repairs centres and west African sub region.

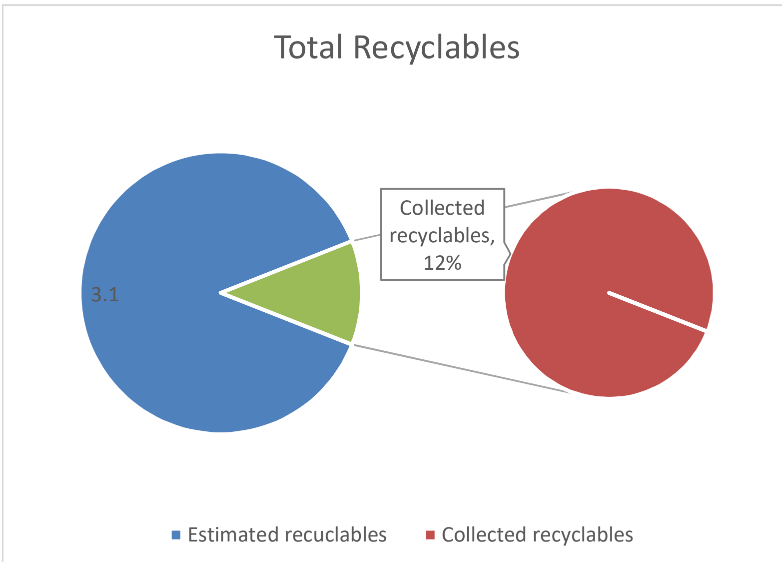

Figure 7: 12% collected out of total recyclables

6.2.2 Tire Derived Fuel (TDF)

Tire Derived Fuel (TDF) are also manually collected and sometimes source collected from the vulcanizing shops. The scraps tires are shredded into tire derive fuel (TDF) on the landfill site. Which are then taken to Lafard cement factory, as fuel in the cement Kiln. It is estimated that, 40% of fossil fuel, will be replaced by TDF in the kiln, to reduce cost of fuel, which in turn will reduce cost of operation, and a source of energy to the cement kiln.

Based on theoretical estimate 1 kg of tire can produce 6450 x 4.1868 kJ of heat (energy) with conversion efficiency of 76% (Ilshad, Navasivayam, et al. 2013), also this thesis result indicated also indicated that 0.04Mt/a of tires presented in the three scenarios can deliver $9.55\times10^{+08}$ MJ/a of energy in the kiln for each of the scenarios.

A 9kg passenger car tire, contained 1.13kg of high grade steel, which can replace in-part iron requirement of cements raw material. Tires also contained rubber, carbon-black and sulphur which are combustibles compound and ash will form part of cement components. (Nakajima, Matsuyuki et al. 1981) as hazardous waste treatment option. Since, tire contain no component that can reduce the quality of cement and as shown from, extensive experience from checking the quality of the product, there is no different in the quality of cement from using tires as fuel and no combustion residue, of either carbon-black or steel.

Tires are completely burnt at elevated temperature of the kiln; therefore, they do not cause black smoke or odour as commonly speculated. Even in normal operation, sulphur oxide and nitrogen oxide in the exhaust gas, present no problem to human health.

6.2.3 Biogas potential

Biogas, constitute a high value gas, that can be used to drive electricity generator. As seen in Table 15, 1.61 Mt/a of MSW, can produce 2.8 million m^3 to 4.4 million m^3, of collectable methane, enough to drive two gas engine capacity of 3060 – 4500 MW/a electrical output). Producing 151TJ per Year, corresponding to an average power demand of 2,500 – 20,000 EU households

6.2.4 Refuse Derived Fuel (RDF)

Mechanical sorting technology was introduced in Scenario 2 and 3, which produced 2.29Mt/a Refuse Derived Fuel (RDF) to drive electrical generator, as a waste management (waste to energy), option. Delivering electrical power of 4699TJ per year as seen in table 14, 27% efficiency is used which is based on the article titled 'Maximising Electrical Efficiency at Waste to Energy Plants', (Nord et al. 2011).

6.2.5 Composting for farming use

Scenario 2 produced 0.64Mt/a of biofertilizer from composting and in scenario 3, 0.27Mt/a of biofertilizer can also be realised from production of biogas from Anaerobic digestion of biodegradable wastes, as seen earlier in table 16. Composting offers a more environmentally friendly and a two-way win, firstly, as a waste treatment option and secondly, biofertilizer is produced for farmers as soil conditioner, instead of chemical fertilizer that has negative impacts on the environment.

6.2.6 Other wastes to landfill

Other wastes, such as Paper and Cardboard, C & D, Organics are left on the landfill site, which have negative impact on the environmental. Some of the waste will eventually rot, but not all especially plastics. The rotting waste causes bad odour and organic waste passes through anaerobic digestion and methane gas is released, which sometimes burn on an open landfill, usually noticed by passers-by and residence close to the landfills, plastics also burn as a result of burning methane gas, which also release carbon and other harmful chemicals into the environment and which has 20 times global warming potential than carbon.

Lagos has raining season between May and September, some years till November, during these period leachates are produced, as wastes decomposes, which can eventually cause pollution. Badly managed landfill sites can cause litter or attracts vermin but Lagos State, has good waste management system in comparison to the rest of the country. Although it still has lots to learn from the developed city across the world. A crucial point of note is that in scenario 1, 3.41Mt/a of the total waste, remain in the landfill, because of unsustainable waste management practice in Scenario 1 but only 0,38Mt/a of the total estimated MSW are landfilled in both Scenario 2 and 3.

7 CONCLUSION AND RECOMMENDATION

7.1 Conclusion

Based on the results obtained in section 6.2, the baseline scenario offers the least environmental friendly option in waste treatment practice, because 72% of the total generated waste is left on the landfill. Less than 5% of the total generated waste is recovered via energy and material recovery.

Scenario 3, offered the best practice, because 75 percent of it methane is converted to carbon dioxide (i.e. from 25CO2e to 1 CO2e). 0.31Mt/a, and 151TJ/a of Biogas produced through anaerobic digestion instead of landfilling as in Baseline scenario. Biogas is used to generate electricity, which might be generated using fossil fuel and fossil fuel contributes significantly to Greenhouse gases (GHG) effect. Therefore, scenario 3 offers environmental and social benefits to the populace.

Scenario 2, is also similar in material output to scenarios 3, but converted 1.61Mt/a of biowaste into 0.67Mt/a of biofertilizer for farming use, which would have been produced with chemicals such as nitrogen, phosphorus, and potassium in chemical fertilizer, which has negative impact on the environment.

7.2 Recommendation

Based on the conclusion in this thesis, Scenario 3 offered power potential of 151TJ/a of Biogas, 4699TJ/a of RDF and 955TJ/a of TDF and scenario 2 offered similar amount of Energy except it converted 1.61Mt/a of its bio-degradable waste into 0.64Mt/a of biofertilizer, instead biogas as seen in scenario 3. Although, scenario 3 could also produce huge amount of biofertilizer as digestion residue from anaerobic process but production of biofertilizer is not an objective for scenario 3 in this thesis. However, Lagos State did not have any large arable land for commercial farming, because of it smaller land size of 3,577 Km^2 according to Vita data (Lagos bureau of statistics), and population of 17,000.00 (world bank, 2014), therefore, the biofertilizer could be sold to Borno state, for farming. Finally, scenario 2 and 3 are recommended, to Lagos State government for implimentation.

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APPENDIX A: RESULT OF THE SURVEY FOR OLUSOSHUN LANDFILL

LAGOS WASTE MANAGEMENT AUTHORITY, LAWMA

LAGOS WASTE CHARATERISATION STUDY

QUESTIONNAIRE FOR DUMP SITE OPERATORS- OLUSHOSUN

DATE & TIME OF VISIT: 03/11/15, 2pm
NAME OF DUMP SITE: OLUSHOSUN
LOCATION OF DUMP SITE INCLUDING LGA OR LCDA: Ojota LGA
SIZE OF FACILITY: 47 Hectares
NAME OF SITE MANAGER: Mr. Adimoju Kabiru
NAME OF SUPERVISOR: -

SN	DESCRIPTION	RESPONSE(S)
1	What are the various origins of the waste coming to your site and how many are they on weekly basis?	
	* Residential/Domestic	yes
	* Industrial/commercial/institutional (ICI)	yes
	* Mixed	yes
2	What are the Categories of the municipal areas where waste came from?	
	*High Density Low Income	Ijora badia, otto, idi araba, makoko, agiliti, maian
	*Low Density High Income	Omole
	*Medium Density High Income	Ikeja GRA, Ogudu GRA
	* High Density Medium Income	ojota
	* Medium Density Low Income	Ebute metta, ikosi
	* Low Density Low Income	oyingbo
3	Categories and average quantities of waste received daily (See attached List)	All categories of waste listed in the Tables are received on site except demolition and construction waste. Average weight = 6000tons(420truck@aver. of 14tons)
4	Types of hauling vehicles used for collection and disposal of wastes (Please List)	1. Compactor truck 2. Double dino truck 3. Skip Truck 4. Trailer truck

SN	DESCRIPTION	RESPONSE(S)
5	Are there any other activities performed on the site (e.g. recycling and aluminium can collecting)?	yes
6	Do you receive waste from any nearby manufacturing centres? If so please list.	yes
7	What portion of the waste comes from out of state?	None
8	Do the municipal areas relevant to this centre practice curb side recycling?	yes
9	What hours of the day does your employees work?	Day and Night Shift
10	What time does the first truck come into the dump site?	6am
11	What are the best hours for us to conduct the sorts?	Between 9am -1pm
12	Do you have a machine that is able to mix and divide the waste?	No
13	How does the MSW vary seasonally and during holidays? Please give proportions or percentages.	High during dry season, Average during wet season
14	What portion of the waste originates from distant areas due to transfer trailers? Name the areas (e.g. TLS and the proportions that comes from them)	Lagos Island
15	List the types and estimated carriage capacity of each of the trucks that come to your site? (e.g. compactor trucks, side loaders, rear loaders, mini trucks, tippers, skip trucks and open back trucks	Compactor truck – 9tonnes Skip truck – 2.8tonnes Open back truck – 14tonnes Trailers – 30tons
16	How many trucks carrying Residential MSW arrive at the dump site daily from:	Average of 420 trucks
	* LAWMA Collection Trucks	40 trucks
	* PSP Collection Trucks	370 trucks
	* Others (Please List)	10trucks
17	How many trucks carrying Commercial/Industrial/Institutional Wastes arrive at the dump site daily from:	
	* LAWMA Collection Trucks	-
	* PSP Collection Trucks	-
	* Others (Please List)	-
18	List the names of PSP Operators that make use of your dump site and give the proportion of wastes dumped by them daily.	To be submitted by LAWMA
19	How do you unload your trucks?	Trucks tipping on platform and then push with a pay loader (mechanically)
20	Do you receive self-hauled garbage?	No
21	How many entrances (i.e. gates) are used by Commercial vehicles to enter the Dump Site	Two (Entrance and exit gate)
22	What are the peak times of arrival by Commercial waste trucks (if applicable)	-
23	Do you take construction and demolition waste?	No
24	What is the number of commercial waste vehicles that arrives at the dump site per day	-
25	Will the day of the week significantly affect the waste stream?	Yes
26	Do you conduct any material recovery practices?	Yes

SN	DESCRIPTION	RESPONSE(S)
27	Do you have a waste-to-energy facility?	On - going
28	How do you conduct your record-keeping?	Manually
29	Are you able to accommodate an area large enough for us to perform the sorts?	Yes
30	On some evenings we may need to wrap up samples for overnight storage, and we will also need to store the equipment we use for the following day. Can we safely store the items on the site?	Yes

APPENDIX B: SAMPLING PLAN

LAGOS WASTE CHARACTERISATION STUDY - REVISED NUMBERS AND ALLOCATION OF WASTE SAMPLES

EGORY	OLUSOSUN	Samples	SOLOUS	Samples	EPE	Samples	EWU-ELEPE	Samples	Total per Income Category
ow Income	Ijora Badia	1	Badagry	1	Jakande Estate	1	Majidun	1	
	Otto	1	Oto Awori	1			Odogunyan	1	
	Idi Araba	1	Iba	1			Ita Oluwo	1	
	Makoko	1					Ijede	1	
	Agiliti	1							
	Maidan	1							
mples		**6**		**3**		**1**		**4**	14
igh Income	Omole	1	Raji Rasaki Estate	1	Banana Island	1	Banana Island	1	
mples		**1**		**1**		**1**		**1**	4
y High Income	Ikeja GRA	1		1	Parkview	1	Parkview	1	
	Ogudu GRA	1		1		1		1	
mples		**2**		**2**		**2**		**2**	8
edium Income	Ebute Metta	1	FESTAC	1			Ibeshe	1	
	Ikosi	1	Satellite Town	1			TOS Benson Estate	1	
							Lowa Estate	1	
							TLS Trucks	1	
mples		**2**		**2**		**0**		**4**	8
y Low Income	Alimosho	1	Alimosho	1			Ikorodu Central	1	
mples		**1**		**1**		**0**		**1**	3
w Income	Oyingbo	1			Epe	1	Imota	1	
							Isiu	1	
							Agbede	1	
							Itamaga	1	
mples		**1**		**0**		**1**		**4**	6
p Site per day		**13**		**9**		**5**		**16**	43
Per Week (6 days)		78	0	54	0	30	0	96	258