UNIVERSITY OF OULU

FACULTY OF TECHNOLOGY

# Evaluation of improvement priorities for municipal solid waste management in Ogun State, Nigeria using experiences from Finland.

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# TIIVISTELMÄ OPINNÄYTETYÖSTÄ

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Työn nimi

**Jätehuollon edistymisen prioriteettien arviointi Ogunin osavaltiossa Nigeriassa Suomesta saatujen kokemusten pohjalta**

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Tiivistelmä


Suurimmassa osassa kehitysmaita jätehuolto on edelleen alkutekijöissä. Se koostuu yhdyskuntajätteen vähäisestä uudelleenkäytöstä, puutteellisesta keräyksestä, matalasta kierrätysasteesta, puutteellisesta jätteenkäsittelystä ja jätteen laajamittaisesta hävittämisestä ennen sen asianmukaista käsittelyä.

Yhdyskuntajätteen sisältö on muuttunut ajan myötä vaarallisemmaksi, jonka vuoksi sen asianmukaisesta keräämisestä, uusiokäytöstä, kierrättämisestä, käsittelystä ja hävittämisestä on tullut entistäkin tärkeämpää. Myös jatkuvasti kiihtyvän väestön kasvun myötä näiden maiden on tarpeellista kehittää sellainen jätehuollon rakenne, joka hyödyntää jätehuollon hierarkiaa, kestävän kehityksen periaatteita ja integroidun jätehuollon lähestymistapaa.

Tämä tutkimus arvioi yhdyskuntajätehuollon käytäntöjä Suomessa. Arviointi perustui lainsäädäntöihin ja käytäntöihin, jotka siivittivät tietä tämän päivän ihailtavaan jätehuollon järjestelmään Suomessa. Tutkimus huomioi myös ratkaisevia avaintekijöitä, kuten jätteen käsittelyn ja hyödyntämisen teknologian tason, jätteiden vastuualueet, maantäytön tekniset vaatimukset ja laajennetun tuottajavastuun (Extended producer responsibility, EPR), joka vaikuttaa tehokkaaseen jätehuoltoon Suomessa.

Tutkimuksen tavoitteena oli suunnitella alhaalta ylöspäin suuntaava jätehuollon kehys Ogunin osavaltiolle (Nigeria). Kehys voisi olla sovellettavissa myös muihin kehitysmaihin/kaupunkeihin, jotka ovat Ogunin osavaltion kanssa samassa lähtötilanteessa sekä taloudellisen, että teknologisen ja sosiaalisen kasvun näkökulmasta. Tutkimuksessa paljastui, että jätehuollon kehysten kehityssuunnitelmaa rakennettaessa tulisi pohtia myös sitä, kuinka saataisiin jätteiden keräilijät ja pk-yritykset tehokkaasti osaksi jätehuoltojärjestelmää. Ilman tuottajavastuuta kehitysmaiden jätehuollon kasvu ja kehitys olisi aikaa vievää. Elintasoa ja kansalaisten tietoutta ympäristönsuojelusta Nigeriassa tulisi parantaa, jotta voitaisiin varmistaa nopea ja tehokas jätteidenhuoltojärjestelmä.


Muita tietoja

# ABSTRACT
# FOR THESIS

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<table>
<tr><td colspan="2">Degree Programme (Master's Thesis)<br>Environmental Engineering</td><td colspan="2">Major Subject (Licentiate Thesis)</td></tr>
<tr><td colspan="2">Author<br>Oloko Kayode Adekunle</td><td colspan="2">Thesis Supervisor<br>Pongrácz, E., Prof., D.Sc.(Tech)</td></tr>
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Abstract

Municipal solid waste management (MSWM) is still at its starting phase in most developing countries. This phase constitutes of low municipal solid waste (MSW) re-use, inadequate collection, minor recycling, improper waste treatment and immense waste disposal prior to appropriate treatment. The contents of present MSW generated around the world has become more hazardous than in the past, making it necessary for proper collection, re-use, recycling, treatment and disposal. Also, as population growth continues to increase enormously in these countries, it has become necessary for them to develop a MSWM structure that utilizes the waste management hierarchy, the sustainable development principles and the integrated solid waste management approach.

This study evaluated MSWM practices in Finland. The evaluation was structured around the legislations and practices that paved way to the present day admirable MSWM system in the country. The study also considered key performance indicators such as waste treatment and recovery technology level, actors/responsibilities of waste, the technical requirements of landfills and the Extended producer responsibility (EPR) that influences the effective waste management in Finland.

The goal of this research was to plan a MSWM framework that applies the bottom-up approach for Ogun state (Nigeria). Nevertheless, the framework could be applicable to other developing cities/countries that are in the same situation as Ogun State as they witness economic, technological and social growth. The study revealed that any MSWM framework development plan for developing countries should consider how to effectively merge scavengers and SME's into the MSWM system. The growth and development of MSWM system for developing countries would be time consuming without an EPR scheme. The standard of living and the citizens awareness to environmental protection in Nigeria needs to be improved in order to ensure a speedy and effective MSWM system.


Additional Information

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# LIST OF ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| AD | Anaerobic digestion |
| ADBG | African development bank group |
| APC | Air pollution control |
| AVI | Regional State Administrative Agencies (Finland) |
| BAT | Best available technology |
| Cr(VI) | hexavalent chromium |
| $CH_4$ | methane |
| C:N:P:S | Carbon:nitrogen:phosphorus:sulphur |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| COS | Carbonyl sulfide |
| C/N ratio | Carbon-to-nitrogen ratio |
| C&D | Construction and demolition waste |
| EEE | Electrical and electronic equipment |
| EC | European Commission |
| EFTA | European Free Trade Association |
| ELV | End-of-life vehicle |
| EPR | Extended producer responsibility |
| EU | European Union |
| FEPA | Federal Environmental Protection Agency (Nigeria) |
| GDP | Gross domestic product |
| GHE | Greenhouse effect |
| Gw | Gigawatts |
| $H_2O$ | Water |
| $H_2S$ | Hydrogen sulfide |
| HCL | hydrogen chloride |
| HCN | Hydrogen cyanide |
| LAWMA | Lagos Waste Management Authority (Lagos State, Nigeria) |
| LFG | Landfill gas |
| LFGTE | Landfill gas to energy |
| MSW | Municipal solid waste |

| | |
|---|---|
| MSWM | Municipal solid waste management |
| NESREA | National Environmental Standards and Regulation Enforcement Agency (Nigeria) |
| NGO | Non-governmental organization |
| $N_2O$ | Nitrous oxide |
| $NO_x$ | Nitrogen oxide |
| $NO_2$ | Nitrogen peroxide |
| NH3 | Ammonia |
| OECD | Organization for Economic Cooperation and Development |
| PCDD/F | Polychlorinated debenzo-p-dioxins and dibenzofurans |
| POPs | Persistent organic pollutants |
| PPP | Polluter pays principle |
| PRO | Producers responsibility organization |
| RDF | Refuse derive fuel |
| SME's | Small and medium-sized enterprises |
| $SO_2$ | Sulfur dioxide |
| Sox | Sulfur oxides |
| USAID | United States Agency for International Development |
| UNDP | United Nations Development Programme |
| VAT | Value added tax |
| WFD | Waste Framework Directive |
| WEEE | Waste electrical and electronic equipment |
| 3Rs | Reduce, Re-use and Recycle |

# CONTENTS

# 1 INTRODUCTION

Waste in its solid, liquid or gaseous state could play a significant role in the deterioration of the environment if not properly managed. A large portion of the many environmental problems around the world can be narrowed down to inefficient waste management. Developed countries are steadily finding solutions to many of these problems. In some cases, they even have alternative solutions to choose from in addressing one issue. The same may not be said about developing countries? Most developing countries are growing tremendously in economy, technological advancement and population. This growth inevitably results in an increased waste generation.

When developed countries started their industrialization in the 1800s, they were not aware of the magnitude of the environmental problems they would eventually have to tackle. Therefore, they built systems did not take this issue into account. Developing countries have now the option of continuing their development on a much cleaner basis than developed countries originally did. The problem lies in the fact that this cost more, and the concern is whether taking the environment into consideration would slow economic growth down. Developing countries need to have the political will and support from the developed world to base their growth on clean systems from these earlier stages of development?

Waste is any object or substance which the holder disposes of, intends to dispose or is legally required to dispose. Waste management is considered to be the collection, transportation, effective usage and treatment of waste including the inspection of these operations and the aftercare of treatment sites (Directive 2008/98/EC).

Municipal solid waste (MSW) means all refuse waste fractions from households, in addition to similar waste fractions that are disposed from industries, commercial establishments, construction and any other sector within the municipal system. The collection of these wastes is done by or on behalf of municipal authorities and are disposed using waste management systems (European Statistics 2016). The definition of MSW varies from country to country and this results in variety in their waste composition. Important to state is that most definitions of MSW used in different countries do not include industrial waste, commercial waste, sewage waste, agricultural waste or medical waste, except if their composition is similar to household waste.

The amount of MSW generated annually is often lower than the amount of waste generated in other waste economic sectors. However, the focus on municipal solid waste management (MSWM) is necessary because of its diverse composition, distribution relationship among other sources of waste, and its unique link to consumption or consumer patterns (Blumenthal 2011).

**Note:**

- Municipal waste is the same as "Municipal solid waste" in this work.
- This work excludes industrial waste/pollution that can't be referred to as MSW.

This master's thesis considers the MSWM process overview and describes the fundamentals of MSWM practices in the EU. Further, waste management legislation are reviewed and the future targets they set as basis for better effective practices. MSWM options assessment are also considered in Chapter 2 while waste recovery options are studied in Chapter 4 which will provide a basis for selecting the best option applicable for different MSW sector.

# 2 WASTE MANAGEMENT LEGISLATION IN THE EUROPEAN UNION

The EU and national targets are the main drivers for better waste management practices in the EU (Fischer *et al.* 2013). The main tool in reaching these targets has been through the introduction and development of environmental legislation. The legislation further acted as blueprint that demonstrates to citizens and government officials on how to sustainably address wastes and waste management.

According to the European Environment Agency (2015), the most crucial targets regarding MSWM in the EU are;

- The biodegradable waste targets aimed to reduce the production of methane ($CH_4$) gas caused by the disposition of biodegradable wastes to landfill (Directive 1999/31/EC).
- The recycling target for packaging and packaging waste (Directive 94/62/EC) as a means to reduce packaging waste quantity; and
- The recycling target concerning household and other similar waste in the waste framework directive (WFD). This target is aimed at minimizing the adverse consequences of waste generation and creating a European recycling society (Directive 2008/98/EC).

The most significant waste legislation in the EU is the WFD has it provides the basic concepts of waste and waste management (European Union 2010). To achieve the goal of this work, it is of great importance to explain the influential waste related EU legislations that have resulted in an efficient MSWM practice in the EU. Some of these legislations exist as framework directives, some as treatment methods directives and some are targeted to some specific waste streams (Figure 1).

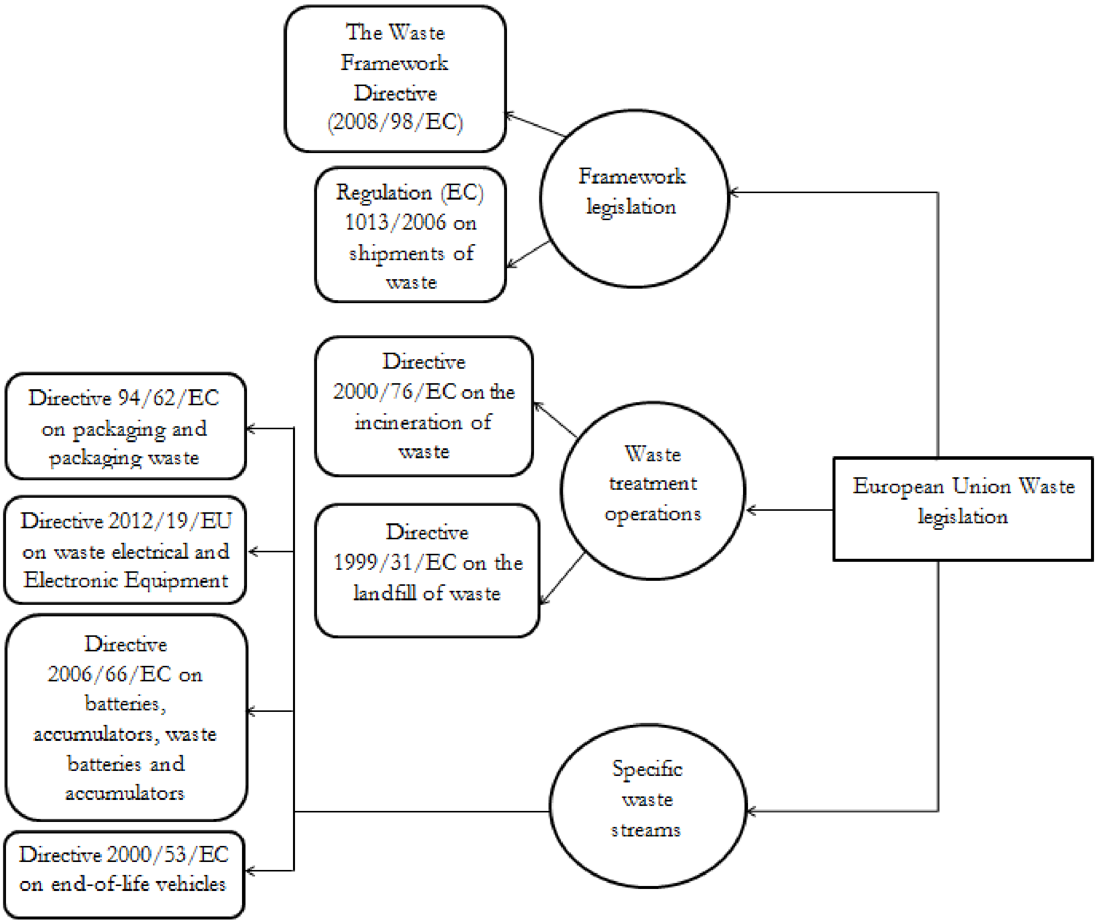



Figure 1. Prominent European Union waste legislations related to municipal solid waste management (Modified from European Commission 2005).

One of the most important principles behind efficient MSWM practice among EU member states is the upholding waste legislation that exists to address specific issues. The structure in the Figure above as we can see is quite diverse but with precise aims and parameters. The two framework legislation addresses the definition and characteristics of waste and MSW and also the transportation of waste and MSW across international borders. The two waste treatment operations legislation on the other hand, concentrate mainly on the principles of waste and MSW treatment while the third section conveys laws tackling specific waste and MSW contents.

## 2.1 European Union Waste Framework legislation

The protection of the environment from the adverse effects of improper waste management led to the creation of the WFD and the waste shipment regulation. The first version of these two pieces of legislation was adopted in 1975, but the new versions are explained in details below. The WFD, waste shipment regulation and the hazardous waste directive (the hazardous waste directive is excluded from this thesis work) provide the regulatory structure of MSW and for waste in general (European Commission 2005).

### 2.1.1 The waste framework directive 2008/98/EC

The directive introduces and defines the elementary concepts and terms that are related to waste and waste management. It introduces the polluter pays principle (PPP) which mandates the responsibility of waste on the waste producer; the present or previous waste holder. It also introduces the extended producer responsibility (EPR) to compel manufacturers to produce more environmentally friendly products. The WFD also explains the waste management hierarchy in a prioritized order to be followed by the Member States. The hierarchy shall be implemented by considering the options that yield the most environmental friendly outcome; nevertheless, it places utmost importance on waste prevention (Directive 2008/98/EC). Figure 2 presents the summarization of the WFD. In the next few paragraphs, this work will briefly introduce each of the three components of the WFD.

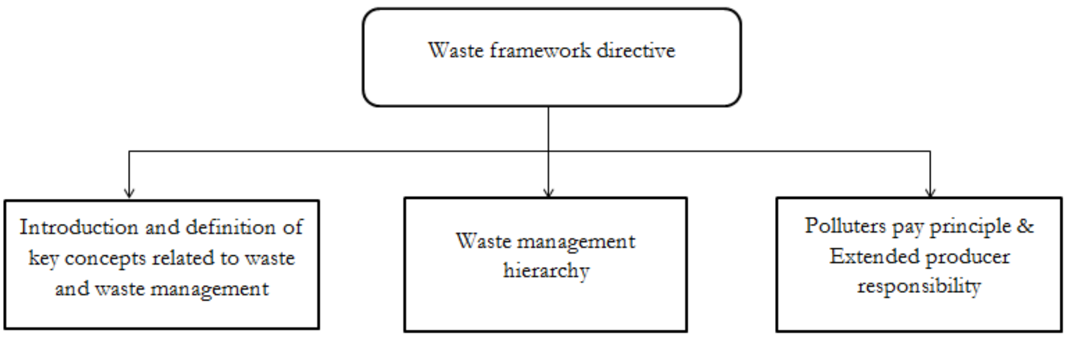



Figure 2. A schematic representation of the waste framework directive (Directive 2008/98/EC).

The directive sets some ambitious targets for 2020 concerning re-use, recycling and material recovery. A 50% preparation of re-use and recycling of some generated household waste; and a preparation of 70% re-use, recycle and recovery (material) of non-hazardous construction and demolition (C&D) waste. It nevertheless mandates the formulation of waste prevention programmes for individual member states by 12th of December 2013 (Directive 2008/98/EC).

**Key concepts related to waste and waste management in the WFD**

Major waste and waste management key concepts were introduced and defined clearly in the WFD to clarify their scope. Some of the keywords and concepts include waste, recovery, prevention and re-use (Directive 2008/98/EC). Table 1 provides an overview of relevant contents introduced in the WFD.

Table 1. Main contents of the waste framework directive (Directive 2008/98/EC).

| Article number | Article Details and coverage |
|---|---|
| Article 3 | Defines the key words and concepts related to waste and waste management (definition of the terms such as waste, bio-waste, prevention, re-use, recovery, preparing for re-use, recycling, disposal etc.). |
| Article 4 | Introduces the waste management hierarchy in a prioritized order. |
| Article 8 | Provides European Member States with the general requirement needed to address issues/products related to extended producer responsibility. Such as, Member States may consider legislative or non-legislative measures to ensure that any persons (natural or legal) who professionally develops, produces, processes, handles, sells or imports products has extended producer responsibility. |
| Article 14 | Mandates the cost of waste management on the original waste producer or by the current or previous waste holders. |
| Article 15 | Provides information about the actors of waste management responsibilities. |
| Article 28 and 29 | Mandates the establishment of waste prevention programs and waste management plans. |

**Waste management hierarchy**

The hierarchy is considered while planning waste related legislations and policies by the EU and its member states. It is the foundation of any efficient waste management practice as it lays down in prioritized order the best practices towards the protection of human lives and the environment. If necessary, Policies and legislations can however ignore to utilize the structure of the waste hierarchy on some certain conditions; technical feasibility; economic viability and environmental protection (Directive 2008/98/EC).

However, there are some limitations attached to the adoption of the waste management hierarchy. The hierarchy seems to lack scientific reason, for example, what is the scientific basis that materials recycling should always be a preferred option to energy recovery. Also, the hierarchy has been set up without considering costs hence the economic affordability is unpredictable (McDougall *et al.* 2008). Figure 3 presents the hierarchy principles: waste prevention; preparing for re-use; recycling; recovery and disposal (Directive 2008/98/EC).

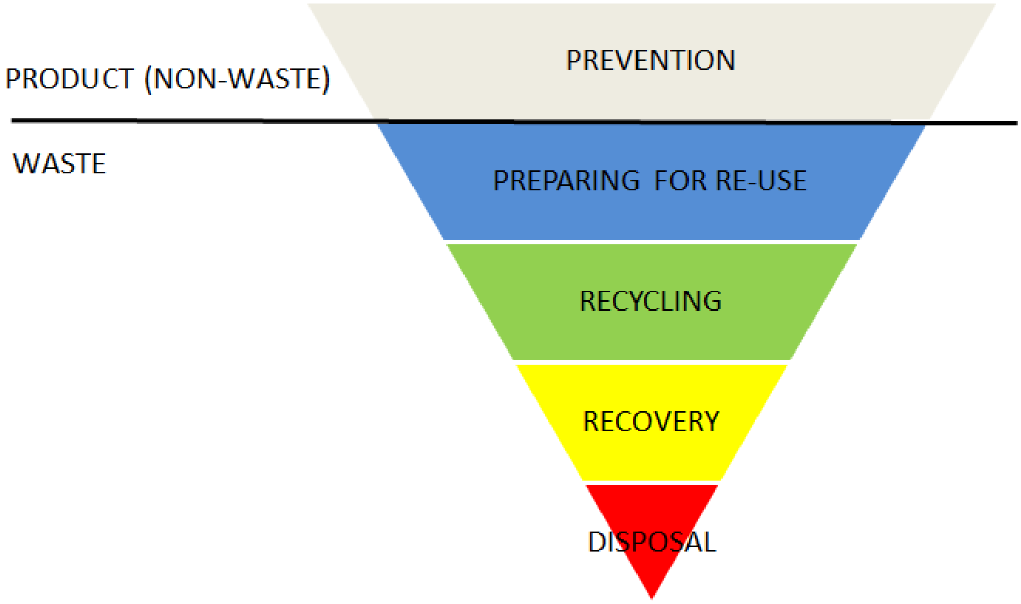



Figure 3. Waste management hierarchy (Directive 2008/98/EC, Wilts *et al.* 2015).

**<u>Waste prevention</u>**

According to the WFD (Directive 2008/98/EC), "Waste prevention means measures taken before a substance, material or product has become waste, that reduces;

- the volume of waste. The avoidance is done by ensuring re-use of goods or by extending the life span of products;
- the adverse impacts of the generated waste on the environment and human health or;
- the content of harmful substances in materials and products."

Waste prevention is at the top of the hierarchy which makes it the most desirable option of waste management. The logical concept of waste prevention is that one does not address what does not exist. Waste prevention does not only limit the existence of waste and the protection of the environment. It is also very economical for manufacturing companies to practice has it yields them more profit. Product re-use is often considered as a form of waste prevention as it results in the reduction in the quantity of waste generated (Laner & Rechberger 2009).

If waste prevention is globally implemented and effectively monitored – which is a highly difficult task – it could play an important role in the reduction of emissions and climate change mitigation (Gentil *et al.* 2011). Proper implementation of waste prevention measures should be structured around accurate planning. The plan should contain a clear analysis of potential impact and barriers. It is also very vital to specify the targets and measures to be taken for precise waste streams to enhance successful implementation (Salhofer *et al.* 2008).

There is a firm link between the purchasing power of the consumer and waste prevention activities. Consumers with a high environmental awareness could make good use of their purchasing power to protect the environment by ignoring to buy in excess or choose to buy only environmentally friendly products. Their actions often prompt producers to rethink the their product design, the amount and types of raw materials used, life cycle assessment and product service life (Cooper 2005, McKerlie *et al.* 2006). This means that developing countries could address waste prevention sooner than expected once the citizens become more environmentally aware.

**Preparing for Re-use**

It is considered as the second most preferred option in the waste management hierarchy. The WFD defines preparing for re-use as an operation that checks, cleans and repairs wastes products or materials for re-use (Directive 2008/98/EC).

**Recycling**

Recycling is any operation that involves the reprocess of waste materials into products, materials or substances to be used for their initial used or other purposes. Most often, Recycling includes the change in the physicochemical properties of the products, materials or substances (Directive 2008/98/EC). The benefits of recycling cannot be overemphasized; Diversion of enormous amounts of waste away from landfill, employment generation, employment growth, reduces the need to extract new raw materials which simultaneously secures the availability of critical resources and the reduction of emissions (European Environment Agency 2013). Therefore it is desirable to recycle rather than incinerate without energy recovery.

In the work done by Oliveira & Rosa (2003), they attribute recycling success of MSW to the immediate post-collection garbage separation. This technique is one of the selective garbage collection schemes developed to boost recycling. Troschinetz & Mihelcic (2009) lists some factors that influence the recycling of MSW in developing countries. The principal factors include stakeholders, government policies and finances, household education and revenue, technological and human resources, waste collection and segregation method, MSWM personnel education, MSWM administration and plan, local recycled-material market, land availability and waste characterization.

Developed countries have been highly successful in recycling because they nurture a mature database. This has enhanced the growth of recycling research which has positively influenced industrialized recycling activities. Researches have focused on technical applications and socioeconomic factors that correlate with recycling (Kishino *et al.* 1999; Troschinetz & Mihelcic 2009).

**Recovery**

Recovery is an operation in which waste serves a useful purpose by replacing other materials to fulfill a particular function (Directive 2008/98/EC). Energy recovery has significantly helped to reduce the greenhouse effect (GHE) from waste landfilling (Lombardi *et al.* 2006). One of the advantages of waste energy recovery plants is that they are specifically designed to safely and effectively dispose of municipal waste (Miranda & Hale 1997).

Monte *et al.* (2009) explained in their work that incineration with energy recovery is fast becoming the main waste recovery method. The future of energy recovery in the EU is bright; production of energy from MSW has doubled since 1995. Bio-waste amounts to about one-third (88 million tonnes) of household waste derived across Europe on a yearly basis. With this amount, energy recovered as biogas or thermal energy could play a significant role in meeting the EU 2020 target on renewables (European Union 2010). However, Oliveira *et al.* (2003) points out that energy recovery through incineration could be too costly for some developing countries to practice. The problems related to energy recovery are the environmental and health damage caused by the release of hazardous chemicals. However, they are being controlled by different environmental limits (European Union 2010).

**Disposal**

It is regarded as the least option of the waste management hierarchy. Disposal is "any operation which is not recovery even where the operation has as a secondary consequence the reclamation of substances or energy" (Directive 2008/98/EC).

One of the numerous adverse effects of disposing, is that disposal sites houses $CH_4$ and carbon dioxide ($CO_2$) emissions which occur due to the breakdown of biodegradable carbon (C) compounds operated on by anaerobic bacteria (Lombardi *et al.* 2006). Landfilling in the EU fluctuates with policy effects providing a strong driver (Mazzanti & Zoboli 2008).

**Extended producer responsibility (EPR) in waste management**

The Organization for Economic Cooperation and Development (OECD 2001) defines EPR to be "an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a products life cycle". The main goals of an EPR should be: waste prevention and reduction, efficient product re-use and recyclability, reduced consumption of national resources during the production of products and internalization of environmental costs into product prices (Langrova 2002). The implementation of an EPR should involve both the upstream and downstream stages of a products lifecycle (Thorpe *et al.* 2004). Mandatory and voluntary products subjected to the extended producer responsibility in the EU are highlighted in Table 2 below.

Table 2. Mandatory and voluntary products subjected to the Extended producer responsibility in the European Union (European Commission 2012, Ympäristöministeriö 2013d).

| Mandatory Extended producer responsibility products among European Union Member States | Voluntary Extended producer responsibility products among European Union Member States |
|---|---|
| Waste electrical and electronic equipment | Farm practices |
| Batteries and accumulators | Medicines and medical waste |
| End of life vehicles | Plastic bags |
| Tires | Photo-chemicals and chemicals |
| Waste oil | Newspapers |
| Paper and card | Refrigerants |
| Packaging waste | Pesticides and herbicides |
| | Lamps, light bulbs and fittings |

Kojima *et al.* (2009) explain that apart from placing the management and collection responsibilities of some used or outdated products on producers, this approach has also played a significant role in promoting the reduce, re-use and recycle (3Rs) concepts in developed countries. Packaging waste, WEEE and End-of-life Vehicles (ELV) are examples of waste subjected to EPR. Also, Krikke *et al.* (2003) (as cited by Nnorom and Osibanjo, 2008) explains that EPR legislations consider supply chain players such as importers and retailers to be responsible for end-of-life items.

EPR practices have worked out well among the EU member states, especially in situations where other environmental policy measures are active (McKerlie *et al.* 2006). On the other hand, Nnorom & Osibanjo (2008) claim that developing countries have multiple challenges in the management of products subject to EPR; WEEE. Problems such as; lack of state-of-the-art recycling and waste disposal facilities. Besides, the research work done by Kojima *et al.* (2009) divulged that identification of producers, imitation and smuggling are also problems associated to developing countries and the implementation EPR for recycling systems. The high increment in the amount of internally generated WEEE and trans-boundary movement of e-waste into developing countries makes the implementation of EPR in these countries an overdue process (Nnorom & Osibanjo 2008).

McKerlie *et al. (*2006) established ten recommendations for *Advancing Extended Producer Responsibilities in Canada*. Six of these recommendations can be applied as a framework to develop an effective EPR practice or legislation for developing countries as they are solutions to some problems faced by some developed countries:

- Mandate the full responsibility of products (throughout its entire life cycle) to producers. This involves the collection, recycling, disposal, the cost of operating the producer responsibility organization (PRO) and the consumer education.
- Clearly state/define the purpose of the legislation. The EPR is mostly understood to be just the return and acceptance of end-of-life products. However, the main goal of the EPR which is to strengthen sustainable product design, reduction of material usage and increased recycling is often neglected.
- Ensure efficient competition in the producer responsibility organization (PRO) sector by avoiding monopolies. For example, Germany has at least five producer responsibility organizations handling the E-waste of the country as at 2005.

- Provide and encourage the avenue for industries to create individual EPR systems that suit their activities.
- Ensure that collection facilities are easy to locate and in the option of being in distant or remote places, residential pickup services or other convenient systems should be adopted.
- Ensure flexible communication exists among shareholders and government parastatals to facilitate coordination and cooperation needed to implement legislation, activities and workshops.

A sustainable environment advocacy group "Zero Waste Europe" explains that about 70% of MSW in Europe are product wastes, of which EPR schemes cover ca 45% of these product wastes. However, only 18% are collected using these schemes. The report concludes that the present EPR schemes are insufficient in the quest to actualize a circular economy or zero-waste in the EU. Hence, they emphasize the need to revise the present day EPR approach. They also explained that the EPR schemes have majorly focused on the downstream stage of waste management of products by the development of collection strategies and technologies that enhance waste sorting and recycling. The way forward suggested is to extend the producer responsibility to all the phases of a product's life-cycle. They believe this approach would increase the applicability to 3R's on products, reduce the toxic and hazardous substances used on products and achieve the main target of Zero Waste that everything produced can be re-used, recycled or composted (Zero Waste Europe 2015).

### 2.1.2 Regulation 1013/2006 on shipments of waste

The regulation addresses and regulates the movement (import, export or transit) of waste among the countries of the EU, Non-EU, European Free Trade Association (EFTA) and the Organization for Economic Cooperation and Development (OECD) that have signed the Basel Convention. This restriction positively influences the illegal trafficking of waste to developing countries. Member states are authorized to determine the penalties for trafficking (Regulation 1013/2006). This regulation has been revised in 2014 placing more attention on the inspection system of member states due to complain about massive illegal WEEE dumping to developing countries (Regulation 1013/2006). The Regulation 660/2014 mandates member state to make available comprehensive inspection plans on shipments of waste by 1st of January 2017 (Regulation 660/2014).

## 2.2 Directives on waste treatment operations

These directives were aimed at addressing environmental emission parameters that were neglected by the WFD. They offered limit parameters for the incineration of waste and the landfilling of waste. The decision was made as health and environmental problems aroused from the pollution of incineration of waste and landfilling (European Commission 2005).

### 2.2.1 Directive 2000/76/EC on the incineration of waste

The directive aims to limit emissions caused by activities of waste incineration and co-incineration plants. However, the directive exempts some plants that treat for example some agricultural wastes, cork waste and radioactive waste. It sets certain emission limit values (legally binding) on some persistent organic pollutants (POPs) such as dioxins and furans during the treatment of MSW. A legal binding limit value for the emission of mercury (Hg) of 0.08 mg/m3 was set for municipal waste incineration. The Directive also relates to Council Directive 1999/30/EC to place limit values on sulphur dioxide ($SO_2$), nitrogen peroxide ($NO_2$) and nitrous oxide ($N_2O$), particulate matter and lead (Pb) in ambient air (Directive 2000/76/EC).

### 2.2.2 Directive 1999/31/EC on the landfill of waste

The main aim of the directive is to prevent or reduce adverse effects that could be caused by landfilling of waste on the environment. The directive also introduces landfill related terms alongside their definitions (e.g. eluate and leachate), it provides standard procedures before waste materials/products can be landfilled (Directive 1999/31/EC). The directive classifies landfills based on their presumed waste intake properties;

- landfill for hazardous waste intake;
- landfill for nonhazardous waste intake and
- landfill for inert waste intake.

The directive restricts the disposal of some specific waste substances (e.g. liquid waste, used tires and flammable waste). It also provides stringent operational and essential technical requirements for landfills to be followed by member states. On the 2nd of July 2014, a legislative proposal was adopted with the main aim of eradicating landfilling of recyclable waste (e.g plastics, paper and metals) in non-hazardous waste landfills by 2025 (Directive 1999/31/EC).

## 2.3 Directives on specific waste streams

These directives were set up to improve specific waste streams that resulted in a high environmental impact if not properly handled. Most of them proved to be difficult to be re-used or recycled and since there were large volumes of their waste contents there was a need to provide precise legislation with specific limits and future targets (European Commission 2005).

### 2.3.1 Directive on 94/62/EC packaging and packaging waste

This Directive aims at increasing the re-use of packaging, recycling and recovery of packaging wastes. It emphasizes on some targets to be reached in order to enhance recycling and recovery once the directive is fully adopted by member states; recovering between 50-65% weight of packaging waste within 5 years; recycling of packaging materials contained in packaging waste by 25-45% with a minimum of 15 % weight for each packaging material. "The concept of extended producer responsibility is mentioned in Art 4 (1) second indent as a "may be introduced" soft law requirement" (Directive 94/62/EC). Monier *et al.* (2014) explain that there is a continuous progress from EU member states in to achieve the set targets; on re-use, recycling and recovery targets. However, there are still uncertainties caused by incomplete and unreliable data from member states.

This directive has been revised four times, with the latest on the 29th of April, 2015 in regards to the concern of lightweight plastic carrier bags consumption. The most important goals introduced by the new amendment are for member states to include more measures to tackle the problem. Either or both measures should: ensure that individual consumption per annum does not surpass 90 lightweight plastic carrier bags by 31st of December 2019 and 40 lightweight plastic carrier bags by 31st of December 2025; ensure that by 31st of December 2018, lightweight plastic carrier bags are not provided free of charge during the sale of goods or products (Directive 94/62/EC). However, very lightweight plastic carrier bags are exempted from both targets (Directive 2015/720/EU).

### 2.3.2 Directive 2012/19/EU on waste electrical and electronic equipment

This directive is a recast of Directive 2002/96/EC that entered into force on the 23rd of February 2003 with the aim to prevent, re-use, recycle and recover WEEE while also introducing the EPR on electrical and electronic equipment (EEE) products. A need for an amendment arouse when the EU noticed the fast and continuous increment in the WEEE stream (European Union 2016).

The recast Directive 2012/19/EU entered into force on the 24th of July 2012 with the main aim of achieving a collection rate of 45% of the average weight of EEE placed on the market in three preceding years. This is a target that should be met by 2016 with an intention to increase the re-use and recycling of WEEE. This Directive is relevant to be mentioned considering the separate collection mandated on WEEE.

### 2.3.3 Directive 2006/66/EC on batteries, accumulators, waste batteries and accumulators

This Directive replaces Directive 91/157/EEC as the former fails to address efficiently the risks posed by waste batteries and lacks the provision of an adequate system for waste batteries collection and recycling. Directive 2006/66/EC has also been amended three times; twice in 2008 in relation to implementing powers bestowed on the European Commission (EC) and the placing of batteries and accumulators on the market; in 2013 to restrict the use of cadmium (Cd) and Hg on some specific products (European Commission 2014).

Directive 2006/66/EC restricts the improper discarding of waste batteries and accumulators to minimize pollution towards the environment by promoting effective collection and recycling (life cycle thinking). It prohibits the sales of specific batteries and accumulators containing Hg and/or Cd and sets some collection targets for member states (Directive 2006/66/EC). European Commission (2014) concludes that the initial objective of this directive has been achieved; high collection rates of wastes and increased consumer awareness but narrates that the 45% collection rate target by 2016 on all member states might not be achievable.

### 2.3.4 Directive 2000/53/EC on End-of-life Vehicles

The Directive sets some targets in order to enhance the re-use and recycling of ELV. It proposes that new vehicle manufacturers must ensure that; a minimum of 85% by weight per vehicle should be reusable and/or recyclable by 1st of January 1 2006; a minimum of 95% by weight per vehicle should be reusable and/or recyclable by 1st of January 2015 (Directive 2000/53/EC).

The directive slightly restricts the use of Pb, Hg, Cd or hexavalent chromium (Cr(VI) or $Cr^{6+}$) when assembling vehicle components. It also directs member states to ensure that final holders of ELV can dispose them at authorized treatment facilities, without charging fees (Directive 2000/53/EC). As at 2014, Finland, Netherlands and some other few countries have met the targets set by the ELV directive (Monier *et al.* 2014).

# 3 MUNICIPAL SOLID WASTE MANAGEMENT IN FINLAND

The annual volume of MSW generated in Finland has experienced mainly a rise in the last two decades. The management of MSW on the other hand has continuously improved within this same time period, especially in the area of energy recovery and composting but more attention still needs to be placed on MSW prevention techniques.

## 3.1 Main driver of municipal solid waste management development in Finland

The concept of the Finnish waste policy and legislation are structured around the EU waste management hierarchy. The Finnish waste legislation addresses almost all types of waste and in some cases they include sticker standards and limits than those presented by the EU (Ympäristöministeriö 2013a). The first waste act in Finland came into effect in 1979 mandating municipalities to oversee the management (administration, enforcement and financing) of local waste issues. The new waste law came into effect in 2012. The major contributions are the introduction of a well detailed definition of waste related terms and the full subjection of some group of products to EPR system (Piippo 2012).

The European and National MSW targets are responsible for the MSWM development in Finland (Sokka *et al.* 2007). This explains the positive effects legislations and targets have on MSWM, hence, making it a necessity for developing countries to adopt the idea of developing legislations and setting achievable targets. The first National Waste plan of Finland covered 1998-2005. The latest National plan *"Towards a recycling society"* was approved in April 2008 and is active till 2016 (Fischer 2013). The major aims of this latest National Waste Plan in Finland are highlighted in the Table 3 below.

Table 3. Key objectives of the National waste plan in Finland (Ministry of Environment in Finland 2009).

| Category | Aims |
|---|---|
| Annual target | Municipal solid waste volume between 2.3-2.5 million tonnes. |
| Future targets | |
| Volume | Municipal solid waste volume lesser than 2.3 million tonnes by 2016. |
| Recycling | 30% of total municipal solid waste volume should be recycled by 2016. |
| Energy recovery | 30% of total municipal solid waste volume should be energy recovered by 2016. |
| Composting | 20% of total municipal solid waste volume should be composted by 2016. |

## 3.2 Municipal solid waste generation in Finland

MSW in Finland increased tremendously in 2002-2008. 2009 and 2010 are only the years the country has been able to meet up with the annual range of 2.3-2.5 million tonnes within the last six years. At the moment, it looks unmanageable to meet up with 2016 target of not generating more than 2.3 million tonnes of waste (European Statistics 2016). There has been a short period of reduction in waste amounts during 2012-2014. However; it is too short a time to make a conclusion of a declining waste generation tendency, even though a similar decline was experienced in 2009-2010. We also can't conclude that these reductions were prompted by waste prevention initiatives or other causes. It is worth to mention that Finland experienced two economic recessions in 2007-2008 and 2012-2013 (Kaitila 2015).

According to the MSW generation increment experienced in 2006-2008, 2011-2012 and the MSW amount of 2014 (2.6 million tonnes), Finland is far from achieving its MSW generation target for 2016 - not generating more than 2.3 million tonnes by 2016 (European Statistics 2016). It is also too short a time to make such claims but these are the periods consumers had the financial freedom to determine whether to buy more or less by considering personal consumer want and need. This confirms that there is likely to be a link between MSW generation and financial stability. It seems that without the recession, the efforts to reduce MSW generation have not been very successful. Therefore, considering the waste management hierarchy which prioritizes waste prevention, the annual targets set through the Finnish National waste plan (keeping MSW generation range between 2.3-2.5 million tonnes) and the 2016 target, this work would not adopt the MSW prevention initiatives practiced in Finland. Figure 4 illustrates the annual MSW generation from 2002-2014. The data for 2015 is not yet available.

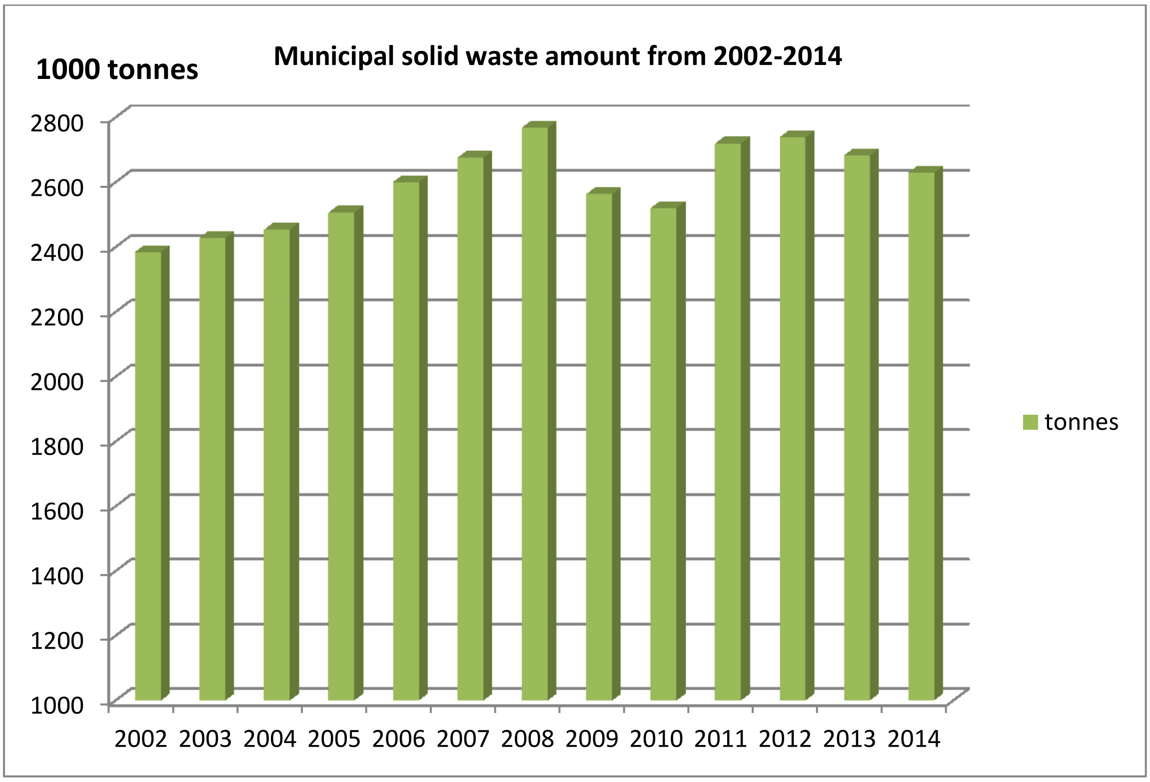



Figure 4. Annual municipal solid waste amount from 2002-2014 (European Statistics 2016, Piippo 2012, Ympäristöministeriö 2014).

**<u>Composition and sources of MSWM in Finland</u>**

According to Official Statistics of Finland (2015), the largest composition of MSW is the energy waste which is also regarded as the unsorted mixed waste while the lowest composition is the glass waste. In cases where there is no separate landfill waste container, the landfill waste and energy waste are collected in the same container. Therefore, waste collected as landfill waste would be suitable for energy waste (City of Pori Environmental Agency 2015). Examples of waste regarded as energy waste and landfill waste in Finland are listed in Table 4.

Table 4. List of waste addressed as energy waste and landfill waste in Finland (City of Pori Environmental Agency 2015).

| Types of energy waste | Types of landfill waste |
|---|---|
| Packaging plastics, plastic bags, cans, pots and bottles | Shoes, leather and atificial leather and rubber, vaccum cleaner dust bags |
| All plastic packages used to preserve food items | Incandescent lamps |
| Styrofoam | Animal hair and cat litter |
| Textiles, clothes and rags | Ceramics and porcelain dishes |
| Dirty papers and cardboard, napkins | Cigarette ends and ashes |
| Packaging on drink packs (12-packs) | Diapers and sanitary pads |
| CD and DVD-records | Coated technical clothes made rainproof |
| Plastics with the recycling label 1,2,3,4,5,6,7 and/or the letters PET, PE-HD, PE-LD, PE, PP, PS, PA | PVC-products (recycling label 3): plastic toys, hoses, credit cards, plastic folders, toy and tool packages |

Information gathered by Piippo (2012) explains that household waste generates about 60% of MSW volume, while the remaining 40% comes from service sectors. Table 5 illustrates the compositions of MSW in Finland. Knowing the actual compositions and sources of MSW is important to determine how much future waste can be subjected to recycling, recovery and EPR. Hence, it will be applied as part of solutions in the framework development of this work.

Table 5. Municipal solid waste composition in Finland in 2014 (Official Statistics of Finland 2015).

| Types of waste | Amount [tonnes] |
|---|---|
| Energy waste (unsorted mixed waste) | 1 349 905 |
| Separately collected waste | 1 140 097 |
| Paper and cardboard | 363 208 |
| Organic waste | 397 396 |
| Glass | 11 768 |
| Metal | 56 225 |
| Wooxd | 50 845 |
| Plastic | 50 998 |
| Waste Electrical and Electronic Equipment | 59 373 |
| Other separately collected waste | 150 284 |
| Other | 139 877 |
| Total | 2 629 879 |

## 3.3 Waste management services in Finland

The Finnish Waste Act (646/2011) explains that waste management in Finland involves the waste collection, transportation and treatment. These services are organized by municipalities, companies and producer responsibility organizations (PRO). As at 2016, there are 33 public waste management companies in Finland providing waste management services for the 5 million citizens (Jätelaitosyhdistys 2016a).

### 3.3.1 Responsibilities over waste

In a situation where the municipality is not responsible for the organization of MSW, the private individuals, property owners or companies become primarily responsible for managing of the waste (Finnish Waste Act 646/2011). Understanding the roles and responsibilities played by each stakeholder enhance the effectiveness of MSWM and would help to broaden the MSW responsibilities in the framework development of this work. Waste management responsibilities in Finland are compiled in Table 6 in Appendix 1.

The role of EPR can never be overemphasized when it comes to MSWM. In the year 2006, from the 2.6 million tonnes of MSW generated, EPR system was responsible for the management of about 502,071 tonnes, that is 19.3% of the total MSW volume. Estimated amounts of some MSW subjected to the EPR system are presented in Table 7.

Table 7. EPR on some specific MSW sectors in 2006 (Modified from Piippo 2012, Ympäristöministeriö 2010).

| Waste sector | Producer organisations | Collected waste [tonnes] |
|---|---|---|
| Packaging waste | | 107 200 |
| | Suomen Uusiomuovi Oy | 15 400 |
| | Suomen Keräyslasiyhdistys ry | 49 600 |
| | Mepak-kierrätys Oy and Suomen Palautuspakkaus Oy | 26 400 |
| | Puupakkausten kierrätys PPK Oy | 15 800 |
| Paper waste | | 355 931 |
| | Paperinkeräys Oy | 301 376 |
| | Suomen Keräystuote Oy | 54 555 |
| | | 38 940 |
| Waste electrical electronic equipment | | |
| | Flip ry | 946 |
| | ICT-tuottajaosuuskunta-TY | 5 336 |
| | Pohjoismaiden Electroniikkakierrätysyhdistys ry NERA | 11 823 |
| | SELT ry | 546 |
| | Ser-Tuottajayhteisö ry | 20 289 |
| Total | | 502 071 |

### 3.3.2 Collection and transportation of waste

The responsibility of organizing waste collection points and containers lies on property-owners or housing companies. The duty of waste producers is to take their waste to these containers at the collection points. Nevertheless, MSW companies have independently created collection points for recoverable waste nationwide (e.g paper, metal and glass) due to their market value. MSW sectors (papers, glass, cardboard, organic waste, hazardous waste etc.) are separately collected in other to enhance their handling and utilization (Piippo 2012). The work done by Piippo (2012) explains that there are two types of collection containers (Table 8) used for waste collection with different colors symbolizing the intake of various waste sectors.

Table 8. Differences between the two containers used in Finland (Piippo 2012, Molok 2016).

| Surface collection containers | Deep collection containers |
|---|---|
| Small in volume capacity; | Large in volume capacity; |
| bio-waste container size (140 or 240 liters), other types of waste (240 or 600 liters) | bio-waste, glass and metal container size (1300 liters), dry waste (5000 liters) |
| Requires large surface space since it is on the ground surface | Uses underground space and require less ground surface space |
| Involves high management cost due to frequent emptying, at least once a week by garbage trucks (depending on the waste volume generated weekly and on waste regulations) | Involves lesser management cost due to occasional emptying, at least every second week by garbage trucks (depending on the waste volume generated weekly and on the waste regulations) |
| Constant odor | Inconsistent odor due to coolness of the ground |

Most households make use of the 240 or 600 liters waste containers while public sectors and regional collecting points make use of 600 liters or large scale containers. The highest volume of MSW collected yearly is mixed waste from both households and public sectors. About 95% of these wastes are collected from surface containers (manually moveable containers) while the remaining 5% are from deep collection containers (Piippo 2012). Either or both of these two collection containers can be adopted to achieve the goal of this thesis work putting in mind the eradication of odor, capacity intake and management cost. The two waste collection bin options (surface or deep collection bins) to be used are illustrated in Figure 5 below.


Figure 5. Surface and deep waste collection options (Molok Oy 2016, Witre Oy 2016).

Private waste companies are usually in charge of MSW transportation since municipalities do not possess waste collection vehicles (Piippo 2012). Municipalities sometimes directly organize and set the price of transportation on behalf of property owners. The advantage of this method is that municipalities could purchase transportation services at a lower price from companies selected by using competitive bidding (20-40% cheaper than transportation arrangement made by property holders). Nevertheless, another option is for homeowners to directly secure a waste transportation company by itself (Jätelaitosyhdistys 2016b).

### 3.3.3 Waste sorting

Sorting of MSW before disposing is the social responsibility of the waste disposer. Apathetic attitudes and inadequate information often result to improper sorting. Piippo (2012) explains that efficient sorting of MSW in households and companies results in the active MSWM practice (material and energy recovery) in Finland. Depending on the region in the country, household wastes in Finland are sorted into six different waste containers; bio-waste, paper, carton, glass, metal and mixed waste. Other waste such as hazardous waste, batteries, and WEEE contents might have different waste collection points (Infopankki 2016). Waste sorting plays an important part in both material and energy recovery not just in Finland but in other European countries. Hence, it is important to consider sorting in the planning phase of MSWM (Piippo 2012).

### 3.3.4 Municipal solid waste treatment

Landfilling of MSW as experienced significant decrease. In 2006, 1,504 million tonnes of MSW were landfilled while just about half of that amount was landfilled in 2014. This has led to momentous reduction in $CH_4$ generation from landfills. However, this decrease is indirectly proportional to increase in energy recovery. Separate collection technique of paper and board waste, organic waste, wood waste, WEEE, metal waste and plastic waste has significantly enhanced waste recycling and energy recovery. This has led to the constant reduction of MSW landfilling (Official Statistics of Finland 2015).

The landfill target of no more than 20% of MSW has been achieved already in 2014. The 30% energy recovery from MSWM has also been achieved. The composting target of 20% is on the right track depending if there is a significant increment experienced in 2015. Material recovery target of 30% can't be achieved as the pattern of change is not consistent (European Statistics 2016).

Finland has produced excellent results in the management of some specific waste streams most especially on products (papers, WEEE and tires) liable to EPR system. Technical landfill requirements on EU member states with the 2007 deadline were also met. Direct targets and division of EPR mandated through national legislations made these a success story (Fischer 2013). Figure 6 illustrates the MSW treatment percentage of 2006-2014 and the 2016 targets.

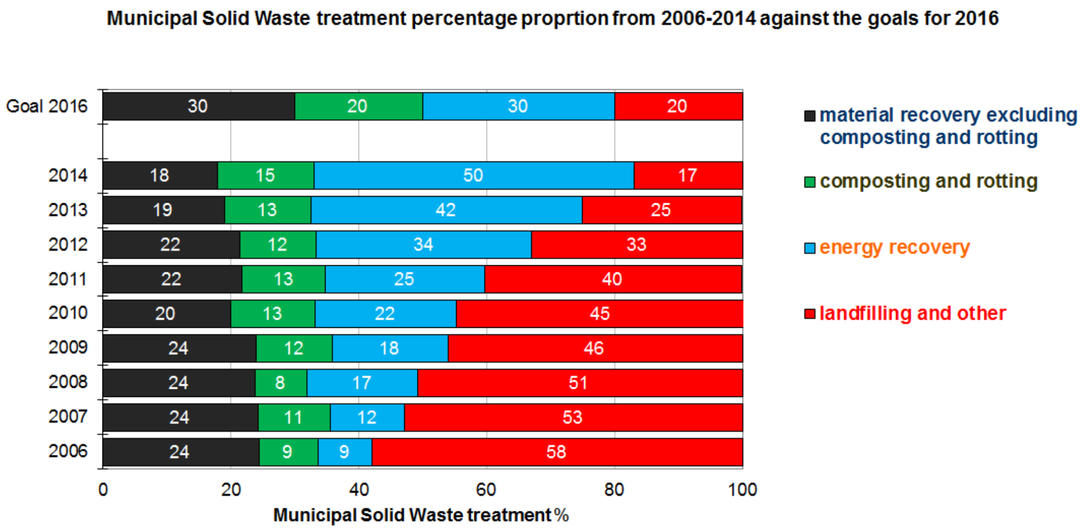



Figure 6. Trends in the municipal solid waste percentage treatment in 2006-2014 against the 2016 targets (Modified from European Statistics 2016, Piippo 2012, Ympäristöministeriö 2014).

As at 2005, Finland had 140 municipal waste landfills, in 2016, all had been closed down except for 35 new modernized landfills that meet the technical requirement of the EU landfill directive (Aurinko 2015). If the development trend in MSW landfill reduction should continue, soon there would be no MSW in landfills (Official Statistics of Finland 2015). This work would consider the technical requirements met by Finnish landfills.

## 3.4 Recovery rates in Finland

There are presently eight functioning or under construction incineration plants and 14 waste co-incineration plants (Official Statistics of Finland 2014). These plants use different kinds of combustion technique (Jätelaitosyhdistys 2016c). Energy recovery has improved tremendously within the last 8 years while recycling has been at an almost stagnant position within the same time frame. As at 2008, energy recovery rate was at 17% while recycling was at 24% of the total generated MSW (Piippo 2012, Ympäristöministeriö 2014). In 2014, energy recovery rate was at 50% while recycling is at 19%. Almost all of glass waste (96%), paper wastes (86%), metal waste (99.9%) and WEEE (99.9%) were recovered as material in 2014. All these waste sectors are actually waste products subjected to the EPR system. This once again shows the need and importance of a functioning EPR system. About 33% of the total MSW generated where recovered as material, while about 50% were recovered as energy (European Statistics 2016).

According to Piippo (2012), an essential requirement needed to improve recycling and energy recovery of waste is a readily available market that is ready to consume the products. One of the most fundamental things to put in mind is that material or energy recovery should be of lesser environmental and financial cost than when producing with virgin products. The improvement noticed in the Energy recovery rate of MSW can be attributed to improved sorting and efficient separate collection (Piippo 2012). Table 9 illustrates the recovery and landfilling of different waste sectors in 2014.

Table 9. MSW recovery rates and landfilling in 2014 (Official Statistics of Finland 2015).

| Types of waste | Amount | Treatment method | | |
|---|---|---|---|---|
| | [tonnes] | Material recovery [tonnes] | Energy recovery [tonnes] | Landfilling [tonnes] |
| Mixed waste total | 1 349 905 | 15 122 | 903 671 | 431 112 |
| Separately collected waste; | 1 140 097 | 826 185 | 300 869 | 13 043 |
| Paper and cardboard | 363 208 | 315 627 | 47 457 | 124 |
| Organic waste | 397 396 | 354 990 | 35 560 | 6846 |
| Glass | 11 768 | 11 357 | 4 | 407 |
| Metal | 56 225 | 56 196 | 29 | 0 |
| Wood | 50 845 | 2 961 | 47 625 | 259 |
| Plastic | 50 998 | 4 497 | 46 455 | 46 |
| Waste Electrical and Electronic Equipment | 59 373 | 59 333 | 40 | 0 |
| Other wastes | 150 284 | 21 224 | 123 699 | 5 361 |
| Others | 139 877 | 15 019 | 111 280 | 13 578 |
| Total | 2 629 879 | 856 326 | 1 315 820 | 457 733 |
| Treated % from total waste | | 33% | 50% | 17% |

## 3.5 Economic instruments and municipal solid waste in Finland

Economic instruments are incentives used to regulate production, consumption, disposal and environmental responsibility to develop a sustainable environment. Economic instruments include pollution tax and solid waste tax (OECD 2003). As of 2007, employment related to waste management in Finland were 4,300 while the overall profit of waste management companies was ca 1750 million euros (Piippo 2012, Ympäristöministeriö 2010). Sokka *et al.* (2007) explain that investments to address biodegradable waste alone in Finland were estimated to €350 million per year until 2009 and to €430–480 million per year until 2016. With the exemption of the cost covered by the EPR system, waste producers/holders paid ca 1148 million euros on waste management in 2010 (Piippo 2012, Ympäristöministeriö 2010).

This cost on MSWM is very expensive when compared to the volume and treatment cost of other waste sectors. This can be attributed to the massive investment needed to purchase and maintain stringent operational landfills, waste incineration plants, material recovery facility and other treatment facilities. Most remuneration generated in waste management comes from reception fees of waste and the selling of the recovered material and energy (Piippo 2012). The framework should consider that MSW cost on waste producers is expensive to achieve proper management. Table 10 summarizes the net costs attached to waste producers producing different wastes. Households and public services in the table exclude cost of composting.

Table 10. Net costs of waste management paid by waste producers on different waste sectors (Modified from Piippo 2012, Ympäristöministeriö 2010).

| Waste producer | Waste amount [Million tonnes/year] | Costs [Million euros/year] | Average costs [Euros/tonne] |
|---|---|---|---|
| House building and earthwork | 23 | 440 | 19 |
| Extractive activities | 22 | 60 | 3 |
| Industrial activities | 18 | 92 | 5 |
| Households and public services | 2 | 414 | 205 |
| Energy management | 2 | 24 | 15 |
| Agricultural industry | 2 | 13 | 6 |
| Trade and other private services | 1 | 65 | 109 |
| Water (H2O) supply services | 1 | 40 | 40 |
| Total | 71 | 1148 | |

### 3.5.1 Waste charges and taxes in Finland

The principal aim of waste taxation is to reduce the volume of waste landfilled and encourage waste recovery (Piippo, 2012). Tax is levied on all waste deposited at landfills on the conditions that; its utilization is technically feasible and environmentally justifiable; and that with the imposition of tax, waste can be made more commercially exploitable (Ympäristöministeriö 2013c). Waste tax is however not collected from wastes that are well treated e.g. through composting or incineration. From 1st of January 2016, the waste tax changed from 50 euros/tonne to 70 euros/tonne (Waste Tax Act 1126/2010). Waste tax have not been able to enhance the reduction of MSW generation even though they have positively reduced the volume of construction and demolition (C&D) waste, commercial and industrial activities (Piippo 2012).

MSW charges paid by waste producers cover all the cost of MSWM. This includes transportation cost, facilities and maintenance, decommissioning and landfilling etc. The main aim of waste charges is to encourage waste producers to re-use, reduce and make waste less harmful. MSW charges set on waste producers must be in line with the level of service provided by the municipality (Ympäristöministeriö 2013c).

Some categories of waste can be landfilled without paying of tax waste with no prior technical treatment or utilization alternative to disposal at landfills, or if their utilization is of more environmental harm than good; mineral waste and waste resulting from inorganic chemical processes; hazardous waste and waste used in the structure of landfills which the permit authority finds acceptable (Ympäristöministeriö 2013c).

Drinks packaging taxes aims at improving the re-use of drinks packages, reducing the amount of packages that ends at landfills and to prevent littering. These taxes are paid on the packaging of soft drinks, bottled $H_2O$, beer, alcoholic beverages and some other certain packaging drinks. Present tax is at 0.51 euros/liter. The application of this tax does not involve packages subjected to the deposit-refund system (Ympäristöministeriö 2013c).

### 3.5.2 The cost of producer responsibility systems in Finland

The framework development should contain the overview of the cost of producer responsibility to understand what the structure of EPR system involves. In the EPR system practiced in Finland, the producer means the manufacturer and/or importers of the products while in the case of packaging products subjected to the EPR system, the producer is the packager and/or the importer (Piippo 2012). According to the Finnish Waste Act (646/2011), EPR on packaging products applies to Finnish firms that pack or import products into the Finnish market and make a turnover of at least 1 million euros. This financial breakdown signifies that EPR system involves financial stability for firms to be able to carry out their obligations successfully. EPR is subjected to the following products; printing papers and packing products, batteries and accumulators, WEEE, tires and ELV. Since municipalities are not responsible for waste subjected to the EPR.

Producers organize and pay for the management of these wastes, often the responsibilities are passed to producer responsibility organizations (PRO) by the producers of the different MSW sector (Ympäristöministeriö 2013b). For example, five producer organizations within the country collect and recycle WEEE (Ylä-Mella 2015). Utilization fees collected from producers by producer responsibility organizations are used to cover the costs related to the EPR system on their products. WEEE management cost is estimated to be about 14 million euros as at 2010. In the tire waste sector, recycling cost is about 7-8 million euros (Piippo 2012). Table 11 illustrates utilization fees to be paid on some packaging for 2016.

Table 11. Utilization fees for packaging material for 2016 (Suomen Kuitukierrätys Oy 2016).

| Material | Utilization fee [euro/tonne (including VAT)] |
|---|---|
| Corrugated board for consumers | 7 |
| Corrugated board for companies | 7 |
| Industrial covers and sacks | 17,5 |
| Industrial shelves | 17,5 |
| Cardboard and paper packaging | 44 |
| Liquid carton packaging | 74 |
| Plastic packages for consumers | 95 |
| Plastic packages for companies | 40 |
| Aluminium packages for consumers | 120 |
| Aluminium packages for companies | 10 |
| Sheet tin packages for consumers | 120 |
| Sheet tin packages for companies | 10 |
| Steel packages | 10 |
| Glass bottles with reward | 135 |
| Wooden packages | 0,65 |

### 3.5.3 Types of municipal solid waste management cost in households and public services

The cost covered by the waste producer is needed for all the steps involved in MSWM, from the first step of collection to every step along the line till the waste are landfilled or recovered except of course on waste materials that are subjected to the EPR System. MSW collection is mostly done by using property specific system while the other option available is the regional waste collection (Piippo 2012, Ympäristöministeriö 2010).

**Property specific waste collection**

Wastes are collected in different waste sections; energy waste, paperboard and cardboard, bio-waste and paper sections. The first cost by single-family houses is the cost attached to the containers, putting in mind how much waste they generate. This cost covers the purchasing and maintenance of these containers. The rental price for 240 and 600-liter containers are between 10-50 euros and 14-50 euros respectively. The next cost is for emptying the waste container and this covers the transportation, Value added tax (VAT), treatment of the waste and the wastes that are landfilled (Waste tax). This cost may include the management of hazardous waste, recoverable and consultation services. The emptying fee is directly proportional to the number of times these containers are emptied (Piippo 2012, Ympäristöministeriö 2010, 30-32). The mixed waste fee subsidizes the fees attached to the management of bio-waste and energy waste. Profits made from recoverable and excess energy sales are put into consideration when deciding on waste charges to be paid by waste producers (Piippo 2012, Ympäristöministeriö 2010, 31-33).

As at 2010, the average cost of emptying a bio-waste container (7.09 euros) from a single family household is more expensive than that of emptying mixed waste (6.48 euros) and energy waste (5.53 euros). The range of the emptying cost of each waste sector differs; bio-waste containers (3.17 to 16.71 euros), mixed waste containers range from 3.78 to 11.95 euros while energy waste container is from 3.5 to 8.54 euros (Piippo 2012, Kuluttajavirasto 2010). Only half of the municipalities make use of the bio-waste collection while only one-fifth of the municipalities have organized the collection of energy waste (Piippo 2012, Kuluttajavirasto 2010). These prices have however increased as the cost of MSWM continuously increases as waste technologies advance.

The total cost/Municipal charge of mixed waste management paid by waste producers (households and public services) is ca. 340 million euros as at 2010. This covers all the cost relating to transportation, treatment and containers maintenance (Piippo 2012, Ympäristöministeriö 2010).

**Regional collection**

This second waste collection system is mainly applied to two conditions; when waste is produced in lesser amounts and when waste has unique characteristics that make it unsuitable for normal waste transportation. The former also applies to mixed waste that is produced in little quantity and/or produced in sparsely populated areas (Piippo 2012, Ympäristöministeriö 2010, 25).

The 2010 annual cost of MSWM paid to service providers by households and public services are ca 211 million euros, which accounts to 41 euros per capita/year. On the other hand, the total cost paid by households and public services for waste management in that same year accounts to ca 414 million euros/year (Piippo 2012, Ympäristöministeriö 2010 40-41).

## 3.6 What to learn from the municipal solid waste management in Finland

This work acknowledges that there are two main important things to learn from the MSWM in Finland; the landfill technical operations and the energy recovery system. This logic is backed up by the fact that the landfill target of no more than 20% of MSW has been achieved already in 2014. This was achieved by the increase in energy recovery. The targets and responsibilities attached to the technical requirements for landfills have also been fulfilled (Fischer 2013). Hence, the landfilling operation in Rusko waste center would be studied.

Also, Finland has achieved magnificent results in the management of some specific waste streams most especially on products (papers, WEEE and tires) liable to EPR system (Fischer 2013 and Ylä-Mella 2015). Therefore, the framework development would include an EPR system on some MSW sectors and the composting of organic waste practiced in Finland. Figure 7 illustrates the core and essential practices learnt from the MSWM in Finland.

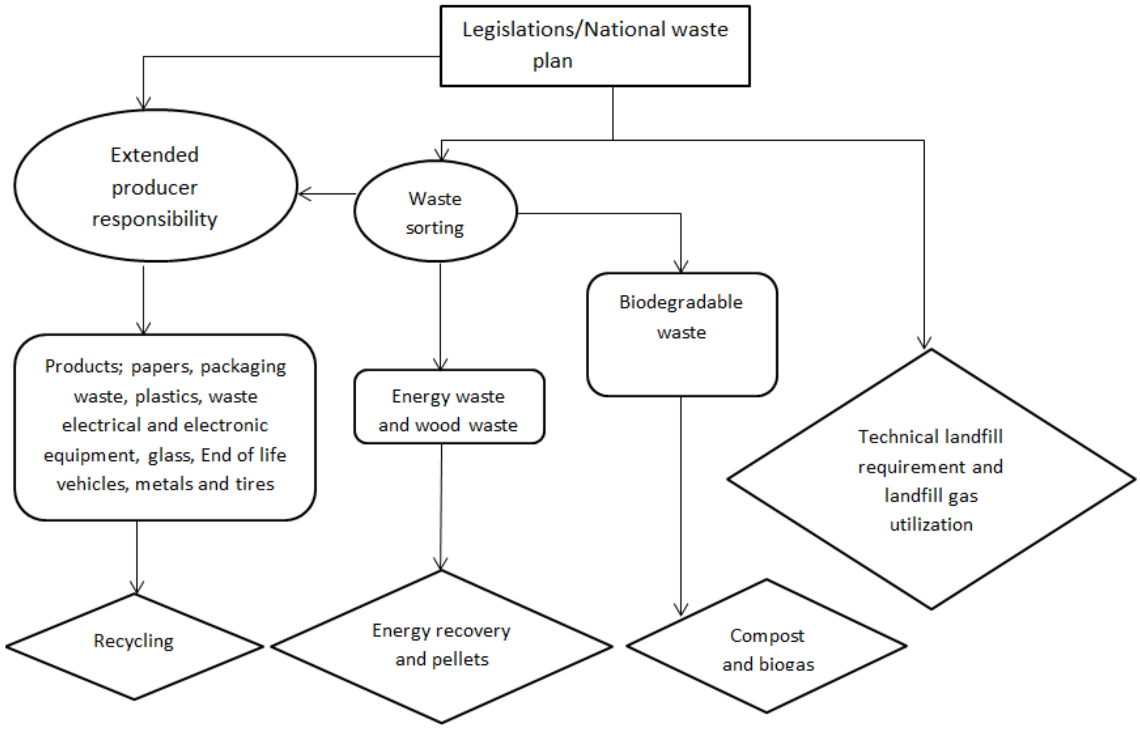



Figure 7. Important concepts from the municipal solid waste management in Finland.

The most difficult tasks to be implemented from the Figure above would be the EPR and the waste sorting practice. An average Nigerian is naive about the reasons to protect the environment and efficient waste sorting can only be achieved when the citizens show concerns towards the environment. Developing an effective EPR system would be faced with challenges such as the non-existence of any PRO for imported or locally produced goods and the government's unreadiness towards MSWM.

## 3.7 Landfills and technical requirements in Finland

As at the end of the 1900s, Finland had over 561 landfills and by 2005, 140 municipal waste landfills existed. In 2015, 35 modern landfills existed in Finland while the others were all closed down according to the landfill technical requirements set by the EU (Aurinko 2015). The EU directive on the landfill of waste (99/31/EC) sets some landfill characteristics for landfill operations which includes; $H_2O$ control and leachate management, protection of nearby soil and $H_2O$, minimization of nuisances and hazards, stability of the mass of waste and associated structures, prohibition of illegal dumping in the facility and LFG control. According to the national legislation on landfilling of waste, landfill owners are obliged to apply for an environmental permit before the commencement of operation. The environmental permit is granted based on environmental impact assessment of the landfill's whole life cycle (VNp 861 1997). The main objective of the environmental permit procurement is to confirm that the landfill owner has a prepared plan on how to protect the landfill and its environs by utilizing the Best Available Technique (Aurinko 2015).

**Landfill gas (LFG) utilization design**

Landfills are one of the greatest sources of anthropogenic methane. Hence, making it necessary for LFG to be collected treated and used (Hayles 2005). The utilization of LFG to generate heat and/or electricity should not be seen as a reason to encourage untreated waste disposal to landfills. The conscious disposal of untreated waste to produce LFG does not comply with the waste management hierarchy. This work only considers the LFG utilization as a temporary solution to reduce $CH_4$ generation in landfills prior to the start and development of the waste management practices in Ogun state. Landfilling in Finland as reduced extraordinary by creating ways for waste to be recovered for material use and energy. Most have been energy recovered. Finland has strict operational and technical requirements in their landfilling system and that is why this Chapter looks into the Oulu MSWM LFG utilization project.

The Rusko landfill operation can be dated as far back as the 60's. It has a land space of 93 hectares, making it one of the biggest landfills in Finland. It is under the operational responsibility of the Oulu MSWM. The Oulu MSWM handles the waste of 14 municipalities with over 220,000 populations. The major operation is landfilling. However, they undertake composting, recycling and hazardous waste treatment operations. Waste intake includes bio-waste, industrial, hazardous and residual waste. Annual residual waste and construction waste treated are 60,000 and 30,000 tonnes respectively. Revenue is generated from MSW services such as waste tax and the sale of LFG. In 2005, total revenue was 8,004,584 euros, from which sales from LFG was 476,141 euros while 2,910,071 was paid as waste tax. (Hayles 2005).

The Rusko waste center had been utilizing the $CH_4$ produced at the landfill since 2005. Some of the harmful $CH_4$ is recovered and delivered for usage at the Oulu University Hospital and the Paroc rock mineral wool factory. The other portions are utilized within the Rusko waste center for their heating needs (Oulun Jätehuolto 2016). Collection and pumping of LFG started in 1997. In 2005, about 6,700 $Nm^3$ of LFG was produced with the aid of two pumping stations. (Hayles 2005). In October 2006, the waste center decided to modify the utilization of the LFG by installing a micro turbine plant (Oulun Jätehuolto 2016). The plan was electricity production (195 – 200kW) while the remaining would produce heat energy (300kW). This is enough to light and heat 60-single-family homes annually (Hayles 2005). Presently, the electricity and heat are used in the waste center while the remaining electricity is sold to the national power grid for public consumption (Oulun Jätehuolto 2016).

**LFG collection and pumping at Rusko Landfill**

The Landfill houses 35 vertically drilled collection wells feeding two pumps, and 4 new wells constructed in the middle of 2006. In order to generate energy, the presence of siloxanes in LFG needs to be eradicated to prevent erosion of turbines and other metal surfaces. The total collection rate of $CH_4$ in the landfill is about $1000m^3/h$ with an estimated atmospheric emission rate of $60m^3/h$. The 6.7 million $Nm^3$ of $CH_4$ pumped in 2005 was an equivalent of 34440MWh of energy (Hayles 2005). Paroc ltd (heat) and Oulu Energia (process steam) purchased about 33566MWh while the rest (874MWh) was utilized by the waste center. The quantity of LFG collected has increased on yearly basis. The Leachate is prevented from escaping into groundwater has it is pumped back into the landfill and used to provide moisture while enhancing decomposition and LFG production. The pumping installations at Rusko consist of moisture removal, dryers and filters and are fully automated (Hayles 2005). The installation of collection lines for pumping of LFG is shown in Figure 8.


Figure 8. Installation of landfill gas collection lines at Rusko landfill (Hayles 2005).

In consideration of the path taken by the Rusko waste center in 1995-2006, a roadmap to LFGTE organization and development is mapped out. Figure 9 illustrates the steps to be taken to make proper usage (Heat or electricity) of LFG.

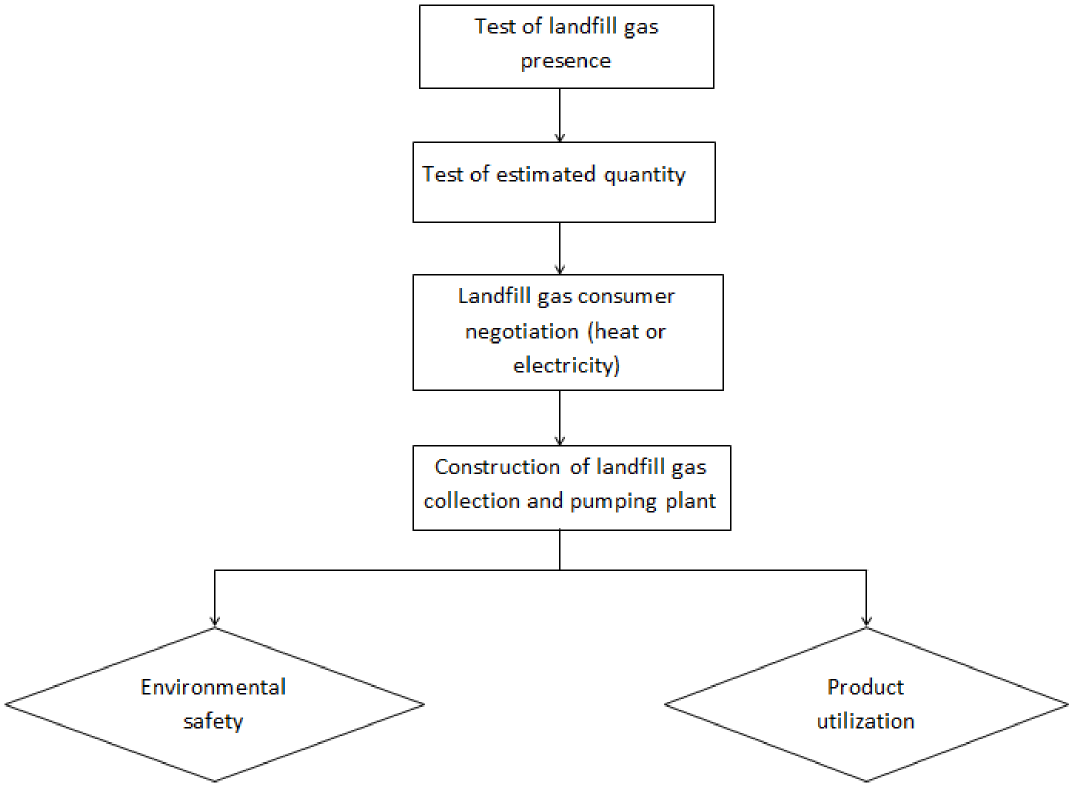



Figure 9. Paths towards the production of heat and electricity from landfill (Hayles 2005).

This roadmap should act as a prototype to developing countries. It would help them to outline the path to an efficient LFGTE utilization. This roadmap is necessary because some developing counties and cities have tried to utilize LFG in the past but the project later turned out to be abandoned projects due to technical difficulties.

**The Plant and Guaranteed Environmental Condition**

The plant consists of compressors (rotary piston blower), water chillers, water separators and gas filters. The plant has a load capacity of 500Nm$^3$/h. The objective of the plants is to allow the controllable flow of gas through the entire system by maintaining the required low pressure needed by the input pipes (Hayles 2005).

The secret of ensuring that the environment is well protected while utilizing LFG in the center is regular maintenance and fault detection tests of the plant and its environs. One of the most important regular tests is the constant study of the effects of the waste treatment both on the surface waste and ground water around the center. Another major test regularly carried out is leakage tests on the LFG pipes (Oulun Jätehuolto 2016a, Oulun Jätehuolto 2016b).

## 3.8 Possible future trends of municipal solid waste management in Finland

It is still quite complicated to conclude that MSW in Finland is reducing due to waste prevention strategies or economic recessions. Nevertheless, the next National waste plan should consider waste prevention more seriously. Landfilling in Finland according to the trends of 2006-2014 would continue reduce constantly. Recycling of MSW in general needs to be improved despite the success recorded in the EPR system on some MSW sectors. Composting is experiencing a stagnant growth and might continue to be stagnant. However, the composting target for 2016 can't be achieved considering the trend experienced in 2009-2014. There is a need to reduce energy recovery but it seems the energy recovery would instead continue to rise since the growth is inversely proportional to the landfill reduction.

# 4 WASTE RECOVERY TECHNOLOGIES

Waste recovery technologies provide opportunities for the utilization of the material and energy content embedded in waste. There are also other series of different recovery operations that can be found in the Annex II section of the WFD (Directive 2008/98/EC). These technologies can be classified as thermal, biological and mechanical treatment of waste (Arena 2012). Figure 10 illustrates common waste recovery technologies. Each of them has some unique advantages and disadvantages which will be further elaborated later.

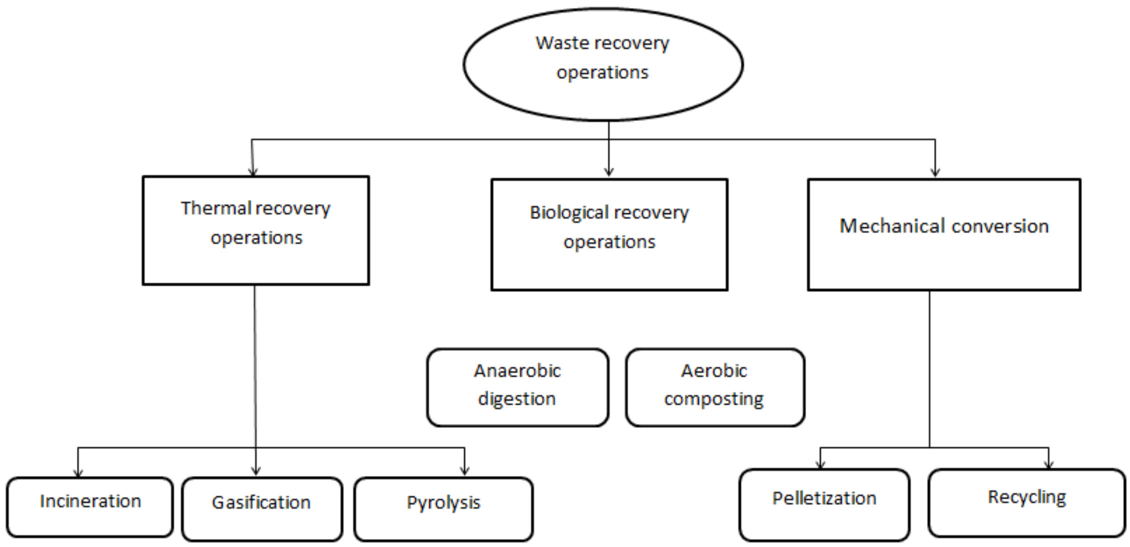



Figure 10. Breakdown of waste recovery technologies (Arena 2012).

A advanced thermal waste recovery technologies combine the use of all thermal recovery operations (incineration, gasification and pyrolysis) in an integrated approach, however, the individual usage of each form of technology is still widely used worldwide as some technologies render very high electrical efficiencies (Malkow 2004). The biological waste recovery options are aerobic and anaerobic (Sharholy *et al.* 2008) while recycling and pelletization are the most common mechanical recovery options (Asnani 2006, Louis *et al.* 2011).

## 4.1 Thermal recovery operations

Thermal recovery processes offer advantages over non-thermal recovery processes. Some of them are the ability to treat different types of MSW, high reduction of MSW mass (70-80%), low land-use and the total destruction of organic contaminants. However, ultimately, these technologies will result in greenhouse gas emissions (Arena 2012).

### 4.1.1 Incineration

'MSW incineration' renders useful energy (heat or electricity or both) by converting waste to high-temperature flue gases mostly of $CO_2$ and $H_2O$ while simultaneously reducing the mass, volume and chemical characteristic of MSW materials; raw or residue. The temperature needed for operation is between 850°C and 1200°C (Arena 2012, Tang 2012). There are three types of combustion technologies utilized for burning of waste; grate technology, rotary kiln and fluidized bed (DEFRA 2013, Tang 2012). The choice of use between this three lies in the characteristics of the MSW, cost and availability of skilled labor (Tang 2012). There is more usage of grate technology systems used in Europe than the other two combustion technologies (DEFRA 2013, Zhang *et al.* 2010). Figure 11 illustrates MSW incineration characteristics, the main product and by-products.

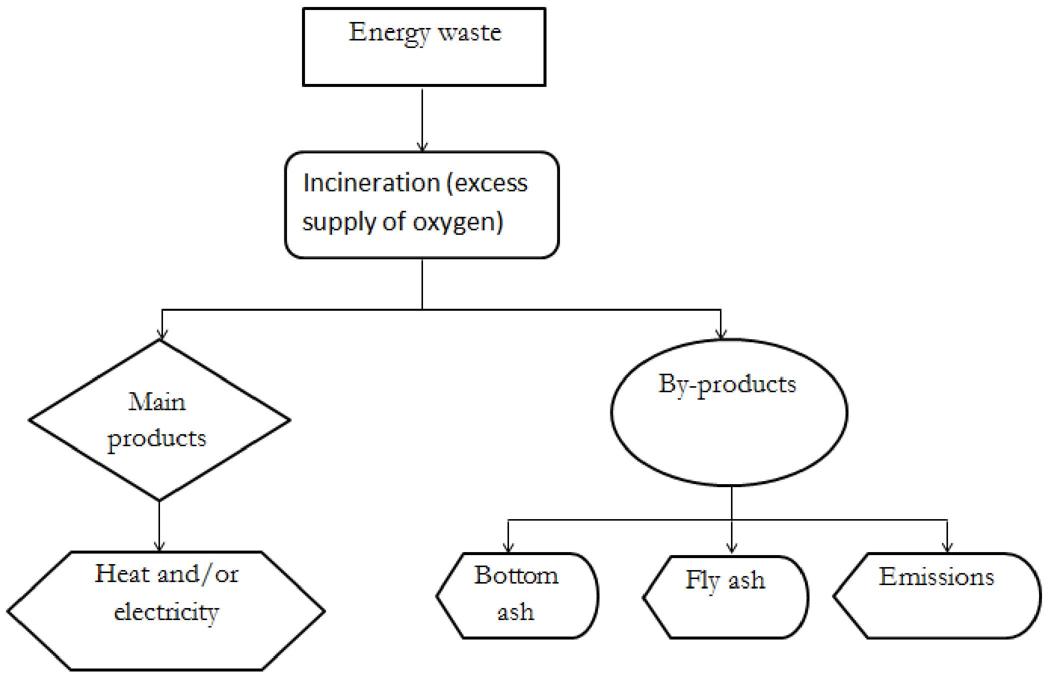



Figure 11. Breakdown of municipal solid waste incineration characteristics, the main products and by-products (Arena 2012, Aubert *et al.* 2004, DEFRA 2013).

The problem associated with incineration is that it also generates wastes; bottom ashes; 250-300 kg/m3 of MSW, fly ashes, greenhouse gases and air pollution control (APC) residues; 25-50 kg/m3 of MSW. However, the fly ashes blend well with concrete as they behave like inert fine sand while bottom ashes are largely used as raw material for road construction (Aubert *et al.* 2004). According to the research work by Arena (2012), apart from $CO_2$, incineration process of MSW produces pollutants; Sulfur dioxide ($SO_2$), hydrogen chloride (HCL), Polychlorinated debenzo-p-dioxins and dibenzofurans (PCDD/F), nitrogen oxide ($NO_x$) and particulate.

**<u>Grate Incineration process technique</u>**

The process involves the passage of waste through the combustion chamber by a mechanically actuated grate. The combustion chamber has two openings; one for the intake of raw materials and the second is for the ash discharge. The end of the grate passes the ash discharge to cool the remaining non-combustibles (DEFRA 2013). Some plants have two combustion chambers in other to have sufficient time to maintain enough high temperature in a view to eradicate toxic organic pollutants (Tang 2012).

To clean the flue gas, mechanical and chemical methods are utilized. The solid particles are removed with the aid of gravitational and centrifugal forces; single or multiple cyclones (Tang 2012). Energy (electricity and/or heat) is then recovered through water pipes lined up on the wall at the top of the furnace. This converts the $H_2O$ into a high-pressure steam by utilizing the combustion heat. The high-pressure steam is then directed into a turbine that drives an electricity generator (Tang 2012).

**<u>Barriers of MSW incineration in developing countries</u>**

The main obstacles between developing countries and MSW incineration are; high cost attached to investment, operation and maintenance. The technology also requires highly skilled labor which is scarce in these countries (Tang 2012).

### 4.1.2 Gasification

It is the conversion of MSW to fuel or synthesis-gases through gas-forming chemical reactions. The end result is a hot fuel gas as known as producer gas or syngas (Arena 2012). Gasification just like pyrolysis involves the removal of glass, metals and inert materials before the whole process (DEFRA 2013). The resultant syngas consist primarily of hydrogen ($H_2$) and carbon monoxide (CO) and $CH_4$ with an average net calorific value of

7.5 – 17.5 MJ/$m^3$. This value range makes it suitable for energy generation (electricity and heat) and for chemical conversion to various useful products (Arena 2012, Svetla *et al.* 2014). The advantage of gasification over incineration is its electrical generation efficiency (Murphy & McKeogh 2004). Figure 12 illustrates the characteristics of MSW gasification, the main products and by-products.

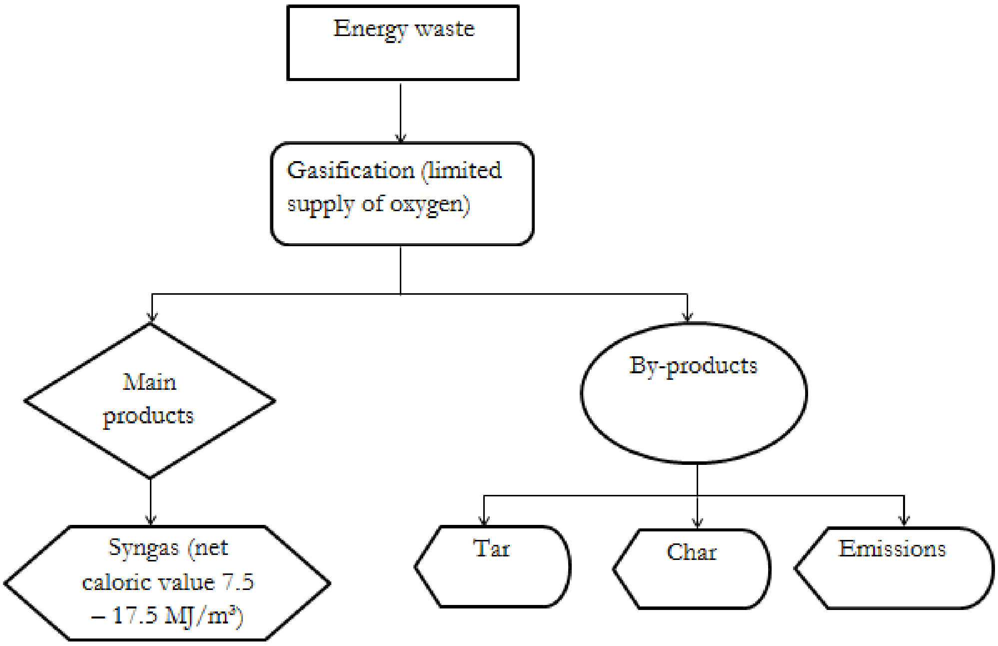



Figure 12. Municipal solid waste gasification characteristics and its end products (Arena 2012, DEFRA 2013).

The process also generates pollutants such as hydrogen sulfide ($H_2S$), Ammonia ($NH_3$), hydrochloric acid (HCL), carbonyl sulfide (COS) hydrogen cyanide (HCN), alkali, char, tar and particulate (Arena 2012). An appropriate and efficient gasification technology for MSW recovery is an environmentally sound process (Svetla *et al.* 2014). Gasification requires the use of partial oxidation but not as much as the oxygen needed for incineration (DEFRA 2013).

**MSW gasification technique**

The gasification of MSW is a convoluted process that involves series of physical and chemical interactions that occur at different temperatures higher than 600°C. The exact process temperature depends majorly on the reactor type and the MSW characteristics (Arena 2012). There are three different types of waste gasification processes which are classified based on their oxidation medium (oxidizing agent): partial oxidation with air or oxygen-enriched air or pure oxygen; steam gasification and plasma gasification (Arena 2012). The Plasma gasification process as its advantage over other processes as it has no restriction to particle size, moisture content, ash content, non-catalytic and catalytic process. However, the cost of investment is high (Svetla *et al.* 2014).

The process steps of MSW gasification include a sequence of successive endothermic and exothermic steps (pretreatment of waste, heating and drying). To form the syngas, carbon reacts with stoichiometric quantities of air and stream during the pyrolysis and gasification stages at a temperature 400-1000°C (Svetla *et al.* 2014).

The general process chain of MSW gasification technology leads to a very limited release of dioxins and furans, thereby health risks attached to the whole process are petite. Research has continuously proven that gasification has a very high efficiency when it comes to MSW energy recovery. Gasification produces an intermediate product that has a very wide range of applications; liquid fuels, energy generation and chemicals manufacturing processes (Arena 2012).

### 4.1.3 Pyrolysis

Pyrolysis involves the thermal decomposition of MSW to gasses and char in the absent of stoichiometric oxygen, mainly using an external source of energy, since it is an exothermic reaction (Arena 2012, Brunner 2002). The syngas produced mostly has a net calorific value of 10-20 $MJ/Nm^3$ (DEFRA 2013). Pyrolysis operates in a lower temperature than the other two thermal processes between 300°C and 850°C. The energy derived by using pyrolysis technology is also cleaner than that generated using incineration due to the emission of lower amounts of $NO_2$ and $SO_2$ which results from the low temperature and reducing conditions needed for operation (Chen *et al.* 2014, Malkow 2004). It is considered as an alternative to incineration for MSW energy and resource recovery. Pyrolysis plants as an advantage of its scale flexibility over incineration plants as the scale capacity of the latter is kiloton/day (Chen *et al.* 2014). Figure 13 presents simple MSW pyrolysis characteristics.

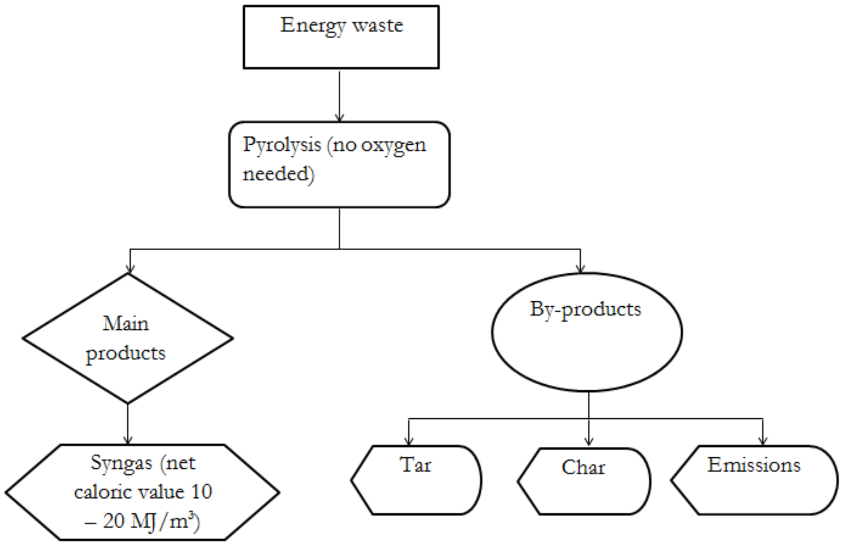



Figure 13. Municipal solid waste pyrolysis characteristics and its end products (Arena 2012, DEFRA 2013).

The gasification process produces CO, $H_2$, $CH_4$ and other hydrocarbons but at the same time produces pollutants such as $H_2S$, $NH_3$, HCL, HCN, tar and particulate (Arena 2012, Chen 2014 and DEFRA 2013). Much attention is also needed to purify the gas exiting the reactor to adequately protect human lives and the environment (Brunner 2002). Pyrolysis has the disadvantage of not being able to process raw and/or wet MSW. Hence, mechanical separation of food waste as well glass, ceramics, rubbers, leathers, metals and other inert materials have to be done from the about to be processed MSW materials (Chen 2014 and DEFRA 2013). The MSW fractions that are best recovered by pyrolysis are unrecyclable papers, cloth materials, unrecyclable plastics and yard wastes (Chen 2014). This shows that for an efficient pyrolysis recovery, they should have been a sufficient MSW sorting of different unneeded MSW sections.

**MSW pyrolysis technique**

The pyrolysis process relies heavily on the type of process conditions employed; heating rate and residence time in the reactor, operating temperature and direction of flow gas etc. (DEFRA 2013). Different types of reactors used have a slight difference in their individual working conditions. For example, rotating kiln reactor would operate at temperatures between 300-850°C. The source of heat of the kiln is external and MSW material is fed in from one end of the kiln which rotates slowly and creates a tumbling action (DEFRA 2013). The residence time is about 1 hour which is due to the external source of heat which is transported into the reactor by the reactor wall. The pyrolysis system would initially involve a mechanical crushing and shredding of the MSW materials. Other systems include the heat exchanger, separation unit, $H_2O$ trap, gas flow meter and rotameter (Chen *et al.* 2014).

## 4.2 Biological recovery operations

Biological are the best alternatives for the treatment of biodegradable MSW fractions. Among the different biological treatment methods, anaerobic digestion (AD) is the most cost-effective due to its high energy recovery rate and low environmental impact (Mata-Alvarez *et al.* 2000).

### 4.2.1 Anaerobic digestion

AD is an efficient biological process (renewable source of energy) to treat a broad range of biodegradable waste (Khalid *et al.* 2011). It operates in the absent of oxygen with an end result of biogas which is rich in $CH_4$ and $CO_2$ (Rapport *et al.* 2008). One cubic meter of biogas generates about two kWh of electricity and depending on the CHP unit it could also generate two kWh of heat (SEAI 2007) Source separation of the organic waste fraction of MSW contributes to a high yield of AD end product. The growth of AD over the years, especially in European countries can be attributed to the mandatory pretreatment and target for disposal reduction of biodegradable materials to landfills which was introduced by EU directives (Rapport *et al.* 2008).

The AD phases of operation involves four stages of metabolic reactions; hydrolysis, acidogenesis, acetogenesis and methanogenis to produce biogas (Khalid *et al.* 2011). Biodegradable waste dumped in landfills undergo a natural AD process that produces $CH_4$ and $CO_2$ into the environment that pollutes the environment. Under controlled process/system, this same AD process happens but the end products are valuable resources (Khalid *et al.* 2011). Under controlled system, AD is mostly carried out at mesophilic temperatures of 35°C which yields rich Biogas (Khalid et al. 2011). Temperature and retention time among other ambient conditions in the digester are one of the most important factors needed to enhance the AD process; speed and stability (SEAI 2007).

**AD technique**

Single stage digesters are simple to design, build and operate and are less expensive. However due to the rapid acid production process during hydrolysis, the organic loading rate is limited by the ability of methanogenic organisms to withstand the sudden PH decline. On the other hand, the two stage digesters provide unlimited OLR as it separates the initial hydrolysis and acid-producing fermentation from methanogenesis. This separation requires additional reactors and handling systems (Rapport *et al.* 2008). The European market makes use of the single (one)-stage digesters more than the two-stage digesters and also uses the dry digestion system over the wet systems. The common use of the dry system is because of its lower diffusion rates which protect the microbes. The wet system diffuses the toxic and inhibitory compounds of MSW very quickly and this could shock the microorganisms (Rapport *et al.* 2008). Nevertheless, the choice of AD technology to be adopted depends largely on the composition of the waste stream, co-product markets and other site-specific requirements (Rapport *et al.* 2008).

The environmental condition of the AD operation is that $CH_4$ production is high when PH level is kept at 6.8-7.2 (Ward *et al.* 2008). Moisture content range of 60-80% in AD results in the highest $CH_4$ production (Khalid *et al.* 2011). A nutrient ratio of elements of C, nitrogen (N), phosphorus (P) and sulphur (s) at (C:N:P:S - 600;15;5:3) improves methanization process (Fricke *et al.* 2007). The optimum carbon-to-nitrogen (C/N) ratio that enhances efficient AD is experienced at 20-35 (Guermoud *et al.* 2009).

**Uniqueness of AD and barriers of biogas production in developing countries**

The major advantage of AD is that it results in a very little environmental impact as the sealed environmental process prevents the exit of $CH_4$ into the atmosphere (Khalid *et al.* 2011). Other advantages include little land space for operation, microscopic pollution (odours), investment needed is not as high as other waste recovery technologies and technical difficulty experienced is medium. It mitigates $CH_4$ emissions from landfills and displaces fossil fuel based power generation (IUT 2010).

Some notable barriers have hindered the growth and development of biogas in developing countries. A larger factor lies in the cost of operation, others include: lack of awareness of biogas opportunities, technical difficulties (equipment and skilled labor), lack of government policies to favor biogas production and Socio-cultural factor (Akinbami *et al.* 2001).

### 4.2.2 Aerobic composting

Composting is the bacterial conversion of biodegradable MSW in the presence of oxygen. The breakdown produces compost (Sharholy *et al.* 2008), heat, CO and $H_2O$ (Enviros 2007). While the composting process is ongoing, the waste volume is also reduced by 50-85%. When the input materials is clean food waste and free he of pathogens and impurities, the compost produced is of high agricultural value that is free from bacteria and odor. This makes it an excellent fertilizer for agricultural purposes (Sharholy *et al.* 2008). Apart from treating MSW, aerobic composting of biodegradable MSW would be of great importance to countries that have a high biodegradable MSW volume if adopted (sufficient returns from waste recovery). The aerobic process is a relatively dry process that is used for MSW materials with high solids content. One of the factors that enhance aerobic composting is ensuring that the MSW have a good physical structure to enable free passage of air through the material. The whole process of aerobic composting is majorly associated with high thermophilic temperatures at 55-70°C as this temperature last several weeks more than the mesophilic temperatures (Enviros 2008, Gajalakshmi & Abbasi 2008). This high-temperature range also leads to the destruction of potential pathogenic organisms in the MSW contents.

**<u>An overview of Aerobic composting technique</u>**

The technique for composting is simple as aerobic organisms use organic matter as a substrate. As the microorganisms decompose the substrate, there is a breakdown of compounds from complex to simpler compounds. The final organic breakdown is what is known as the compost. There are four phases involved in the aerobic composting process; the mesophilic phase, the thermophilic phase, cooling phase and the compost maturation phase (Gajalakshmi & Abbasi 2008). The mesophilic phase is the beginning of the process and this is known to be when the microbial activity (organic matter degradation) starts to be effective. The temperature also starts to increase. After the mesophilic phase is the thermophilic phase; it is known to be the most active phase of composting, the fastest microbial activities are experienced at this stage, so also is the temperature increment as most oxygen are consumed. The cooling stage comes afterwards; this stage witnesses a reduction in temperature and microbial activities. The last stage is known as the compost maturation phase then begins as the compost temperature drops to the level of ambient air and this leads to the formation of the matured compost (Gajalakshmi & Abbasi 2008).

## 4.3 Pelletization

The end result of pelletization is Refuse Derive Fuel (RDF) pellets which can be used as fuel feeds for industrial furnaces by replacing coal and also for domestic purposes by replacing wood (Asnani 2006, Zafar 2015). The waste products generated after the process are mostly dust, NOx, sulfur oxides (Sox), CO and $CO_2$ (Louis *et al.* 2011, Zafar 2015). Pelletization process works well with mixed MSW (Asnani 2006). However there would be a need for pre-processing to produce pellets with high quality (Zafar 2015). The pelletization process of MSW is energy intensive and not suitable for wet MSW; too much moisture might require a long drying process (Asnani 2006, Louis *et al.* 2011). Most often, the sorted dry biomass section of MSW (especially that from the wood industry) is used because they produce RDF pellets with high quality (Louis *et al.* 2011). The process involves the drying of the MSW after sorting and then the compression (crushing) under high pressure into the needed size. The calorific value of RDF pellets could be around 4000 kcal/kg. This value depends strongly on the quantity of organic waste present in the MSW feed, the additive used and the binder material used (Asnani 2006, Zafar 2015).

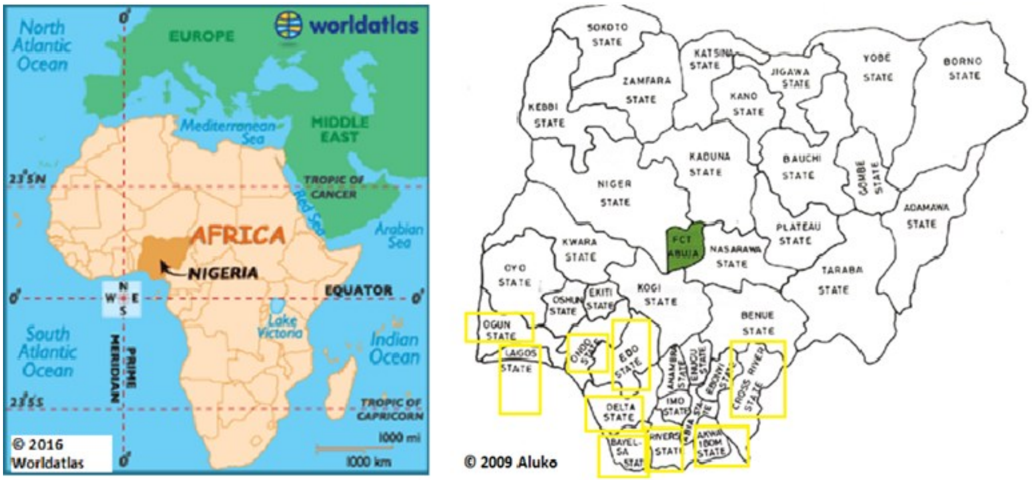
# 5 MUNICIPAL SOLID WASTE MANAGEMENT IN NIGERIA

It is acceptable to claim that MSW and other waste in Nigeria are generated faster than they can be managed; efficiently collected, transported, treated and safely disposed of (Ministry of Environment in Nigeria 2005). The constant increase in population and industrialization should have simultaneously resulted in an increased attention to the protection of the environment and public health but that is not the case. There is a large gap between the protection of the environment and the constant growth of the economy, population and industrialization. There is high negligence in the part of the government when it comes to MSWM. A large percentage of the citizen's also have a lackadaisical attitude towards environmental protection.

## 5.1 Nigeria in a nutshell

Nigeria is located on the Gulf of the guinea on Africa's western coast. It is home to over 180 million inhabitants excluding those in diaspora. The official language spoken is English as the country was colonized by the British. However, there are three other major languages spoken (Hausa, Igbo and Yoruba). The country gained independence in 1960 and has since then experienced both military and democracy system/form of government. The country covers an area space of over 924,000 square kilometers and has two major rivers (River Niger and Benue) that cross across several neighboring countries. Lagos used to be the capital of the country but Abuja became the new capital of the country in 1991. The coastal states of the country are Akwa-Ibom, Bayelsa, Cross-Rivers, Delta, Edo, Lagos, Ogun, Ondo and Rivers from the country's 36 states (Omole and Isiorho 2011, OPEC 2016). These coastal states are the country's all oil producing states except for Ogun state (Omole and Isiorho 2011, Vanguard 2016). The country's primary natural resource is petroleum (which constitutes about 35% of the Gross domestic product – GDP) while it is also blessed with natural gas, coal, limestone and arable land (OPEC 2016). The country experienced a constant 7% annual GDP growth throughout the last decade. However there has been a stagnant economic growth since the end of 2015 due to the global downfall of oil prices and massive effect of past government's corruption (ADBG 2016, Asogwa *et al.* 2016). The petroleum exports revenue accounts for over 90% of the country's total exports revenue (OPEC 2016) and the country remains Africa's largest Oil producer (Africapedia

2016). The GDP/capital is estimated to be about €2,825 (OPEC 2016). As at the 25th of June 2016, the currency of the country is Naira (₦) in which €1 equates to ₦344 (Small world 2016). Figure 14 shows the location of Nigeria in Africa and the 36 states of Nigeria with emphasis on the nine coastal states and the capital city.




(a) (b)

Figure 14. (a) Location of Nigeria in Africa and (b) the 36 States of Nigeria (World atlas 2016).

All of the coastal states except for Lagos, Ogun and Ondo produce lots of petrochemical wastes as a result of petroleum exploration (Omole and Isiorho 2011). Nigeria signed the Bamako Convention in February 2008 but is yet to implement the proceedings of the convention (Terada 2012). The biggest challenges faced by the country are the insecurity in the northeastern (Boko haram) part of the country, corruption, increasing unemployment and income inequality. One of the potentials of the country lies in the growth of Lagos state as it is one of the seven mega-cities in Africa with a high potential for series of industrial activities, innovation and employment opportunities (Asogwa *et al* 2016).

## 5.2 Ogun State in Brief

Ogun state is the closest state to Lagos state and has continuously shared in both the good and ill fortunes of Lagos State. Ogun State has five times a larger land space than that of Lagos and comprises of 20 local governments (16,720 compared to 3,577 $km^2$). Just like major mega-cities around the world, Lagos state is characterized by congestion and heavy traffic, this has made a lot of industries and businesses relocate to Ogun State over the years even though their consumption target is Lagos State (Omole and Isiorho 2011). The growth and development of a cleaner environment in Ogun State would attract more investors to the state more than what is presently experienced. Table 12 illustrates major features of Ogun State.

Table 12: Major characteristics of Ogun state (Omole and Isiorho 2011).

| Category | Characteristics |
|---|---|
| Major economic activities | Brewing |
| | Foam production |
| | Plastic and rubber production |
| | Quarrying |
| | Textile and wood production |
| Rural/Urban ratio | 66/34 |
| Land Area ($km^2$) | 16,409 |
| Estimated Population (2011) | 3,751,140 |

## 5.3 Insight on Municipal solid waste management

MSWM in Nigeria is faced with inadequate data collection, unskilled labor, government negligence, little financial funding, and poor implementation of policies (Awosusi 2010, Ifegbesan 2010). It is very difficult to account precisely the amount of MSW generated annually; only rough estimations exist. Bakare (2016) gives an estimated volume of 3.2 million tons per annum of which all types of waste are mixed e.g. C&D waste, medical waste and MSW. Another problem is that past and present records of collection and disposal are not adequately kept by the responsible authorities (Kadafa *et al.* 2012). A major issue that cannot be overlooked across the country is the problem of scavengers as they alter the composition of MSW (Nnaji 2015). However, they could be used more efficiently as they are presently been used in Lagos State by merging them to fit into the MSWM system. There is also a high lackadaisical attitude of the public towards the environment. No matter how educated they seem to be, even high school students are not aware or are knowledgeable about the environmental issues associated with the improper disposal of MSW. Academic premises (school management) also practice open burning of MSW (Ifegbesan 2010).

Many cities have a poor MSWM hereby the worst option of waste management hierarchy (landfilling) is highly used. Landfilling of all sort of MSW has led to the inclusion of heavy toxic metals in agricultural soils and ground water contamination. In most cities, there is a lack of relevant waste data; past or present (Nnaji 2015).

## 5.4 Sources and compositions of municipal solid waste

In the last two decades, MSW in Nigeria has been increasing in quantity and characteristics. Average value of MSW generation in Nigeria is 0.49kg/capita/day. Different cities actually have different estimated averages of MSW generation as Abuja generates over 0.57kg/capita/day, Lagos with 0.63 kg/capita/day (Nnaji 2015) and Ogun with 0.60 kg/capita/day (Babayemi & Dauda 2009). There is a seasonal variation (mostly up rise) in MSW generation across the country. This change is experienced during June-December as this is the harvest period for agricultural products. Unique growth is notable in December due to a highly celebrated festive period that comes with enormous spending on goods and services (Nnaji 2015).

The major source of MSW across Nigeria is from households, other influential sources are industrial, commercial, educational and agricultural establishments. Major contents of the MSW include unsorted food remains, papers, glass, metals, nylon, clothes, wood, bottles, rubber, plastics, WEEE (Babayemi and Dauda 2009, LAWMA 2016) It is estimated that about 50 percent of the total MSW in Nigerian cities are food waste (Nnaji 2015). With efficient sorting and collection, these biodegradable contents can be collected and recovered into biogas or compost, instead, they are mixed up with hazardous waste contents by scavengers along the collection and disposal chain.

Rising amount of packaging waste is alarming as there is a high use of polythene bags for one of the largest consumer products; sachet water. Though recyclable, only a minor percentage is actually recycled due to the inefficient waste collection system throughout the country. This leads to public dumping which later block the easy passage of wastewater in drainage canals and results also in farmland clogging (Nnaji 2015). Another disturbing MSW content is disposable diapers as they contain substances made from sodium polyacrylate and tend to be harmful (respiratory diseases) if not properly treated or disposed (Nnaji 2015).

## 5.5 Waste management services

Waste management services should involve active waste sorting, waste collection, waste transportation, waste treatment and safe waste disposal. However, these services are not being provided in Nigeria efficiently. Even though Lagos State offers waste collection and waste transportation, the waste treatment services are lacking almost entirely. Some waste recovery operations are available (composting) in Lagos State but not in full capacity. In Abuja, some recycling is being carried out but just by the informal sector with the unrecyclable MSW fractions being dumped at landfills. Effective waste management services would not be fully actualized until all actors of waste management partake and assume their individual responsibilities (Imam *et al.* 2008).

### 5.5.1 Actors in waste management

The documentation of those responsible for waste management in Nigeria exists. The Ministry of Environment in Nigeria has since 2005 provided the guidelines of waste responsibilities at different levels and sectors. Some of the main goals of the policy guidelines are to promote waste minimization at source through re-use, recycling and energy recovery while minimizing final disposal however possible. The ultimate aim proposed by the policy is to privatize the waste sector in order to make it more competitive as this act would develop the sector while also creating more employment opportunities (Ministry of Environment in Nigeria 2005). Also, these policy guidelines have a mission statement regarding MSWM in Nigeria. However, the quantity of MSW to be reduced and the year of achievability have not been included. The effect of this is that, the rate and growth of the development of MSWM in Nigeria might not be rapid.

Another key effort to manage waste in the country led to the National Environmental Standards and Regulation Enforcement Agency (NESREA) Act of 2007. The law replaces the Federal Environmental Protection Agency (FEPA) act of 1988 and the main aim is to protect, monitor and promote sustainable development of the environment and its natural resources (Ijaiya 2013, NESREA 2007). Table 13 summarizes the Nigerian Government's lists of waste actors and their responsibilities at different levels in Appendix 2.

Years after the waste policy guidelines have been provided by the Nigerian Government, the country has still not witnessed a breakthrough towards the practice of an effective MSWM. MSW treatment prior to disposal is not done in any part of the country.

Stakeholders including the government are not paying enough attention towards the protection of the environment in terms of MSWM. There is insufficient funding, no national waste related legislation, no master plan for waste or MSWM at the national level. Lagos State is the only state in the right direction towards an efficient practice of MSWM even though their major MSW operation is MSW collection (LAWMA 2016, Nnaji 2015).

### 5.5.2 Waste sorting

Active waste sorting in Nigeria can be said be nonexistent. In the few states where waste sorting is done, not all households participate. This can be attributed to low material recovery and little recycling of MSW. In Abeokuta (Ogun state), which is located in the southwest of the country, it was observed by Achi *et al.* (2012) that about 56% of the households sort their MSW (due to financial benefits as there is a company that pays for sorted plastic bottles). Ukpong and Udofia (2011) however noticed in Uyo (Akwa Ibom state) that no MSW sorting was done in households prior to disposal. Some sorting activities are experienced in some parts of Lagos State (Wecyclers 2014). Most are plastics bottles, plastic bags and aluminum cans from households while some biodegradable MSW are also sorted in some marketplaces (LAWMA 2016 and Wecyclers 2014).

In order to have an efficient MSW recycling and MSW recovery, there has to be an effective sorting especially at source. Waste sorting can only be achieved by dissemination of adequate information to the public on how to sort and why it is necessary to participate.

### 5.5.3 Collection and transportation of waste

Most MSWM authorities in states where they exist encourage the use of plastic bins to collect MSW followed by waste bags (polythene), paper bags, iron drums and sacks. The choice however largely depends on the characteristics of the MSW, cost, durability and waste collection transportation system (Nnaji 2015). There is a small collection rate of waste in Nigeria in general and this is highly attributed to technical and management failures from MSWM authorities (frequent breakdown of waste collection vehicles and insufficient manpower), poor road network and refusal to pay waste collection tariffs (Nnaji 2015). Nowadays, private firms have found safe haven in waste collection, their collection services are highly efficient but come at a higher cost for waste disposers than the state-owned MSWM organizations (Nnaji 2015). Inefficient waste collection leads to littering and indiscriminate dumping in the country as waste producers are in haste to dispose large quantities of waste to prevent offensive odor and insects (Nnaji 2015).

Research conducted by Babayemi and Dauda (2009) in Abeokuta (Ogun state) found out that 49.8% of 201 respondents did not have access to collection services in their area of residence. An active MSW collection system does not exist in all the 36 States except in Abuja, Port Harcourt and Lagos State.

In Lagos for example, waste collection frequency depends on the collection agreement made between the waste disposer and Lagos Waste Management Authority (LAWMA) but most waste is picked up once a week. The system of waste collection practiced in the whole of Lagos is door-to-door. (LAWMA 2011). A 240 liters bin is provided for every household in Lagos after the annual payment of the land use charge through the land records company (Iriruaga 2012). Agboje *et al.* (2014) discovered that a waste collection crew consisting of a driver and 2 or 3 other members per truck in Lagos State were mostly uneducated and received a monthly salary of ₦ 7,000 (€19) to ₦ 30,000 (€81) depending on the service providers.

### 5.5.4 MSW treatment

About 80% of residents in Nigerian cities (apart from Abuja) dispose their waste by unauthorized open dumping, burying, burning and other unconventional means (Nnaji 2015). Most city authorities in Nigeria have created open waste dumpsites due to manage MSW properly. These dumpsites are however characterized with long distances far away from communities and since the MSW collection pattern is not reliable, residents dump MSW in illegal open grounds/any free land available e.g drainage canals, unused railway tracks and roadsides (Nnaji 2015). These open dumpsites and/or landfills lack the necessary or modern requirements of landfills which would have resulted in the protection of human lives and the environment. The surrounding areas of these dumpsites are characterized by frequent odor, surface and ground water contamination, rodent activities and smoke from constant refuse burning.

## 5.6 Recovery rates and recycling of wastes

In most Nigerian cities, recycling and recovery of waste is done by the informal sector (scavengers or itinerant waste buyers) and that makes the availability of a comprehensive data of recycling and other waste recovery methods quite impossible (Iriruaga 2012). In Lagos state, there are three major landfills and two temporary sites of which from the 9,000 metric tonnes of waste generated daily only 1,200 tonnes of this waste is converted to useful forms; compost (250 bags of 25kg on daily basis), paper bailed, recycled plastic and paper. This is achieved with the participation of private sectors (LAWMA 2016). Also in Lagos State, there is a waste to energy plant at Ikosi market that generates biogas by using the market waste. The biogas produced is used to operate a 2KVA generator at the same market (Iriruaga 2012). There is an ongoing waste tire recycling to oil in Lagos State. 1 ton of waste tire costs about 40.93€ while the generated waste tire crude oil could be sold out at 510€/Ton and 1 ton of the tire metals is sold for about 292€ (Henan Doing mechanical Equipment Company 2015). In one of the landfills utilized by Lagos State, it is said that the collection of LFG exists but the information about the amount collected or used is not available.

## 5.7 Economic instruments and municipal solid waste management

The employment potential of waste management is not fully utilized in Nigeria, as of the 36 States, only Lagos State has been able to use the waste management sector for proper job creation (Iriruaga 2012). As of 2015, LAWMA has been able to create about 25,000 jobs (News Agency of Nigeria 2015). The Federal Government of Nigeria allocated over 66 million euros to the Ministry of Environment for 2016. However, the main aim of the allocation (at least 10%) is to be used for the Oil spillage clean up in the Niger delta region (Vidal 2016) while the growth and development of waste management in the country is not the top priority, at least, according to this year's Environmental budget.

### 5.7.1 Waste charges and taxes

At the time of writing this thesis, waste charges are available only in Lagos State. Lagos State through its Private Sector Participation (PSP's) charge waste disposers ₦200 (0.53 cents) per room, ₦750 (€1.99) per flat and ₦ 300 (0.79 cents) per shop. These charges came into effect in late 2014 and were the first time there was an increment in more than six years (Babatunde 2014). These charges in the real sense are not enough to carter for all the services of an effective MSWM. Hence, there is a need to review this amount for the state government to provide all the services of a MSWM. The problem this review might face is the high poverty level in the country as this could lead to waste generators disposing waste to any open and free land available.

### 5.7.2 Producer responsibility and waste electrical and electronic equipment

Launching Producer responsibility strategy in Nigeria is still an ongoing plan that was estimated to be functional in the first quarter of 2016. One of the major problems has been the slow response of multinational companies to create an EPR plan for their products. However, the government has been able to formulate operational guidelines of the EPR policy on both locally made and foreign products. The main aims of this policy are to eradicate hazardous products, control trans-boundary movement of sub-standard products in and out of the country and enforce quality standards of goods and service in order to protect human lives and the environment (Anukum 2015, George-Adagbo 2015). Companies subjected to this EPR plan are those that produces products and/or packaging materials such as aluminum, batteries, chemicals, ELV's, glass, paper, pesticides, pharmaceuticals, plastics, tetra pak, tin, tires, steel and waste electronics (Iyiola 2016). For the EPR to be active, dissemination of consistent information to the public is important as they are the product uses and waste generators. It is also paramount that the EPR system is used as a waste prevention tool.

In the last decade till date, Nigeria remains one of the fastest growing telecom markets in the world. These devices are not produced within the country and therefore are mainly imported. Recovery of WEEE should be the responsibilities of the importers. However, most of the devices are not catered for once they are disposed by their users and since there are no electronic recycling facilities in the country, WEEE end up in landfills mixed with other MSW contents (Ongondo *et al.* 2011). Also, Nigerians import different used electronics from the United States (45%) Europe (45%) and Asia. However, it has been estimated that from the estimated 500 containers that are imported every month, over three-quarter of them is WEEE materials that can barely be re-used which find there ways in landfills in large quantities (Terada 2012). It is still very unclear why the country has not yet actualized the objectives of the Basel Convention as this could be a major way to control the importation of WEEE (Terada 2012).

## 5.8 Possible future trends of municipal solid waste management

Since over 50% of the MSW generated in Nigeria are biodegradable waste, there is a high possibility of compost and biogas production once the MSW can be efficiently sorted (Nnaji 2015). MSWM could develop rapidly in Nigeria but this is only possible if the public develops a positive attitude and awareness towards environmental issues and practices (Ifegbesan 2010). The country could develop a legal instrument and other national legislations aimed at regulating the importation of EEE and WEEE by implementing the Basel Convention once there is concern by the Federal Government of Nigeria (Terada 2012).

# 6 NEEDS ANALYSIS FOR MUNICIPAL SOLID WASTE MANAGEMENT IN OGUN STATE

Majority of the waste volume in each state of Nigeria is food waste (Kadafa *et al.* 2013). Hence, the framework would excessively mandate pellet, compost and/or biogas production (waste recovery) from biodegradable MSW. However, they should be mapped out plans on waste prevention plans with clear targets on how to reduce waste in general most notable the biodegradable MSW section. As at 2016, Ogun State is not one of the 5 states in Nigeria that has any waste management legislations or plans, that shows how important it is to develop one within the next few years.

To achieve a functional MSWM system, the first step would be to define the term MSW and its characteristics. This would simplify the whole MSWM process. For example, the exclusion of certain hazardous waste products, tires, hospital waste, WEEE, C&D waste and batteries from the group of MSW features would provide a high level of recycling or material recovery of the sorted MSW materials. The framework structure of the Ogun State MSWM would adopt the order of the waste management hierarchy, the principles of sustainable development and integrated solid waste management approach (UNEP 2005). The comprehensive framework needs to:

- Provide waste reduction/prevention instruments that are principally aimed at achieving the continuous reduction/prevention of the quantity of MSW in Ogun State over time. This should also aim to reduce the quantity of harmful substances in materials and products that are produced in the State which are difficult to recycle e.g. plastic bags and polystyrene (Rogoff and Ross 2016, UNEP 2005).
- Provide information which would enhance the re-use of MSW products by both waste producers and business entities. This can be achieved by a comprehensive plan focused on continuous public education of the citizens and the enforcement of responsibilities through the EPR system (UNEP 2005).
- Provide information that would enhance a recycling plan aimed at the recycling of papers, packaging waste, plastics, WEEE, glass, ELV's, compost production (organic waste) and recovery of materials to be used as direct or indirect raw material inputs for the production of new products (UNEP 2005).
- Provide information that would enhance MSW treatment and energy recovery process options suited for energy and biodegradable waste contents.

- Provide information that would lead to reduction of waste volume prior to disposal (UNEP 2005).
- Provide information that ensures the disposal of residual MSW in an environmentally sound manner generally in landfills (ensuring that the landfills have the modern technical requirements to protect the citizen's health and the environment).

The needs mentioned above would be addressed in the next Chapter by following the structural pattern in Figure 15 below. The MSWM framework would have 4 sections; the financial aspect, identification of key stakeholders, operational elements and continuous educational awareness.

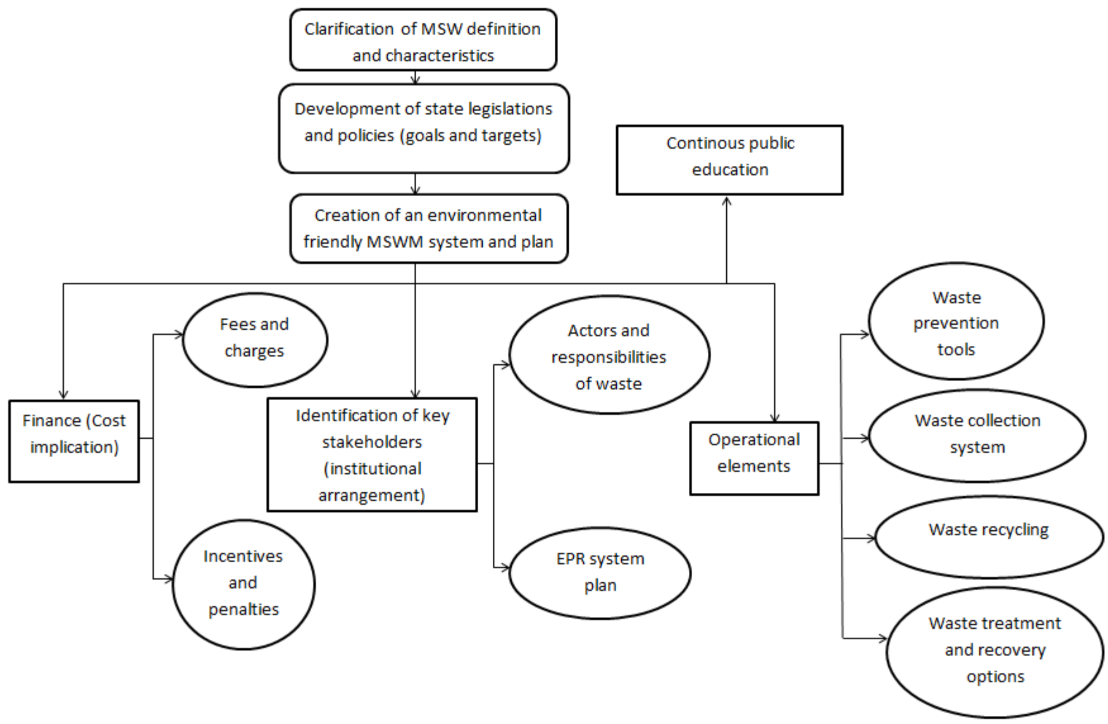



Figure 15. The structural framework for municipal solid waste management in Ogun State.

One of the major determinants related to the success of any project is the cost implication attached to realizing the project. Effective MSWM is very costly, hence it is crucial to have a well-structured plan on how to fund and maintain the project. The corruption that exists in developing countries makes it seem difficult to finance an effective MSWM. However, once the government becomes more transparent and interested in environmental protection, the investment needed to carter for an effective MSWM would be generated. The proper distribution and understanding of roles and responsibilities by each stakeholder would not only simplify the MSWM practice but also lead to rapid development of the sector. The operational elements attached to MSWM are a very diverse tool that should be understood by the citizen's and this can only be achieved by continuous public education and awareness. The effect of a sound continuous public education towards the advantages of practicing an efficient MSWM would result to the protection of human lives and the environment.

# 7 FRAMEWORK DEVELOPMENT OF MUNICIPAL SOLID WASTE MANAGEMENT IN OGUN STATE, NIGERIA

The proposed framework starts with a profound definition of MSW and well-detailed explanation of the characteristics of MSW. This is important to ensure effective MSW re-use, recycling, treatment, recovery and disposal. The MSW definition below is suggested to be adopted for Ogun state:

*MSW means all refuse waste fractions from households, in addition to similar waste fractions that are disposed from industries, commercial establishments, construction and any other sector within the municipal system. Examples of wastes in the category of this above definition include; food waste, furniture, garden waste, glass materials, metals, paper, paper board and paper products, plastics, street sweepings and textiles* (European Statistics 2016).

This definition and its characteristics should be presented in a waste legislation. It is crucial that the legislative piece would highlight clear future goals, achievable targets, the waste management approach, activities and environmental permits procedures for waste related activities. According to Fischer (2013) highlighting the above information has been one of the tools that had positively influenced an effective waste management development in Finland. The legislative piece should also present strict penalties for violators; this would act as one of the waste prevention tools. An important scheme that should follow the legislative piece is a MSWM plan that gives an in-depth clarification of aims and objectives to be achieved, waste prevention tools and measures of achieving them.

## 7.1 Finance

The financial aspect related to MSWM has been a significant factor hindering the development of MSWM in developing countries. MSWM cost of operation is expensive and if the state is not able to bear the full cost of the project they can solicit for funds and/or incentives. Just like LAWMA, Ogun state can partner with local, foreign organizations and NGO's such as Clinton foundation, USAID (United States Agency for International Development) and UNDP (United Nations Development Programme) to provide funds and/or incentives for the development of their MSWM (LAWMA 2016).

### 7.1.1 Fees and charges

Fees to be collected from waste producers (households, companies etc.) should be sufficient enough to carter for each service of MSWM; waste collection, waste transportation, waste treatment and waste disposal. Therefore, It would be important to present a waste fee that corresponds with the ₦ 18,000/€54 minimum wage. However, the waste fees currently collected by Lagos State (₦200 (0.53 cents) per room, ₦750 (€1.99) per flat and ₦300 (0.79 cents) per shop) is not enough to carter for all the services of an efficient MSWM and should not be adopted.

Also, waste taxes and fees are aimed at reducing the amount of waste to be landfilled. In order words, they act as a waste prevention tool as they encourage the re-use, recycling and waste recovery of MSW. The waste taxes and fees should also be high enough to achieve its aim as a waste prevention tool and also be able to carter for the services of the MSWM. They should have different ranges of the waste fees and taxes depending on the volume and characteristics of the MSW.

### 7.1.2 Incentives and penalties

The introduction of incentives has enhanced recycling in Finland, especially in the recycling of plastic, cans and glass bottles. This is done in the form of deposits to citizens once they return the items for recycling. This approach should be adopted in Ogun State as it would positively influence on citizens for participating in recycling. Apart from introducing this idea to large manufacturing industries in the state, this can also be proposed as a nationwide project as this would start the needed reforms in the mind of the people towards environmental protection through recycling participation.

There should be penalties attached to violations of the planned MSWM activities most especially for illegal dumping of MSW. These penalties should be addressed to businesses, domestic households and individuals. The lower volume of illegally dumped MSW should attract minor costs while the higher volume attracts higher cost and most likely some civil service activities. The refusal to pay for MSWM services should also be made an offence and should apparently draw penalties. The stated penalties should be inscribed in the legislative piece. For example, there should be a total ban on dumping of MSW with a fine of ₦100,000 (€290) for households and ₦250,000 (€726) to companies for both State and National level.

## 7.2 Identification of key stakeholders

Profound information about roles and responsibilities of stakeholders would enhance the effectiveness of any MSWM. A clear statement needs to publish on who answers to what and how. Each stakeholder either through a top-down or bottom-up approach needs to understand its roles, responsibilities and at what stage. One of the crucial importance of identifying key stakeholders as resulted to the EPR system in the developed world. This EPR has turned out to become one of the key fundamentals of MSWM must especially in MSW recycling.

### 7.2.1 Actors and responsibilities of waste

One of the most crucial actors in a MSWM system is the waste disposers. Their mandatory responsibilities for the state should be to prevent waste however possible, sort there about to be disposed waste and pay for the services of the MSWM. Their optional responsibility should be to partake in the decision making of environmental related issues. Product manufacturers or PRO's should be mandated to produce an EPR system, most especially for companies that produce large scale aluminum, batteries, chemicals, ELV's, glass, paper, pesticides, pharmaceuticals, plastics, tires, steel and WEEE which are produced locally or imported. Some crucial responsibilities to be included to actors in Table 13 are presented in Table 14.

Table 14. More responsibilities to be added to the present Actors of waste in Nigeria.

| Actors | Stages | Major roles and responsibilities |
|---|---|---|
| The Federal Government of Nigeria | National level | Mandate the Ministry of environment to establish a National plan with clear future targets, especially on the reduction of biodegradable MSW. |
| | | Mandate the establishment of the EPR scheme as soon as possible. |
| Ministry of Environment | National and International level | Establish a National Waste Plan and monitor the compliance of the plan throughout the entire country. |
| | | Develop waste related legislations and provide technical support to States and local governments. |
| State Government | State level | Provide plans on how best to tackle waste problems in their respective states. |
| | | Provide incentives to scavengers and small and medium-sized enterprises (SMEs). |
| NESREA | | Merge with the Ministry of Environment to share information and adequate resources (a subordinate of the ministry). |

### 7.2.2 EPR system plan

The EPR system should be made formulated in a way that product manufacturers or PRO's would not only focus on the downstream (collection, recycling and treatment) end of life stage. They should make a 50% focus on the upstream (manufacturing sustainable products, reduction of material usage during the production of products which results to waste prevention and less usage of hazardous materials) stages of their products lifecycle. Major waste materials that should be subjected to the EPR system include WEEE, batteries and accumulators, tires and ELV's.

Nigeria imports a large volume and wide variety of products on daily basis. A significant portion of which is electronic devices. However, majority are already WEEE by the time they are imported into the country. In the quest to reduce this generated WEEE, it would be of paramount importance to ensure that imported EEE are in good working conditions in accordance to the EU regulation 1013/2006 on shipment of waste and the Basel Convention. For the large domestically produced products that would fall within the category of the EPR system, the manufacturers should be required to make a logical EPR plan that would result in a future circular economy. One of the main reasons why the EPR system in developed countries has been effective is due to the existence of other environmental policies followed by the citizens (both product manufacturer and waste producers). Such laws include those that have been mentioned in Chapter 2.1, 2.2 and 2.3. This makes it necessary for both the state and national authorities to understand that the success to be recorded with the EPR system is related to the creation of other environmental policies.

## 7.3 Continuous public education

Citizen's environmental literacy on why and how to participate in the protection of the environment is a significant tool in the waste management of any country (European Commission 2005). It is one of the most significant waste prevention tools that developing countries need to invest in continuously because only when the citizens are aware of the problems, then they can help provide solutions.

An effective MSWM needs time to develop and one of the key factors that determine how fast or slow the development would be is the citizens attitude towards the plan of the government. The change in attitude would however take time to develop and that is the reason why proper quality planning is needed. The crucial results will be achieved by focusing on adults must especially on those who have not developed that environmental responsibility from childhood. The awareness plan would inform them on why and how they should participate in waste management activities, the advantages of their participation towards the protection of human lives and the environment, the link between their daily consumption pattern of products and how it negatively affects the environment if the waste outcome is not properly treated. The result of this continuous public education would gradually lead to the reduction of open waste burning into land and water bodies, increment in citizen's participation in decision making of waste related activities and general improvement of MSWM practices.

Planning for the future is essential for development. Hence, it would be necessary to invest in kids by providing them with different forms of advertisement that would develop their curiosity towards the protection of the environment as they grow. Their curiosity towards questions and the events around them would help them and their immediate society/community to participate in MSWM.

## 7.4 Operational elements

The operational elements of the MSWM are the main services that are involved in MSWM. Waste prevention tools are schemes to be carried out by both product manufacturers and waste producers in order to prevent waste generation. In the situation of Ogun State, the producer-consumer chain of biodegradable products requires effective waste prevention plans. Waste collection is meant to be carried out by the state government after waste producers have paid for the waste collection operations. The recyclable MSW materials are recovered as material while most of the non-recyclable MSW materials are treated and/or recovered as energy.

### 7.4.1 Waste prevention tools

Waste prevention is the most favored option in the waste management hierarchy; hence, plans should be developed on how waste in the state would be reduced. For this to be achieved, the compositions of MSW in the state would need to be accurately studied. Another important tool to achieve waste prevention is considering where these wastes are generated and at what percentages (households, businesses etc). Also, product manufacturers within the state and the country should endeavor to produce more products that can be easily re-used, recycled and/or recovered. Waste producers through their purchasing power should limit the excess purchase of goods and services (most especially biodegradable products as there is constant unstable electricity in the country presently) while at the same time, buy more of environmental friendly products.

Another important waste prevention technique can be aimed at producer-consumer food chain. The objective of this is to reduce the amount of biodegradable waste that is generated along that distribution chain. This can be targeted to restaurants and markets.

### 7.4.2 Waste collection system

Coherent and comprehensive MSW sorting is the starting point of an effective MSWM once the MSW has been generated. The bridge between MSW materials and effective recycling, treatment or recovery is the waste collection system. Waste collection cost is up 70-90 percent of the total MSWM costs (USAID 2004). Two options are applicable for the type and size of waste collection bins/containers to be used; surface collection and deep collection containers. The type and size to be used would depend on factors such as the annual temperature of the state (since temperature would influence the characteristics of biodegradable MSW), cost of procurement, capacity intake and odor eradication. For a proper waste collection system, it would be important to know how much MSW is accurately generated per capita in the state. This would review the contents of the other 50% composition of MSW generated in the state since about 50% is biodegradable waste. However the case, it would be important plan to have a separate collection bin for biodegradable MSW and other MSW sections such as mixed waste, energy waste.

Separate collection techniques would enhance high recycling and energy recovery while simultaneously reduce landfilling of MSW. However, it would not be economical to mandate more than two waste containers for every household. Therefore the state would have to consider if there should be a need for waste reception points in every street for some MSW components. This collection points would be majorly influenced by number of households in each street. A post collection garbage separation is necessary to boost recycling and recovery.

### 7.4.3 Waste recycling

To develop a recycling scheme for sachet water bags, plastic bottles and cans, the state government should invest in a center that recycles the above waste materials in large quantities. For example, plastic bottles made from polyethylene terephthalate (PET) could be recycled to manufacture consumer items (Stan Edom 2016). This would lead to a high growth of recycling while simultaneously protecting the environment and serve as an opportunity for employment creation.

### 7.4.4 Waste treatment and recovery options

The non-recyclable MSW materials should be treated and/or recovered with the BAT (Best available technology). The recovery options of pyrolysis, incineration and gasification could be used individually or combined in an integrated approach. However the case, paramount factors that would influence the options to be chosen would be the cost price attached to procurement, by-products due to recovery process, maintenance and availability of skilled personal. The biodegradable MSW can be subjected to compost or biogas production (electricity). The large scale production of biogas from biodegradable MSW in the 36 states of the country would help provide some of the needed electricity supply. Nigeria presently needs 160 gigawatts (Gw) to carter for its citizen's demand but as at January 2016, the country is only able to provide 5Gw (OGTV 2016).

The technical requirements for landfill structures and operation used by Finland can be adopted to update the current conditions of 6 major dumpsites in Ogun state. These technical requirements were presented in the latest EU Directive 1999/31/EC on the landfill of waste. Some of the essential requirements include:

- Classification of landfills to know the characteristics of its intake. Landfills could be classified into three classes: hazardous waste landfills, inert landfills and MSW landfills. The main reason for this classification is that it enhances LFG utilization since the MSW landfills have been separated from inert and hazardous waste intake.
- Protection of the surrounding environment (surface water, groundwater and soil structure) and human lives by structural liners and leachate treatment systems.
- Restriction of the dumping of liquid waste, used tires and flammable waste from landfills.

Proper adoption of the above requirements would lead to the closure of landfills that do not meet up with the technical requirements. The closure would help to reduce the amount of GHG emissions generated in the state. Adequate clean-up operations should be done on the closed landfills to reduce or eliminate existing contaminations to surrounding land and water bodies. Landfill gas to energy (LFGTE) could be a practice necessary for waste recovery for the State, at least they would answer for some electricity demand in the state. However, the idea of LFGTE should not be considered as a reason to dump untreated MSW in landfills as waste disposal is the least favored option in the waste management hierarchy. The LFG utilization design structure in Chapter 3.7 (Figure 9) could be adopted.

## 7.5 Framework application

The most realistic approach to start and develop an efficient MSWM based on the present situation faced by the State would be to apply a slow but steady approach on a scale of preference order. In consideration of the MSW development phases illustrated by Goran *et al.* (2015) and Figure 7, Ogun State is divided into 4 zones for administrative purposes. Each zone consists of 5 local government areas. Also, the division was necessary in order to adequately capture every volume of MSW in the state. The separated zones are illustrated in Figure 16 below.

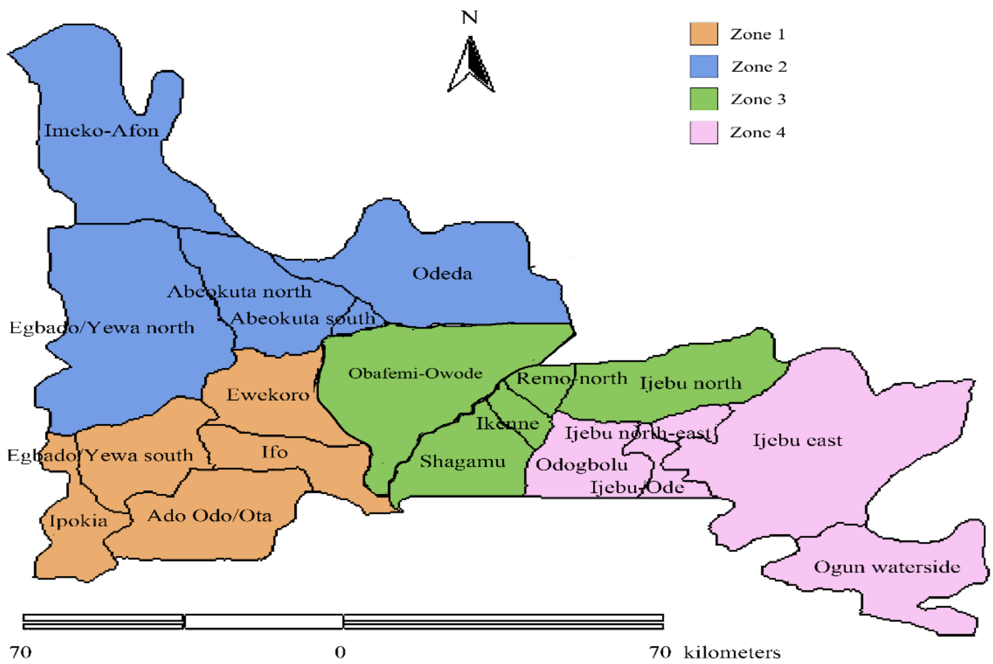



Figure 16. Separation of Local government areas in Ogun state into 4 zones (Shotuyo and Oduntan 2013).

Researches have concluded that waste collection is a continuous problem being faced in developing countries due to insufficient planning (Bakare 2016, Nnaji 2015). Plans based on achievable targets, recovery options, and efficient treatment can only be possible when there is accurate knowledge about the actual composition and volume generated in the State. The characteristics of each zone in terms of population and space area are presented in Table 15.

Table 15. Classification of local government areas of Ogun State into zones (Ogun State Government 2016, Omodele *et al.* 2014)

| Zones | Local Government Area | Estimated Population (Based on 2006 population) | Land Area ($km^2$) |
|---|---|---|---|
| Zone 1 | Ifo, Ado-odo/ota, Ipokia, Yewa south and ewekoro | 1,440,228 | 3,251 |
| Zone 2 | Yewa north, Imeko Afon, Abeokuta north, Abeokuta south and odeda | 825,406 | 6181 |
| Zone 3 | Obafemi-owode, remo-north, ikenne, shagamu, Ijebu-north | 950,345 | 3334 |
| Zone 4 | Ogun waterside, Ijebu-east, Ijebu-ode, Ijebu-north-east and odogbolu | 535,161 | 4085 |

It is estimated that the State generates about 2250 tonnes/day (821,250 tonnes/year) based on the 2006 population census (no concrete information based on the present population). The present population of the whole State in general should have increased tremendously by now. However, the zone separation can be utilized. The entire state in the 4 different zones would need 45,000 deep containers of 1300 liters each. The calculations for the amount of waste generated and the amount of waste containers is in Appendix 3. Estimations were made on the length and population density per acre of each street (street network) as no information is available. Calculation based on the distance of waste to landfill was omitted. The decision to make use of deep containers is due to the characteristics it upholds which can be found in Table 8.

The frame application as three phases Goran *et al.* (2015);

- Phase 1: Prioritization of waste collection

- Phase 2: Prioritization of biological treatment of biodegradable waste
- Phase 3: Prioritization of recycling and waste incineration (waste recovery)

Each phase as its listed tasks based on the Action priority matrix. The time period of each phase is 20 months and all phases simultaneously operate in all four zones. Total cost implication attached to the procurement of containers in all four zones is €13,500,000 (if the containers are produced in the Nigeria, there might be a one-third reduction in the price). The total number of trucks needed for the four zones is 478 trucks (this would eventually depend on the amount of trips allocated to each truck and the distance of waste containers to landfills or recovery plants). The cost implication of the 478 trucks is €21,043,950 for the four zones. The calculation is summarized in Appendix 3.

### 7.5.1 Phase 1

Based on the logical MSW development phases concluded by Goran *et al.* (2015), Phase 1 prioritizes waste collection above all other issues the State might be faced with. This would ultimately result to the control of improper waste disposition and open waste burning. At this phase excessive waste sorting is not needed except for those the citizens are sorting for the SME's. The prioritized action and steps in phase 1 is illustrated in Figure 17.

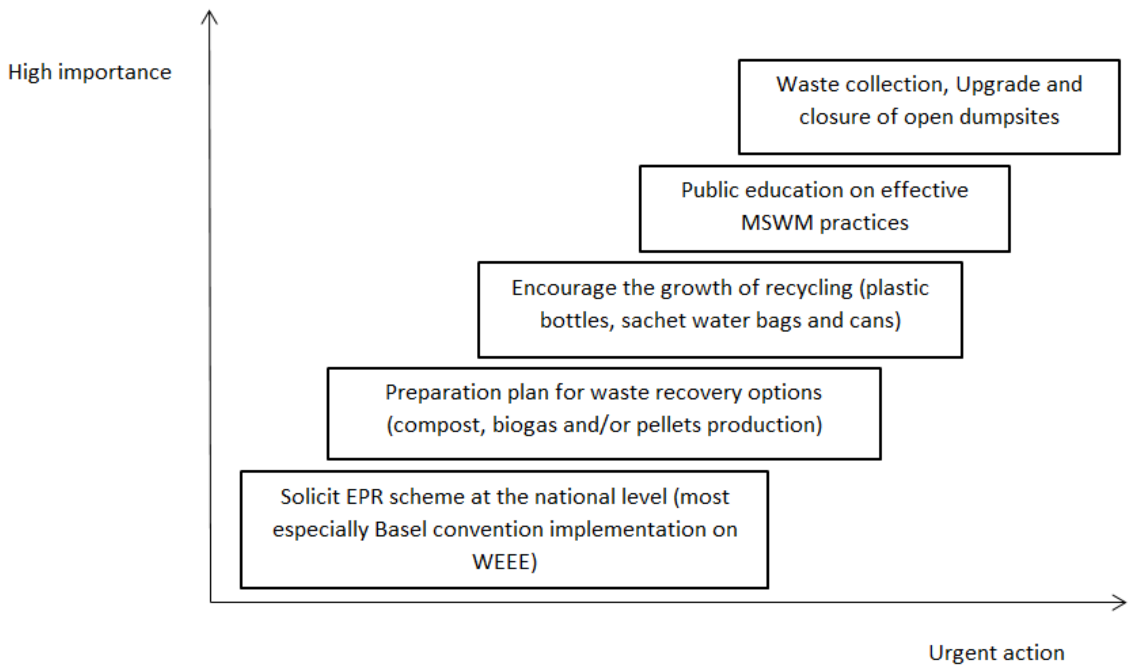



Figure 17. Details of action steps in prioritized order of phase 1.

The next prioritized step after waste collection would be to start the dissemination of adequate public awareness on the reasons and how to participate in MSWM and the ill effect of improper MSWM practices. The awareness plan should be an elongated informative piece clearly stating future aims and objectives. Recycling of plastics, water sachets and cans should be encouraged by providing financial and equipment assistance to SME's (scavenger's) in the zone. The next step would be the preparation plan of waste recovery options (compost, pellet and/or biogas production). The last issue in phase 1 would be for the State to initiate plans with the national environmental body to implement the EPR scheme on both locally and imported goods. Calculations of waste containers, trucks and cost implication of each zone for phase 1 are summarized in Appendix 3.

**Prior framework application of phase 1**

There are some fundamental tools to be put in place before the commencement of each phase. These tools are necessary as without them, phase 1 might not be able to achieve its aims and objectives. The tools to be carried out before phase 1 application include:

- Introduction of legislations and waste management plan
- Location of 3 largest open dumpsites in the 4 zones that could be classified into the three classes (MSW, inert and hazardous) of the Finnish landfill classification in the nearest future
- Partnership and financial assistant to Scavengers and SME's
- Procurement of additional small vehicles and tricycles to assess inadequate road networks for SME's and scavengers

Some of the solicited funds mentioned in Chapter 7.1 could be used in the procurement of mini waste trucks and tricycles. It is also possible that these funds could be used for alternative procurements or needs. However the case, the funds should be used in a prioritized order of equipment's needed to solve waste management issues. Figure 18 illustrates some procurement that could aid waste management practices of the SME ventures.


Figure 18. Simple waste management equipment's to aid small and medium-sized enterprises activities (Alibaba 2016, Wecyclers 2016).

**Achievements at the End of Phase 1**

The accomplishments under listed below depend largely on the prior framework application steps listed above. If the prior steps are not considered before the phase 1 application, there might be slight differences in the overall achievement after the end of phase 1. The results based on prior application steps are:

- The upgrade of selected dumpsites to the technical requirements suggested in Chapter 7.3.4. One of the selection criteria's would be the presence of adequate LFG.
- The landfill classification into the three options as mentioned in Chapter 7.3.4 would be ongoing
- The non-selected dumpsites would have been closed down in all zones (commencement of treatment on the closed sites would begin)
- The waste collection scheme would have collected at least 90% of generated waste in all zones.
- The plan on compost and biogas recovery operation would commence.
- The recycling of at least 82,131 tonnes/year of plastic bottles, sachets and cans by scavengers and SME's in the whole state which is 10% of the total waste generated.
- The growth of SME's and increased participation in citizens in MSWM would create job opportunities.

### 7.5.2 Phase 2

Phase 2 prioritizes waste sorting especially for biodegradable waste which reduces the amount of biodegradable waste sent to MSW classified landfill. The benefits of this prioritized task leads to the reduction of the amount of methane produced in MSW landfills, reduction in the deterioration of human health and the environment. The prioritized action and steps in phase 2 is illustrated in Figure 19.

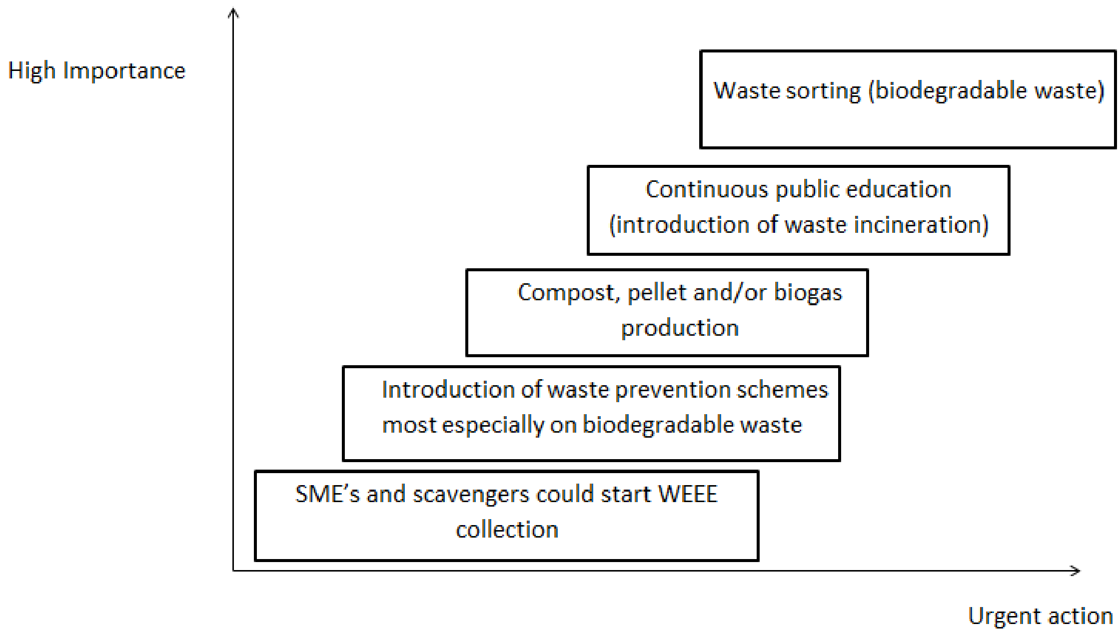



Figure 19. Details of action steps in prioritized order of phase 2.

The next step would be to continue the public education from phase 1. At this stage, the public education would introduce waste incineration activities (its advantages and disadvantages). Compost, pellet and/or biogas production would also commence depending on which of them has the highest market demand. Waste prevention schemes on reduced waste generation should be introduced with a major focus on the reduction of the volume of biodegradable waste.

With the plans and steps from phase 1, the SME's should have made enough capital to convert their establishments into PRO'S of imported products must especially for WEEE. That is if the EPR scheme is active before the commencement of phase 2. However, if the EPR scheme is still inactive yet, the SME's should broaden their collection and recycling activities towards the collection of WEEE. No additional containers are needed to be purchased. Three out of the existing six containers in each street can be converted to biodegradable waste collection containers. Calculations related to phase 2 are summarized in Appendix 4.

**Prior framework application for Phase 2**

Also, there are some fundamental tools to be put in place before the commencement of phase 2. Just like in phase 1, these tools would aid the aims and objectives of this phase. The tools to be carried out before phase 2 application include:

- Construction of centralized compost/pellet plant at least two months before the start of phase 2 or
- Construction of anaerobic digester for biogas production at least two months before the start of phase 2
- Readily available market for compost, pellet and/or biogas

**Achievements at the end of Phase 2**

Just like in phase 1, the achievement level of phase 2 depends largely on the prior foundations laid before the commencement of the action steps of phase 2. The most significant achievement is that 50% of MSW waste produced annually, mostly biodegradable waste (1012 tonnes/day = 369,594 tonnes/year) is averted from landfills, and this would have enhanced GHG production. Others include:

- Source of income for the state, returns from compost, pellet and/or biogas sales
- Increased citizen's participation in MSWM

### 7.5.3 Phase 3

Phase 3 prioritizes waste incineration or any other form of waste recovery options for energy waste. For this phase to be successful, the EPR scheme system should have been implemented in the country. The EPR scheme would enhance the separation collection of WEEE, waste batteries and accumulators and other waste materials mentioned in Chapter 7.2.1

Either the singular usage of any of the options or the integrated usage is allowed. The most significant factors that would determine the option to be used would depend on the cost of procurement, availability of skilled personnel and the by-products usage or control. The prioritized action and steps in phase 3 is illustrated in Figure 20.

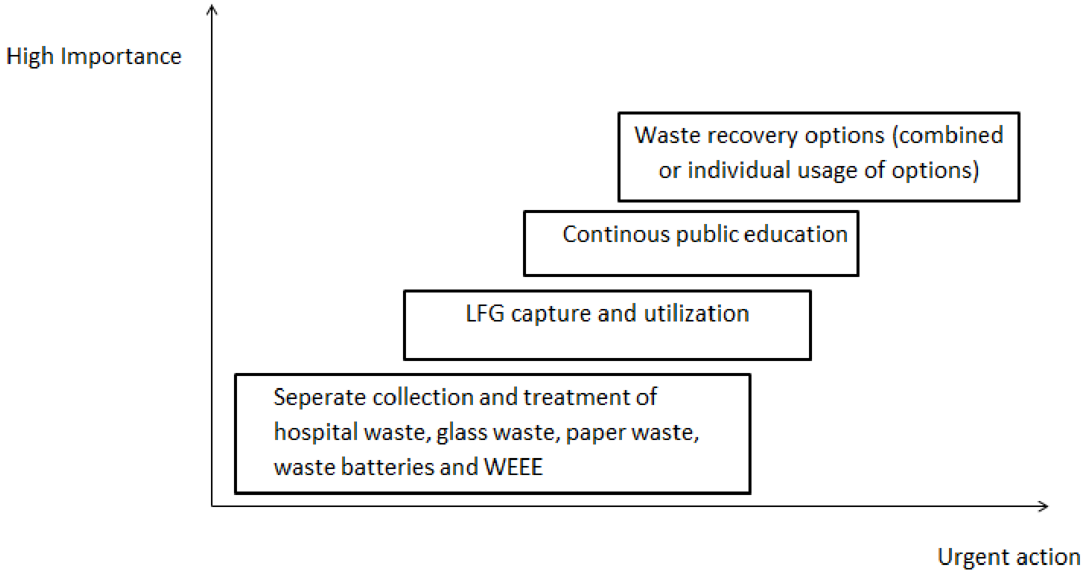



Figure 20. Details of action steps in prioritized order of phase 3.

The continuous public education continues as the next prioritized step. This should entail the future plans and continuation of the awareness campaign from phase 1 and 2. LFG capture and utilization is also implemented at this phase. An available market should be ready to utilize the electricity. It is important that the State considers necessary lessons learnt from the mistakes of developing cities/countries that ventured in the LFG capture and utilization. The next step is the separate collection and treatment of EPR subjected waste materials.

**Prior framework application of phase 3**

The most important tool needed to make this phase a success is the implementation of the EPR system throughout the country. This would enhance the separate collection and treatment of waste materials subjected to the EPR scheme. Other critical phase 3 prior steps include:

- Completion of waste recovery plants at least two months before the commencement of phase 3

- Depending on the choice of technology. They should be an available plan for by-product usage

**Achievements at the end of Phase 3**

At the end of phase 3, this is the end of all phases with a time frame of 60 months. The State would have been able to achieve an effective MSWM system that would continue to develop and grow. The achievements of the action steps in phase 3 include:

- Landfilling of any waste composition without prior treatment would have reduced tremendously
- Very high public participation in MSWM
- Intensified recycling for both biodegradable and non-biodegradable waste
- Energy recovery and sale

# 8 DISCUSSION

Any MSWM framework development plan for developing countries/cities should consider how to effectively merge scavengers and SME's into the MSWM system. The scavengers are too many to be neglected. The growth and development of a MSWM system for developing countries would be time consuming without an EPR scheme. This is a very essential tool needed to control the movement of WEEE into their countries.

The standard of living in Nigeria needs to be improved in order to ensure a speedy and effective MSWM system. The low minimum wage in the country would continue to hinder effective MSWM practices because the cost attached to an effective MSWM (proper waste collection, waste treatment, waste recovery and waste disposal) is very high. The present wage makes it difficult for waste producers to pay the actual waste fees required to cover for all the expenses attached to each service of an effective MSWM.

A new population census is required and realistic estimation of population growth in the country in order to make adequate future plans for MSWM both for the state and at the national level. This would enhance the future realistic MSWM targets. There is also need for a continuous public education on environmental protection as only this would change the people's attitude from their present inappropriate habits.

The Ogun state government would be making a good decision in investing in MSWM as this would enhance the protection of human lives, the environment, and creation of job opportunities. The capital return of investment would be gotten through tax collection on the job created, sales of recoverable MSW products, sales from compost and/or biogas production (there is also a bright future in the recovery syngas in Ogun state). The state government should ensure that waste employees are well paid, this would encourage them to be diligent at work.

The present open dumpsites both in Ogun State and around the country need to be upgraded based on the technical requirements presented in this thesis work. Also, there is a need for a national waste management plan as the contents/characteristics of MSW as evolved (the MSW of today contains more hazardous contents as a decade ago). It is important that this plan has clear and specific targets. The ministry should also consider the implementation of individual legislations to address some specific MSW sectors with high hazardous contents e.g. WEEE, ELV, batteries etc. These legislations should state clearly the penalty for violators. This would enhance the aims and objectives of the EPR scheme. Ogun state and the ministry of environment should develop a database for waste management, this would enhance research and innovation.

Development in social infrastructure would enhance MSWM development greatly. Therefore, both the state and federal government needs to improve in the development of social infrastructures such as good road networks, affordable housing, proper city planning and quality education.

# 9 CONCLUSIONS

This research work has highlighted the relevance of environmental legislations in the creation and development of a municipal solid waste management (MSWM) system. MSWM in any country is highly dependent on the contents of its environmental legislations and on future targets. The European Union (EU) waste framework directive (WFD) has appeared to be the catalyzing force of MSWM development among EU Member states. Hence, it is important that the planning of a new MSWM system considers some of its approach and contents. Other EU legislations mentioned in this thesis are also vital tools that could be utilized in the creation of a new effective MSWM system for Ogun State.

It is very important that the actual contents and quantity of the municipal solid waste (MSW) generated/capita is known in Ogun State and Nigeria. This is necessary because it outlines the key areas to focus on to achieve a circular economy and also present the MSW compositions that require quick waste prevention schemes. The MSW generated by a country like Nigeria should be able to create job opportunities if appropriately utilized. The re-use and recycling of MSW would help large and small businesses grow as both raw and secondary materials would be readily available. The negligence of MSWM would only continue to deteriorate our environment and when the environment suffers, the citizens would suffer sooner or later. The actual cost needed to be paid by Nigerians to effectively manage waste is still a puzzle that needs to be unraveled. The waste management hierarchy prioritizes waste prevention, making it a necessity to create waste prevention tools for biodegradable waste in the state and in the entire country. That might be very challenging since adequate power supply and common social amenities that could reduce wastage along the consumer-producer distribution change are currently absent.

The Extended producer responsibility (EPR) scheme has played a significant role in the development of MSWM among EU Member States. They have efficiently collected, treated and disposed waste products subjected to the EPR scheme. If EPR schemes are adopted in developing countries, what are the incentives that encourage multinational companies to fulfil their duties to collect, treat and dispose these same waste products from developing countries?

MSWM is a costly investment and it seems developing countries might not be rich enough to cater for the financial magnitude. Is this the real case or is corruption the culprit holding down MSWM development in these countries. Maybe, the citizens, communities and institutions need to develop more environmental awareness in order to pressurize the Government to make the right investment towards the protection of human lives and the environment.

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# Appendix 1

Table A1. Waste management responsibilities and roles in Finland (Finnish Waste Act 646/2011)

| Actors | Stages | Roles and Responsibilities |
|---|---|---|
| EU | International level | Provision of legislations that introduces waste management conditions, policies and targets for all European member states. |
| Ministry of Environment | National and International level | Development and monitoring of national and local policies using international standards and demand.<br>Participation in the preparation of European and global waste policies.<br>Creation of sub-departments that promote, guide, monitor and direct waste management in the whole country. |
| Regional State Administrative Agencies (AVI) | Regional and Municipal level | Regulation of environmental permits related to waste management activities (e.g. landfills and waste incineration plants) with major environmental impacts. |
| Centers for economic development, transport and the environment (ELY centers) | Regional and Municipal level | Provision of guidelines for waste management activities in municipalities.<br>Preparation of regional waste management plans.<br>Management of the registration of professional waste carriers and transporters in the waste management database. This aids data collection. |
| Centers for economic development, transport and the environment (ELY Pirkanmaa) | National level | Management of Extended producer responsibility compliance on subjected products Waste Electrical and Electronic Equipment, tires, paper and packaging products etc.) throughout the entire country. |
| The Finnish Environment Institute | National and International level | Management of the international waste shipment activities. |
| Municipalities | Municipal level | Management of environmental permits of waste management activities with minor environmental impacts.<br>Management of public administrative functions (e.g. the waste treatment system and municipal waste tariff) related to waste management within the municipality range.<br>Note: most municipalities have assigned the service function of waste management to private companies. |

| | | |
|---|---|---|
| Producers (EPR) | National and/or International level | Management of the upstream and downstream responsibilities of products subjected to EPR. Provision of information to product users about subjected EPR products to enhance collection and re-use. Provision of clear labeling of product properties and clarification of subjected Extended producer responsibility products to enhance collection and re-use. |
| National supervisory authority for welfare and health | National level | Prevention of risks to human health caused by waste. |
| Citizens (waste holder) | National and International level | Contribution on issues concerning environmental permit by influencing decision making (arbitrary personal decision). Organization of waste management unless otherwise provided by municipality, Extended producer responsibility or region. |
| Non-government organizations (NGO) related to the environment, health and nature. | National and International level | Contributions on issues regarding environmental permits for waste management activities by partaking in decision making. Creation of environmental awareness among citizens and Government organization. |

# Appendix 2

Table A2. Roles and responsibilities of different actors in Nigeria (Ministry of Environment in Nigeria 2005)

| Actors | Stages | Some of their important Roles and Responsibilities |
|---|---|---|
| The Federal Government of Nigeria | National level | Develop, review and update the policy guidelines on solid waste management.<br>Develop a waste management master plan for the country and ensure its implementation.<br>Develop waste related legislations and provide technical support to States and local governments.<br>Create funds for MSWM programmes and development. |
| National Environmental Standards and Regulations Enforcement Agency (NESREA) | National and International level | Enforce all environmental standards, regulations, rules, laws policies and guidelines on both private and public sectors.<br>Coordinate with both national and international environmental stakeholders.<br>Monitor the compliance of international environmental agreements, importation and exportation of waste.<br>Issue permits for environmental related activities throughout the country. |
| State Government | State level | Support and ensure the implementation of policy guidelines and master plan of MSWM.<br>Establish State legislation and data collection concerning MSWM.<br>Provide public education and MSWM research at the state level.<br>Provide land space for waste management facilities. |
| Local Government | Local level | Implement and enforce the policy guidelines and master plan of MSWM at the local government level.<br>Issue registration and license regarding waste management operations.<br>Provide the public with necessary information and education about waste management practices. |
| Private sectors | Local and International level | Comply with policy guidelines and master plan of MSWM.<br>Participate in MSWM on cost recovery basis.<br>Establish wide range of researches in relation with MSWM.<br>Promotion of public education of MSWM. |
| | Individual level | |

| | | |
|---|---|---|
| Citizens (waste holder) | | Adopt environmental friendly habits and practices into day to day activities.<br>Comply with policy guidelines and master plan of MSWM.<br>Support and patronize recycled products.<br>Pay for MSWM services. |
| NGO'S related to the environment, health and nature. | National and International level | Create and promote environmental awareness though campaigns to the general public. |

# Appendix 3

Table A3. Calculations related to phase 1

| Zone 1 (1,440,228 population) | Estimated calculations |
|---|---|
| Estimation of total generated waste (0.60 kg/capita/day) | 864 tons/day = 315,360 tons/year |
| 10% estimation that total generated waste is recyclable plastic, sachet water and cans picked by SME's and scavengers. This is not collected by the waste collection system. | 86.4 tons/day = 31,536 tons/year |
| Leftover generated waste to be transported by waste trucks (10% of 0,60 kg/capita/day = 0,54 kg/day) | 777.6 tons/day = 283,824 tons/year |
| Waste containers needed for 283,824 tons/year based on 1 kg = 8,42 liters for uncompacted residential waste (Mississippi department of environmental quality 2007). | 500 people per street of 2.8328 hectares of land = 270 kg/day (2273 liters/day). Pick up frequency of twice (3.5 days) a week = $\frac{3.5\ \text{days}\times 2273\ \text{liters/day}}{1300\ liters} = 6$ deep collection containers (1,300 liters) per street. Total containers needed are 17,280 deep collection containers in Zone 1. |
| Waste trucks needed (capacity of 5000kg). 1kg of compacted waste = 2,246 liters (Mississippi department of environmental quality 2007) | 188 trucks |
| Cost of containers. 1 container = €300 (Lounais-Suomen Jätehuolto Oy 2016) | €5,184,000 |
| Cost of trucks. 1 truck at € 44025 (Alibaba 2016) | €8,276,700 |

| Zone 2 (825,406 population) | Estimated calculations |
|---|---|
| Estimation of total generated waste (0.60 kg/capita/day) | 495 tons/day = 180,675 tons/year |
| 10% estimation that total generated waste is recyclable plastic, sachet water and cans picked by SME's and scavengers. This is not collected by the waste collection system. | 49.5 tons/day = 18,067 tons/year |
| Leftover generated waste to be transported by waste trucks (10% of 0,60 kg/capita/day = 0,54 kg/day) | 445.5 tons/day = 162,608 tons/year |
| Waste containers needed for 162,608 tons/year based on 1 kg = 8,42 liters for uncompacted residential waste (Mississippi department of environmental quality 2007) | 500 people per street of 2.8328 hectares of land = 270 kg/day (2273 liters/day)<br>Pick up frequency of twice a week = 6 deep collection containers (1,300 liters) per street.<br>9,900 deep collection containers in Zone 2 |
| Waste trucks needed (capacity of 5000kg). 1 kg = 2.246 liters for compacted residential waste (Mississippi department of environmental quality 2007) | 103 trucks |
| Cost of containers. 1 container = €300 (Lounais-Suomen Jätehuolto Oy 2016) | €2,970,000 |
| Cost of trucks. 1 truck at € 44025 (Alibaba 2016) | €4,534,575 |

| Zone 3 (950,345 Population) | Estimated calculations |
|---|---|
| Estimation of total generated waste (0.60 kg/capita/day) | 570.2 tons/day = 208,123 tons/year |
| 10% estimation that total generated waste is recyclable plastic, sachet water and cans picked by SME's and scavengers. This is not collected by the waste collection system. | 57.02 tons/day = 20,812 tons/year |
| Leftover generated waste to be transported by waste trucks (10% of 0,60 kg/capita/day = 0,54 kg/day) | 513.18 tons/day = 187,310 tons/year |
| Waste containers needed for 187,310 tons/year based on1 kg = 8,42 liters for uncompacted residential waste (Mississippi department of environmental quality 2007) | 500 people per street of 2.8328 hectares of land = 270kg/day (2331 liters/week).<br>Pick up frequency of twice a week = 6 deep collection containers (1,300 liters) per street.<br>11,400 deep collection containers in Zone 3 |
| Waste trucks needed (capacity of 5000kg). 1 kg = 2.246 liters for compacted residential waste (Mississippi department of environmental quality 2007) | 120 trucks |
| Cost of containers. 1 container = €300 (Lounais-Suomen Jätehuolto Oy 2016) | €3,420,000 |
| Cost of trucks. 1 truck at € 44025 (Alibaba 2016) | €5,283,000 |

| Zone 4 (535,161 Population) | Estimated calculations |
|---|---|
| Estimation of total generated waste (0.60 kg/capita/day) | 321 tons/day = 117165 tons/year |
| 10% estimation that total generated waste is recyclable plastic, sachet water and cans picked by SME's and scavengers. This is not collected by the waste collection system. | 32.1 tons/day = 11,716 tons/year |
| Leftover generated waste to be transported by waste trucks (10% of 0,60 kg/capita/day = 0,54 kg/day) | 288.9 tons/day = 105,448 tons/year |
| Waste containers needed for 105,448 tons/year based on 1 kg = 8,42 liters for uncompacted residential waste (Mississippi department of environmental quality 2007) | 500 people per street of 2.8328 hectares of land = 270 kg/day (2231 liters/day).<br>Pick up frequency of twice a week = 6 deep collection containers (1,300 liters) per street.<br>6,420 deep collection containers in Zone 4 |
| Waste trucks needed (capacity of 5000kg). 1 kg = 2.246 liters for compacted residential waste (Mississippi department of environmental quality 2007) | 67 trucks |
| Cost of containers. 1 container = €300 (Lounais-Suomen Jätehuolto Oy 2016) | €1,926,000 |
| Cost of trucks. 1 truck at € 44025 (Alibaba 2016) | € 2,949,675 |

# Appendix 4

Table A4. Calculations related to phase 2

| Zone 1 | Estimated calculations |
|---|---|
| Estimation of biodegradable waste left after phase 1 recycling (0.27kg/capita/day) | 388.8 tons/day = 141,912 tons/year |
| Waste containers needed for 141,912 tons/year based on 1 kg = 8,42 liters for uncompacted residential waste (Mississippi department of environmental quality 2007) | 500 people per street of 2.8328 hectares of land = 135 kg/day (1136 liters).<br>Pick up frequency of twice a week = 3 deep collection containers (1,300 liters) per street.<br>8,640 deep collection containers in Zone 1 |

| Zone 2 | Estimated calculations |
|---|---|
| Estimation of biodegradable waste left after phase 1 recycling (0.27kg/capita/day) | 222,7 tons/day = 81,120 tons/year |
| Waste containers needed for 81,120 tons/year based on 1 kg = 8,42 liters for uncompacted residential waste (Mississippi department of environmental quality 2007) | 500 people per street of 2.8328 hectares of land = 135 kg/day (1136 liters).<br>Pick up frequency of twice a week = 3 deep collection containers (1,300 liters) per street.<br>4,950 deep collection containers in Zone 2 |

| Zone 3 | Estimated calculations |
|---|---|
| Estimation of biodegradable waste left after phase 1 recycling (0.27kg/capita/day) | 256.89 tons/day = 93,764 tons/year |
| Waste containers needed for 93,764 tons/year based on 1 kg = 8,42 liters for uncompacted residential waste (Mississippi department of environmental quality 2007) | 500 people per street of 2.8328 hectares of land = 135 kg/day (1136 liters).<br>Pick up frequency of twice a week = 3 deep collection containers (1,300 liters) per street.<br>5,700 deep collection containers in Zone 3 |

| Zone 4 | Estimated calculations |
|---|---|
| Estimation of biodegradable waste left after phase 1 recycling (0.27kg/capita/day) | 144,45 tons/day = 52,724 tons/year |
| Waste containers needed for 81,120 tons/year based on 1 kg = 8,42 liters for uncompacted residential waste (Mississippi department of environmental quality 2007) | 500 people per street of 2.8328 hectares of land = 135 kg/day (1136 liters).<br>Pick up frequency of twice a week = 3 deep collection containers (1,300 liters) per street.<br>3,210 deep collection containers in Zone 1 |