Assessment of the Regenerative Potential of Organic Waste Streams in Lagos Mega-City

by

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ABSTRACT

There is never a better time for this study than now when Nigeria as a country is going through the worst time in power supply. In Lagos city about 12,000 tons of waste is generated daily, and is expected to increase as the city adds more population. The management of these waste has generated great concern among professionals, academia and government agencies. This study examined the regenerative management of organic waste, which accounts for about 45% of the total waste generated in Lagos. To do this, two management scenarios were developed: landfill methane to electricity and compost; and analyzed using data collected during field work and from government reports. While it is understood that landfilling waste is the least sustainable option, this study argued that it could be a viable method for developing countries.

Using U.S EPA LandGEM and the IPCC model, estimates of capturable landfill methane gas was derived for three landfills studied. Furthermore, a 35-year projection of waste and landfill methane was done for three newly proposed landfills. Assumptions were made that these new landfills will be sanitary. It was established that an average of 919,480,928m^3 methane gas could be captured to generate an average of 9,687,176 MW of electricity annually. This makes it a significant source of power supply to a city that suffers from incessant power outages.

Analysis of composting organics in Lagos was also done using descriptive method. Although, it could be argued that composting is the most regenerative way of managing organics, but it has some problems associated with it. Earthcare Compost Company processes an average of 600 tons of organics on a daily basis. The fraction of waste

processed is infinitesimal compared to the rate of waste generated. One major issue identified in this study as an obstacle to extensive use of this method is the marketability of compost.

The study therefore suggests that government should focus on getting the best out of the landfill option, since it is the most feasible for now and could be a major source of energy.

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CHAPTER ONE

BACKGROUND TO THE STUDY

1.0 Introduction

Managing urban areas has become one of the most important development challenges of the 21st Century (Wilmoth, 2012). Waste management is a vital component for successful urban management that requires proper and efficient approaches because of associated health and environmental problems. Achieving waste management goals has become a global concern especially in developing countries where the largest rate of urbanization is occuring. These countries often have weak resiliency in terms of infrastructure development to manage their waste streams (Pijawka, 2015).

According to the 2014 *World Urbanization Prospects* report by the United Nations Department of Economic and Social Affairs, India, China and Nigeria's populations will increase exponentially between 2014 and 2050. Lagos, the largest city in Nigeria, currently has a population of about 22 million and an annual growth rate of between 6-8% compared to the 2.4% for the nation (Lagos State Bureau of Statistics, 2014). A simple projection provides an estimate of what the mega-city's population will be in 2050 if the percentage increase continues. The sure fact is that as the population of the city increases so will the quantity of waste generated.

According to the World Bank, the per capita waste generation in the city of Lagos is estimated at 0.5kg/person/day (UNDESA, 2014), with a total waste generation of between 10,000 to 12000 metric tons per day. Only about 50% of the waste generated makes it to landfills, while the other 50% is indiscriminately disposed in an environmental unfriendly manner (Oshodi, 2013). Apparently, this figure will increase proportionately with the increase in population forecasted. As we look into the future of this problem, the following questions need to be addressed: what do we do with this enormous waste stream; what plans and facilities are on the ground to combat the huge environmental risks of improperly managing it; is there sufficient landfill capacity; what are the future plans to accommodate the huge increase in waste quantity which inevitably will result from the projected population increase; and is there potential to divert some of the waste stream in an environmental-friendly manner?

Over the years, the management of waste generated in Lagos has become a formidable task for the government, leading to the creation of the Lagos Waste Disposal Board (LSWDB) in 1977 now the Lagos Waste Management Authority (LAWMA). LAWMA, is responsible for managing landfills and supervising activities of private waste collection and transportation under Public-Private Partnerships. The recent administration of LAWMA under the leadership of Ola Oresanya, has achieved great success especially in reducing the chaotic eyesores of illegal dump sites in Lagos through several initiatives such as expanding and improving the physical conditions of landfills and the sorting of recyclable materials sent to landfills. With increasing concern over the three legal landfills (Olushosun, Solous and Abule-Egba) approaching their life spans, there is a proposal by LAWMA to construct three new sanitary landfills in the suburbs of the city. The vision of new landfills is laudable and proactive for the future environmental condition of the city, if only the potential resources in these wastes is harnessed.

From a sustainability point of view, landfill waste disposal is the least desirable option for effective waste management due to the associated environmental and health impacts. Landfills were referred to by John Lyle as a practice of sweeping dirt under the rug. In the book ‘regenerative design for sustainable development’ (Lyle,1994), it was argued that the problem of handling solid waste is associated with its definition as unwanted and worthless material to be discarded after use. Arguing that this definition leans on the assumption that energy and materials used can cease to exist in a functional sense, Lyle established a contrary opinion based on the laws of thermodynamics. This Law demonstrates that energy continuously degrades, and materials change form and state but are never destroyed. In other words, waste can change from one form to another and the remains can pose environmental dangers to ecosystems. Therefore, it is pertinent to adopt waste management strategies that assimilate, filter, store and produce new uses to reduce the adverse impacts and enhance regenerative uses. The capturing of Landfill gases (LFGs) in landfill can make it a sustainable system where the gases are used for heating or electricity purposes, rather than allow it to flow freely in the atmosphere and contribute to climate change. For the City of Lagos, it is only a matter of time before the new landfills are saturated and overwhelmed given the burgeoning population growth and the changing lifestyles of residents due to economic growth. Thus, there is an apparent need for the adoption of a more sustainable management system rather than a technical end-of-the pipe solution for waste. Regenerative possibilities should be looked at for Lagos and that is the focus of this study.

The universal approach to managing urban waste has been categorized into six- prevention, minimization, reuse, recycling, energy recovery and landfill disposal, from the most to least preferred (See Figure 1) based on environmental, social and ecological benefits. The most economical of the methods is disposal of waste in landfills and open dumps, which explains why it is the most widely used approach. Most developed countries have established policies to encourage cities to move up the hierarchy of waste management methods from landfilling to prevention - the most favored option for environmental benefits. As illustrated in Figure 1, prevention of waste is the greenest option but almost impossible to achieve especially with increasing population and global economic prosperity. Therefore, options such as “reduce, reuse, recycle” are pushed for in cities today. Not all waste can be managed using the 3Rs. However, other ideas such as regenerative systems of managing organic waste are gaining momentum. Hammarby Sjostad exemplifies this model of regenerative waste management through a closed-loop system, where waste is returned into the cycle, in order to produce other resources such as biogas and compost.

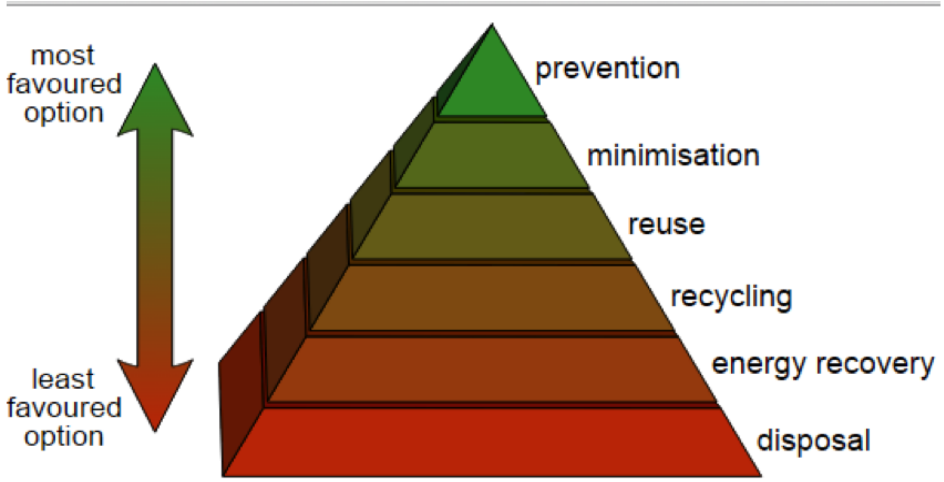

Figure 1: Waste management hierarchy. (Source: www.waste-to-energy.com)

With the current emphasis of LAWMA on recycling initiatives, about 1,200 metric tons of waste (which accounts for about 10% of the daily generation) is now being converted to other useful resources under formal arrangements with the private sectors. For example, arrangements include a contract with Waste to Compost Plant at Ikorodu 8%, Waste Paper bailed at Ojota 1%, Plastic/Nylon recycling at Ojo and Ojota 2% (LAWMA, 2014). When compared to the statistics of waste generation characteristics in the city, it can be concluded that recycling activity is still at the embryonic stage and there is a need for more aggressive, but economically and environmentally viable, recycling initiatives to be implemented.

One initiative that looks promising and could bring about tremendous environmental improvements, increase the life spans of the proposed landfills, and result in the development of new industries is the diversion of ‘organic waste’. This research will focus on the regenerative potential of the organic waste stream in Lagos in order to maximize benefits that lead to increased quality of life in the city.

1.1 Justification of the Study

According to LAWMA, over 47% of the 12,000 tons of waste generated per day in Lagos is organic waste, constituting the bulk of landfilled waste in the city. Out of the 2,058,600 tons of organic waste generated annually, only about 8% is converted into compost through the current LAWMA initiative. The rapid urbanization of the city has a growth rate of about 8%, which implies more waste will need to be disposed either in landfills or through other means. It is imperative to know that out of the three legal landfills in the city, two have less than five more years to operate, putting more pressure on the Olushosun landfill, which is estimated to have less than twenty more years to operate.

These landfills are not sanitary. Therefore, after the degradation of organic waste, there would likely be obnoxious odors emanating from uncollected methane gas, as well as leachate contaminating the ground water. Methane, a greenhouse gas (GHG), is 21 times more potent than CO_2, staying in the atmosphere for a long period and contributing greatly to climate change. It has become imperative to find ways to reduce causative greenhouse gases such as methane and carbon dioxide from landfills.

In order to reduce the emission of these gases, several cities are diverting organic waste from landfills or converting them to other useful purposes such as biogas, electricity, power, heat on site and making compost to improve agriculture production. According to the United Nations report on Sustainable Cities in 2009, one of the current global innovations to achieve green and brown synergy, is eco-efficiency by using waste products to satisfy urban energy and material resource needs. To become more environmentally sustainable, alternative ways of managing organic waste is necessary, especially with the impending increase in population projected for Lagos, and the high cost of siting and operating new landfills.

1.2 Purpose of Study

This study aims to analyze the regenerative potential of organic waste using landfill and composting scenarios, with a view to evolving a more sustainable systems approach to its future management. In order to achieve this, the study will answer the following questions:

1) Considering the characteristics of waste and landfill conditions, would it be possible to capture LFGs?
2) How much methane has been produced in landfills since inception to closing?
3) What are benefits that the city can derive from capturing landfill methane gas?
4) What is the regenerative potential for this waste stream utilizing composting?
5) What lessons can Lagos learn from organic waste management best practices?

1.3 Statement of Problem

The challenges of managing the anthropogenic by-product of 'waste' is experienced in both developed and developing countries. Although the problem is more pronounced in the developing world due to lack of proper and advanced infrastructure, the ongoing debates on sustainability and climate change have exposed that waste infrastructure such as sanitary landfills are not completely problem-free. Hence, there have been initiatives to address the problems of solid waste. These programs vary from country to country. Some of which are zero waste programs, waste-to-energy initiatives, cradle-to-cradle endeavors, and others. It is, however, disheartening to know that little attention has been paid to this environmental issue in developing countries, where most of the world's population increase will occur in the next thirty years. The recent World Bank report on Global Waste Management found that over 50% of developing countries waste are organic, which has the potential to be used for regenerative processes such as biogas for clean energy, composting to improve soil conditions, employment generation and so on, if properly managed (World Bank Report on Global Solid Waste Management, 2012). It is to this line of inquiry that this study intends to explore the potential benefits of organic waste diversion from landfills and open dumps in the city of Lagos, one of the world's megacities.

Organic waste has three potential uses: soil improvement, animal raising and as a source of energy (Schumache Center for Technology and Development, 2012). For example, stakeholders in Nigeria are beginning to show interest in the use of biofuel as a source of alternative energy for Nigeria industries and communities. In a recent interview, the Nigerian former Minister for Power, 'Prof Chinedu Nebo', cited Lagos as one of the states that could benefit from the enormous amount of daily organic waste generated (Punch Newspaper, 11th of January, 2015). Furthermore, an account of electricity generation in a fruit market in Lagos through the use of the combined traditional grinding machine and the power generating set, was reported on British Broadcasting Corporation in 2014 (http://www.bbc.com/news/wprld-africa-29531723), affirming the increasing awareness and potential of the benefits of Lagos' untapped 'organic waste' resources. There is absolutely no doubt about these aforementioned potentials. Without an adequate study on the assessment of waste and landfill characteristics, which will help ascertain the quantity and presence of methane gas that could be used, it will be unrealistic to predict and provide a management plan to optimize these potentials.

Organic waste has diverse components with different chemical characteristics that impact its' degradation efficiency. For instance, wood chips, agricultural waste and other plant matters are resistant to biodegradation because of the presence of lignin, cellulose and hemicellulose (Vogler, 2014). Therefore, the need for a baseline composition study on organic waste streams in Lagos is important not only to reveal the potential benefits that could be tapped by government agencies, private investors, companies and even informal sectors, but also help in the selection of technologies to yield optimal results.

Several studies have been carried out on waste characterization in different cities of the world, with the majority focused on the entire waste stream. In 2008, Gomez et al characterized waste generated in Chihuahua City, Mexico into organic, paper and plastic. They further established that there is a relationship between the rate and composition of the waste stream, and the socio-economic level of the residents. In addition, Nans and Baryram (2008) conducted a 52-week characterization study of Municipal Solid Waste in Gumushane, Turkey to determine the percentage of components, their specification weight and the chemical components that influence management techniques. However, none of these studies deducted the importance of managing waste based on its characteristics. Other studies such as Themelis and Uloa (2007) focused on the efficiency rate of capturing landfill methane compared to using industrial anaerobic digestion reactor. Spokes et al 2006, also carried a study in three landfills to elucidate total methane balance and their oxidation rates. Most of the studies done on LFGs were geared towards the problems of landfill methane as a contributor to climate change (Lou&Nair 2009). Unlike these studies, this research will focus on quantifying the benefits that can be accrued from landfill methane to the Lagos mega-city based on the huge organic component of waste disposed in the city while, and the possibility of composting the organic fraction to improve urban agriculture in Lagos and its' environs. The purpose of this study is to provide policy makers with information on how to plan for the organic waste stream in the city based on its regenerative properties.

1.4 Study Area

Lagos city is the most populous city in Nigeria with a population of over 22 million people in 2015 (Lagos Bureau of Statistics, 2015). The city is water locked with a limited land mass of approximately 1533 km^2 which limits physical development. The city has great diversity in terms of population structure, income, education and ethnicity. Over 250 ethnic groups reside in Lagos (See Figure 2:Map of Lagos). The city receives inflow of people from every part of Nigeria and even beyond. Lagos is not just a land of opportunity for people who seek it, it is also the economic hub of Nigeria. Over 25% of Nigeria's total gross domestic product is generated in this mega-city (www.worldpopulationreview.com/world-cities/lagos-population). Located around the Gulf of Guinea in the Atlantic Ocean in a tropical rainforest climate, the city of Lagos is built on several low lying islands, tropical marshes, reclaimed lands, and a coastal mainland area that sprawls out into neighboring Ogun state and sits below sea level, placing it at considerable risk for coastal flooding (Encyclopedia Britannica, 2015; Filani, 2012). In its present form, Lagos' overflowing urban agglomeration area of 907 km^2 holds a UN estimated population of 13 million people (Demographia World Urban Areas, 2015) while its metro footprint extends 1533 km^2 (Filani, 2012) and includes over 21 million residents. Inside the contiguous built up area, its estimated urban density (14500 ppl/km^2) exceeds both Kolkata's (12200 ppl/km^2) and Cairo's (8900 ppl/km^2), but drops considerably outside the urban core to 5000 ppl/km^2 in its informal settlement areas due to characteristic low quality unsanctioned development sprawl. While this density level appears low when compared globally to other cities, in Africa it is contrastingly quite high (especially in Nigeria). (Demographia World Urban Areas, 2015; Filani, 2012).

Figure 2: Map of Lagos metropolitan (Source: www.Lagos.gov)

Lagos displays a multi-nuclei urban structure with multiple central business districts and is principally governed by the Lagos State Government, a state which is separated into five sub regions and further divided into 20 local government areas and below those 57 local government council areas. The city's metro area presently includes 16 of these local government areas and continues to expand into neighboring states. With so many administrative units, cooperation and parastatal agencies have proven essential to building towards effective management of urban policies and municipal areas (Filani, 2012).

With its continuing rapid expansion above 10 million people, Lagos has achieved status as a mega-city according to UN population criteria (United Nations, 2014), although its considerable challenges distinguish it from comparable metro population Global North cities like New York City (Brookings Institution, 2014), given its high levels of crime and poverty, dual formal and informal economies, and novel forms of urban spatial population density (Madj and Tabibian, 2015). Moreover, with a city GDP of only $80 billion USD in 2010 according to the government (Lagos State Development Plan, 2012), Lagos' population boom has not yet stimulated a parallel rise in economic activity, as globally it lags behind peer developing cities like Cairo ($102 billion) and Bangkok ($307 billion) (Brookings Institution, 2014). Nevertheless, within the region, the city has established itself as a growing hub of opportunity, trade, and innovation that continues to attract large numbers of rural-urban migrants with its $2900 USD per capita income, which is nearly double the Nigerian average (CP Africa, 2013).

With over 66% of the population living in informal settlements, environmental management such as sanitation and solid waste has been a formidable task for government. As a matter of fact, Lagos is popularly referred to as a 'mega-city of slums'. The rate of solid waste generation in Lagos increases every day with the influx of people, adding to an already congested city. With a current population of over twenty-one million, the city generates over 12,000 metric tons of waste per day, of which only about 50% makes it to landfills (LAWMA, 2014).

According to LAWMA's 2014 report, 45% of waste generated in the city is organics, followed by plastic (15%), paper (10%), putrescible (8%), glass (5%) and textile (4%) (Figure 4).

There is absolutely no doubt that Lagos will face more problems in the near future if a more sustainable approach is not designed to tackle waste management. This is especially true if the forecasted population increases actually reach forty million people by 2050, resulting in changing lifestyles and growing industrial development. While the population of the city is increasing at an estimated annual rate of at least 3.6%, the municipal authority in charge of waste is collecting, on the average, almost 10% less refuse per capita every year (Onibokun et al, 2000). A major cause of this is the multiplication of informal settlements with lack of access and the inability of government to charge collection fee in these areas.

Waste collected from the different areas of the city under the PSP partnership are disposed of in the three legal landfills, while uncollected waste is dumped indiscriminately in unauthorized places such as rivers, canals, drainages or burned on illegal dumpsites. There is growing concern of the environmental problems caused by the Olushosun, Solus and Abule-Egba landfills because the city has developed enormously to where they are located, thereby causing nuisance to residents living around this area. Culturally the residents of city dump their waste in drains, canals, rivers, or burn it in their backyards. However, the incessant seasonal flooding experienced in most part of the city has increased the awareness for better and safer disposal methods.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

To effectively manage organic waste in our environment, there is a need to understand the whole concept of waste. This includes its origin, type and disposal options, which should be based upon the evaluation of the potential environmental, social and economic benefits. This section is tailored to examine the concept of waste with a focus on the organic fraction and regenerative approach to its management.

2.1 The Concept of Waste

Waste is an inevitable by-product of humans. According to Brunner (2002) and Lyle (1994), waste is defined as materials considered worthless and to be disposed of Christensen (2010), in explaining the concept of waste, applied the economic concept of redundancy, which is a stage in the life of a product when it loses its "value and needs to be discarded". However, Lyle stated that the problem of waste management starts with its myopic definition that leans on the assumption that energy and materials used can cease to exist in functionality. He established this using the laws of thermodynamics, which proves that materials change form and state but are never destroyed. Hence, he argued, that perceiving waste in this sense could help decide the adoption of a more sustainable and regenerative management techniques. Another feature that plagues the management of waste is its classification. There is no uniform classification system for waste items because of their diversity. Therefore, it is most often grouped based on multiple features such as the physical state (solid, liquid and gas), original use, material type (glass, paper, and so on), physical properties (combustible, compostable and recyclable), origin (domestic, commercial, agricultural), and safety level (hazardous, non-hazardous) (McDougall et al 2001).

Urbanization has been a major catalyst for waste volumes generated in cities all over the world. In fact, solid waste generation is inextricably linked to urbanization and economic development of cities. However, in the 2012 World Bank Report on the Global Review of Solid Waste Management, it was established that global waste volumes are increasing faster than the rate of urbanization. A possible reason for this is the influence of other factors such as improved economic development and standard of living of the citizens. Several studies have shown the correlation among waste volume, standard of living and disposable income. This forms the basis for the division of countries based on income levels in the World Bank Report. The World Bank report estimates that in 2001, almost 1.3 billion tons of Municipal Solid Waste was generated globally every year and this will increase to about 2.2 billion tons by 2050. This calls for greater attention by government, especially municipal governments that are often responsible for the management of solid waste.

Over the years, there has been controversy on what constitutes Municipal Solid Waste (MSW) and what does not. The characterization of MSW depends on the perspective of the organization or field of scholars defining it, often varying from country to country due to differences in waste policies. According to the Organization of Economic Co-operation and Development (OECD) (2008), municipal waste is collected and treated by, or for, municipalities. It covers waste from households, including bulky waste, similar waste from commerce and trade, office buildings, institutions and small businesses, yard and garden, street sweepings, contents of litter containers, and market cleansing.

In 2007, the Pan American Health Organization (PAHO) defined MSW as Solid or semi-solid waste generated in population centers, including domestic and commercial wastes, as well as those originating from small-scale industries and institutions (such as hospitals and clinics), market street sweeping, and public cleansing. The IPCC (2007) classified waste to include food waste, garden (yard) and park waste, paper and cardboard, wood, textiles, nappies (disposable diapers), rubber and leather, plastics, metal, glass (and pottery and china), and other (example; ash, dirt, dust, soil, electronic waste). Others classify MSW into two broad categories, organics and inorganics. Professionals interested in the chemical components of waste rather than its physical state often adopt this form of classification. Although the proper classification of waste is necessary to develop a suitable management strategy, the truth is that there is no single classification method that can address the diverse nature of solid waste.

2.2 Solid Waste Management

In the eighteenth and nineteenth century, the concern about waste management was focused on health and safety. Today, attention is shifting to a holistic and sustainable approach with a focus on environmental effectiveness, economic affordability and social acceptability (Shekdar, 2009). Solid waste management is a complex exercise that involves various stakeholders, municipal government, households, private organizations and many others as well as and the diverse activities from production of goods to when it finally becomes waste and is collected, transported, and disposed. This has led to the development of modern management tools such as computer simulation models, life cycle assessments, cradle to grave assessments, and so on, to adequately address the inevitable by- products of man's activities. However, there is no one-size-fits-all method given the many factors that influence waste generation, composition and variations from place to place.

The political, legal, socio-cultural environment, economic factors and availability of resources often influence the effectiveness of waste management in countries. In developed countries, waste management is governed by legislative tools that are classified as either, end-of -pipe regulation or strategic targets (McDougall 2003). End-of-pipe regulations are high-level directives with no details on how waste system should operate. They provide technical regulations such as emission standards that fine tune waste operations systems, promoting best available technologies and practices. A good example is the United States' Resource Conservation and Recovery Act (RCRA)'s solid waste program section D, which encourages the environmental departments of each state to develop comprehensive plans to manage nonhazardous industrial and municipal solid waste (U.S. Environmental Protection Agency).

Strategic targets focus on specific aspects that are usually based on the hierarchy of solid waste management prioritized by the national or municipal government. This ranges from reduction, reuse, recycle, compost, incineration, landfilling or other methods. Examples of this form of regulation include: the German Packaging Ordinance, which lays down guidelines on recycling packaging wastes. Others are the EC Packaging and Packing Waste Directive in Europe, and the Solid Waste Disposal Act Amendments of 1980 in the United States that targets hazardous waste dumping (McDougall et al, 2003,p11). However, in developing countries, waste management has received little attention both at the national and local levels. There is lack a of legislation and policies for realistic long-term waste management planning, despite the increasing population. This often results in the use of inappropriate technology and methods. In 2011, a study carried out by Diaz of the CalRecovery, found that foreign experts, who are unfamiliar with the areas, write most existing plans for waste management in developing countries (Daiz, 2011). This major drawback needs to be addressed because policies and legislations are the vehicles on which effective waste management systems are based.

Beyond the legislative framework, the proper characterization of waste goes a long way in deciding which system is best for what kind of waste. The most widely used but vague classification is organic and inorganic waste. It is very easy to categorize waste into these two groups but they do not help environmental planners determine what materials are present in the waste streams which often leads to mismanagement.

2.3 Organic Waste

Organic wastes are often regarded as biodegradable waste that comes from plant and animals. This broad definition helps in the understanding the concept, but not in making management decisions. The main components of organic wastes are household food waste (fruits, vegetables, meat, etc.), agricultural waste, human and animal waste. The quantity of organic waste is appreciable in the overall global waste stream, with low-income countries having the largest organics content (World Bank Report on Global Solid Waste Management, 2012). In the process of breaking down organic waste, there is the accompanying release of leachate, which contaminates the ground water, leads to production of methane gas, a very potent GHG. Therefore, a continuous concerted effort is required to properly manage this waste.

2.4 Organic Waste Generation and Characterization

As mentioned earlier, organic waste is generated from several sources and comprised of diverse materials with a common attribute of being decomposable by bacteria action. Although there is yet to be a study that scientifically establishes the relationship between the level of development of a country and the quantity of organic waste generated, the World Bank study on global waste reported more organic waste is being generated in the low-income countries (see Figure 3). Municipal waste streams usually contain food waste, yard waste from plant trimming and gardening, and residue from industrial food waste processing. Municipal organic waste has a high moisture content which mixes with inorganic materials and leads to the generation of leachate and odors, making management very challenging. Lyle (1994) and Walter (1986) argued that organic waste must be classified further because of the influence of chemical composition on biodegradability which can render management techniques such as composting, inefficient.

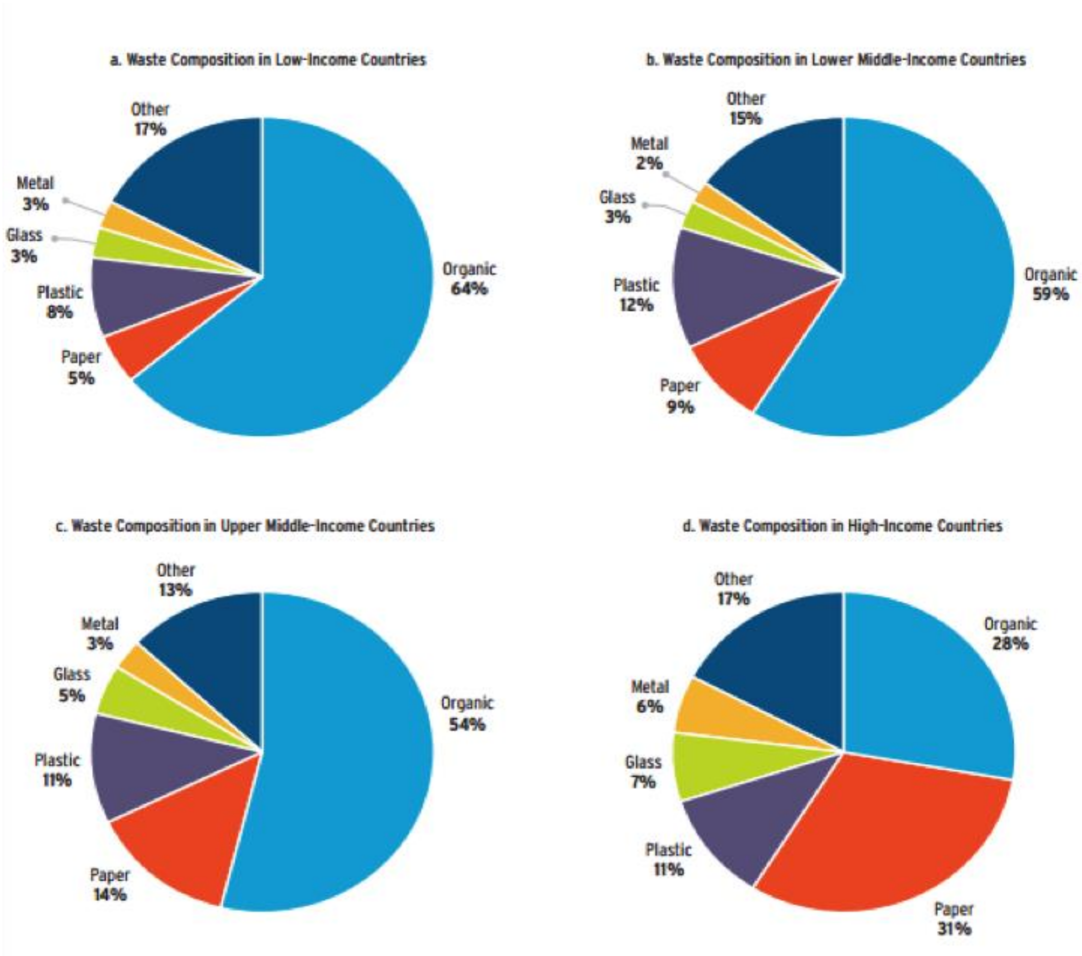

Figure 3: Waste Composition by Countries' Economic Development
Source: World Bank Report 2012 on Global Solid Waste Management.
www.worldbank.org/urban/whatawaste/Globalaccount.

2.5 Organic Waste Management – the global practice

Until recently, landfilling of organic waste was the most common practice in developed countries. While in developing countries, the absence of adequate facilities has led to dumping of organic waste in open dumps sites, gutters and canals. The ongoing discussion about climate change has awakened the consciousness of cities, decision makers, professionals and academia to rethink sustainable strategies for managing waste, in order to reduce humankinds' environmental footprint. This is because the greenhouse gases emitted from the decomposition of organic waste contributes greatly to climate change, especially methane which accounts for about 50% of the total LFGs, and has a 21 times potency with ability to stay in the atmosphere for a very long time than carbon dioxide.

World Class Cities are gradually moving towards regenerative systems by capturing LFGs or diverting organic waste from landfills, not only to reduce the emission of methane gas, but to maximize the use of resources and possibly eliminate waste. For example, Quebec City's target is to divert 60% of its organic waste generated by 2015 and permanently ban organic waste from landfills by 2050. Interestingly, as of 2014, they have surpassed the target for 2015 (Montreal Organic Waste Management plan Update, 2014). Swiss Kompogas produced 27 million Kwh of electricity and biogas in 2009 generated from organic waste collected in Switzerland (http://www.kompogas-utzenstorf.ch/). In 2013, Austin started a residential organic waste collection program in order to achieve the set goal of 90% waste diversion from landfills by 2040. In addition, the city of Philadelphia launched a new composting program to achieve 2.5 million pounds of waste diversion from landfills annually (BioCycle, Waste360 publication, January 2013).

Although the largest portion of developing countries' waste is organics, only a few of them use composting systems. Cities such as Accra, Ghana establish a small-scale composting system in order to help ease the waste situation as early as 1985 (GATE

Questions and Answers No3/89). In the World Bank report on Global Solid Waste Management, a comparison of waste management methods was made in the Organization for Economic Co-operation and Development (OECD) Countries and African Countries (see Table 1). African Countries are still struggling with the issue of waste management; hence, they need to step up the game to be able to improve the quality of public health and promote environmental sustainability.

Table 1: Comparison of Waste Management Methods (percentage)

AFR		OECD	
Dumps	2.3	Dumps	–
Landfills	2.6	Landfills	242
Compost	0.05	Compost	66
Recycled	0.14	Recycled	125
Incineration	0.05	Incineration	120
Other	0.11	Other	20

Source: World Bank Report 2012 on Global Solid Waste Management. www.worldbank.org/urban/whatawaste/Globalaccount.

Organic waste decomposes in landfills and uncontrolled dumps, which leads to the production of methane (CH_4). Methane is one of the major Green House Gas (GHG) that contribute to climate change. The countries of Asia, Latin America, and Africa together account for about 40% of the total annual methane emitted from landfills. This is equal to around 37 million metric tons of CO_2 equivalents (EPA, 2012). In developed countries landfill CH_4 emissions has been stabilized due to widespread initiatives of LFGs capturing. Developing countries however are continuing to improve towards controlled (anaerobic) landfilling practices (Bogner et al., 2008). Therefore, from a sustainability perspective, opportunities to reduce greenhouse gas emissions lay in finding better solutions for organic waste treatment, thereby reducing uncontrolled anaerobic decomposition and methane emissions (UN-Habitat, 1996).

2.6 Regenerative method of managing organic waste

All materials exist in a biological nutrient cycle or a technical nutrient cycle (Bergman, 2012). Hence, regenerating garbage as input for another use is important to sustain life on earth. The organic waste stream can be considered a biological nutrient material that can safely be returned to the earth through regenerative methods such as landfill gas capturing, anaerobic digestion and composting, instead of sending them to landfills which results in the waste of resources if efforts are not made to capture LFGs. Applying the concept of sustainability to waste management is very important to both developed and developing countries.

In the book '*Regenerative Design for Sustainable Development',* Lyle makes a strong case for changing the perception of 'waste' as 'useless', to waste as 'resources', that could be tapped by creating closed-loop systems in the management. This would produce cycle for products from cradle back to cradle, known as a regenerative system. Regenerative systems encompass a whole pattern of things from birth to death and incorporate feedback information through active public participation. The regenerative model is a resource management approach that advocates for the use of conversion and assimilation disposal methods, or 'closing the loop', and returning both materials and nutrients to beneficial use. This is crucial to ensure productivity and food security (Scheinberg et al., 2010; Wilson, 2007).

Several communities today are planning both short-term and long-term approaches to achieve a zero-waste goal using a number of these methods. Hammarby Sjostad exemplifies the regenerative model of waste through the creation of a recycling model based upon systems integration. As of 2013, only 5% of the waste generated in Hammarby went to landfills, the remainder was used to generate energy (for every one ton of waste, 3000Kwhs of energy is generated) or converted to compost used to improve the quality of soil (Latts, 2013). The complex regenerative model has been simplified for decision makers through the Hammarby model (see Figure 4).

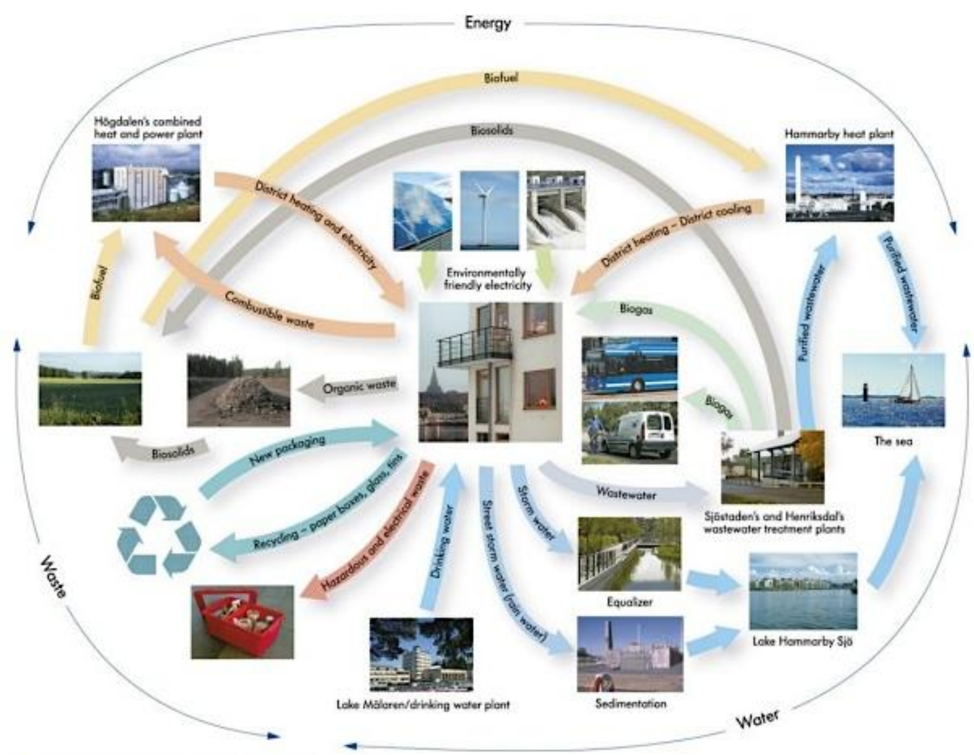

Figure 4: Hammarby Regenerative Model. Source: Lena Wettren, Bumling AB

It is good to learn from cities like the one described above in order to attain environmental sustainability. However, because of the uniqueness of cities in terms of their social, financial, natural and political fabrics, it is imperative that management techniques chosen is feasible, implementable and sustainable. With technology advancement, several ways of regenerative management of organic waste has helped cities select suitable methods.

2.7 Sustainable Ways of Managing Organic Waste

There are several ways by which organic waste could be managed, depending on the financial cost a city is willing to bear. Traditionally, food residue waste are used for livestock feeds, which makes it the most economical and environmental friendly. But, as waste volume increases, other methods such as landfilling, composting and anaerobic digestion system become desirable. Just as was said earlier, these methods require different levels of management and investment. Therefore, taking a quick look into each of these methods will help justify the importance of this study.

2.8 Landfilling Organic Waste

Landfilling organic waste is the most common practice all over the world. It is the cheapest and least sustainable method. Scholars refer to it has a 'wasteful method of managing waste', and with huge environmental and public health risk (Lyle 1992, Brunner 2002& Christensen 2010). During the decomposition process of organic waste in landfills, several GHGs, which contributes to global warming are emitted. However, the method becomes regenerative if these gases are tapped and re-used. One of the main benefits of landfilling is the optional gas capture and energy reuse system. Methane and carbon dioxide capture has the ability to be compressed to produce natural gas and electricity that can power buildings and motor vehicles as well (Welch, 2015). In the opinion of Lyle (1994), landfills are storage for trash assumed to decompose fast but unfortunately not only slow but some of the waste will not decompose at all. Some decades back, landfills were designed in an unsanitary manner, which lead to leachate contaminating groundwater and uncollected methane polluting the atmosphere. Today, most landfills in the developed countries have addressed these issues through improved technology. Lyle in his book *Regenerative Design for Sustainable Development,* argued that that the problem of leachates contaminating groundwater is not completely solved by the heavy plastic liners placed in sanitary landfills. He argued that the liners used have a thirty-year lifespan as against the decomposition process which may take hundreds of years (Lyle, 1994).

Diverting Organics from landfills would significantly reduce the emission of greenhouse gases that increase climate change. Although new technologies of laying pipes in sanitary landfills have facilitated the collection of methane gas, only a small portion of energy embedded in solid waste is returned for reuse compared to the anaerobic digestion method. Lyle argued that even with this improvement in landfill construction, it remains a degenerative way to managing organic waste.

According to the World Bank Guidance report in 2006, a sanitary landfill is the most cost-effective system of solid waste disposal for most urban areas in developing countries. Composting of solid waste costs 2-3 times more than sanitary landfills, and incineration costs 5-10 times more. Therefore, examining this method as one viable way in which the city of Lagos could manage its' huge waste volume is not out of place, considering both the environmental and economic benefits.

2.9 Composting

Composting is a regenerative method of returning organic waste back to the soil to improve fertility. The process involves the biological decomposition of organic material into humus, the most basic compound of soil. Composting is used as the controlled decomposition of organic material, unlike in landfills, where decomposition cannot be controlled. Decomposition occurs by microorganisms that secrete hydrolytic enzymes that break down organic material and produce heat (Allen et al, 2015). MacCready et al, (2013) established that at least 40 different species of bacteria can be present in a compost pile including aerobic and anaerobic bacteria, along with fungi and insects. The ideal composting process differs from the decomposition that takes place in landfills due to the presence of oxygen which makes the process aerobic and therefore methane is minimally produced (Allen et al, 2015). In general, methane production is reduced if aerobic conditions in the pile are maintained, which makes an environmental friendly method. However, composting process requires quality management, and appropriate quality of feedstocks. These two factors are very important and will determine the quality of compost derived. It is a fact that all organic matter will eventually decompose, but, some materials are more suitable for composting than others. The raw materials which are most appropriate for composting include: vegetable and fruit waste, farm waste, crop residues, yard waste, household kitchen waste, human excreta and animal manure (Hoornweg et al, 2000). Therefore, a specialized collection is required from the generators of compostable waste to achieve high quality compost. This may be a difficult task especially in cities in developing countries, where waste are co-mingled with other waste materials. Aside from this, there are other universal constraints associated with composting such as the non-profitability, which makes it difficult to secure finances for operation; nuisance potential, such as odors and rats; poor marketability due to perverse incentives on inorganic fertilizer subsidies (Hoornweg et al 2000).

2.10 Anaerobic Digestion (AD)

AD is the decomposition of organic substances in the absence of oxygen through bacteriological activity. There are four major activities that occur during this process: hydrolysis, acidogenesis, acetogenesis and methanogensis, (see Figure 5), (Adriana 2014). The final product from this process is biogas and digestate, which can be used as fertilizer. AD provides an effective waste management process across an entire supply chain, which takes into consideration all the principles of sustainability. It also encourages industrial symbiosis, where one industry's waste becomes resources for another.

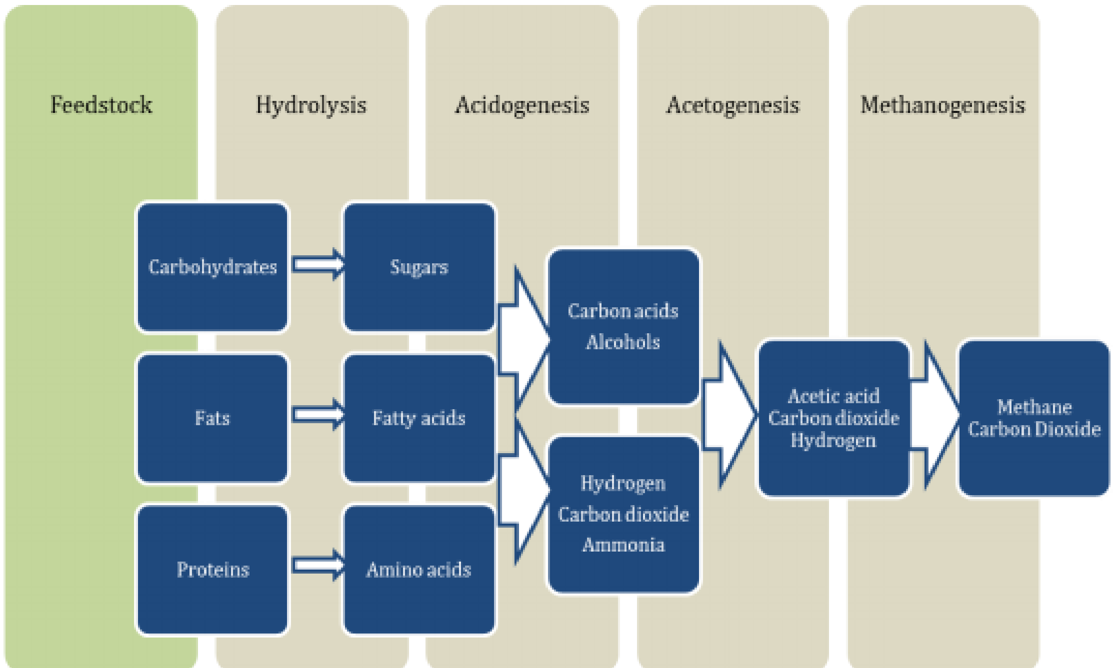

Figure 5: AD process stages 1. Source: Al Seadi, Teodorita, et al. Biogas Handbook. Esbjerg: University of Southern Denmark Esbjerg, 2008. ISBN 987-87-992962-0-0.

AD is widely used in Europe and is starting to gain acceptance in the United States, especially in the past decade due to improved designs of facilities (Waste360, 2014). It is highly scalable and can be used to treat organics in different quantity. However, profitability of AD operation has been the greatest hurdle. The installation and operation of AD is usually costly especially when compared to the immediate benefits. In the opinion of Rathburn (2014), other underlining factors forestall the ability of AD to yield the maximum economic benefits. Some of which are: quantity and quality of feedstock, waste stream management and logistics, government legislation, and the marketability of its by-products (energy).

2.11 Solid Waste Management in Lagos

The rate of waste generation in Lagos increases everyday with the influx of people, adding to an already congested city. With a current population of over twenty-two million, the city generates over 12,000 metric tons of waste per day, of which only about 50% makes it to landfills. According to LAWMA's 2014 report, 45% of waste generated in the city is organics, followed by plastic (15%), paper (10%), putrescible (8%), glass (5%) and textile (4%) (Figure 4). This indicates that organic waste needs proper attention to be able to diminish waste management problems as experienced in the megacity.

There is absolutely no doubt that Lagos will face more problems in the near future if a more sustainable approach is not designed to tackle waste, an inevitable by-product of urbanization. This is especially true if the forecasted population increases actually

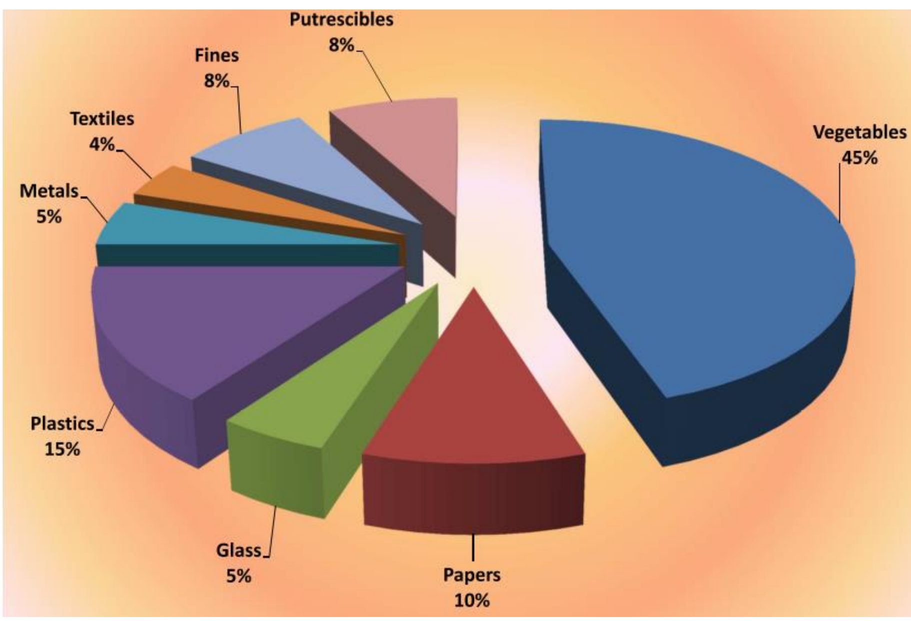

Figure 6: Solid waste proportion in the city of Lagos
(Source:LAWMA,2014)

reach forty million people by 2050, resulting in changing lifestyles and growing industrial development. The problem of waste management faced in the past by the city gave birth to several institutional arrangements. Until 1977, municipal solid waste was being managed at the local levels. At that time, Lagos State Government intervened by the establishing the Lagos State Refuse Disposal Board (LSRDB) due to the growing menace of waste resulting from improper management at the local level (Oresanya, 1998). In 1991, LSRDB was renamed Lagos State Waste Management Authority (LAWMA) by virtue of Edict No 55 of Lagos State. This Edict gave LAWMA a commercialized autonomous authority with statutory duties of collecting and disposing of municipal and industrial waste in the city, and providing commercial services to the State and Local Governments. In an effort to serve the ever-increasing population of Lagos, LAWMA established a partnership arrangement with the private sector called the Private Sector Participation (PSP) in 1997, to collect waste from designated areas of the city. (See appendix for the list of PSP and the areas they serve). In spite of all these efforts, less than 75% of waste generated in the city is being collected (Popoola, 2001).

While the population of the city is increasing at an estimated annual rate of at least 6%, the municipal authority in charge of waste is collecting, on the average, almost 10% less refuse per capita every year (Onibokun et al., 2000). A major cause of this is the multiplication of informal settlements with lack of access and the inability of government to charge collection fees in these areas.

Waste collected from the different areas of the city under the PSP partnership are disposed of in the three legal landfills, while uncollected waste is dumped indiscriminately in unauthorized places such as rivers, canals, drainages or burnt on illegal dumpsites. There is growing concern of the environmental problems caused by the Olushosun, Solus and Abule-Egba landfills because they are unsanitary and waste is often burned instead of being covered with soil layers (see figure 7). This results in contaminated ground water and foul odors due to uncollected methane gas. Culturally the residents of Lagos dump their waste in drains, canals, rivers, or burn it in their backyards. However, the incessant seasonal flooding experienced in most part of the city has increased the awareness for better and safer disposal methods. Below are some of the

Figure 7: Waste Burning on a Landfill in Lagos

Pictures of paste waste collection method in Lagos

Pictures of waste situation in Lagos city.

CHAPTER THREE

Methodology

3.0 Introduction

The empirical analysis of this study is focused on the Lagos mega-city with specific attention to the volume of the organic waste generated in households, businesses and markets that deal with organic items, which forms about 45% of the city's waste stream. To estimate the potential benefits of managing these wastes in a sustainable and regenerative manner, analyses were conducted. The focus was on two scenarios: landfill methane to electricity and composting. This involved collection of historical data of waste deposited in the three landfills studied and specialized organic waste quantity collected in markets for composting. Data needed for the analysis was obtained from LAWMA documents, and from Ably Carbon Report on pre-feasibility study of LFGs capturing in the three landfills. Also, field survey of landfills and the Earthcare Compost facility was carried out in from June to early August 2015.

3.1 Scenario Analysis

Scenario analysis was performed in order to evaluate a future management plan through consideration of different plausible options. This analysis places the benefits of project alternatives side by side, therefore helping city officials and other stakeholders make informed decision. For this study, two waste management methods were considered: scenario1-Landfill methane to electricity and scenario2-composting. The economic impacts of using either of the two scenarios was done using different projection tools that have been used in other studies. For the landfill methane to electricity scenario, U.S EPA LandGEM and IPCC model for calculating the amount of methane generated in landfills was used.

3.1.1 Scenario 1: Landfill Methane to Electricity

Landfilling waste is often the least preferred option of managing waste and as such is always referred to as the worst-case scenario. According to Doka (2009), landfills are designed for the storage of waste and are assumed to be partly submerged below after closure. According to scholars, this method of managing organic waste does not facilitate nature's recycling process, hence altering nature's regenerative ability. However, the potential benefits of eventual regenerative products after chemical and biological processes in landfills, such as LFGs, are often ignored. Therefore, analysis of the three landfills in the city was carried out to calculate how much methane can be converted to electricity and assess if it is a worthwhile investment for the city.

According to LAWMA, there are three legal landfills that serve the city of Lagos, Olushosun, Abule-Egba and Solous, two of which have reached their life span and no longer receive waste. This increased pressure on the Olushosun landfill which is located conspicuously in the heart of the city and, which residents and visitors believe to be a poor scene that defines this megacity of opportunity. However, from LAWMA officials it seems that plans are underway to construct three new sanitary landfills to be located at the suburbs (Epe, Ikorodu and Mowe) due to land availability there. Baseline data on waste volumes needed for this analysis was extracted from the Ably Carbon report and LAWMA documents. The historical data of waste deposited in the three landfills was given to Ably Carbon for the prefeasibility study of capturing methane. The reliability of this data is questionable because there was no weigh-bridge in the landfills but are the only data that were available as baseline data for this study.

3.1.2 Landfill Analysis tools

In order to estimate how much methane gas can be captured for the purpose of electricity generation, the U.S EPA's Landfill Gas Modeling software was used, while some parameters needed for the analysis was based on the IPCC default model for developing countries. LandGEM is a Microsoft Excel-based software application that uses a first-order decay rate equation to calculate estimates for methane and LFG generation. LandGEM is the most widely used LFG model and is the industry standard for regulatory and non-regulatory applications in the United States (http://www3.epa.gov/lmop/documents/pdfs/pdh_chapter2.pdf). Below is the model used in building the software.

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} kL_o \left(\frac{M_i}{10} \right) e^{-kt_{ij}}$$

Where: QCH4 = estimated methane generation flow rate (in cubic meters [m3] per year or average cfm)

i = 1-year time increment

n = (year of the calculation) – (initial year of waste acceptance)

j = 0.1-year time increment k = methane generation rate (1/year)

Lo = potential methane generation capacity (m3 per Mg or cubic feet per ton)

Mi = mass of solid waste disposed in the ith year (Mg or ton)

tij = age of the jth section of waste mass disposed in the ith year (decimal years)

Historical waste deposits data in each landfills, open and close date of landfills, temperature and other parameters discussed in chapter 4 was inserted into the software to calculate methane gas generated since inception to close of landfills.

3.1.3 Scenario 2: Composting

Composting is another form of managing organics, which requires low technological operating cost and health risk. It is an aerobic biological process in which organic material is decomposed by microorganisms under controlled conditions (Paul, 2009). The biodegrading process consists of three stages: thermophilic (heating period), maturing (stable period), and cooling (stable and mature period) (Yoshida et al, 2012). The product is a loosely structured soil-like material that can be handled, stored and applied to the land for soil improvement without adversely affecting the environment (Lyle, 1994). Composting can be used for managing organic waste as small as household quantities and as large as the entire city quantities. It is often considered the cheapest and safest method for managing organics, but it has some environmental disadvantage if not properly monitored. Some of the adverse effects are the bad odor, leachate that attracts flies, and emission of CO_2 and CH_4. All this will be considered in the evaluation section of the study.

In 2006, Earthcare Nigeria Limited under public-private partnership with LAWMA, started processing organic waste from five major sources to compost. The plan was that about 20% of waste generated in the city will be diverted from landfills, with a long-term effects of boosting food production, creating jobs, and reducing the cost of health-care. The compost facility is located on a 35.494 hectare of agricultural land at Odogunyan farm settlement, in Ikorodu Local Government Council of Lagos State. The facility shares a boundary with the Lagos State Polytechnic.

3.2 Data Collection

Field Studies were carried out to characterize organic waste, however, it was discovered that it is difficult due to the manner in which waste is comingled from the source. Therefore, the classification carried out by LAWMA was used. Data on the three landfill characteristics such as date of opening and closing, annual waste deposits, waste depth, site condition and so on, was retrieved from the Ably Carbon prefeasibility report prepared for LAWMA in 2012, plus interviews. LAWMA officials were interviewed to solicit information about the project feasibility and background baseline data. In addition to this, population data was obtained from Lagos Bureau of Statistics and a projection of population to 2050 was done using the growth rate of 3.19%. The population data was then used to project how much waste would be generated in each year using LAWMA's 0.65kg waste generation percapita.

Pictures taken during field survey at Olushosun landfill in Lagos

CHAPTER FOUR

ASSESSING THE WASTE TO ENERGY AND COMPOSTING OPTIONS FOR LAGOS WASTE

4.0 Introduction

The focus of this chapter is to report findings from analyzed data based on the two regenerative scenarios: the landfill waste to energy and waste to compost scenarios. To achieve this, the chapter is divided into two sections. The analysis of the landfill waste to energy scenario is the focus of section 4.1. This includes the potential transformation of two main landfills, a section of a third landfill in Lagos, and three landfills that are being planned. Based on parameters from the literature such as landfill factors, the amount of methane gas generated in each landfill from inception to end of life was calculated using the US EPA LandGEM software (Pipatti et al, 2006). The results were then used to evaluate how much electricity can be generated from the collected methane gas for each year. Also, projections were made on the overall benefits to Lagos of solid waste that would be generated in the city in terms of electricity over the next 20 years. These projections were accomplished by projecting the population of the city into a 20 year time period, using the annual growth rate of 0.35 received from the Lagos Bureau of Statistics, and multiplying it by the 0.65kg per capita of waste generation (LAWMA, 2010). The methane generation rate and electricity that could be generated from the projected waste, was calculated using the same method and parameters as analysis for the existing landfills.

The compost scenario will be the focus of section 4.2. This will involve a critical evaluation of the efficiency of the only compost facility in Lagos, Earthcare Compost, visited during the field trip to Nigeria in 2015. During interviews with workers in the facility, it was discovered that the company is going through hard times due to difficulties in the marketability of the compost. All these and many other issues will be analyzed to determine if it is a worthwhile method of managing organic waste in Lagos.

4.1 Landfill Scenario

In Lagos, the organic components of Municipal Solid Waste (MSW) accounts for around 45% of the total waste generated on a daily basis (LAWMA,2010). A large portion of household and commercial waste generated is deposited in landfills across the city, where a complex series of reactions occur that decomposes the organic fraction of the waste, and that is then converted to landfill gases, of which methane is about 50%. A landfill option for managing waste can be considered sustainable and environmentally friendly if the landfill methane is captured and re-used appropriately. This is because management of waste should be considered holistically with the economic costs, social acceptability and environment consequence. Therefore the context of developing countries, landfill option seems to be the most feasible in the short-run. Presently, the city of Lagos does not have any LFG collection systems in any of its landfills. Therefore, biogas generated from organic waste deposits is allowed to flow freely to the atmosphere. This analysis will be done based on assumptions through application of standards required for the efficient capturing of landfill methane and the outputs expected. Furthermore, in a study carried out by Ably Carbon in 2012, a French firm, to evaluate the feasibility of capturing LFG in landfills in Lagos, some sections of one of the landfills were reported to lack the capability to produce enough methane that can be utilized, while two others were feasible in producing biogas.

4.1.2 History of landfills in Lagos

Lagos has been facing serious challenges with waste management for quite a long time. Given the huge population (over 22 million) and political instability, there has been neglect in this service area. In the past, local governments were in charge of collection and management of waste in their areas, but this arrangement did not work well in the city. The city became an eye sore, filled with overflowing garbage. This led to the creation of the Lagos Waste Management Authority (LAWMA) in 1991, which now oversees waste management activities in the megacity.

There are three legal landfills where collected waste is disposed: Olushosun, Abule-egba and Solus. Two of these landfills are said to have reached their life spans and capacity since 2009, but they still continue to receive waste due to the lack of capacity in the other landfills in the city. There are current plans to construct three new landfills in the city to meet the demand of the ever growing population, but construction has not yet begun.

Google Map showing Olushosun and Abule-Egba Landfills

4.1.3 Olushosun Landfill Site

This landfill is located in the northern part of Lagos within the Ikeja Local Government and receives approximately 40% of the total waste deposits from Lagos (LAWMA, 2010). Its size is 42.7 hectares and it had a life span of 20 years from the time it began operation. The site was originally dug up for laterites used to fill up roads in the city in the early 1900s, which created open trenches that were not suitable for any physical urban development. According to the information extracted from the feasibility study conducted by Ably Carbon as provided by LAWMA, the landfill site would be closed by 2017. But from interviews conducted while in the field, the site is estimated to have space to still take waste for up to an additional 10 years. The site conditions are also favorable to the generation of methane gas and was judged to be the most viable site for LFG generation (Ably Carbon, 2012). Due to the fact that there has been no record of waste deposited at this site until 1992, the landfill start-up date was assumed to be 1992 and is expected to be closed in 2017 (see Table 4.4). Also, since wastes are comingled in the city, it is hard to know the exact volume of organics present in the landfill, but a 45% organics fraction has been established by the waste management agency, LAWMA (2010). Therefore for analysis, the organic fraction of waste in this landfill will be around 45% of the overall waste dumped annually.

4.1.4 Abule-Egba Landfill

The site occupies land of about 10.2 hectares in the Western part of Lagos in the Alimosho Local Government and receives waste from the densely populated area there. The life span originally was approximately for only 8 years but went past the estimated closure. The landfill opened in 1995 and closed in 2009. It is an unmanaged landfill with an average depth of 8 meters and with an unknown quantity of waste present. However, in the feasibility report (Ably Carbon,2012), an estimate of the quantity of waste present was given by LAWMA, but these data cannot be trusted because there was no weigh-bridge at this landfill. Therefore, the reliability of the amount of methane that could be tapped from this landfill depends on the accuracy of the waste quantity data presented by LAWMA. This data issue is dealt with later in the chapter.

4.1.5 Solous Landfill

The Solous landfill is situated along Lagos State University – IBA Road. Soluos II - is on 7.8 hectares of land with an average life span of 5 years and is presently closed. Soluos III- a new landfill site with approximately 5 hectares of land has an average life span of 5 years. The Solous landfill is divided into three parts called Solous I, Solous II and Solous III. Solous II and Solous III were ruled out for capturing LFG due to unfavorable conditions at the site, such as constant fire outbreaks (Ably Carbon, 2012). Again, waste deposit tonnage data in this landfill may not be accurate due the unavailability of a weigh bridge, but this is the only valuable data available from LAWMA.

4.1.6 Methodology

The only known LFG study that has been conducted so far in Nigeria, used the U.S EPA LandGEM software Version 3.02. This software has been utilized in this analysis (Landfill Waste to Energy Scenario) to evaluate the amount of methane generated in the landfills of interest. In 2010, the Centre for People and Environment (CPE, 2010) released the first feasibility report of producing landfill gas in Nigeria, based on three different landfills in different regions of Nigeria. The study was sponsored by the United States Environmental Protection Agency to determine the economic benefit of capturing methane for electricity in Nigeria. For Lagos the only study carried out on LFGs was done by Ably Carbon. The study was to essentially show the possibility of capturing landfill gas and benefiting from the carbon credit program through Clean Development Mechanism (CDM) established under the 1997 Kyoto Protocol. It essentially analyzed factors such as soil conditions, temperature, chemicals that together would conclude if methane gas could be captured at landfill sites. Therefore, the analysis here will utilize the same model used by CPE to analyze landfill methane in three landfills in Nigeria, and some of the information an methane feasibility factors in Ably

Carbon study was applied in this analysis. This research will break down quantitatively the amount of methane and subsequently how much electricity could be generated now and in the future, if the necessary infrastructure is built to tap this waste resource. Unlike the prefeasibility report which just estimates the *quality* and *possibility* of capturing LFG available from landfills for the purpose of developing a "Clean Development Mechanism (CDM) Carbon Credit project of LFGs" capture and utilization, this study analyzed the quantity of methane generated in landfills from inception to closure and then estimated how much electricity could be generated from this. In addition to this, a twenty year projection of methane and subsequent electricity generation, was made for the three proposed landfills based on the overall waste generation in the city. This has not been done earlier.

The Landfill Gas Emissions Model (LandGEM) is an automated estimation tool with a Microsoft Excel interface that can be used to estimate emission rates for total landfill gas, methane, carbon dioxide, nonmethane organic compounds, and individual air pollutants from municipal solid waste landfills (http://www3.epa.gov/ttncatc1/dir1/landgem-v302-guide.pdf). This software was published by the U.S EPA in 2005 and has been used widely in the United States and internationally (Global Methane Initiatives, 2012).

The accuracy and reliability of the results generated using this model depends largely on a number of input data. The model uses the first-order decomposition rate equation to estimate annual emissions of landfill gas over a time period that is being defined by the user.

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} kL_o \left(\frac{M_i}{10} \right) e^{-kt_{ij}}$$

Where

QCH4 = annual methane generation in the year of the calculation (m3 /year)

i = 1 year time increment

n = (year of the calculation) - (initial year of waste acceptance)

j = 0.1 year time increment

k = methane generation rate (year-1)

Lo = potential methane generation capacity (m3 /Mg)

Mi = mass of waste accepted in the ith year (Mg)

tij = age of the jth section of waste mass Mi accepted in the ith year (decimal years, e.g., 3.2 years)

In order to estimate how much electricity could be generated from the methane gas produced in each landfill every year, Abraxas Energy Consulting’s Energy Conversion Calculator was used (www.abraxasenergy.com/energy.resources). This enables the calculation of methane gas in cubic meters to be converted to electricity in Megawatt (MW).

4.1.7 Input Parameters

There are a number of landfill characteristics that affect the quality and quantity of LFGs generated and which determines how much electricity can be generated from Lagos landfills. Several of the important characteristics will be discussed here.

LandGEM relies on several model parameters to estimate landfill gas generation.

- Landfill area

  The total dimension of the area used for landfilling is needed to accurately determine the waste capacity. The size of each of the three landfills evaluated are stated in the landfill history section earlier. The biggest landfill in the city of Lagos is Olushoshun with about 47 hectares of land, followed by Abule-Egba with 9 hectares and Solus with 5 hectares.

- Open and closed year of landfill

  Important for accurate estimation is the year the landfill was opened and closed or anticipated to be closed. This enables the software to calculate the amount of landfill methane present on site right from inception and into the future.

- Methane Correction Factors (MCF)

  Waste disposal practices vary in the control, placement of waste and management of the site. Waste depth is very important factor and can help determine the methane correction factors (MCF) for landfills. This simply helps determine the fraction of waste that degrades either aerobically or anaerobically (Pipatti et al,2006). In the IPPC’S 1996 manual, sites are divided into four (unmanaged disposal sites, managed landfills, semi-aerobic landfills, and unknown management practice in a landfill) to specify the default methane correction factor based on waste depth and management of landfills.

Table 4.1: SWD Classification and Methane Correction Factor (MCF)

METHANE CORRECTION FACTOR TABLE			
	Site Management	Depth <5m	Depth >5m
1	Unmanaged Disposal Site	0.4	0.8
2	Managed Landfill	0.8	1.0
3	Semi-Aerobic Landfill	0.3	0.5
4	Unknown	0.4	0.8

Source: IPCC, 2006

For the three landfills assessed, in this thesis, the methane correction factor of 0.4 was used because all three are unmanaged and have depths greater than 5 meters (see table 4.10) while a correction factor of 1.0 was used for the three proposed sanitary landfills.

- Landfill cover

  The material used to cover up waste piles will determine the retaining capacity of methane on landfill sites. Sites covered with thick and well-aerated material will retain more methane than the ones with weak covers. Laterite, which has good retaining ability, is being used at the Olushosun site, while other types of clay soil were being used in the other landfills. This is a significant factor in determining the amount of methane gas remaining in the landfills after closure. Among the three landfills in Lagos, Olushosun has the best cover, which is laterite. This prevents leakage of methane gas from waste into the atmosphere. Abule –Egba and Solus used clay, which has weaker retention strength than laterite. None of the three landfills have geomembranes in place. This reduces the possibility of retaining the estimated quantity of methane gas in place. The model factors this in to determine how much methane is retained in the landfills each year.

- Temperature

  Temperature at landfill areas or locations contributes greatly to microbial activity of waste which impacts methane production. The optimal temperature range for methane generation is between 75^0F to 120^0F (Minesota Pollution Control Agency;www.pca.state.min.us). A higher or lower temperature may not result in the production of methane gas in landfills. Lagos has a perfect temperature, an average of 82^0F in the three landfills, which is favorable for the production of landfill methane.

- Waste composition

In producing methane gas, the content of waste in landfills is a very significant factor. Waste composition affects both the methane generation rate and the total amount of methane produced. Wastes containing higher biodegradable organic content, such as food waste, wood and paper, will produce more methane than more inert material such as concrete, bricks, plastic and glass. Given that it is the decomposition of organic waste that leads to methane gas generation, it is important therefore to know the volume of organic waste on site. According to LAWMA's report in 2012, about 45% of waste generated in Lagos is organics. Therefore we can assume that 45% of waste in the three landfills is organics (see Table 4.2).

Table 4.2: Waste components in Lagos

Waste components	**Percentage volume**
Organics	45
Plastics	15
Papers	10
Putrescible	8
Fines	8
Metals	5
Glass	5
Textiles	4
Total	100

(Source: LAWMA, 2012)

- Methane Content of LFG

  According to the International Panel on Climate Change's report in 2006 (IPCC,2006), a default value of 50% is considered to be the methane fraction of total landfill gas. Landfill gas consists mainly of CH4 and carbon dioxide (CO2). The CH4 fraction F is usually taken to be 0.5, but can vary between 0.4 and 0.6, depending on several factors including waste composition (e.g. carbohydrate and cellulose). The concentration of CH4 in recovered landfill gas may be lower than the actual value because of potential dilution by air, so F values estimated in this way will not necessarily be representative (http://www.ipcc-nggip.iges.or.jp/public/gp/english/5_Waste.pdf). Therefore, for the analysis of methane quantity, this default value (0.5) was applied to the model.

- Methane generation constant

  The potential methane generation capacity (L0) describes the total amount of methane gas potentially produced by a metric ton of waste as it decays (Global Methane Initiative, 2012). It depends almost exclusively on the waste composition and the moisture content. A higher cellulose content in refuse results in a higher value of L0, this will determine the biodegradability of landfill waste and methane generation rate. This explains the reason why the L0 used for Lagos landfills is 82.0 Mg, given the high organic component and moisture. Although the potential methane generation capacity may never be reached at sites in very dry climates, the L0 is viewed as being independent of moisture above a certain minimum threshold.

Table 4.3 shows the summary of all inputs explained above for each of the three landfills. Apart from the landfill sizes and depth, all other factors for analyzing the landfills using LandGEM software are the same.

Table 4.3: Summary of the input factors for the three landfills evaluated

Inputs	Olushosun	Abule Egba	Solous 1
Landfill area	47 ha	9 ha	5 ha
Average depth	12 meters	11 meters	10 meters
Mean Average Precipitation	1600mm/year	1600mm/year	1600mm/year
Methane content of LFG	50%	50%	50%
Methane generation constant(k)	0.08%	0.08%	0.08%
Methane generation potential (Lo)	82 Mg	82 Mg	82 Mg

Fraction of degradable organic content (DOCf)	50%	50%	50%
Site design &management practice	Unmanaged landfill with depth of waste >5m	Unmanaged landfill with depth of waste >5m	Unmanaged landfill with depth of waste >5m

Source: LAWMA & Ably Carbon, 2012

4.1.8 Olushosun Landfill Analysis

Table 4.4 shows the annual record of waste dumped in OLushosun landfill, which is about 40% of the total waste generated in Lagos city (LAWMA). Some parts of the landfill were closed in 2007 due to attainment of the 12m desired height above the surface for the landfill planned by the Waste Management Agency. New cells were opened up to receive waste starting from 2008, and the entire landfill is proposed to be closed by 2017 (Ably Carbon, 2012).

Table 4.4: Waste deposited in the Olushosun Landfill

Year	Waste Deposited (Metric Tons)
1992	165909.09
1993	174204.55
1994	182914.55
1995	192060.91
1996	201663.64
1997	211746.36
1998	222333.64
1999	233450.91
2000	245123.64
2001	257379.09
2002	270248.18
2003	283760.91
2004	297949.09
2005	312846.36

2006	328489.09
2007	344912.73
2008	567814.55
2009	596205.45
2010	626015.45
2011	657316.36
2012	690181.82
2013	724690.91
2014	760925.45
2015	798971.82
2016	838920
2017	880866.36

Source: LAWMA,2012 extracted from Ably Carbon Report

However, interviews with some LAWMA management officials revealed that the landfill has capacity to receive waste for another 10years. This was assumped to be too speculative, hence the anticipated closed date given officially by LAWMA was used for analyzing the quantity of methane recoverable from this landfill, which is 2017.

4.1.9 Projection of Methane Gas Available in Landfills

Using the U.S. EPA Landfill Gas Emission Model (LandGEM) software and adapting default values for calculating landfill methane in specified environmental conditions from IPCC, a comprehensive output table was derived showing: waste accepted on a yearly basis, waste in place cumulatively, total landfill gas generated from the landfills every year and methane available in site. It is worth noting that the model used here is specifically designed for U.S landfills, which are sanitary, hence limitations are expected. However, the use of IPCC values for unmanaged landfills will limit the errors expected. In addition to estimating methane gas generation in the three landfills, Abraxas Energy Consulting's Energy Conversion Calculator was used to convert the estimated methane volume to electricity. This gave us a rough estimate of electricity output that could have been generated every year from each of the landfills.

Table 4.5 summarizes methane recovery projections for Olushosun landfill. Methane production was estimated from the year the landfill started in 1992 to 2020. Although, the landfill is expected to close in 2017, an overall quantity of methane production by 2020 for the three landfills was estimated. In the first year, 1992, methane production is zero. This is because it takes time for decomposition of organic waste for it to begin the production of methane. Production begins from 1993 and continues to increase progressively to 2018, a year after the expected year of landfill closure. The year 2018 is the peak of methane production, after which the production begins to decrease. This implies that capturing of gas in this landfill requires quick action for viable return on investment. A total estimate of methane gas that could be captured in the Olushosun landfill from 1992 to 2020 is about 496,787,641 cubic meters, the total accumulated methane over time. With the assumption that technologies that will enable full capture of methane gas produced, a total of about 5,244,440 MW of electricity could be generated for city use. However, due to the fact that no capturing has taken place, significant amount of this gas would have been lost to the atmosphere, and unfortunately we cannot determine how much is left.

Table 4.5: Estimated Methane and Electricity generation at Olushosun landfill.

Year	Waste Accepted		Waste-In-Place		Methane		Electricity
	(Mg/year)	(short tons/year)	(Mg)	(short tons)	(Mg/year)	(m3/year)	MW/year
1992	165909.09	182500	0	0	0.00	0.00	0
1993	174204.55	191625	165909.09	182500	700.61	1050156.61	11086.19
1994	182914.55	201206	340113.64	374125	1382.39	2072081.17	21874.35
1995	192060.91	211267	523028.18	575331	2048.52	3070568.22	32415.08
1996	201663.64	221830	715089.09	786598	2702.07	4050181.78	42756.57
1997	211746.36	232921	916752.73	1008428	3345.92	5015261.55	52944.63
1998	222333.64	244567	1128499.1	1241349	3982.85	5969963.22	63023.14
1999	233450.91	256796	1350832.7	1485916	4615.52	6918278.31	73034.22
2000	245123.64	269636	1584283.6	1742712	5246.49	7864052.60	83018.48
2001	257379.09	283117	1829407.3	2012348	5878.24	8810997.30	93015.09
2002	270248.18	297273	2086786.4	2295465	6513.18	9762710.91	103062.05
2003	283760.91	312137	2357034.5	2592738	7153.64	10722710.93	113196.49
2004	297949.09	327744	2640795.5	2904875	7801.92	11694434.30	123454.68
2005	312846.36	344131	2938744.5	3232619	8460.28	12681255.12	133872.26
2006	328489.09	361338	3251590.9	3576750	9130.93	13686500.98	144484.34
2007	344912.73	379404	3580080	3938088	9816.07	14713473.81	155325.79
2008	567814.55	624596	3924992.7	4317492	10517.89	15765446.09	166431.15
2009	596205.45	655826	4492807.3	4942088	12107.04	18147443.00	191577.19
2010	626015.45	688617	5089012.7	5597914	13693.89	20526009.54	216687.01
2011	657316.36	723048	5715028.2	6286531	15284.63	22910391.88	241858.23
2012	690181.82	759200	6372344.5	7009579	16885.25	25309579.90	267185.75
2013	724690.91	797160	7062526.4	7768779	18501.58	27732338.41	292762.09
2014	760925.45	837018	7787217.3	8565939	20139.38	30187258.97	318677.96
2015	798971.82	878869	8548142.7	9402957	21804.27	32682790.48	345022.55
2016	838920	922812	9347114.5	10281826	23501.82	35227278.89	371883.96
2017	880866.36	968953	10186035	11204638	25237.56	37828998.18	399349.54
2018	0	0	11066901	12173591	27016.97	40496196.15	427506.36
2019	0	0	11066901	12173591	24939.81	37382700.63	394638.11
2020	0	0	11066901	12173591	23022.34	34508582.03	364296.89
Total						**496787641**	**5244440.15**

Source: Author's field work

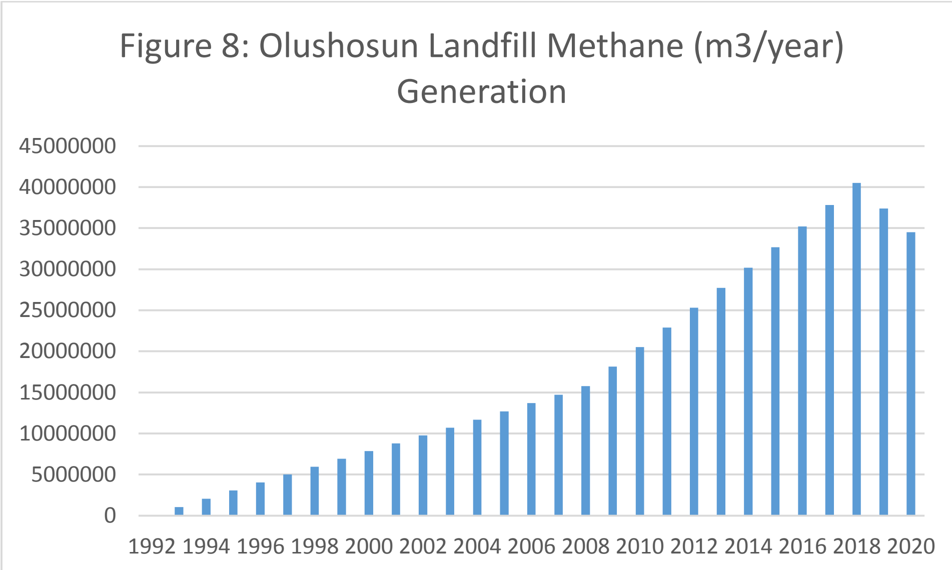

Figure 8: Olushosun Landfill Methane Generation

4.1.10 Abule Egba Landfill Analysis

A total of 2,628,726 metric tons of waste has been deposited in Abule-Egba landfill at closing in 2009 (see Table 4.6). The landfill has an average height of 11meters, and it was considered 'unmanaged'. It served low income neighborhoods in the Alimosho Local Government Area (LGA), the largest LGA in the Lagos state. The waste tonnage data in this landfill may not be accurate due to the absence of a weigh bridge at the time the landfill was still functioning; however, the study will assume that the waste data used in the Ably Carbon report is correct, because it was provided by the Lagos State Waste Management Authority (LAWMA).

Using the U.S EPA LandGEM software, an analysis of the methane present on site was calculated (see Table 4.7). The amount of landfill methane gas was calculated for each year of operation. For each year in which waste was deposited in this landfill from inception to closing and a projection to the year 2020, a cap year for the three landfills for the sake of this research, a total of **149,105,317.6m^3 (**cubic meter) of methane would have been produced. If capturing methane commenced at the start of the landfill, a total of **1,574,060.74** MW of electricity would be generated and this amount could have been used to substitute for the energy needed in the city. Just as said earlier, capturing and generating of methane and electricity is contingent on the type of equipment used and the time operations begin.

Table 4.6: Waste Tonnage of Abule- Egba landfill

Year	Metric Tons Disposed	Cumulative Metric Tons
1995	70,000	70,000
1996	74,200	144,200
1997	78,652	222,852
1998	83,371	306,223
1999	88,373	394,597
2000	93,676	488,272
2001	99,296	587,569
2002	105,254	692,823
2003	111,569	804,392
2004	111,569	915,961
2005	167,354	1,083,316
2006	251,031	1,334,316
2007	375,547	1,710,893
2008	564,820	2,275,713
2009	353,012	2,628,726

Source: The Lagos Waste Mangement Authority (LAWMA), 2012

Table 4.7: Estimated Methane and Electricity generation at Abule Egba Landfill

Year	Waste Accepted		Waste-In-Place			Methane	Electricity
	(Mg/year)	***(short tons/year)***	***(Mg)***	***(short tons)***	***(Mg/year)***	***(m^3/year)***	**MW**
1995	70,000	77,000	0	0	0.00	0.00	
1996	74,200	81,620	70,000	77,000	295.60	443079.77	4677.46
1997	78,652	86,517	144,200	158,620	586.21	878678.74	9275.95
1998	83,371	91,708	222,852	245,137	873.28	1308967.14	13818.38
1999	88,373	97,210	306,223	336,845	1158.20	1736043.31	18326.9
2000	93,676	103,044	394,596	434,056	1442.34	2161945.51	22823.02
2001	99,296	109,226	488,272	537,099	1727.03	2588669.26	27327.82
2002	105,254	115,779	587,568	646,325	2013.56	3018157.89	31861.8
2003	111,569	122,726	692,822	762,104	2303.22	3452338.30	36445.31
2004	111,569	122,726	804,391	884,830	2597.28	3893109.45	41098.4
2005	167,354	184,089	915,960	1,007,556	2868.73	4299992.50	45393.75
2006	251,031	276,134	1,083,314	1,191,645	3354.89	5028695.83	53086.45
2007	375,547	413,102	1,334,345	1,467,780	4157.02	6231025.02	65779.09
2008	564,820	621,302	1,709,892	1,880,881	5423.29	8129065.05	85816.14
2009	353,012	388,313	2,274,712	2,502,183	7391.48	11079220.23	116960.05
2010	0	0	2,627,724	2,890,496	8313.92	12461873.26	131556.31
2011	0	0	2,627,724	2,890,496	7674.71	11503758.91	121441.78
2012	0	0	2,627,724	2,890,496	7084.65	10619307.90	112104.89
2013	0	0	2,627,724	2,890,496	6539.96	9802856.71	103485.86
2014	0	0	2,627,724	2,890,496	6037.14	9049177.27	95529.49
2015	0	0	2,627,724	2,890,496	5572.99	8353443.46	88184.83
2016	0	0	2,627,724	2,890,496	5144.51	7711200.20	81404.86
2017	0	0	2,627,724	2,890,496	4748.99	7118334.96	75146.16
2018	0	0	2,627,724	2,890,496	4383.87	6571051.36	69368.65
2019	0	0	2,627,724	2,890,496	4046.82	6065844.92	64035.33
2020	0	0	2,627,724	2,890,496	3735.68	5599480.60	59112.06
Total						**149105317.6**	**1574060.74**

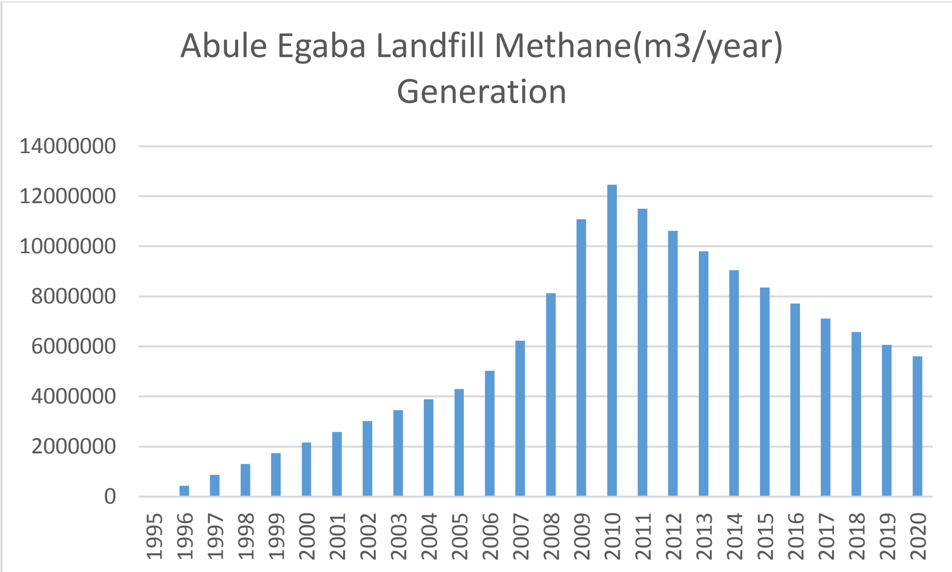

Figure 9: Graph of methane gas generation in Abule-Egba Landfill

4.1.11 Solous 1 Landfill Analysis

The Solous landfill is divided into three parts called Solous I, Solous II and Solous III. Solous II and Solous III were ruled out of the possibility of capturing LFGs (Ably Carbon,2012), due to unfavorable conditions. Again, waste deposit tonnage data in this landfill may not be accurate due the unavailability of a weigh bridge, but was the only valuable data available from LAWMA.

Solous I has the least methane generation capability of the three landfills studied due to its size, period of waste deposition and quantity of waste deposited. According to LAWMA, waste was only deposited at this landfill for a period of 10 years. The total quantity of methane is estimated to have been generated from 1996 to 2006, and a projection of fourteen years after being active is **101,198,084.1 m^3.** From this estimate of methane gas available in this landfill, a total of about **1068318.3 MW** electricity could be generated (See Table 4.9). However, this is contingent on when the gas capturing project starts and the nature of technology used.

Table 4.8: Waste deposited in Solous I landfill

Year	Metric Tons Disposed	Cumulative Metric Tons
1996	100,122	100,122
1997	106,512	206,634
1998	113,311	319,945
1999	120,544	440,489
2000	128,238	440,489
2001	136,423	705,150
2002	145,131	850,282
2003	154,395	1,004,677
2004	164,250	1,168,927
2005	264,375	1,415,302
2006	184,781	1,600,083

Source: LAWMA, 2012 extracted from Ably Carbon Report

Table 4.9: Potential Methane and Electricity generation in Solous I Landfill

Year	Waste Accepted		Waste-In-Place		Methane		Electricity
	(Mg/year)	*(short tons/year)*	*(Mg)*	*(short tons)*	*(Mg/year)*	*(m^3/year)*	*MW/year*
1996	100,122	110,134.00	0	0	0.00	0.00	0.00
1997	106,512	117,163	100,122	110,134	422.80	633743.33	6690.24
1998	113,311	124,642	206,634	227,297	840.08	1259209.01	13293.1
1999	120,544	132,598	319,945	351,940	1253.99	1879622.31	19842.62
2000	128,238	141,062	440,489	484,538	1666.62	2498118.77	26371.9
2001	136,423	150,065	568,727	625,600	2080.01	3117763.76	32913.31
2002	145,131	159,644	705,150	775,665	2496.19	3741576.86	39498.72
2003	154,395	169,835	850,281	935,309	2917.14	4372548.06	46159.7
2004	164,250	180,675	1,004,676	1,105,144	3344.85	5013646.33	52927.58
2005	264,375	290,813	1,168,926	1,285,819	3781.29	5667833.92	59833.65
2006	184,781	203,259	1,433,301	1,576,631	4606.98	6905487.50	72899.19
2007	0	0	1,618,082	1,779,890	5033.09	7544178.73	79641.66
2008	0	0	1,618,082	1,779,890	4646.12	6964154.71	73518.52
2009	0	0	1,618,082	1,779,890	4288.91	6428725.05	67866.15
2010	0	0	1,618,082	1,779,890	3959.17	5934461.18	62648.35
2011	0	0	1,618,082	1,779,890	3654.77	5478198.12	57831.72
2012	0	0	1,618,082	1,779,890	3373.78	5057014.24	53385.4
2013	0	0	1,618,082	1,779,890	3114.39	4668212.50	49280.94
2014	0	0	1,618,082	1,779,890	2874.94	4309303.27	45492.04
2015	0	0	1,618,082	1,779,890	2653.91	3977988.29	41994.45
2016	0	0	1,618,082	1,779,890	2449.87	3672146.02	38765.76
2017	0	0	1,618,082	1,779,890	2261.51	3389818.01	35785.31
2018	0	0	1,618,082	1,779,890	2087.64	3129196.42	33034
2019	0	0	1,618,082	1,779,890	1927.13	2888612.37	30494.23
2020	0	0	1,618,082	1,779,890	1778.97	2666525.29	28149.72
Total						**101198084.1**	**1068318.3**

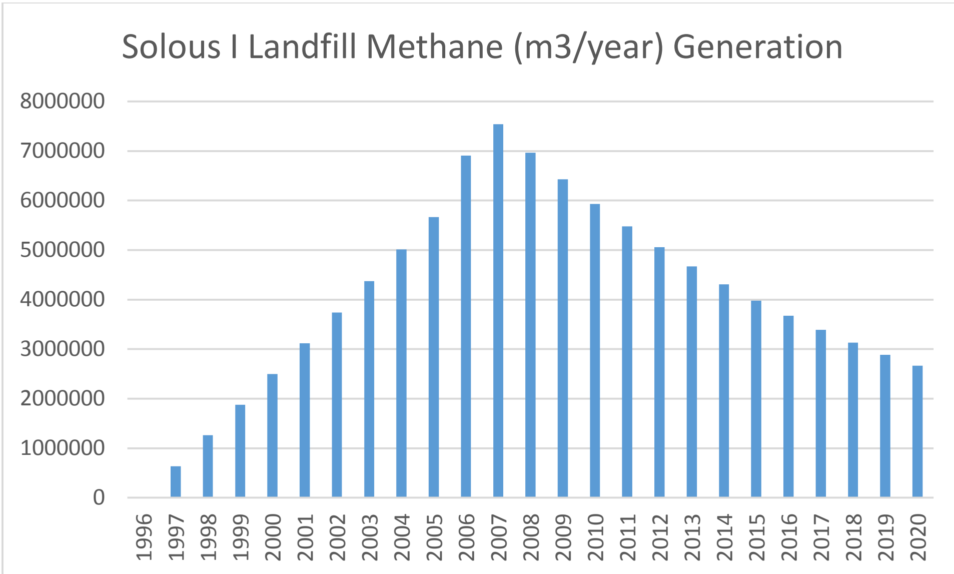

Figure 10: Graph of methane in Solous I Landfill

4.1.12 Projection of Future Methane and Electricity Generation Capacity of Lagos Landfills.

The analysis shows that Lagos has had the capacity to generate a significant amount of electricity in the past from landfill gas but unfortunately nothing has been done. However, all hope is not lost as there are a still considerable amount of methane gas present on these three landfills. To avoid the further waste of resources produced in landfills, this study also estimates how much methane and electricity Lagos can get from future waste that will be produced and disposed in the three new landfills. This is done by projecting the population and waste generation in the city to the year 2050 by the addition of three new landfills that will come on line soon. According to the Lagos Bureau of Statistics data, Lagos had a population of about 23,305,971 people in 2015. Using this as base year, with an annual estimated growth rate of about 3.19%, a projection of the population of the city was done. Also, given that the daily per/capita waste generation in the city is 0.65kg (LAWMA, 2012), an estimate projection of waste tonnage from 2015 to 2050 was calculated. An assumption that only 75% of the total waste generated each year will make it to landfills was also made. This is because of the history of indiscriminate and illegal waste dumping that is a practice in the city. This facilitated the estimation of how much methane gas could be recovered from the estimated landfilled waste, and how much electricity could be generated from it. As new landfills we assumed they will be sanitary and well managed.

The total methane that would be generated in Lagos based on the estimated waste that would be generated and deposited in the three new proposed landfills in Lagos is

32,181,832,493 m^3 from 2015 to 2050. This could be a huge source of energy for the city as an estimated 339,051,194.6 MW (see Table 4.11) could be produced over time. The question is what percentage of the energy need for the city could be generated for the city. Currently, the city gets its energy supply from hydro and thermal power sources. Investing in landfill methane capturing would add to the energy mix and strengthen the supply, which has fallen below demand for several decades. According to Siemens' Green City Index report of 2010 (Simens,2010), the total per/capita electrical use by residents of Lagos is 222KW per/capita/day. In order to calculate the annual electricity needed from the projection year, the population in each year was multiplied by the per/capita electricity per day, to get an estimate of the city household energy demand. The result of the estimates is shown in Table 4.11. The total energy demand from 2015 to 2050 is 340,811,241.8MW. Surprisingly, the amount of electricity that could be generated from landfill methane, 339,051,194.6 MW, was just a bit below the household need in the city of Lagos. This is a considerable amount of an energy source for the city if investment is directed in this direction. However, it will be a wild claim to say electricity generated from LFG will cater to 95% of the energy demand in the city of Lagos. This is because the City of Lagos is the most industrialized city in Nigeria, and therefore has a huge energy demand aside from residents' needs. Unfortunately, there is no data to ascertain what percentage of the total electricity demand in the city would be provided from LFG. It is worthy to note that for the city to be able to harness this huge energy potential from landfills, there is need for huge investment right from the construction phase to transmission to grids.

Table 4.10: Population waste generation projection for the entire city of Lagos in the three new landfills.

Year	Population projection	Waste generation (0.65kg/percapita)	Waste deposited in landfills (assuming that 75% was disposed in landfills) (metric tons)
2015	23,305,971	15148881.15	11361660.86
2016	24,051,762	15633645.30	11725233.98
2017	24,821,418	16133921.70	12100441.28
2018	25,615,704	16650207.60	12487655.70
2019	26,435,406	17183013.90	12887260.43
2020	27,281,339	17732870.35	13299652.76
2021	28,154,342	18300322.30	13725241.73
2022	29,055,281	18885932.65	14164449.49
2023	29,985,050	19490282.50	14617711.88
2024	30,944,572	20113971.80	15085478.85
2025	31,934,798	20757618.70	15586214.03
2026	32,956,712	21421862.80	16066397.10
2027	34,011,326	22107361.90	16580521.43
2028	35,099,689	22814797.85	17111098.39
2029	36,222,879	23544871.35	17658653.51
2030	37,382,011	24298307.15	18223730.36
2031	38,578,235	25075852.75	18806889.56
2032	39,812,739	25878280.35	19408710.26
2033	41,086,747	26706385.55	20029789.16
2034	42,401,522	27560989.30	20670741.98
2035	43,758,371	28442941.15	21332205.86
2036	45,158,639	29353115.35	22014836.51
2037	46,603,715	30292414.75	22719311.06
2038	48,095,034	31261772.10	23446329.08
2039	49,634,075	32262148.75	24196611.56
2040	51,222,366	33294537.90	24970903.43
2041	52,861,482	34359963.30	25769972.48
2042	54,533,049	35446481.85	26584861.39
2043	56,298,747	36594185.55	27445639.16
2044	58,100,306	37765198.90	28323899.18
2045	59,959,516	38973685.40	29230264.05
2046	61,878,221	40220843.65	30165632.74
2047	63,845,324	41499460.60	31124595.45
2048	65,901,790	42836163.50	32127122.63
2049	68,010,648	44206921.20	33155190.90
2050	70,186,988	45621542.20	34216156.65

Table 4.11: Projection of future electricity that would be generated from Lagos landfills from 2015-2050

Year	**Waste Accepted**		**Waste-In-Place**		**Methane**		**Electricity**	**Current Electricity need(using 222Kw percapita X population)/ 1000* (1000=1MW)***
	(Mg/year)	(short tons/year)	(Mg)	(short tons)	(Mg/year)	(m3/year)	(MW)	MW
2015	10328783	11361660.86	0	0	0	0	0	5173926
2016	10659304	11725233.98	10328782.6	11361660.9	43616.97	65378209.4	7286.01	5339491
2017	11000401	12100441.28	20988086.22	23086894.8	85276.25	127822006	1349379.11	5510355
2018	11352414	12487655.7	31988487.38	35187336.1	125173	187623944	1980690.48	5686686
2019	11715691	12887260.43	43340901.65	47674991.8	163488.9	245056232	2586986.16	5868660
2020	12090593	13299652.76	55056592.95	60562252.3	200392.9	300372354	3170942.1	6056457
2021	12477492	13725241.73	67147186.37	73861905	236042.8	353808593	3735052.67	6250264
2022	12876772	14164449.49	79624678.85	87587146.7	270585.7	405585418	4281645.3	6450272
2023	13288829	14617711.88	92501451.12	101751596	304158.8	455908777	4812894.11	6656681
2024	13714072	15085478.85	105790280.1	116369308	336890.8	504971292	5330832.57	6869695
2025	14169285	15586214.03	119504351.8	131454787	368901.9	552953365	5837365.12	7089525
2026	14605816	16066397.1	133673637.3	147041001	400374.3	600127773	6335371.4	7316390
2027	15073201	16580521.43	148279452.8	163107398	431270.3	646438350	6824258.46	7550514
2028	15555544	17111098.39	163352654.1	179687920	461764.6	692146816	7306789.22	7792131
2029	16053321	17658653.51	178908198.1	196799018	491951.3	737394139	7784451.82	8041479
2030	16567028	18223730.36	194961519.5	214457671	521919.2	782313469	8258651.9	8298806
2031	17097172	18806889.56	211528547.1	232681402	551752.3	827030849	8730720.06	8564368
2032	17644282	19408710.26	228625719.4	251488291	581530.5	871665857	9201918.63	8838428
2033	18208899	20029789.16	246270001.5	270897002	611329.6	916332208	9673448.09	9121258
2034	18791584	20670741.98	264478900.7	290926791	641221.9	961138311	10146452.87	9413138
2035	19392914	21332205.86	283270484.3	311597533	671276.6	1006187781	10622026.8	9714358
2036	20013488	22014836.51	302663398.7	332929739	701559.9	1051579933	11101218.32	10025218
2037	20653919	22719311.06	322676886.5	354944575	732135.5	1097410220	11585035.11	10346025
2038	21314845	23446329.08	343330805.6	377663886	763064.7	1143770653	12074448.48	10677098
2039	21996920	24196611.56	364645650.2	401110215	794407.1	1190750194	12570397.6	11018765
2040	22700821	24970903.43	386642569.8	425306827	826220	1238435114	13073793.2	11371365
2041	23427248	25769972.48	409343391.1	450277730	858559.5	1286909337	13585521.23	11735249
2042	24168056	26584861.39	432770638.8	476047703	891480.2	1336254754	14106446.21	12106337
2043	24950581	27445639.16	456938694.6	502632564	924998.2	1386495417	14636822.03	12498322
2044	25748999	28323899.18	481889275.7	530078203	959243.7	1437826552	15178709.64	12898268
2045	26572967	29230264.05	507638275	558402102	994227.8	1490264919	15732285.97	13311013
2046	27423302	30165632.74	534211242.3	587632367	1030002	1543887112	16298359.6	13736965
2047	28295087	31124595.45	561634544.8	617797999	1066616	1598769011	16877731.57	14173662
2048	29206475	32127122.63	589929631.5	648922595	1104097	1654949532	17470812.72	14630197
2049	30141083	33155190.9	619136106.7	681049717	1142545	1712579514	18079195.39	15098364

2050	31105597	34216156.65	649277189.3	714204908	1181983	1771694488	18703254.69	15581511
Total						32181832493	339051194.6	340811241.8

4.2 Compost Scenario

The Earthcare Compost Company in Lagos started operations in 2009 to divert organic waste being generated in five major sources, saw dust from Oko Baba Sawmill, Ebute-Metta; animal waste from the Oko Oba Abattoir; fruits and vegetables from Bolade fruit market; Domestic Waste from the Ojota / Ikorodu Road axis and the markets at Ikorodu town; and domestic waste from Oregun dump site (Revised Environmental Impact Assessment of Earthcare Compost, 2009). However, due to transportation logistics and waste quality, the company has so far been receiving organic waste generated in fruit and vegetable markets alone. At inception of the project, LAWMA officials carried out campaigns to sensitize traders and the general public on the need to separate their waste and dump them in a waste truck that will be parked in certain locations of the markets (See figure 12). These waste trucks are then taken to the compost facility at night on a daily basis, so as not to interfere with the biodegradability process of the organic waste.

Although the manager of the facility did not release the data of waste brought from different areas, a rough estimate was given by the LAWMA recycling department. On the average, the facility receives about 600 tons of organic waste per day from fruits and vegetables markets such as Mile 12 and Bolade market (LAWMA,2012), but has the capacity to process 1,500 metric tons per day. The garbage is then delivered to the composting facility by trucks, received at the facility entrance and run across the weigh bridge to establish the weight of the waste delivered. The presorted waste will be shredded and processed. Rows are formed on compost pads made of cement concrete and a synthetic polymer laid for strength, durability and low permeability (See Figure 11). The site is designed to direct all rainwater to a catchment pond for reuse as moisture for the composting rows (Revised Environmental Impact Assessment of Earthcare Compost, 2009).

The two inoculants are added, mixed by a plough and trimmed to form a row, trimmed and monitored for temperature, moisture, carbon dioxide and oxygen. The compost row covers are used to shed rainwater while also allowing a continuous exchange of natural gases from the compost row with the surrounding air as part of the row management regime (Revised Environmental Impact Assessment of Earthcare Compost, 2009). The finished compost is tested for heavy metals, pathogens; and moved to the screening area. The screened compost is then bagged. From every 600 metric tons of organic waste, an average of 250 bags (50kg) of compost is produced per day (LAWMA, 2016). This implies that an average of 91,250 bags of compost are produced every year.

Being the first of its kind in Nigeria, one would think the marketability of the composts produced should not be a problem, but the reverse is the case. Just like in all other countries, marketing of compost in Nigeria has been a huge challenge due to several reasons. During the field study it was gathered from officials in Earthcare Compost that the price of chemical fertilizers compete greatly with price of composts, due to government subsidy on chemical fertilizers. Currently, a bag of chemical fertilizer after deduction of government's subsidy sells for #2,700 ($13.50), while a bag of compost sells for #3,500 ($17.50). This serves as a disincentive to farmers who would have patronized organic compost to improve soil condition. On the other hand, there has been a hot debate in the field of agriculture on the dangers of using compost for farming. This is because of the quality of compost which usually contains toxic chemicals which varies from country to country. Earthcare Compost is aware and mindful of the likelihood of too much toxic chemicals in compost, hence they take samples of every batch of compost produced to International Institute of Tropical Agricultural (IITA) for testing, in order to determine types and quantities of compost nutrients. One will expect that this should clear the doubt of wary farmers, but we cannot be sure if this improves marketability of the product.

Also, there is an information gap between, the producer (Earthcare Compost Company) and consumers (farmers) of compost in terms of environmental impacts, benefits and cost savings. In other countries such as Indonesia, demonstration farms were started to show the people what can be achieved through the use of compost. Marketing of compost to people who have been using inorganic fertilizer should go beyond word of mouth alone. Although, the field officer at the compost facility said they partnered with Department of Agriculture, Lagos State Polytechnic to give each student of the department a free bag of compost to use for their compulsory farming project. This is one way to market compost in the city. However, establishing a demonstration farm accessible to the entire public will be quiet helpful to publicize the benefit of using compost.

According to World Bank, 80% of waste generated in low to middle income countries are compostable, hence composting can be a great way to divert waste from landfills and prevent the emission of methane gas (Hoornweg et al, 2000). However, this will depend on the manner in which waste is being handled, for example, in the city of Lagos waste are not separated from the source, it becomes hard to achieve this diversion rate. Even with the specialized collection done by Earthcare compost company from markets, they still receive wastes that are comingled. The overall effect of this could be production of low quality compost, therefore there is need for careful sorting on arrive at the facility, which adds significantly to the cost production.

Figure 11: Rows of organic waste divided into furrows for aerobic process

Figure 12: Waste truck parked in a market to collect organic waste

Figure 13: Rows of waste undergoing curing period

4.2.1 Profitability of Compost in Lagos

It is difficult to measure the profitability of composting in the city, due to lack of cooperation of officials of Earthcare to release finacial statement information. A generic 'yes, it is profitable' was the only answer received from the general manager of the company. Logically this cannot be true if the profit comes from selling compost prodced, since they are facing a problem with patronage. Further subtle findings revealed that Earthcare Compost company has a partnership with the Ministry of Agriculture to supply compost to farmers in the state. The ministry pays for it on quarterly basis, giving the company a stable market, even if they still have a large number to unsold. As said earlier, this definitely could not be the source of profitability. In an interview with the head of recycling department, Mrs. Adeyo, it was gathered that LAWMA pays Earthcare for every ton of waste taken from the markets. This is to cover the running cost of composting. Apart from this, Earthcare is registered as a Clean Development Mechanism (CDM) project. According to the Wold Bank report, Earthcare Compost has about 30,000 cabon credit in total by 2015 (http://wcarbonfinance.org/UCFT2), therefore the company gets a huge sum of money from CDM. Although, it could not be determined who gets this money, whether Earthcare Compost or LAWMA, because the information was not relaeased. But the fact that they receive funds to keep processing waste is quiet interesting and encouraging.

CHAPTER FIVE

SUMMARY OF FINDINGS, RECOMMENDATIONS AND CONCLUSION

5.1 Introduction

The focus of this chapter is to present the summary of the major findings of the study, draw conclusions, and make recommendations as to how to use regenerative methods for larger impacts and environmental benefits.

5.2 Summary of findings

Findings from the study show that there are large opportunities for the City of Lagos to benefit from the methane produced in landfills. In Olushosun, the biggest landfill in the city, a total of 496,787,641 cubic meters of methane gas would have been produced starting from 1997 to the end of 2020, and an estimated 5,244,440 MW of electricity could subsequently be generated. The same goes for the two other landfills, Abule-Egba and Solous 1, where an average of **149,105,317.6m^3** and **101,198,084.1 m^3** methane gas would be produced cumulatively and can be used to produce an estimated **1,574,060.74** MW and **1068318.3** MW of electricity respectively for use in the city. However, because capturing equipment is not presently on these landfills, it is hard to ascertain how much gas is left and can be captured for electricity production. But if action is taken sooner rather than later, a considerable amount of this gas could still be captured in Olushousun landfill, because it is the only landfill currently active.

Furthermore, it was established that Lagos has great potential to recover much methane in the future. For the three new proposed sanitary landfills in the city of Lagos, there is the possibility of recovering an estimated 32.2 billon m^3 of methane from 2015 to 2050, which could be used to produce 339,051,194.6 MW of electricity over that time period. Amazingly, the household energy needs for the entire city of Lagos, with over 21 million people, can be met if the methane generated on the proposed landfills is efficiently captured and converted to electricity. Overall from 2015 to 2050, the total household energy demand is estimated to be 340,811,241.8MW, while 339,051,194.6 MW can be produced from landfill methane gas.

With regards to composting, Earthcare Compost Company, the only compost company in Nigeria, collects organic waste from vegetable and fruit markets close to it. On a daily basis an average of 600 tons of waste is processed to produce 250 bags (50kg per bag) of compost. Unfortunately, the company is facing difficulty with marketing of compost. The study established that the absence of demonstration farm to show farmers who would rather use inorganic fertilizer for better yields could be a main cause of the lack of patronage. Also there is need to tackle other issues such as price of compost taking into consideration the price of government subsidized chemical fertilizers and ensuring good quality compost that contains all needed nutrients is produced.

5.3 Recommendations and Conclusion

From the major findings summarized above, there is clear indication that Lagos can benefit greatly from the advantage of having 45% of its' waste being organic. Although, scientists have established that organic waste is the most threatened of all waste types due to the methane production after decomposing, a gas believed to be 21 times potent than carbon dioxide, and a key contributor to climate change. However, this study has been able to establish that the bad omen that comes with organic waste can be turned around to become a blessing to the city of Lagos. For decades now, electricity generated in the city has fallen short of demand which is seen in the incessant power outages putting the city in darkness and forcing people to use personal generators. Therefore, if an average of 9,687,176 MW electricity can be produced from landfill methane gas annually, why not explore this opportunity to the maximum. Of course, it could be argued that to achieve this level of electricity generation from landfill gas, there is need for huge investment to install equipment for tapping and converting to electricity. Very true, but it is not unachievable for Lagos considering the possibility of registering the construction and operation of the three new landfills as CDM, and being able to get funds from developed countries in the form of carbon credit.

As said earlier, landfill methane to electricity option seems to be the most visible for the city of Lagos given the manner of waste collection and transportation. Although it could be argued that waste management best practices in developed cities today is leaning towards zero waste and diversion of organic waste from landfills to combat climate change and extension of lifespans of landfills. These organic waste diversion are sent to compost facilities and used to produce heat and electricity using Anaerobic Digestion (AD). Diversion of organic waste is possible in these cities because of the use of different disposal cans for different type of waste. One key factor that makes waste diversion possible is sorting from the source of generation. This is a big challenge in Lagos, as wastes are comingled and collected that way for disposal. Therefore diversion of organic waste in Lagos is not feasible for now, but can be achieved in the long run with a lot of households and industry sensitization and education.

Composting seems not to be optimizing the benefit of huge organic by-product generated in Lagos because of some problems that were identified earlier. The major challenge with composting is marketing the product to farmers in the city. To tackle this challenge, the management of Earthcare Company needs to start a demonstration farm to show farmers the benefits of using compost. Also, the general public should be sensitized on the benefit of eating organically grown food products, rather than the chemically fertilized ones. This will stimulate demand for their product in return. Furthermore, the compost company should strive to receive more waste in order for it to achieve the daily processing capacity of 1,500tons. This means expanding its service to other markets, abattoirs and saw mills. However, for the long term future of composting method to be used to manage organic waste in the city, there is need for a comprehensive partnership with government of some states that are rich in agriculture to encourage farmers to use organic compost, This can be done by providing subsidies for compost and disengaging or reducing chemical fertilizer subsidies as a disincentive.

In conclusion, for the City of Lagos to be able to sustainably manage the huge amount of waste in the future and now, there is need for a more holistic approach. Combination of landfill, compost and aerobic digestion methods could bring a long-term solution and transition from landfilling organics to diverting it for other purposes. Also, there is need for the waste management authority, LAWMA, to be diligent with data collection as this is key to making good decisions and formulating policies to address future problems. Automating the city's waste collection system whereby waste can be measured as it is picked up from houses is one important way to keep track of what happens at household level.

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