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ENVIRONMENTAL AND ECONOMIC ANALYSIS OF SOLID WASTE MANAGEMENT ALTERNATIVES FOR LAGOS MUNICIPALITY, NIGERIA

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ABSTRACT

Municipal solid waste management has emerged as one of the greatest challenges facing environmental protection agencies in Lagos, Nigeria. Waste is typically disposed of without consideration for environmental and human health impacts, leading to its accumulation in cities, towns and uncontrolled dumpsites. Various governmental and non-governmental organizations have been encouraging developing countries to implement integrated waste management options that provide improved environmental outcomes for municipal solid waste management. The need for this encouragement is due to the realization of the impact of climate change and the increasing awareness of the role of waste as a contributor to greenhouse gas emissions. This case study presents the current solid waste management practices and problems in Lagos, Nigeria and analyzes options for improvement. To measure the potential impact of these improvements, life cycle assessment (LCA) was applied to the Olusosun landfill site in Lagos, Nigeria. This allows comparison of the expected environmental impacts of different technologies to help decision-makers. Recommendations were made also for improvement in governmental policies towards waste reduction and public awareness of the importance of waste reduction.

Keywords: Life Cycle Assessment, Green House Gas, Municipal Solid Waste, Recycle, Material Recovery Facility

INTRODUCTION

Lagos is the economic hub of Nigeria and is its largest city in terms of population. Although Lagos state is the smallest state in Nigeria, with an area of 356,861 hectares of which 75,755 hectares are wetlands, it has the highest population, which is over five per cent of the national total. The state has a population of 17 million out of a national estimate of 150 million. The UN estimates that at its present growth rate, Lagos state will be the third largest mega city the world by Y2015 after Tokyo in Japan and Bombay in India (Lagos state government, 2012).

In Lagos state, 37% of the land area is home to over 85% of the population. The rate of population growth is about 600,000 per annum with a population density of about 4,193 persons per sq. km. In the built-up areas of Metropolitan Lagos, the average density is over 20,000 persons per square km.

Government demographic trend analyses reveal that the State population growth rate of 8% will result in Lagos state capturing 36.8% of Nigeria's urban population estimated at 135 million. The implication is that whereas country population growth is between 4 and 5% and global growth is approximately 2%, Lagos population is growing twice as fast as the rest of the country, four times faster than the rest of the world, and ten times faster than the large American cities of New York and Los Angeles. This has grave implications for urban sustainability in general (Lagos state government, 2012) and solid waste management in particular.

Utilization of LCA principles to guide municipal waste system design, though not a complete sustainable livelihood strategy, aligns well with the framework for sustainable rural livelihoods (Scoones, 1998). The framework can be applied over a range of different scales and therefore is applicable beyond a solely rural context. Application of LCA principles create potential for generation of both economic/financial capital, human capital, as well as a reduction in the depletion rate of natural capital.

MUNICIPAL SOLID WASTE OVERVIEW

Municipal solid waste (MSW) is defined as non-air and sewage emissions created within and disposed of by a municipality, including household garbage, commercial refuse, construction and demolition debris, dead animals, and abandoned vehicles (Igbinomwanhia, 2011). Municipal solid waste is generally made up of vegetable matter, textiles, rubber, plastics, paper, metals and glass. The last three components are recoverable, reusable and recyclable.

While most types of plastic are recyclable and safe to reuse at least a few times, studies have indicated that some materials used for making the plastic bottles can contain trace amount of Bisphenol A (BPA), a synthetic chemical that interferes with the body's natural hormonal messaging system. Also repeated re-use of such bottles causes wear and tear that can increase the chance that chemicals will leak out of the tiny cracks and leach diethylhexyl phthalate (DEHP)—a probable human carcinogen. Proper care must be observed to determine the type of plastic that can be recycled. (Environmental Magazine, 2012)

Municipal solid waste disposal sites worldwide account for up to 20% of global emissions of methane, the second most significant contributor to greenhouse gas (GHG) (World Resource Institute, 2012). This need not be the case, as under proper management landfills can in fact have a positive carbon balance. However such management entails the capture and destruction of methane gas emitted from these landfills, an undertaking that has been too costly for many developing countries to implement (Aboyade, 2004).

According to a UNIDO Report, across Africa, waste management suffers from limited technological and economic resources as well as poor funding which collectively result in the prevalent low standards of waste management. This is exacerbated by public perception of waste disposal as a welfare service issue and hence the reluctance to pay for waste disposal especially among the poor. The legal and institutional/administrative framework for the environmentally sound management of waste is either lacking or inadequate. Not all the countries have ratified the Multilateral Environmental Agreements (MEAs) on wastes and chemicals (in particular the Basel, Stockholm, and Rotterdam Conventions). Comprehensive national waste legislation is lacking although several African countries including Nigeria have piece meal legislation on hazardous waste management. (Mwesigye, et al., 2009)

It has generally been overlooked by the government and regulators that municipal solid waste is a significant contributor to GHG emissions and therefore is a health issue and a major challenge to public health safety, especially in lower income neighborhoods. While proper management of MSW disposal sites can be taken for granted in many developed countries, it still is a major challenge for developing countries like Nigeria, as many of the developing countries lack funding and technology to improve their disposal systems.

Africa as a whole and Lagos state Nigeria in particular urgently need infrastructural, institutional, legal reforms and changes in attitude. Adoption of Environmentally Sound Management (ESM) of wastes can include many initiatives such as: Waste Minimization, focusing on the promotion of the “3Rs” – Reduce, Reuse and Recycle; Waste to Wealth Initiatives (e.g., ILSR, 2012) towards poverty reduction and alleviation; Corporate Social Responsibility by producers of wastes; and involvement of multiple stakeholders, for example, under the New Partnership for Africa's Development (NEPAD) Initiative. Alternative options in waste management that should also be explored include Public-Private Partnerships and Waste Exchange.

LAGOS STATE SOLID WASTE MANAGEMENT

The most recently reported per capita waste generation in Lagos state is 0.5kg/day (Oresanya, 2008). The types of municipal solid wastes generated in Lagos state, Nigeria encompass domestic, industrial, agricultural, sewage and other wastes including wastes from the medical, electrical and electronics industries. These wastes include both non-hazardous and hazardous materials. Historical and specific data relating to waste generation and characterization in Lagos state is generally lacking, in some instances not available.

According to Lagos State Waste Management Authority (LAWMA), 53% waste generation in Lagos state is from vegetable matters (food waste) and other putrescibles, while the remaining 47% is composed of other waste components. (Lagos state waste management authority, 2012)

Waste is typically disposed of without consideration for environmental and human health impacts, leading to its accumulation in cities, towns and uncontrolled dumpsites. Co-disposal of non-hazardous and hazardous waste without segregation is common practice. Municipal Solid Waste (MSW) management has continually been an intractable problem beyond the capacity of most African governments. This has resulted in refuse heaps being dumped in urban landscape in heavily populated cities as only about 40 to 50% of waste is reportedly being collected (Mwesigye, et al., 2009).

The changing lifestyles and consumption patterns of the population in general and the growing urban middle class in particular are increasing the complexity and composition of waste streams in Lagos. The fast growing use and rapid turn-over in information and communication technology (ICT) creates a growing E-waste stream for which there is not yet any waste management capacity, leading to co-disposal of E-waste with municipal waste in dump sites. This problem is extensive as many developed countries export obsolete and nonfunctioning e-waste to developing countries, including Nigeria, where environmental enforcement is weak.

Lack of proper waste management system and lack-luster enforcement in environmental regulations has resulted in waste being disposed of without consideration for environmental and human health impacts. This has resulted in refuse heaps being dumped in open fields and on sidewalks in heavily populated cities. In addition, open burning of waste in developing countries like Nigeria is a significant local source of air pollution, constituting a health risk for the communities. This act of uncontrolled open burning is practiced by many in front of their houses or on the streets. Government waste management authorities also engage in this open burning at the landfill sites. Lack of government regulations makes this practice a constant act that is not penalized. GHG emissions of carbon dioxide (CO_2) emerge when waste containing carbon is burnt (e.g. plastics; synthetic textiles).

The fact that municipal solid waste landfill is a significant contributor to the generation of greenhouse gas (GHG) emissions and associated with negative health impacts has generally been overlooked by the Nigerian government and regulators. From a sustainability point of view, landfill waste disposal is the least preferred option in waste management because it is essentially an end of pipe solution and it has the most detrimental impact on the environment. However, due to ease of waste handling in terms of technical expertise and costs, the proportion of MSW that will continue to go to landfill sites is likely to remain high in Lagos municipality. What this says is that, regardless of the fact that landfills are least preferred options for sound MSW management from an environmental perspective, trends indicate that such landfills will be prevalent for the foreseeable future.

LAGOS MUNICIPALITY SOLID WASTE MANAGEMENT

The Nigerian Government included in its National Policy for the Environment that solid waste must be collected and disposed of in effective and environmentally safe manners (Aboyade 2004). The Lagos State Government has similar policies but despite such policies at both federal and state levels, the waste problems still persist and are most obvious in the larger cities.

In 1977 the Lagos State Waste Disposal Board (LSWDB) was formed and charged with oversight of collection and disposal of solid waste from commercial and residential sources. The actual operations were contracted out to a foreign company, Messrs. P.D. Pollution Control of England and paid for 100% by the state government (Odunaiya, 2001). This development brought marked improvements in MSW management of Lagos state which hitherto was decentralized between the various local government areas that made up the metropolis. However, the improvements could not be sustained because the rapidly increasing population coupled with increasing corruption and administrative inefficiency, led to rising costs which the state's budget could no longer adequately fund.

In 1988, with the help of a World Bank loan, LSWDB was able to acquire equipment such as compactors, loaders and excavators. The loan was also used in the construction of the Olusosun landfill. The LSWDB itself was reorganized in a bid to commercialize its operations into the Lagos State Waste Management Authority (Bamgbose, Arowolo, & Oresanya, 2000). Not surprisingly, the performance of LAWMA was no better than its predecessor and it was later decentralized and Local councils again became responsible for collection of domestic MSW. The institutional arrangement was fraught with a lack of coordination between relevant units, and difficulties in revenue collection.

Currently, LAWMA is jointly managed by the sanitation units of both local government councils and State government through its Ministry of Environment. The Lagos State sanitation law of 1998 provided legal backing to LAWMA until 2000 when a bill with the same title was passed by the state house of assembly. According to the Law, LAWMA is charged with the collection and disposal of industrial and commercial waste as well as management of landfill sites and management of transfer loading stations.

WASTE GENERATION AND COMPOSITION

Various studies have been conducted on the per capita daily waste generation in Lagos state. In a thesis by Aboyade, divergent views of waste generation in Lagos state are discussed. Table 1 shows different estimates of per capita waste generation in Lagos state. Note that there is a wide range, with the largest estimate being 238% of the smallest and further note that the estimates get increasingly larger over time.

Table 1: Waste Generation in Lagos State

State	Per capita daily waste generation (kg/day)
Lagos	0.5kg (Ola Oresanya, 2008)
	0.21kg (Bamgbose et al, 2000)
	0.35kg (Cygnet, 2002)

According to LAWMA website, 53% waste generation in Lagos state is from vegetable matters (food waste) and putrescibles, however, other studies, including a World Bank funded project, provide alternative assessments of waste composition and generation as shown in Table 2.

Table 2: Waste Composition in Lagos State

Waste Type	Waste Composition (%)			
	LAWMA Website (2012)	Cygnet 2002	Lavalin Inc Report (Bamgbose 2000)	World Bank Report (1999)
Vegetables	45	50	68	60
Putrescibles	8			
Paper	10	10	10	14
Textile	4	2	4	
Glass	5			
Plastic	15	22	7	
Metals	5			
Others	8	16	11	26

WASTE DISPOSAL

LAWMA currently operates 3 major landfill disposal sites and some temporary satellite sites: Olushosun Landfill Site, Abule-Egba Landfill Site, and the Solous Sites (Soluos II Soluos IIIand the Soluos Satellite Sites comprised of Owutu (Ikorodu), Sangotedo (Eti–Osa) and Temu (Epe) dumpsites.

The bulk of MSW effort is focused on collection services, to the detriment of proper disposal services. But the city has grown such that the dumpsites have become nuisances and studies have linked leachate from waste to the decreasing groundwater quality (e.g. Assessment of groundwater contamination by leachate near a municipal solid waste landfill (Aderemi, Oriaku, Adewunmi, & Atitoloju, 2011) and Leachate Characterization and assessment of groundwater pollution near municipal solid waste landfill site (Suman, Khaiwal, Dahiya, & Chandra)) The state ministry of environment has in the last year begun extensive rehabilitation of existing dumpsites.

OLUSOSUN MUNICIPAL WASTE DISPOSAL DUMPSITE

We focus our analyses on the Olusosun municipal waste landfill dump site as this dumpsite is the largest of all the landfill dump sites operated by LAWMA and processes approximately 40% of the total waste deposits in Lagos metropolis.

Constructed in 1988, the Olusosun landfill is sited on 42.7 hectares of land. The residual life span of the landfill is 20 years.

MONTHLY WASTE DEPOSIT AT LANDFILL SITES

According to the LAWMA website, approximately 9,000 metric tonnes of waste is generated daily in Lagos. Data available from the website include a 3 month summary of refuse deposited between January – March 2009 and a 1 month summary of refuse deposited for the month of July 2011. Table 3 shows the refuse collected between January – March 2009 at all landfill sites and Table 4 shows a summary of refuse collected over that period at the Olusosun site..

Table 3: Summary of Waste Deposited at Landfill Sites – Jan – Mar 2009

		JANUARY			FEBRUARY			MARCH			TOTAL		
		Waste (Tonnes)			Waste (Tonnes)			Waste (Tonnes)			Waste (Tonnes)		
LANDFILL		**DOM**	**IND**	**Total**	**DOM**	**IND**	**Total**	**DOM**	**IND**	**Total**	**DOM**	**IND**	**Total**
	LAWMA	18723		18723	28930		28930	41562		41562	89215	0	89215
	LAWMA CONTR.	35180	8800	43980	35800	13460	49260	49275	16200	65475	120255	38460	158715
	P.S.P	91210		91210	82614		82614	114265		114265	288089	0	288089
	M.O.E	2100		2100	2550		2550	3060		3060	7710	0	7710
OLUSOSUN	L.G			0	1075		1075	222		222	1297	0	1297
	TOTAL	**147213**	**8800**	**156013**	**150969**	**13460**	**164429**	**208384**	**16200**	**224584**	**506566**	**38460**	**545026**
	LAWMA	9280	1910	11190	5180	1480	6660	8840	1150	9990	23300	4540	27840
	LAWMA CONTR.	2640	6910	9550	3550	7940	11490	4370	9310	13680	10560	24160	34720
	P.S.P	32640		32640	37680		37680	46970		46970	117290	0	117290
ABULE	M.O.E	510	590	1100	1860	1360	3220	3140	1860	5000	5510	3810	9320
EGBA	L.G			0	160		160	650		650	810	0	810
	TOTAL	**45070**	**9410**	**54480**	**48430**	**10780**	**59210**	**63970**	**12320**	**76290**	**157470**	**32510**	**189980**
	LAWMA	8235		8235	6015		6015	9190		9190	23440	0	23440
	LAWMA CONTR.	1750	2450	4200	2870	2985	5855	6610	5100	11710	11230	10535	21765
	P.S.P	47485		47485	54255		54255	53958		53958	155698	0	155698
	M.O.E	2900		2900	2990		2990	3710		3710	9600	0	9600
SOLOUS	L.G			0	30		30	145		145	175	0	175
	TOTAL	**60370**	**2450**	**62820**	**66160**	**2985**	**69145**	**73613**	**5100**	**78713**	**200143**	**10535**	**210678**
	LAWMA	13564		13564	11060		11060	7160		7160	31784	0	31784
	LAWMA CONTR.	3388	352	3740	708	198	906	145	235	380	4241	785	5026
	P.S.P	4877		4877	4470		4470	5740		5740	15087	0	15087
	M.O.E			0			0	320		320	320	0	320
EWUELEPE	L.G			0			0			0	0	0	0
	TOTAL	**21829**	**352**	**22181**	**16238**	**198**	**16436**	**13365**	**235**	**13600**	**51432**	**785**	**52217**
	LAWMA	5623		5623	9230		9230	920		920	15773	0	15773
	LAWMA CONTR.			0	10123	3055	13178			0	10123	3055	13178
	P.S.P			0	29395		29395	10780		10780	40175	0	40175
	M.O.E			0	500		500	250		250	750	0	750
EPE	L.G			0			0			0	0	0	0
	TOTAL	**5623**	**0**	**5623**	**49248**	**3055**	**52303**	**11950**	**0**	**11950**	**69876**	**3055**	**69876**
	GRAND TOTAL	**280105**	**21012**	**301117**	**331045**	**30478**	**361523**	**371282**	**33855**	**405137**	**982432**	**85345**	**1067777**

PSP = Private Sector Participant, DOM = Domestic, IND = Industrial ((Lagos state waste management authority, 2012)

The average tonnage from Olusosun landfill is extracted from the data provided in Table 3 and the result is presented in Table 4 below.

Table 4: Average Monthly Tonnage from Olusosun Landfill

Period	**Waste (metric tonnes)**
January 2009	156013
February 2009	164429
March 2009	224584
Monthly Average	**181,675**
Daily Average	**6,056**
Annual Average	**2,180,100**

We use the waste composition shown in Table 2 column 1, combined with the waste tonnages from Table 3, to calculate the annual tonnage of specific waste types shown in Table 5.

Table 5: Estimated Composition of Annual Waste Dumped at Olusosun Landfill

Waste Type	Waste Composition (%) LAWMA Website (2012)	Waste Composition (Metric Tonnes)
Vegetables	45	981042
Putrescibles	8	174402
Paper	10	218010
Textile	4	87204
Glass	5	109005
Plastic	15	327024
Metals	5	109005
Fines/Others	8	174408
TOTAL (Monthly)	**100%**	**2,180,100**

LIFE CYCLE ASSESSMENT TO WASTE MANAGEMENT SYSTEM

Life-Cycle Assessment (LCA) is used to study the environmental aspects and potential impacts throughout a product's life from raw material acquisition through production, to use and disposal (i.e. from cradle to grave). In nature and well designed human systems 'waste streams' from all life cycle phases, including disposal, become raw materials in other product cycles and this is termed, 'cradle to cradle.'

The term 'product' refers to material products as well as to service functions, for example treating a certain amount of solid waste. LCA serves to compare different products or processes, to identify key environmental issues, and to optimize processes (Hellweg, 2003). LCA is increasingly being applied to the evaluation of waste management strategies. It should be noted however that there is a fundamental difference between the life cycle boundaries of products and wastes. The life cycle of a product starts with the choice of raw material through extraction of raw materials (with activities such as mining, logging, etc.) and ends with the final disposal of a product.

Utilization of LCA principles to guide municipal waste system design, though not a complete sustainable livelihood strategy, aligns well with Scoones framework for sustainable rural livelihoods (Scoones, 1998). Scoones himself suggests that, in spite of the name, the framework can be applied over a range of different scales including at village, region and national levels [Scoones, 1998, pg 5] rather than exclusively in a rural context. Application of LCA principles create potential for generation of both economic/financial capital (via recovery of recyclables and redirection/delay of capital outlay for landfill) and human capital (through training, employment and improved health practices of recyclers), as well as a reduction in the depletion rate of natural capital (through decreased GHG emissions and redirection/delay of land consumption via landfill and extraction of virgin materials). The potential impact on livelihood in terms of livelihood diversification and poverty reduction occurs via creation of recyclers as a sustainable profession. These impacts would be sustained and supported institutionally by the LAWMA.

Governments can greatly influence final disposal of a product through regulations that ban deposit of certain wastes into the general waste stream and by outlawing certain chemicals. For traditional LCA of designs, this has to be considered at the beginning of material selection.

The life cycle of a waste on the other hand, starts when a material is discarded into the waste stream and ends when the waste material has either been converted into a resource (such as recycled material or recovered energy) or, when it has completed the disposal process (University of Waterloo, 2004).

METHODOLOGY OF LIFE CYCLE ASSESSMENT (LCA)

LCA methodology developed significantly during the 1990s. There is an international standard for LCA, the ISO norms (ISO 14040 and 14044), which provide a framework concerning methodology. According to this standard, LCA consists of four phases shown in (Figure 1):

- In the *Goal and Scope Definition*, the purpose of the study and the boundary conditions are discussed.
- The *Life-Cycle Inventory* phase (LCI) comprises the gathering of emission and resource use data.
- In the *Life-Cycle Impact Assessment* phase (LCIA), potential environmental impacts of these emissions and of resource consumption are quantified.
- In the *Interpretation* phase, conclusions are drawn.

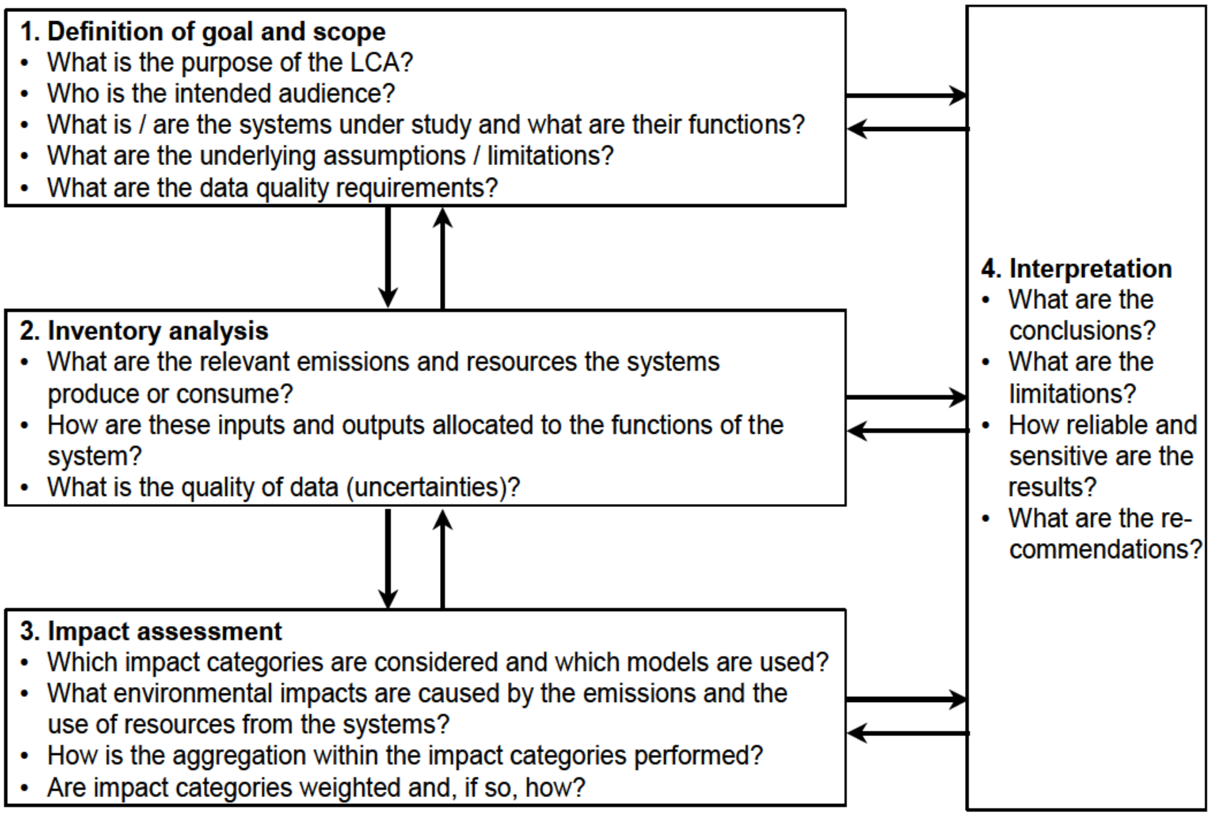

Figure 1: LCA Framework

Source: An Introduction to Life Cycle Assessment (Hellweg, 2003)

GOAL AND SCOPE DEFINITION

The appropriate system boundary for each of the options are defined and discussed below.

<u>THE OPTIONS</u>

The three options considered in this study are shown in Figures 2 to 4. Option 1 (Figure 2) is the current MSWM system in Lagos state undertaken by LAWMA and it consists of three main steps: collection, transportation and landfilling of MSW.

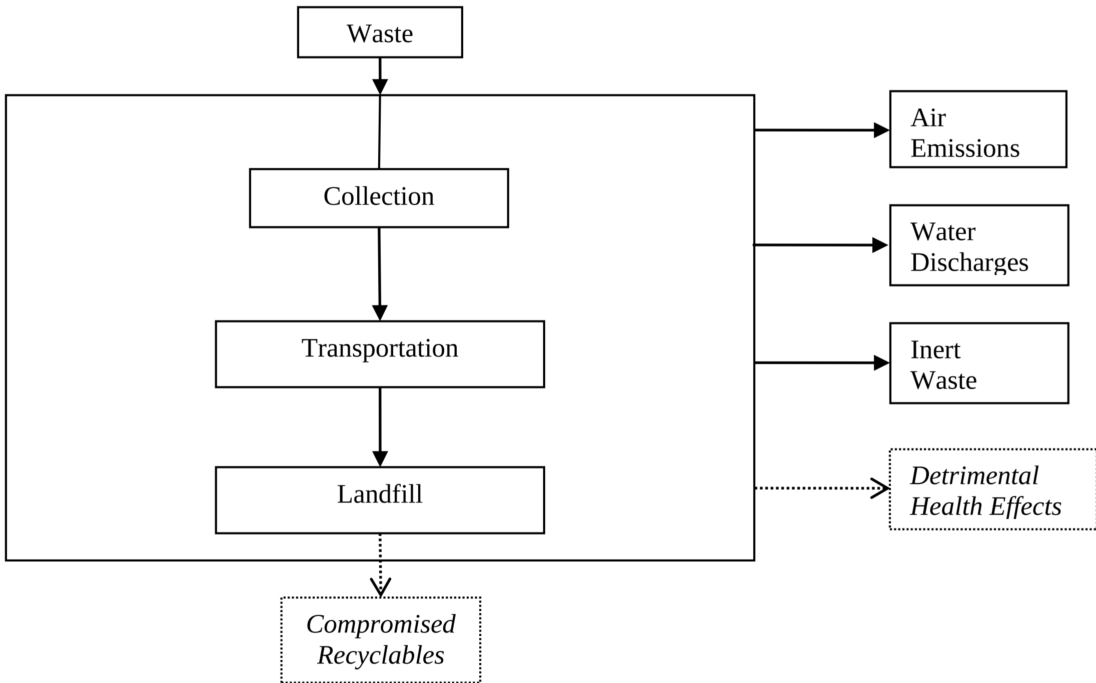

Figure 2: Option 1 with Boundary Definition

Option 2 (Figure 3) is an integrated MSWM system comprised of the collection, transportation, material recovery (MRF) and landfilling.

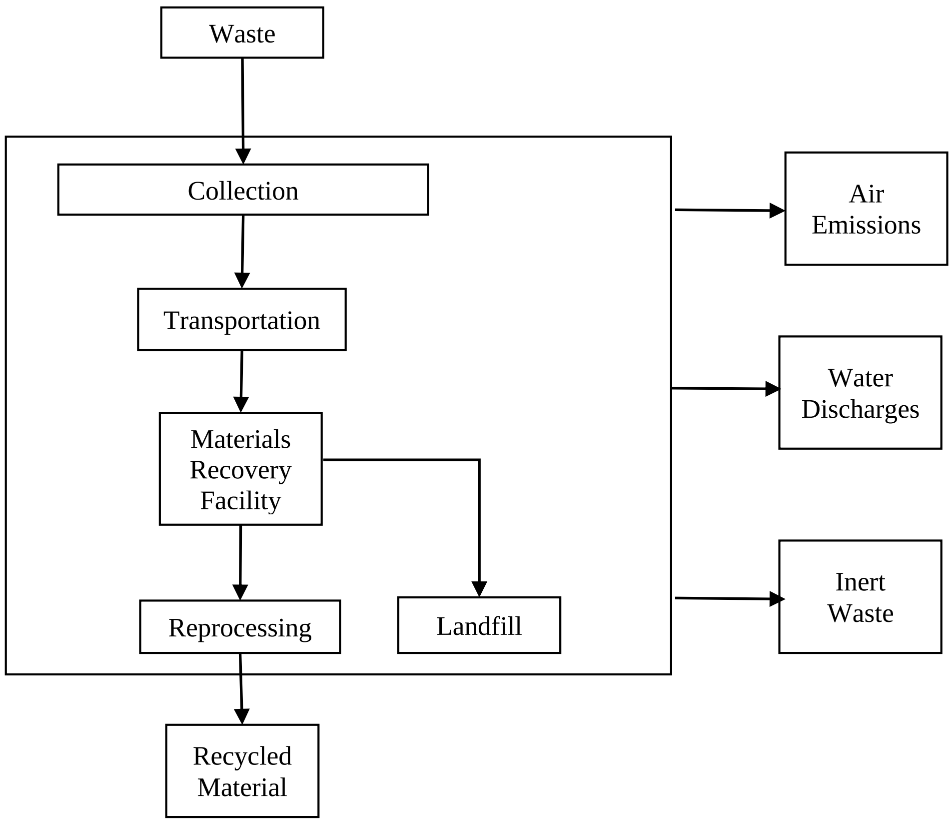

Figure 3: Option 2 with Boundary Definition

Separating material for recycling from material to be landfilled can be a daunting task. In most advanced waste disposal systems, waste collection trucks with multi bin compartments are deployed, however in developing countries, implementing a multi-bin collection system may not be feasible, due to reasons such as transportation logistics, and capital requirements of providing multiple bins to every area. A simpler option is to use a “kerbie box” collection system. These boxes, with well labeled multi compartments as shown in Figures 5 and 6 (such as plastic bottles, paper, and cardboards), are placed in strategic corners of the municipalities for collecting recyclable materials (Wybone Recycling Product, 2012) These boxes are then collected and transported to the material recovery facility to allow efficient recovery of materials for reuse.

The third MSWM option considered (Figure 4) employs the following steps: collection, transportation, material recovery facility (MRF), composting and landfilling. The incorporation of a compost facility is well suited for the type of waste generated in Lagos state. According to LAWMA, 53% of waste is from vegetable matters (food waste) and putrescibles (See Table 5), therefore converting these wastes to compost constitutes a significant reduction in landfill consumption and associated GHG emissions. The composted materials can be packaged and used as soil enhancement for planting, avoiding significant landfill usage, preventing uncontrolled emissions and significantly extending the life of landfill sites.

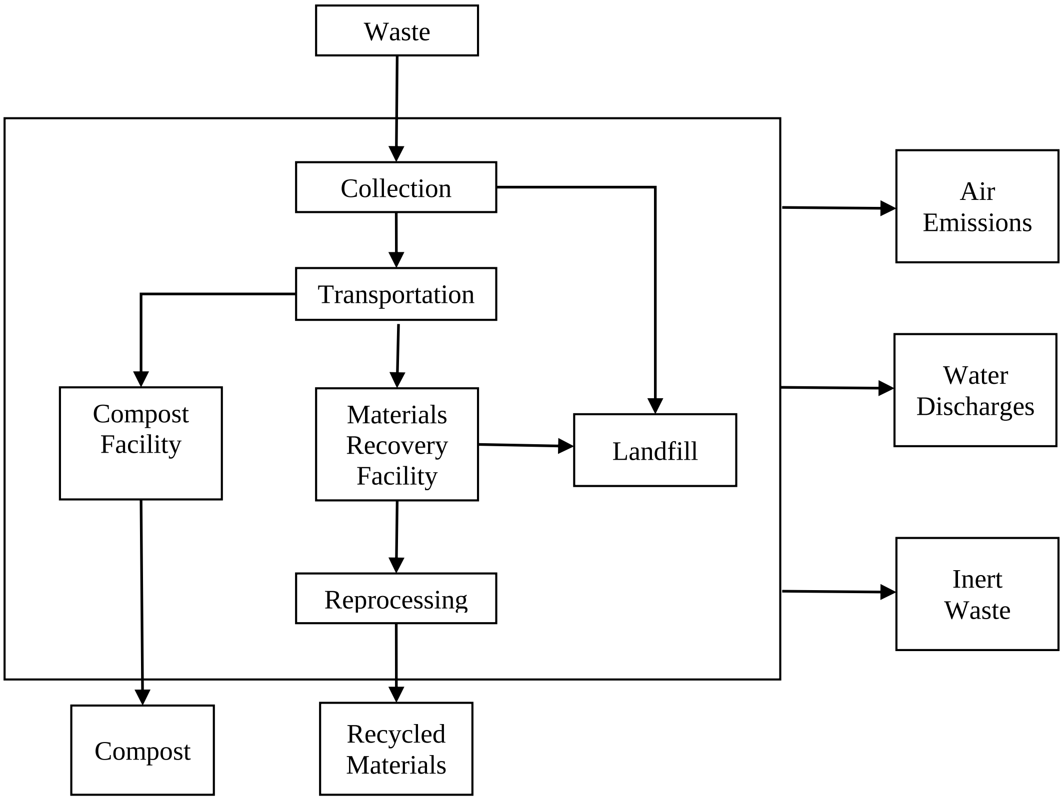

Figure 4: Option 3 with boundary definition

Figure 5: Industrial Kerbie Box

Source: http://www.externalrecyclingbins.co.uk

Figure 6: Labelled Industrial Kerbie Boxes
Source: **http://www.externalrecyclingbins.co.uk**

LIFE CYCLE INVENTORY (LCI)

Data utilized for this study is from published data on Lagos state waste management authority (LAWMA) website, including population projections, waste characteristics and composition by weight and operational data of landfill sites in Lagos state.

The following are limits and assumptions for this study.

- The LCA and optimization will be limited to the Olusosun landfill which is the biggest landfill in Lagos state. The results of this study may be useful for other landfills investigating the feasibility of implementing similar systems.
- The wastes collected are transported directly to the Olusosun site, which reflects the current state of MSWMS in Lagos state (Option 1).
- The MRF (Material Recovery Facility) for option 2 and the compost facility for option 3 will be constructed in close proximity to the Olusosun landfill, with essentially the same transportation requirements.

WASTE REDUCTION MODEL (WARM)

The model used for the LCA is the Waste Reduction Model (WARM) (US EPA, 2012) WARM was developed by United States Environmental Protection Agency (US EPA) and calculates greenhouse gas emissions for baseline and alternative waste management practices. The model incorporates 34 types of materials and five waste management options. These options include source reduction, recycling, combustion, composting, and landfilling. The model calculates emissions in metric tons of carbon equivalent and metric tons of carbon dioxide equivalent across a wide range of material types commonly found in municipal solid waste. In addition, the model calculates energy use for each of the waste management options. WARM accounts for transportation distances to disposal and recycling facilities, carbon sequestration, and utility offsets that result from landfill gas collection and combustion. WARM assesses four main stages of product life-cycles, all of which provide opportunities for GHG and energy emissions reduction and/or offsets. These stages are: raw material acquisition, manufacturing, recycling, and waste management.

DATA INVENTORY ANALYSIS

The data for waste categories and quantities used for the waste reduction model (WARM) to conduct the LCA analysis are presented in Table 6. These are based on the analyses presented in ealier Section 2.4.2. Tables 7, 8 and 9 show the information used in the WARM model analyses to identify the environmental burden associated with options 1, 2 and 3 respectively.

Table 6: Annual Waste Composition and Tonnage

Waste	Tonnes
Paper	218,010
Glass	109,005
Metal/Aluminum	109,005
Plastic	327,015
Organic (Vegetable/Putrescible)	1,155,453
Others (Fines/Others/Textile)	261,612
Total (annual)	2,180,100

Option 1(baseline case) annual waste flow shows that 100% of the waste collected was landfilled. Table 7 presents the information analyzed by the WARM model to identify the environmental burden from the waste managed.

Table 7: Option 1 Annual Waste Flow

Waste Destination	Composition	Tonnes
Landfill	Paper	218,010
	Glass	109,005
	Metal/Aluminum	109,005
	Plastic	327,015
	Organic (Vegetable/Putrescible)	1,155,453
	Others (Fines/Others/Textile)	261,612
Total		**2,180,100**

Table 8 details the percentages of annual waste compositions that will be recycled and those sent to landfill. Studies have indicated that not all plastics are recyclable as traces of synthetic chemicals that interfere with the body's natural hormonal messaging system are found in some plastic materials. To this end, it is estimated that only 50% of the plastic in the waste composition will be safe for recycling, the remaining will be sent to landfill.

Table 8: Option 2 Annual Waste Flow

Waste Destination	Composition	Tonnes
Recycle	Paper	218,010
	Glass	109,005
	Metal/Aluminium	109,005
	Plastic (50%)	163,508
	Subtotal	**599,528**
Landfill	Organic (Vegetable/Putrescible)	1,155,453
	Others (Fines/Others/Textile)	261,612
	Plastic (50%)	163,507
	Subtotal	**1,580,572**
Total		**2,180,100**

Option 2 annual waste flow shows that 27.5% of the waste would be recycled (based on all paper, glass, and metal and 50% plastic being recycled) and 72.5% would be landfilled.

Option 3 waste flow shows three different types of waste disposition (recycle, compost and landfill). There is no current data showing what percentage of organic waste can easily be converted to compost, so we performed a series of analyses with 25%, 50% and 75% of organic waste composted. The information is presented in Table 9.

Table 9: Option 3 Annual Waste Flow

Waste Destination	Composition	Tonnes	Composition	Tonnes	Composition	Tonnes
Recycle	Paper	218,010	Paper	218,010	Paper	218,010
	Glass	109,005	Glass	109,005	Glass	109,005
	Metal/Aluminium	109,005	Metal/Aluminium	109,005	Metal/Aluminium	109,005
	Plastic (50%)	163,508	Plastic (50%)	163,508	Plastic (50%)	163,508
	Subtotal	**599,528**	**Subtotal**	**599,528**	**Subtotal**	**599,528**
	Composition (@ 25% organic waste composted	**Tonnes**	**Composition (@ 50% organic waste composted**	**Tonnes**	**Composition (@ 75% organic waste composted**	**Tonnes**
Compost	Organic (Vegetable/Putrescible) (25%)	288,863	Organic (Vegetable/Putrescible) (50%)	577,727	Organic (Vegetable/Putrescible) (75%)	866,590
	Subtotal	**288,863**	**Subtotal**	**577,727**	**Subtotal**	**866,590**
	Composition	**Tonnes**	**Composition**	**Tonnes**	**Composition**	**Tonnes**
Landfill	Plastic (50%)	163,507	Plastic (50%)	163,507	Plastic (50%)	163,507
	Organic (Vegetable/Putrescible) (75%)	866,590	Organic (Vegetable/Putrescible) (50%)	577,727	Organic (Vegetable/Putrescible) (25%)	288,863
	Others (Fines/Others/Textile)	261,612	Others (Fines/Others/Textile)	261,612	Others (Fines/Others/Textile)	261,612
	Subtotal	**1,291,709**	**Subtotal**	**1,002,846**	**Subtotal**	**713,982**
Total		**2,180,100**		**2,180,100**		**2,180,100**

Table 9 shows the tonnages of waste managed at the ranges considered for organic waste available for composting. With 25% of organics composted, we have 27.5% of the waste recycled, 13.3% sent to the compost facility and 59.2% landfilled. With 50% of organics composted we have 27.5% recycled, 26.5% composted and 46% landfilled. With 75% of organics composted we have 27.5% recycled, 39.8% composted and 32.7% landfilled. This information serves as input data for the WARM model to identify the relative reduction in environmental burden under the various scenarios. For these analyses an average transportation distance of 50 miles to the co-located landfill, material recovery and compost facilities is used.

LIFE CYCLE IMPACT ASSESSMENT (LCIA) RESULTS AND INTERPRETATION

The LCA model results provide a detailed estimate of the environmental impact of each of the options considered. Tables 10 to 13 present the results of the three options considered in terms of the tons of GHG that would escape to the atmosphere.

The WARM model generates the benefits numbers for the baseline and alternate options inputted into the model. These benefit estimates are generated in either metric tons of carbon equivalent (MTCE), metric tons of carbon dioxide equivalent (MTCO2E), or British thermal units (BTU). In addition, WARM calculates other conversion equivalents, such as the number of cars off the road or the number of households' annual energy consumption to place the results in perspective.

Table 10: Comparison of Option Results MTCO2E

Options	Baseline Generation of Material (Tons)	Projected Recycling (Tons)	*Annual GHG Emissions from Recycling (MTCO2E)	Projected Landfilling (Tons)	Annual GHG Emissions from Landfilling (MTCO2E)	Projected Composting (Tons)	Annual GHG Emissions from Composting (MTCO2E)	Total Annual GHG Emissions (MTCO2E)
1	2,180,100	0	0	2,180,100	1,680,685	0	0	1,680,685
2	2,180,100	599,528	(993,666)	1,580,572	1,770,858	0	0	777,192
3 @ 25% organic waste composted	2,180,100	599,528	(993,666)	1,291,709	1,532,190	288,863	(57,098)	481,426
3 @ 50% organic waste composted	2,180,100	599,528	(993,666)	1,002,846	1,293,522	577,727	(114,196)	185,660
3 @ 75% organic waste composted	2,180,100	599,528	(993,666)	713,982	1,054,854	866,590	(171,295)	(110,106)

( ) = Annual GHG emissions avoided by not using material from 100% virgin source

Table 10 shows a comparison between the results of the three options evaluated. In the case of option 1, landfilling was the only disposal method resulting in a 2,180,100 metric tons (100% of waste generated) landfilled annually. Option 2 with a material recovery facility (MRF) incorporated showed an improvement in terms of waste landfilled with 1,580,572 metric tons (72.5%) of total waste sent to landfill and 27.5% sent for recovery. Option 3 created the most improvement with the incorporation of a MRF and a compost facility. This option results in landfilling 1,291,709 (59%), 1,002,846 (46%), and 713,982 (33%) metric tons at the 25%, 50% and 75% composting levels respectively.

The model results indicate that by incorporating MRF in the waste management system before sending the waste to landfill, a reduction in GHG emissions from 1,680,685 MTCO2E to 777,192 MTCO2E is expected. This is an elimination of 903,493 MTCO2E annually. The option with the best emission reduction result is option 3. Incorporating a MRF and a compost facility into the waste management system with a projected MTCO2E elimination between 1,199,258 MTCO2E and 1,790,791 MTCO2E (i.e. the high end composting eliminated all the GHG emissions and was also credited for avoiding the use of 100% virgin source material).

Table 11: Comparison of Option Results for Metric Tons of Carbon Equivalent (MTCE)

Options	Baseline Generation of Material (Tons)	Projected Recycling (Tons)	* Annual GHG Emissions from Recycling (MTCE)	Projected Landfilling (Tons)	Annual GHG Emissions from Landfilling (MTCE)	Projected Composting (Tons)	Annual GHG Emissions from Composting (MTCE)	Total Annual GHG Emissions (MTCE)
1	2,180,100	0	0	2,180,100	458,369	0	0	458,369
2	2,180,100	599,528	(271,000)	1,580,572	482,961	0	0	211,961
3 @ 25% organic waste composted	2,180,100	599,528	(271,000)	1,291,709	417,870	288,863	(15,572)	131,298
3 @ 50% organic waste composted	2,180,100	599,528	(271,000)	1,002,846	325,779	577,727	(31,145)	50,635
3 @ 75% organic waste composted	2,180,100	599,528	(271,000)	713,982	287,688	866,590	(46,717)	(30,029)

(*) = Annual GHG emissions avoided by not using material from 100% virgin source

Table 11 indicates that a reduction of 246,407 MTCE can be expected by switching from current options to one that includes incorporation of a Materials Recovery Facility (MRF), and a reduction of between 327,070 MTCE and 488,397 MTCE for switching from current operations to a system that incorporates an MRF and composting facilities.

Table 12: Comparison of Option Results Energy Savings BTU

Options	Baseline Generation of Material (Tons)	Projected Recycling (Tons)	Annual Energy Consumption from Recycling (million BTU)	Projected Landfilling (Tons)	Annual Energy Consumption from Landfilling (million BTU)	Projected Composting (Tons)	Annual GHG Emissions from Composting (million BTU)	Total Annual Energy Consumption (million BTU)
1	2,180,100	0	0	2,180,100	1,149,785	0	0	1,149,785
2	2,180,100	599,528	(12,754,807)	1,580,572	833,594	0	0	(11,921,213)
3 @ 25% organic waste composted	2,180,100	599,528	(12,754,807)	1,291,709	681,247	288,863	168,696	(11,904,864)
3 @ 50% organic waste composted	2,180,100	599,528	(12,754,807)	1,002,846	528,901	577,727	337,392	(11,888,514)
3 @ 75% organic waste composted	2,180,100	599,528	(12,754,807)	713,982	376,554	866,590	506,089	(11,872,164)

Table 13: Impact Equivalent and Conversion of Benefits

Comparison	Total Annual GHG Emissions Benefit	Equivalent Impact Conversions	
Option 1 to 2	(903,493) MTCO2E or (246,407) MTCE	177,155 Passenger vehicles removed from the road annually	101 million gallons of gasoline conserved annually
	(13,070,998) million BTU	116,261 Households' energy consumption conserved	104 million gallons of gasoline conserved
Option 1 to 3 @ 25% organic waste composted	(1,199,258) MTCO2E or (327,070) MTCE	235,149 Passenger vehicles removed from the road annually	135 million gallons of gasoline conserved annually
	(13,054,648) million BTU	116,115 Households' energy consumption conserved	104 million gallons of gasoline conserved
Option 1 to 3 @ 50% organic waste composted	(1,495,024) MTCO2E or (407,734) MTCE	293,142 Passenger vehicles removed from the road annually	168 million gallons of gasoline conserved annually
	(13,038,299) million BTU	115,970 Households' energy consumption conserved	104 million gallons of gasoline conserved
Option 1 to 3 @ 75% organic waste composted	(1,790,790) MTCO2E or (488,397) MTCE	351,135 Passenger vehicles removed from the road annually	200 million gallons of gasoline conserved annually
	(13,021,949) million BTU	115,824 Households' energy consumption conserved	104 million gallons of gasoline conserved

The benefits and impact equivalence of the options are presented in Table 13. Switching from the current system to one that incorporates an MRF results in an expected reduction of 903,493 MTCO2E (metric tons of CO_2 equivalent) or 246,407 MTCE (metric tons of carbon equivalent) which is the equivalent of 177,155 passenger vehicles removed from the road annually or 101 million gallons of gasoline conserved annually. In terms of household energy conserved, a reduction of 13 million BTU is equivalent to energy consumption of 116,261 households or 104 million gallons of gasoline conserved annually. Similarly the overall benefits and impact equivalents for options that include MRF and composting are also shown in the same table.

ECONOMIC IMPACT

CAPITAL COST ESTIMATE

The initial capital costs for the Material Recovery Facility (MRF) are detailed in Table 14 below. The MRF estimates were obtained from representative estimates given in the US EPA Handbook, Material Recovery Facilities for Municipal Solid Waste (September 1991) and adjusted to 2011 costs based on inflation. Note that significantly lower labor costs in Nigeria could appreciably lower the costs shown in Table 14. Also note that a processing capacity of 1,645 tons per day would be required based on our calculated estimates of 599,528 tons recycled per year.

Table 14: Material Recovery Facility Capital Cost Summary by Throughput

Item	**US$**		
	10 TPD	100TPD	500TPD
Construction Works	511,500	1,870,000	5,390,000
Equipment	342,451	2,670,634	5,437,008
Contingency	102,474	454,063	866,161
Total*	**956,425**	**4,994,698**	**11,693,169**
Adjusted Total**	**1,579,569**	**8,248,916**	**19,311,672**

Source: US EPA Handbook, Material Recovery Facilities for Municipal Solid Waste (September 1991).

TPD: Tonnes per day

* = Based on 1991 information from USEPA

** = Based on Bureau of Labor Statistics 65% inflation rate between 1991 and 2011

The initial capital cost for a composting facility is not evaluated in this report. It is recommended that in further studies, the cost be evaluated to better understand the cost effectiveness to waste management systems in Lagos, Nigeria.

OPERATING COST ESTIMATE

The estimated operating costs for the material recovery facility (MRF) are detailed in Table 15 below. The MRF estimates are given in the US EPA Handbook, Material Recovery Facilities for Municipal Solid Waste (US EPA, 1991) and adjusted to 2011 costs based on inflation.

Table 15: Material Recovery Facility Operating Cost Summary

Category	**US$**		
	10 TPD	100TPD	500TPD
Labor			
Sorters	18,720	237,120	873,600
Others	74,880	249,600	540,120
Overhead[a]	37,440	194,688	569,088
Maintenance	5,850	58,500	202,500
Insurance[b]	9,100	91,000	455,000
Utilities			
Power	2,600	26,000	130,000
Water & Sewage	55	602	2546
Heating[c]	701	7,008	135,040
Fuel	624	6,240	31,200
Outside Services & Supplies	14,997	87,085	293,810
Subtotal	**164,967**	**957,843**	**3,232,904**
O&M Costs ($/TPD)	63.45	36.84	24.66
Residue Disposal	16,250	162,500	812,500
Debt Service	139,319	801,155	2,180,344
Total Annual Cost*	**321,170**	**1,921,535**	**6,225,773**
Adjusted Total Annual Cost**	**530,423**	**3,173,481**	**10,282,079**

Source: US EPA Handbook, Material Recovery Facilities for Municipal Solid Waste (September 1991).

TPD= Tonnes per day

[a]Include social security, vacation and sick leave and insurance

[b]Include workers compensation, property and liability

[c]range of use based on climatic extremes

* = Based on 1991 information from USEPA

** = Based on Bureau of Labor Statistics 65% inflation rate between 1991 and 2011

COST/BENEFIT ANALYSIS

Any cost/benefit analysis should consider both financial and social/environmental aspects. Capital, operation and maintenance, collection and disposal costs comprise the total costs associated with installing a material recovery facility for waste management. These costs are the major costs that must be taken into consideration before embarking on such projects. Keep in mind that while analyses may result in unattractive cost-benefit ratios, such as negative financial consequences, it does not necessarily follow that the project should not be undertaken. Indeed this is one of the functions of government – to undertake projects not likely to be accomplished by the private sector because it is not beneficial financially, but which are in the public interest.

Revenue from the sale of recyclable materials collected from the material recovery facility will also be a financial benefit of utilizing an MRF. The exact revenue from the sales of these recyclable materials is not included in our analysis due to lack of historical local market prices for recovered materials. However we believe there is a market for such recyclables based on the fact that scavengers currently recover some of these recyclable materials from landfill and sell them.

Another benefit of recycling is deferral of “depletion costs”. Recycling and other waste-reducing methods help to reduce cost associated with siting a new landfill due to the fast depletion of landfill space. The declining availability of landfill space, in particular close to urban areas, provides a strong incentive for waste reduction initiatives. Lagos state, with its limited land space and increases in population, is particularly sensitive to such space consumption issues.

Landfills have limited capacity, and so can receive a limited amount of material and have a finite life-span. When full, replacement by another landfill that is generally more expensive to operate and maintain is required. This is due to higher costs of complying with environmental regulations, higher expenses in siting a new location, buying or allocating land, constructing the landfill, operational expenses, and long term maintenance costs after the landfill is closed. Paying the higher cost for a new landfill is avoided by keeping the old landfill open longer with waste reducing methods such as recycling. Often the benefits of such avoided costs are not adequately considered because they are externalities to the costs that can be accounted for.

According to Oresanya (Oresanya, 2008), estimated construction costs for contained landfill with a lifespan of 20 years is $9,500,000. Incorporating a MRF and compost facility to the waste management system of Olusosun landfill will result in an extension of the residual life of the landfill. Tables 16 and 17 present the extended life and the savings generated by extending the life of the site.

Table 16: Landfill Site Residual Life Extension

	Landfill Only	Landfill & MRF	Landfill, MRF & Compost Facility		
			@ 25% organic waste composted	@ 50% organic waste composted	@ 75% organic waste composted
Current Residual Life (yrs)	20	20	20	20	20
% of landfill currently filled	40%	40%	40%	40%	40%
Annual deposit to landfill (Tons)	2,180,100	1,580,572	1,291,709	1,002,846	713,982
Landfill capacity through remaining residual life (tons)	43,602,000	43,602,000	43,602,000	43,602,000	43,602,000
Total landfill residual life (yrs)	20	28	34	44	61
Extension to landfill residual life (yrs)	0	8	14	24	31

Table 17: Savings on landfill life extension – Landfill, MRF & Compost Facility

Description	**Value**			
	Material Recovery Facility only	MRF + composting 25% of organic waste	MRF + composting 50% of organic waste	MRF + composting 75% of organic waste
Landfill Construction Cost	$9,500,000	$9,500,000	$9,500,000	$9,500,000
Landfill Life Span	20 years	20 years	20 years	20 years
Annualized capital charge (20-year period, 5% interest)	$762,305	$762,305	$762,305	$762,305
Extension to landfill life	8 years	14 years	24 years	31 years
Savings from extending landfill residual life	$6,098,437	$10,672,270	$18,295,320	$23,631,455

The annualized capital charge of constructing a new landfill that will be avoided by incorporating a MRF to the waste management system at Olusosun landfill will be $762,305 and over an 8 year period which the landfill life will be extended by, this will result in a savings of $6,098,437 assuming the capital is borrowed at a 5% interest for 20 years. The savings from option 3 (i.e. MRF and compost facility) will range between $10,672,270 and $23,631,455 as presented in Table 17. These savings could be used to offset much of the cost of constructing the MRF.

The savings described above are based on a MRF with capacity to process 500tpd of recyclable material. However the available material for recycle based on this study is approximately 1,645tpd. This implies that the capital cost for the 1,645tpd MRF will be approximately $63.5M (based on 19M for 500tpd facility according to the last data available as of 1991). It is worth noting that there are likely to be economies of scale that will make the capital cost less than the cost provided in this report. Also the evolution of more efficient technologies since the estimation of the MRF capital cost provided by USEPA in 1991 will also have a significant effect on the cost. It is our opinion that further research is needed to determine actual capital cost for constructing a MRF in order to increase the accuracy of the cost.

In addition to the monetary economic benefits associated with the sound waste reduction systems such as Material Recovery Facilities (MRF), there are additional benefits due to the avoidance of other external costs. Particularly, benefits to the environment, human health, and promotion of conservation of nature by preventing noise, smell, health impacts, traffic congestion, land consumption and pollution associated with other disposal methods.

The health risk and release of greenhouse gases from landfill emissions as well as the pollution from incineration will be avoided. These environmental external costs are difficult to quantify, but the benefits are nonetheless gained by society. In the report "Environmental Benefits of Recycling Study" (East West Gateway Council of Governments, 2005), benefits of recycling are explained in detail and show that recycling helps to reduce greenhouse gases that may contribute to global climate change. This also helps the slowing of the harvest of trees, thereby maintaining their carbon dioxide storage benefit. Other benefits discussed are the reduction of air and water pollution emissions, energy savings and natural resource savings (East West Gateway Council of Governments, 2005)

CONCLUSIONS AND RECOMMENDATIONS

The concern over GHG emissions from municipal solid waste (MSW) is ever increasing and steps to curb its effect on the environment are being sought. The need to adopt Environmentally Sound Management (ESM) of wastes including Waste Minimization, focusing on the promotion of the "3Rs" – Reduce, Reuse and Recycle is imperative.

Towards this end, we utilized an evaluation process to estimate the environmental benefits associated with different waste management options for the Olusosun landfill site in Lagos state, Nigeria. The key findings from this research were generated through a life cycle analysis (LCA). Specifically, the LCA indicates that by incorporating a material recovery facility, the Olusosun landfill site will achieve a reduction in GHG of 903,493 MTCO2E which is equivalent to removing 177,155 passenger vehicles from the road annually or conserving 101 million gallons of gasoline on an annual basis when compared with current operations. If using the BTU conversion method, the reduction will be equivalent to avoiding the consumption of 13 Million BTU annually which results in conserving 104 million gallons of gasoline. Depending on the conversion method used, the amount of gasoline conserved is within the range of 101 to 104 million gallons of gasoline. Incorporating an MRF and composting organic wastes will result in GHG reduction in the range of 1,199,258 MTCO2E to 1,790,790 MTCO2E (dependent on % of organic wastes composted) which is equivalent to removing passenger vehicles within the range of 235,149 vehicles and 351,135 vehicles from the road annually or conserving between 135 million gallons and 200 millions of gasoline on an annual basis compared to current operations. These results illustrate the potential reduction in GHG that can be achieved through the adoption of environmentally sound management (ESM) of waste systems.

Salvaging recyclable and reusable items from dump sites and waste collection points has and continues to be a source of livelihood for the urban poor in Lagos. Incorporating a material recovery facility (MRF) into the Olusosun waste management system will lead to an increase in the level of economic activity in Lagos state, creating employment and job opportunities for a substantial number of state residents with recruitment of personnel from the surrounding areas which will greatly benefit communities in which jobs are scarce, and will do so without incurring the health risks of the current ad hoc recycling system. Government policy creating a public-private partnership co-op where community residents set up and operate recyclable collection centers for an agreed compensation with the government is an option that should be considered.

The declining availability of landfill space, in particular close to urban areas, provides a strong incentive for waste reduction initiatives. Lagos state with its limited land space (21% wetland) and increase in population is well suited to benefit from such initiatives. Landfills have limited space, and so can receive a limited amount of trash. Incorporating a material recovery facility into the waste management system helps to avoid paying the higher cost for a new landfill by diverting a portion of the waste stream, keeping the old landfill open longer.

The waste management options we analyzed have clear benefits associated with them, many of which we have been able to quantify. We also quantified the investment costs associated with their implementation. To achieve a mandate for such investment, especially where resources are in short supply, public awareness should be created for the importance of waste reduction through recycling and other means available. This can be achieved using various means such as integration of environmental education with emphasis on solid waste into school curricula beginning with primary/elementary school. Awareness can also be created by sending waste management personnel to do a door-to-door campaign on the benefits of recycling, explaining how it can increase the health of children and adults alike. Other factors that could be applied include media campaign (print, radio, video), local town hall meetings with community leaders, and employing the services of religious leaders to talk about it in churches and mosques.

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