Environmental assessment of municipal solid waste (MSW) disposal options: A case study of Olushosun landfill, Lagos State

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Abstract. Landfills are known to be one of the anthropogenic sources of methane (CH₄) and this gas is an important contributor to global warming. Aside the threat posed by methane, if properly managed, it could be harnessed as a source of energy. The efficient management of landfill generated CH₄ gas would require the accurate prediction, monitoring and utilization of this useful source. Therefore, this study is focused on the life cycle assessment (LCA) of Olushosun landfill in Lagos metropolis. Environmental benefits between operation of landfills with and without gas recovery systems in Olushosun landfill were determined. LCA analysis showed greenhouse gas (GHG) emissions from the present waste disposal system was 3,029,151 tons of carbon dioxide emissions (CO₂). The adoption of sanitary landfill with gas recovery system is a preferred management route for solid waste disposal in Lagos metropolis due to CO₂ emissions reduction of 1,725,761 tons. The results obtained also corroborate the use of LCA as a decision support tool in waste management system. It is therefore recommended that LCA should be implemented in developing countries to reduce long term environmental effects of waste management activities.

Keywords: Greenhouse gas emissions, municipal solid waste, life cycle assessment, landfill, waste, methane

1. Introduction
Municipal solid waste (MSW) management has emerged as a serious issue especially in developing nations due to lack of MSW treatment capacity and improper technologies resulting in environmental degradation [1]. Disposal of waste in landfills is commonly practiced in developing countries due to its cheap operational cost and requirement of unskilled workers. Landfilling is a significant anthropogenic source of methane (CH₄) emissions [2]. Over a time period of 100 years, the global warming potential (GWP) of CH₄ is 25 times of GWP of CO₂ and has an atmospheric residence of 12 ± 3 years [3].

For a healthy environment, effective waste management practices which promote public health, prevent soil and water contamination provide renewable energy benefits and reduce greenhouse gas emissions must be emphasized. There are different waste treatment options available currently with different waste management capacities [4]. A large number of tools have been developed in order to assist decision makers in the identification of areas where specific measures should be taken in order to reduce the
environmental impacts of waste management. These models included linear programming with Excel-Visual Basic, Decision Support Systems, fuzzy logic and Multi Criteria Decision-Making techniques [5]. The life cycle assessment (LCA) concepts and technique is widely used by decision makers as it provides an overview of the environmental aspects of different waste management strategies and also makes possible to compare the environmental impacts of these options [6,7]. A number of studies have investigated the application of LCA in waste management especially in European and Asian countries [8, 9] but literature information is still scarce on the adoption of LCA in evaluating waste treatment options in African countries. It was discovered that lack of awareness, insufficient primary data, and lack of life cycle thinking approach as reasons for limited number/absence of LCAs from developing countries [9].

In Lagos metropolis, increasing population coupled with the spate of industrial developments, has led to the generation of about 13,000 metric tons of MSW daily [10]. Most of these wastes are collected and disposed at Olushosun landfill which lacks a landfill gas (LFG) recovery system. As a result, there are emissions of greenhouse gases (GHG) and fire outbreaks due to open dumping of waste. The aim of this study is therefore to evaluate waste disposal alternatives for Lagos metropolis in a life cycle perspective.

2. Methodology

2.1 Study Site

Olushosun landfill is located at Oregun, in Ikeja Local Government Area of Lagos State. It was established in 1992 and is about 42 ha with waste depth ranging from 8-16 m. It receives an average of 1.2 million m$^3$ of waste annually. Olushosun landfill is a non-engineered landfill which lack LFG collection and leachate treatment systems. The landfill had two cells for waste disposal, namely Cell A (Governor’s platform) and Cell B. Cell A stopped receiving waste since 2003 and was capped with lateritic soil material. After its closure, waste tipping continued in Cell B. The landfill was closed in March, 2018 due to fire outbreak but has been reopened in November, 2018 for continuous waste tipping.

2.1.1 Climate of the landfill.

The climate of the landfill location is similar to Lagos metropolis climate which is characterized by rainy and dry seasons. The monthly mean temperatures of the landfill ranged from 25.2 °C-28.6 °C. The temperatures were highest in March, at 28.6 °C and lowest in August at 25.2 °C. Average precipitation also ranged from 21 mm – 386 mm. The least amount of rainfall occurred in December at about 21 mm while the greatest amount of precipitation occurred in June, with an average of 386 mm. The average annual precipitation was 1693 mm [11].

2.2 Life cycle Assessment

According to ISO 14040 [12, 13], an LCA comprised of four major stages: goal and scope definition, life cycle inventory (LCI), impact assessment and interpretation of results.

2.2.1 Goal and scope definition.

The overall goal of this study is to evaluate environmental impacts of the current waste disposal system at Olushosun landfill with regards to GHG emissions and the potential of GHG emissions mitigation of the installation of a LFG recovery system at the landfill. The system boundary included the collection of waste until disposal in the landfill; leachate collection and treatment were excluded.

2.3 Life Cycle Inventory

The data needed to calculate the LFG emissions from the landfill include the waste composition, landfill opening and closure year, waste disposal rate and landfill site management conditions.
2.4 Life Cycle Impact Assessment
Sanitary landfill with gas utilization was compared with the present waste disposal system. The global warming potential was the main focus of this study due to its impact on the environment.

**Scenario 1 Open dumping of waste**
CH₄ emissions was estimated based on equation 1

\[
CH_4_{emitted} = CH_4_{generated} - CH_4_{recovered}
\]  

(1)

2.4.1 Methane generated.
CH₄ generated from the landfill was estimated based on the first-order decay methodology [14] as shown in equation 2:

\[
Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} M_i L_0 \frac{M_i}{10} (e^{-kt})
\]  

(2)

where

- \(Q_{CH_4}\) = annual methane generation rate (m³/yr)
- \(i\) = 1 year time increment
- \(n\) = (year of calculation) – (initial year of waste acceptance)
- \(j\) = 0.1 year time increment
- \(k\) = methane generation rate constant (yr⁻¹),
- \(L_0\) = methane generation potential of waste disposed (m³/tonne)
- \(M_i\) = solid waste disposed in the year \(i^{th}\) year (tonnes)
- \(t_{i,j}\) = age of the \(j^{th}\) section of waste disposed in the \(i^{th}\) year (decimal years)

2.4.1.1 Input parameters.
Methane generation potential \((L_0)\): This describes the total amount of CH₄ potentially produced by a metric tonne of waste as it decays. For each landfill, CH₄ generation was calculated by equation 3[15]:

\[
L_0 = DOC \times DOC_f \times MCF \times F \times \frac{16}{12}
\]  

(3)

\(DOC\) (degradable organic carbon): is the organic carbon in waste that is accessible to biochemical decomposition. \(DOC\) values for various waste components are shown in Table 1.

### Table 1. DOC content for different MSW components.

| S/N | Waste components                        | DOC content in (%) of wet waste |
|-----|-----------------------------------------|---------------------------------|
| 1   | Paper and textile                       | 0.4                             |
| 2   | Garden and park                         | 0.17                            |
| 3   | Food waste                              | 0.15                            |
| 4   | Wood                                    | 0.30                            |
| 5   | Plastics, Metal, Glass and other inert materials | 0                              |

Source [15]

\(DOC_f\) (degradability factor): This is an estimate of the fraction of carbon that is ultimately degraded and released from solid waste disposal sites (SWDS), it reflects the fact that some degradable organic carbon do not degrade, or degrades very slowly, under anaerobic conditions in the SWDS. This depends on the temperature in the anaerobic zone of the landfill site. The \(DOC_f\) is expressed in equation 4 [16, 17].
where

\[ T \] is temperature in the anaerobic zone in °C. A value of 35°C was used. At 35°C, almost 80% of the \( \textit{DOC} \) would have been converted to LFG [16].

\( MCF \) (Methane correction factor): This takes into account aerobic waste decay that does not produce \( \text{CH}_4 \) at waste disposal sites [15]. It depends on the depth of a landfill and landfill management (Table 2). MCF factor of 0.8 was used for the landfill because it is an unmanaged landfill with waste depth greater than 5.

\begin{table}
\centering
\begin{tabular}{|l|c|c|}
\hline
Management site & Depth & Depth \\
& < 5m & ≥ 5m \\
\hline
Without management & 0.4 & 0.8 \\
With management & 0.8 & 1.0 \\
Semi aerobic & 0.4 & 0.5 \\
Condition unknown & 0.4 & 0.8 \\
\hline
Source [15]
\end{tabular}
\end{table}

\( F \) (fraction of methane in landfill gas): A fraction of \( \text{CH}_4 \) in LFG of 50% was adopted [15, 17].

\( k \) (Methane generation constant): This describes the time taken for the \( \textit{DOC} \) in waste to decay to half its initial mass. It is called half-life and denoted by \( k \) [18]. The rate at which \( \text{CH}_4 \) emissions are generated from decaying material in a landfill depends upon: (1) the waste type (organic material placed in the landfill), the moisture conditions of the landfill (estimated based on average annual precipitation) and temperature [19]. The suggested default values of \( k \) for different waste categories for areas with mean annual precipitation >1000 mm by IPCC [15] was used in this study (table 3). Each \( k \) value was multiplied by their component in the waste stream to determine the overall \( k \).

\begin{table}
\centering
\begin{tabular}{|l|l|c|}
\hline
S/N & Type of waste & \( k \) (yr\(^{-1}\)) \\
\hline
1 & Rapidly degrading waste (food waste) & 0.4 \\
2 & Moderately degrading waste (garden + park) & 0.17 \\
3 & Slowly degrading waste (paper+ textiles) and (wood or straw) & 0.07 and 0.035 \\
\hline
Source [15]
\end{tabular}
\end{table}

Fire Discount Factor (FDF): This was introduced in the estimation of emissions to account for landfill fires due accidental fires or open burning of waste. A fire discount factor of 30% was used [20].

\textbf{Scenario 2: Sanitary landfill with gas utilization.}

In this scenario, methane generated in Scenario 1 was assumed to be collected and utilized with the installation of LFG recovery and collection system. The quantity of \( \text{CH}_4 \) recovered via the LFG recovery system is affected by the collection efficiency and is given by equation 5

\[ \text{CH}_4\text{recovered} = \text{CH}_4\text{generated} \times \text{collection efficiency} \] (5)

By assuming a collection efficiency factor of 75%, actual LFG recovered was estimated. \( \text{CH}_4 \) emission reductions due to LFG recovery were then calculated in CO\(_2\) equivalent (CO\(_2\)-eq) by equation 6 [21]:
\[ r = 21 \rho_c c V \]  

where  
\( r \) = \( \text{CH}_4 \) emission reductions (kg of CO\(_2\)-eq/yr)  
\( V \) = total volume of LFG recovered (m\(^3\)/yr)  
\( \rho_c \) = density of methane in kg/m\(^3\) (0.656kg/m\(^3\))  
\( c \) = average concentration of CH\(_4\) in LFG in %

3. Results and Discussion

3.1 Waste disposal rate

Waste disposal in Olushosun landfill started in 1992 till March, 2018 when it was closed by the Lagos State government due to the fire incidence (Table 4). The landfill receives approximately 40% of the total waste deposits in Lagos state [10]. Waste deposited in the landfill consists of unprocessed wastes of all types, ranging from organic to inorganic and hazardous to non-hazardous wastes.

3.2 Waste Composition

Waste generated and collected in Lagos Metropolis have been observed (Table 5). Putrescibles made up of food waste contributed > 40% while the rest were recyclables (paper, plastics, glass and metals). Hand picking of recyclables by scavengers was responsible for their low percentage in the waste stream.

3.3 Evaluation of MSW Disposal Alternative for Lagos metropolis

Scenario 1: Open dumping

The total CH\(_4\) emissions generated for the period 1992-2020 at Olushosun landfill was 219,886,140 m\(^3\)/yr (Figure 1). The total GHG emissions when converted to CO\(_2\) eq was 3,029,151 tonnes. The findings of this study are confirmed by other researches that open dumping of refuse has a high GWP compared to other landfilling systems [27, 1, 28, 29].

| Year | Waste deposited (metric tons) | Cumulative waste deposited (tons) | Year | Waste deposited (metric tons) | Cumulative waste deposited (tons) |
|------|-------------------------------|-----------------------------------|------|-------------------------------|-----------------------------------|
| 1992 | 165909                        | 165,909                           | 2005 | 312846                        | 3,251,584                         |
| 1993 | 174204                        | 340,113                           | 2006 | 328489                        | 3,580,073                         |
| 1994 | 182914                        | 523,027                           | 2007 | 344912                        | 3,924,985                         |
| 1995 | 192060                        | 715,087                           | 2008 | 567814                        | 4,492,799                         |
| 1996 | 201663                        | 916,750                           | 2009 | 596205                        | 5,089,004                         |
| 1997 | 211746                        | 1,128,496                         | 2010 | 626015                        | 5,715,019                         |
| 1998 | 222333                        | 1,350,829                         | 2011 | 657316                        | 6,372,335                         |
| 1999 | 233450                        | 1,584,279                         | 2012 | 690181                        | 7,062,516                         |
| 2000 | 245123                        | 1,829,402                         | 2013 | 724690                        | 7,787,206                         |
| 2001 | 257379                        | 2,086,781                         | 2014 | 760925                        | 8,548,131                         |
| 2002 | 270428                        | 2,357,029                         | 2015 | 798971                        | 9,347,102                         |
| 2003 | 283760                        | 2,640,789                         | 2016 | 838920                        | 10,186,022                        |
| 2004 | 297949                        | 2,938,738                         | 2017 | 880866                        | 11,066,908                        |

Source [22]
Table 5. Waste composition studies in Lagos Metropolis

| Waste composition (%) | Longe and Ukpebor [23] | Ogwueleka [24] | Oyelola and Babatunde [25] | Balogun-Adeleye et al. [26] |
|-----------------------|------------------------|----------------|---------------------------|-----------------------------|
| Putrescibles          | 41.8                   | 56.0           | 68.5                      | 50.8                        |
| Plastics              | 7.8                    | 4.0            | 2.7                       | 6.7                         |
| Glass                 | 9.0                    | 3.0            | 1.7                       | 2.2                         |
| Paper                 | 16.0                   | 14.0           | 16.9                      | 32.4                        |
| Metals                | 7.4                    | 4.0            | 2.9                       | 4.2                         |
| Garden                | 0                      | 0              | 4.2                       | 0                           |
| Textiles              | 5.1                    | 4.0            | 0                         | 0                           |
| Others                | 12.8                   | 15.0           | 0                         | 0                           |
| Total                 | 100                    | 100            | 100                       | 100                         |

![Figure 1. Methane generation in Olushosun landfill](image)

**Scenario 2: Sanitary landfill with gas utilization**

As shown in Table 6, predicted LFG generation increased from 1,402 in 2009 m$^3$/hr to 2,941 m$^3$/hr in 2018. LMOP [31] reported that internal combustion engines have been used at landfills where sustainable LFG flow rates of approximately 600-1700 m$^3$/hr at 50% methane are maintained. Olushosun landfill can adequately support an internal combustion engine for the period 2009 through 2020. This indirectly leads to CO$_2$ emissions reduction of 1,725,761 tonnes CO$_2$ eq. The total GHG emissions from this scenario are 43% lower than scenario 1.
Table 6. Projection of LFG generation and recovery for Olushosun landfill.

| Year | CH\textsubscript{4} (m\textsuperscript{3}/yr) | LFG (m\textsuperscript{3}/yr) | LFG (m\textsuperscript{3}/hr) | Collection Efficiency (%) | Predicted LFG Recovery (m\textsuperscript{3}/hr) | CH\textsubscript{4} emissions reduction (tons) |
|------|--------------------------------|--------------------------------|--------------------------------|--------------------------|--------------------------------|-----------------------------------------------|
| 2009 | 8,188,153                      | 16,376,306.36                  | 1,869.44                       | 75                       | 1,402.08                         | 92,337.80                                      |
| 2010 | 9,421,325                      | 18,842,650.05                  | 2,150.99                       | 75                       | 1,613.24                         | 106,244.28                                     |
| 2011 | 10,539,440                     | 21,078,881.00                  | 2,406.26                       | 75                       | 1,804.70                         | 118,853.27                                     |
| 2012 | 11,574,658                     | 23,149,316.29                  | 2,642.62                       | 75                       | 1,981.96                         | 130,527.42                                     |
| 2013 | 12,552,604                     | 25,105,207.85                  | 2,865.89                       | 75                       | 2,149.42                         | 141,555.71                                     |
| 2014 | 13,493,808                     | 26,987,615.37                  | 3,080.78                       | 75                       | 2,310.58                         | 152,184.27                                     |
| 2015 | 14,414,806                     | 28,829,612.82                  | 3,291.05                       | 75                       | 2,468.29                         | 162,855.77                                     |
| 2016 | 15,329,016                     | 30,658,031.62                  | 3,499.78                       | 75                       | 2,624.83                         | 172,865.31                                     |
| 2017 | 16,247,435                     | 32,494,869.98                  | 3,709.46                       | 75                       | 2,782.10                         | 183,222.32                                     |
| 2018 | 17,179,275                     | 34,358,550.39                  | 3,992.21                       | 75                       | 2,941.66                         | 193,730.69                                     |
| 2019 | 13,493,981                     | 26,987,961.80                  | 3,080.82                       | 75                       | 2,310.58                         | 119,527.80                                     |
| 2020 | 10,599,255                     | 21,198,510.23                  | 2,419.92                       | 75                       | 1,814.94                         | 152,171.62                                     |

4. Conclusion

The results of this study showed that the environmental implications of energy production from landfill gas (LFG) is a better way to control the emissions of GHG compared to open dumping of waste. Open dumping of waste in Olushosun landfill resulted in CH\textsubscript{4} emissions of 219,886,140 m\textsuperscript{3}/yr for the period 1992-2020 leading to GHG emissions of 3,029,151 tonnes CO\textsubscript{2} eq. However, when CH\textsubscript{4} is utilized for electricity generation, there was a reduction in GHG emissions by 43% at 1,725,761 tonnes CO\textsubscript{2} eq.

The findings of this study also revealed that Olushosun landfill had adequate LFG to generate power for the metropolis based on the waste composition and waste tonnage recorded at the landfill. The results obtained also corroborate the use of LCA as a decision support tool in waste management system. It is therefore recommended that LCA should be implemented in developing countries to reduce long term environmental effects of waste management activities.

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