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RESEARCH ARTICLE

Reducing greenhouse gas emissions from solid wastes management in north eastern Nigeria: An integrated solid waste management approach

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ABSTRACT

The solid waste management (SWM) sector is responsible for the emission of about 5% of all global greenhouse gas (GHG) emissions. In developing countries where the sector is less organised, the carbon footprint of the sector is much higher, so also is the potential for reducing these emissions. This study assessed the potential for reducing the GHGs emission from the SWM sector in northeastern Nigeria. Based on literature study, it was found that open dumping in dumpsites and unsanitary landfills is a solid waste disposal method in the region. It was estimated that 350,822.80 tonnes of MSW is disposed of in dumpsites annually, and anaerobically decomposes 403373.25 tonnes of carbon dioxide equivalent (tCO_2e) into the atmosphere. However, when an integrated solid waste management (ISWM) system, which comprises composting of organic materials, recycling of paper, glass and metals and incineration of garbage, is employed, a reduction in the region's SWM carbon footprint of up to 99.5% is attainable. It was also found that composting is the ISWM element with the highest carbon sink potential, this is because of the high organic matter in the region's wastes. The study suggests public-private partnership so as to be able to reform the SWM sector in the region and make it more sustainable.

Keywords: Carbon footprint, composting, greenhouse gases, incineration, integrated solid waste management, municipal solid waste management

1. INTRODUCTION

Global warming has been on the front burner as the greatest existential threat to humans pre -Covid 19. Its attendant consequences such as loss of biodiversity, floods, drought and submerging of islands are evidence and testament to the threat it poses. The anthropogenic emission of greenhouse gases (GHGs) has been identified as the major contributor to the accelerated warming of the globe [1], [2]. Even though the contribution of the solid waste management (SWM) industry to the global emission of GHGs is just about 5% [3], the potential for further reducing the carbon footprint of the industry is huge, particularly in developing countries where the industry is somewhat informal, less regulated and structured.

The practice of open dumping in unsanitary landfills and open burning is pervasive in developing countries, Nigeria is not an exception [4], this practice has been found to have higher carbon footprint when compared to other SWM techniques such as composting, incineration with energy recovery and anaerobic digestion [5]. This is because of the large quantities of methane that is emitted from the decomposition of the organic fraction of solid wastes, keeping in mind that methane has a high global warming potential - 28 times more than carbon dioxide [6], this makes these methods of solid waste disposal (SWD) unsustainable thus amplifying the need for a cleaner and more sustainable SWM technique.

Integrated solid waste management (ISWM) is widely seen in the waste management industry as the most sustainable SWM method, researchers see it as the solution to achieving a relatively clean SWM industry [7]–[9]. ISWM is a multidimensional approach to SWM, it is the use of a range of different waste management options rather than a single option [10]. The concept of ISWM emerged from the realisation that technical

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solutions alone do not adequately address the complex issue of SWM and that a single choice of approach/method for waste management is frequently unsatisfactory, inadequate, and not economical [10]. ISWM approach to waste management encapsulates the hierarchical order of waste management which priorities waste prevention and reduction in quantities of waste generated over the various existing disposal methods. It is not a strict technical approach to waste handling rather a holistic approach to SWM in an integrated manner.

The various waste management techniques that combine to form ISWM are individually known as its elements. Elements that constitute a typical ISWM model in order of importance are: waste prevention; waste reduction/minimization; re-use of materials and products; material recovery from waste streams (recycling); composting to produce manures; incineration with energy recovery; incineration without energy recovery and disposal in landfills [11]. This hierarchical order is based on the 3Rs of SWM (reduce, reuse and recycle) [12].

The northeast geopolitical region of Nigeria comprises six states: Adamawa; Bauchi; Borno; Gombe; Taraba and Yobe. The region lies within longitude 9.9992 and 13.1520 and latitude 11.8846 and 7.9867 [13]–[15]. As at 2016, the region had an estimated population of 26,263,865 [16]. Open dumping of MSW in unsanitary landfills, dumpsites and sometimes occasional open burning is the SWD method practiced across the region [17]. The chain of SWD in the region essentially entails disposing of wastes at designated waste collection points, the state waste collection agencies routinely collecting the waste from these points and disposing them off at unsanitary landfills and dumpsites. The little form of recycling that exists in the SWM chain in the region is the collection of metal scraps by scavengers from the waste collection points or at the dumpsites.

An estimated 350,822.80 tonnes of MSW is generated on an annual basis in the region [17]. Due to similarity in the culture, traditions, vegetation and climate of the region, there is little variation in the composition of the waste generated in the cities of the region. This makes the formulation of a common ISWM model for the entire region possible. This study seeks to assess the potential role of an ISWM system in reducing the GHGs emission from the SWM sector in North-eastern Nigeria.

2. MATERIALS AND METHODS

To estimate the potential reduction in the quantity of GHGs emission an ISWM approach can bring to the SWM sector in north eastern Nigeria, an extensive literature review was undertaken to first determine the region's current carbon footprint. The composition of the MSW generated in the region was considered so as to determine the ISWM element most suitable for each category of waste generated in the city. Lifecycle carbon footprint approach was used to estimate the footprint for each of the elements of the ISWM system. Standard lifecycle assessment data for each of these elements was obtained from literature.

The elements considered for the formulation of the ISWM model are recycling, composting, and incineration with energy recovery and landfilling of inert materials. These SWD methods were selected to be the elements of the region's ISWM system based on the composition of the waste being generated there. The proposed treatment of MSW generated in the region involves composting of organic materials, recycling of glass, papers and metals, incineration of garbage with recovery of electricity and landfilling of inert materials. Even though reduction in waste generation and reuse of materials are essential elements of an ISWM system, they are excluded from this study since the exact GHGs emissions avoided from these elements cannot be ascertained.

To estimate the emission from the region, the following assumptions were made in line with precedence seen in literature:

1. All glass materials are recyclable.
2. All papers are high grade deinked paper.
3. All metals in the region's MSW are aluminium.
4. The humus obtained from composting is used as a substitute for chemical fertilizer.

Data used for estimating the carbon footprint for each element of the ISWM using the lifecycle assessment (LCA) approach was obtained from literature, and presented in Table 1.

Table 1. ISWM elements and their corresponding LCA carbon footprints

ISWM Element	Carbon Footprint
Recycling of Glass	1.25tCO_2eq/tonne of glass [18]
Recycling of Paper	212kgCO_2eq/tonne of waste [19]
Recycling of Aluminium	3.05tCO2eq/tonne of Aluminium [20]
Composting of Organic Waste	-690kgC/tonne of Composted Waste [21]
Incineration with electricity recovery	-0.179tCO2eq/tonne of incinerated waste [22]

The framework for the ISWM system is seen in Figure 1, this involves the recycling of recyclable materials, composting of organic materials, incineration of garbage and landfilling of inert materials.

In determining the emission from current practice of open dumping so as to be able to estimate the reduction in GHGs emissions that the ISWM system brings. IPCC's waste model shown in equations 1-3 was used [23]. The composition of the waste generated in the region presented in Table 2 was also used for the estimations [17].

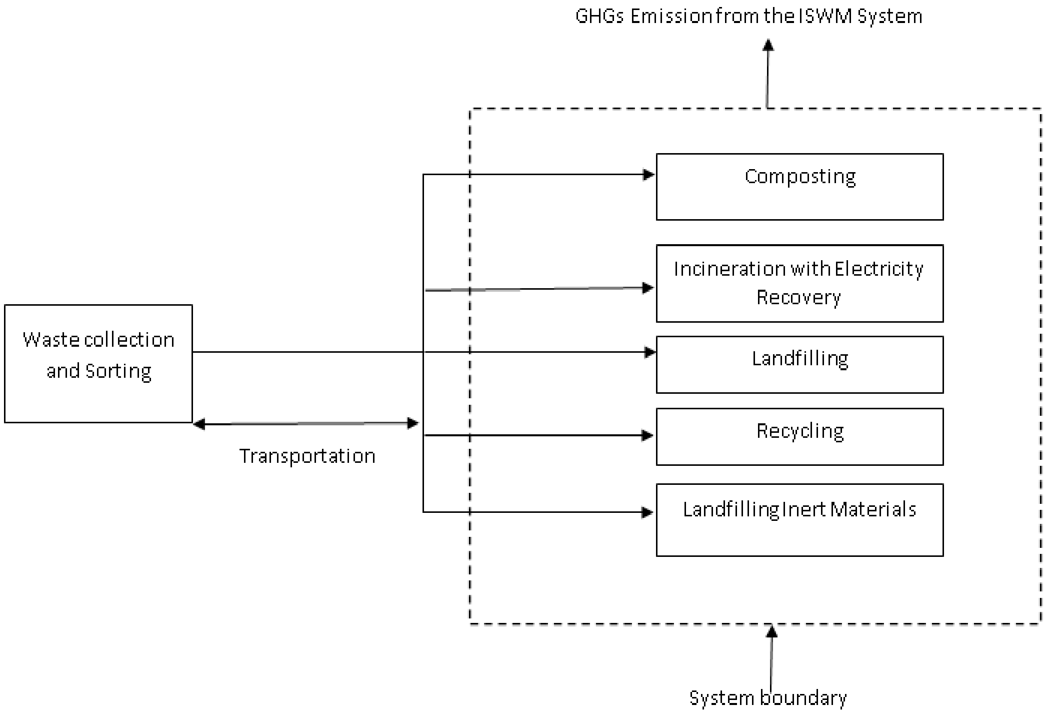

Fig 1. Framework for integrated solid waste management model

Table 2. Composition of municipal solid waste in northeastern Nigeria

Category	% Weight
Food	6.3
Garden Waste	19.0
Plastics	24.4
Paper	8.6
Textiles	2.8
Leather/Rubber	15.3
Glass	4.6
Metal	5.9
Inert Materials	13.2

$$CH_4\ \text{Emissions} = MSW_X \times L_o \times (1 - f_{rec}) \times (1 - OX) \quad (1)$$

Where,

MSW_X = Mass of solid waste sent to landfill in inventory year (metric tonnes)

L_o = Methane generation potential (m^3/tonne)

f_{rec} = Fraction of methane recovered at the landfill (flared or energy recovery)

OX = Oxidation factor (0.1 for managed sites, 0 for unmanaged sites)

$$L_o = MCF \times DOC \times DOC_F \times F \times \frac{16}{12} \quad (2)$$

Where,

MCF = 0.6 for dumpsites and unmanaged landfills

DOC = Fraction of Degradable organic carbon (tonnes C/tonnes waste)

DOC_F = Fraction of DOC that ultimately degrades (0.6).

F = Fraction of methane in landfill gas (0.5)

$\frac{6}{12}$ = Stoichiometric ratio between methane and carbon

$$DOC = (0.15 \times A) + (0.2 \times B) + (0.4 \times C) + (0.43 \times D) + (0.24 \times E) \quad (3)$$

A = Fraction of solid waste that is food

B = Fraction of solid waste that is garden waste and other plant debris

C = Fraction of solid waste that is paper

D = Fraction of solid waste that is wood

E = Fraction of solid waste that is textiles

Global warming Factor of CH4 = 28 [6]

3. RESULTS AND DISCUSSION

It was found that on average, 350,822.80 tonnes of MSW is disposed of at dumpsites and unsanitary landfills in the region. The composition of which includes 21,984.90 tonnes of food wastes; 66,773.27 tonnes of garden and yard wastes; 30,112.29 tonnes of paper wastes; 16,137.85 tonnes of glass; 85,483.82 tonnes of plastics; 9,823.04 tonnes of textile materials; 53,734.36 tonnes of leather and rubber and 46,133.20 tonnes of inert materials. Given this profile of MSW generated and disposed of in dumpsites in the region. It was estimated using IPCC's model that when the waste anaerobically decomposes in these dumpsites and unsanitary landfills, 403,373.25tCO_2e is emitted into the atmosphere on an annual basis. This means for each tonne of MSW disposed of in the region, 1.15tCO_2e is emitted into the atmosphere from its natural decomposition.

If the proposed ISWM model is implemented, it is expected that the emission of GHGs from the management of MSW in the region will reduce. To ascertain this potential reduction, examining the system based on each element of the ISWM model is the logical thing to do.

It has been established by an earlier research that the food waste generated in the country and the atmospheric condition are suitable for composting [24]. And since open windrow composting is what is to be used as the preferred composting method, little technical know-how is required. For composting as an element of the ISWM model, it was found that when the 88,758.17 tonnes of garden and food wastes disposed of in dumpsites in the region on an annual basis is rather composted in an open windrow and the resultant compost is used in place of inorganic fertilizer, a net reduction of GHGs emission of 61,243.14tCO_2e will be attained annually. For recycling, it was estimated that recycling the 67,065.63 tonnes of metals, glass and papers generated in the region will be responsible for the emission of 90,043.35tCO_2e. With each of the three components (metals, glass and papers) responsible for 63,487.23tCO_2, 20,172.31 tCO_2 and 6,383.81 tCO_2 respectively. It was estimated that when the garbage component of the MSW is incinerated and the electricity generated from it substitutes grid electricity, a reduction in carbon emission of -26,678.38tCO_2 can be attained.

Table 3 shows the net carbon footprint for each of the components of the waste generated in the region. Likewise, Figure 2 graphically shows the carbon footprint of each of the elements of the proposed ISWM model.

Table 3. Carbon footprint for each component of municipal solid waste

MSW Component	**Carbon Footprint (tCO_2eq/yr)**
Recycling of Glass	20,172.31
Recycling of Paper	6,383.81
Recycling of Metals	63,487.23
Composting of Food Waste	-15,169.58
Composting of Yard Waste	-46,073.56
Incineration of Plastics	-15,301.60
Incineration of Textiles	-1,758.32
Incineration of Leather/rubber	-9,618.45
Total	**2,121.83**

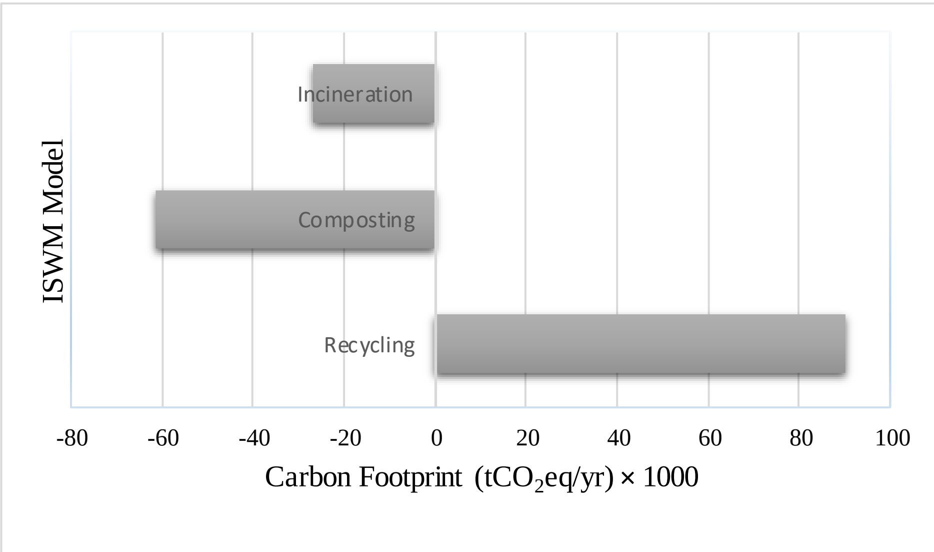

Fig 2. Carbon footprint of each integrated solid waste management element

It can be seen from Figure 2 that in the ISWM model, composting is the largest carbon sink. Giving that 25.3% (88,758.17 tonnes) of the waste disposed of at dumpsites and unsanitary landfills in the region are organic wastes. It is not surprising that a reduction in GHGs emission of such magnitude is attainable from composting of organic wastes and usage of the compost in place of inorganic fertilizer. It is worthy to mention that the low quantity of food waste in the general volume of waste generated in the region is due to the generic manner of dealing with food waste in Nigeria, that is the feeding of household animals with food remnants/waste instead of trashing, this explains the low quantity of food waste reaching dumpsites in the region and the country at large [25]. It can be seen recycling has the highest carbon footprint of all the ISWM elements, recycling is usually an energy intensive process even though not as intensive as production from virgin materials [26], [27].

It is estimated that if the proposed ISWM model is implemented in the region, the net GHGs emission from the regions MSW will be only 2,121.83tCO_2e as seen in Table 3, this is a reduction of 99.5%. By all standards, attaining a reduction in GHGs emission of up to 99.5% is remarkable. Juxtaposing this result with those of studies done in other places, it can be seen that the potential for reduction in the emission of GHGs in Northeastern Nigeria is remarkable. Maalouf and El-Fadel [28] developed an ISWM model and used data from countries around the world to test it, the researchers found that the potential for reduction in carbon footprint ranges from 24 to 95%. Sandulescu [2] found that implementing a particular ISWM model in Bucharest the capital of Romania would bring about a 5% reduction in the city's GHGs emission from SWM. In the same vein, Sun et al., [29] carried out a comparative study of Japan and China, the researchers found that if the ISWM model they developed is implemented strictly in the two countries, there is a potential for reduction in emission of GHGs emission from the SWM sector of up to 181.37 million tCO_2eq and 96.76 million tonnes respectively. It has been noted that the potential for reduction of carbon footprint of the SWM sector is more in developing countries where the sector is somewhat less organised and regulated. This buttresses the point made by Abu Qdais et al., [30] where the researchers stated that "the room for reduction of GHGs is greater in developing countries". Another reason for this aside the less organised nature of the SWM sector in developing countries is the lack of awareness about the need for responsible and climate conscious usage of material and resources among the general populace.

4. CONCLUSIONS

Although it is generally assumed that the contribution of developing economies to global anthropogenic GHGs emission is minute, their rapid population and economic growth is set to make their contribution significant if no action is taken to make resource and material utilisation sustainable in these regions. The SWM sector is one of the key areas in which sustainability needs to be encouraged in developing countries due to the fast growing population and economies in these regions coupled with the adoption of western lifestyle which encourages high consumption and waste generation.

This study examined the possibility of reducing the carbon footprint of the SWM sector of Nigeria's northeastern region by adoption of an ISWM model. Using the LCA approach, it was found that the current annual quantity of MSW disposed of in dumpsites is responsible for the emission of 403,373.25tCO_2eq. It was estimated that if an ISWM model which constitutes recycling, composting and incineration is implemented in the region, there will be a reduction of 99.5% in the emission of GHGs from the disposal component of SWM chain in the region.

Composting was found to be the element of the ISWM model with the highest carbon sink, this is because of the high organic matter content of the waste generated in the region. To successfully implement the proposed model or any other advanced SWM scheme, a number of behavioural and structural changes need to be undertaken. One of the steps to achieving such changes is by enlightening the populace about the implications of excessive waste generation and the need for conscious materials usage and consequently reduction in waste generation. Another is the importance of reusing items that can be reused (items like polythene bags) instead of discarding them after single use. Importantly, the need for waste segregation from source (household and businesses), this reduces the cost, energy and consequently the carbon footprint of the SWM chain. For structural changes, proximity principle which advocates for the processing (sorting, recycling, composting, landfilling and/or incineration) of waste as close to its source as possible should be adopted, this will reduce the carbon footprint associated with the transportation leg of the SWM chain.

Overhauling the SWM sector in the region which is largely government dominated is capital intensive, the current economic realities of the country will not allow governments in the region to undertake such audacious project, as such it is suggested that government partners with investors who can make the necessary investment into the system so as to be able to achieve sustainability in the sector.

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