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Challenges and perspectives of greenhouse gases emissions from municipal solid waste management in Angola

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Abstract

Municipal solid waste (MSW) management contributes substantially to climate change. The greenhouse gases (GHG) emissions from waste collection and landfill activities have a significant contribution. The carbon footprint is an important environmental indicator to express GHG emissions. Nowadays in Luanda, the capital and largest city of Angola, more than 2 million tonnes per year of unselected MSW are sent to landfill. The aim of this work is to evaluate the carbon footprint related to MSW in Luanda. The methodologies used to quantify the carbon footprint were based on the guidelines of the IPCC and the GHG Protocol of greenhouse gases emissions associated with MSW anaerobic decomposition, from the daily operations of the landfill site. The results show that direct landfill emissions are the major contributions to GHG accounting.

Keywords: Carbon footprint; Greenhouse gases; Landfill; Municipal solid waste

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1. Introduction

In the last two decades, the efficient management of solid urban waste has become a concern in developing countries in Africa wherein environmental legislation has been published with a focus on prevention, reuse and recycling of solid urban waste. The production and composition of waste (in particular the carbon content) as well as the technologies used for waste handling and disposal determine the final amount of greenhouse gases (GHG) emissions from a waste management system [1]. The Paris Agreement signed or accepted by all 197 members of United Nation Framework Convention on Climate Change (UNFCCC) in 2018 hopes to restrict global warming to two degrees Celsius. In order to effectively control global warming and climate change, the emission of GHG into the atmosphere should be drastically reduced [2].

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The Guide of the National Greenhouse Gas Inventory of the Intergovernmental Panel on Climate Changes (IPCC) and the GHG Protocol have identified the activities to be included in the calculation and the emissions associated with these activities taking into account the six gases under the Kyoto Protocol. The CO_2, CH_4 and NO_x gases are mainly derived from the burning of fossil fuels, but the first two are also obtained from the decomposition of organic matter and some natural processes [3].

Carbon footprint assessment is a useful tool to measure the environmental impact of activities and products with regard to GHG emissions [4].

A significant amount of the carbon footprint is originated from urban waste treatment systems, particularly at landfill disposal. Although no universally method to calculate the carbon footprint was suggested, in the literature were found methodologies to calculate it. In order to express the magnitude of the emissions and simplify the communication, the values are described in terms of the amount of carbon dioxide equivalent (CO_2eq). The three gases, CO_2, CH_4 and N_2O are normally considered to calculate the carbon footprint [5].

The methodologies of the Department of Environment, Food and Rural Affairs (DEFRA) from UK, concerning the Publicly Available *Standard* (PAS) 2050, GHG Protocol and IPCC, use the emission factor (EF) to calculate the carbon footprint [6]. EF is a ratio that relates GHG emissions to activity. PAS 2050, World Business Council on Sustainable Development (WBCSD) and World Resource Institute (WRI) are understood as reductions of the scope of LCA methodology, in that they address only one of environmental impact category, the global warming [7].

Waste management is defined as, "the collection, transport, recovery and disposal of waste, including the supervision of such operations and the after-care of disposal sites, and includes actions taken as a dealer or broker" [8]. In general Municipal solid waste (MSW) sector is the fourth largest supplier to global emissions of non-CO_2 GHGs that contribute towards global warming and climate change due to their emissions and that approximately contribute 5.5–6.4% towards global methane (550 Tg) emissions annually [6]. Late 2005 the sector of MSW management contributed to GHG account about 1.3 Gt of CO_2eq that ranged 3%–5% of anthropogenic emissions [6].

The MSW landfills are the third largest anthropogenic source of methane, followed by agricultural and enteric fermentation, accounting for 11% of the global methane emissions as biogas. These emissions from landfill are expected to grow up to 816 MtCO_2eq by 2020 [9].

1.1. Classification of impacts

The impacts of global warming potential are classified in terms of CO_2eq and disaggregated into three groups as direct, indirect and avoided impacts; depending on the type of emission [5]. Group 1 includes all direct GHG emissions occurring in waste treatment facilities and associated operations such as fuel combustion. Group 2 includes indirect GHG emissions, i.e. those occurring outside waste treatment facilities but associated with their operations. Finally, Group 3 includes the avoided impacts related to the GHG emissions that have been stopped in the system as a result of the reuse of materials and energies recovered or recycled from the flows generated by the system itself [5].

The IPCC developed the global warming potential (GWP) concept to compare the ability of each GHG to trap heat in the atmosphere relative to other gases [6]. The GWP of a greenhouse gas is defined taking as reference CO_2 and therefore GWP-weighted emissions are measured in tonnes of CO_2 eq (tCO_2eq). GWP values allow comparisons of the impacts of emissions and reductions of different gases. The GWP of the three GHG main gases, CO_2, CH_4 and N_2O are, respectively, 1, 21 and 310 in 100 years [6].

Barton et al. [10] compared GHG emissions for a series of generalized waste disposal scenarios applicable for developing countries. They have concluded that sanitary landfills with no landfill gas capture will have the highest GHG emissions (1.2 t CO_2eq per t of waste disposed), followed by open dumpsites (0.74 CO_2eq per t of waste dumped), sanitary landfills with gas collection and flaring (0.19 t CO_2eq per t of waste disposed) and sanitary landfills with gas collection and electricity generation (0.09 t CO_2eq per t of waste disposed).

1.2. Brief overview of the Angola municipal solid waste management

Angola has recently had an enormous increasing in the urban population due to the rural exodus in search of safety and better life conditions. Angola has signed the Paris Agreement and agreed with the United Nation (UN)

Table 1. Average composition of MSW in MSL.
Source: Landfill operator ELISAL.

Municipal solid waste category	Percentage of waste [wt%]
Putrescible fraction (Food and garden waste)	25
Paper and paperboard	10
Plastics	15
Glass	7
Textiles	8
Metals (ferrous and non-ferrous)	7
Soil	21
Others (fine fraction, inert materials, hazard waste)	7

an unconditional 35% emissions cut by 2030, compared to Business as Usual (BAU) scenario. Angola is committed to fighting climate change and has articulated its intention to reduce GHG emissions, which in 2013 were estimated at 18.49 Mt of CO_{2eq} as reported on the "Intended Nationally Determined Contributions (INDC) of Republic of Angola".

Angola's total GHG emissions in 2014 were 252.09 million of MtCO2eq, totalizing 0.52% of global GHG emissions. The energy sector serves as the predominant source of GHG emissions in Angola, with 49.4% of emissions from energy emissions, 37.4% from land-use change and forestry, 11.7% from agriculture, 0.9% from waste and 0.6% from industrial processes [11].

Luanda, the capital, has a population of nearly 7,098,267 and the population density is 377 inhabitants per km^2 [12]. It covers an area of 18,826 km^2 and currently comprises 9 municipalities, namely Belas, Cacuaco, Cazenga, Icolo and Bengo, Luanda, Quissama, Kilamba Kiaxi, Talatona and Viana. Luanda province, which coincides with the city of Luanda, is administratively organized in 7 urban districts. Today more than 2 million tonnes per year of unselected MSW have been sent to Mulenvos Landfill in Luanda. Five large waste collector companies daily transport 70% of collected wastes to landfill. Mulenvos Landfill (MSL) is known as the Angolan's largest landfill plant. It is located in the Municipality of Viana 12 km in the west part of Luanda and has been in operation since December 2007.

This work aims to develop a comprehensive research to study the contribution of Angolan MSW management sector to the global warming. The study intends to analyse the GHG emitted into the atmosphere by MSW disposal at Mulenvos landfill in Luanda.

The methodologies to quantify the carbon footprint were based on the guidelines of the IPCC and the GHG Protocol of GHG emissions associated with MSW anaerobic decomposition, from the daily operations at landfill site, from the consumption of fossil fuels during waste collection and disposal.

2. Material and methods

The emissions from landfill were estimated using the LandGEM model developed by USEPA. This model allows determining methane emissions amount using the methane generation capacity and the amount of waste disposed. The GHG emissions were analysed using GHG emission factors.

In this study the household wastes, raw materials and energy are considered as main inputs into the system. Energy is consumed to manage waste when disposed. In order to calculate the energy needs for the MSW management it was considered all machines working in daily landfill activities, such as: excavators processing soil, bulldozers to move the wastes, steel wheel compactors to levelling them.

2.1. Landfill waste disposed composition and production

The characteristics of the waste disposed are based on a characterization carried out in the late 2014. The composition of waste deposited in Mulenvos landfill expressed as a percentage by weight of total mass is shown in Table 1. The organic fraction of MSW is about 25 wt%. This relatively high fraction of organic waste is considered to be a characteristic of MSW in Angola, as well as in several developing countries in Africa [13].

Table 2. Annual disposed and accumulated wastes from 2007.
Source: Landfill operator ELISAL.

Year	Disposed wastes [Mg]	Accumulated wastes [Mg]	Year	Disposed wastes [Mg]	Accumulated wastes [Mg]
2008	1,023,403	1,060,691	2013	2,632,375	11,317,538
2009	1,545,596	2,606,287	2014	2,169,612	13,487,150
2010	1,884,464	4,490,750	2015	1,809,240	15,296,390
2011	1,931,406	6,422,156	2016	1,511,804	16,808,194
2012	2,263,007	8,685,163	2017	2,277,260	19,085,454

Regarding MSW production in Luanda province the estimated MSW per capita in 2012 was 0.65 kg/(inhabitant day), with a maximum of 1.0 kg/(inhabitant day) for the city of Luanda and a minimum of around 0.30 kg/(inhabitant day) for suburban municipalities [14].

Since 2008 the landfill has received a significant amount of waste, as shown in Table 2. Trucks daily unload, at landfill, more than 6000 Mg of MSW collected from all municipalities. In 2017, the total amount of waste disposed at MSL reached at about 19,085,454 Mg, as shown in Table 2.

2.2. Landfill gas and methane generation

LandGEM model takes into account the local weather conditions and can be described mathematically by Eq. (1):

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} k L_0 \left(\frac{M_i}{10} \right) e^{-k t_{ij}} \tag{1}$$

where: Q_{CH_4} is the annual generation rate of methane, in the year of calculation, in [m^3 $year^{-1}$], i is the time increment in one year, n is the total number of years being modelled, j is the time increment in 0.1 years, k is the methane generation rate in [$year^{-1}$], L_0 is the methane yield in [m^3 CH_4. $Mg_{waste}{}^{-1}$], M_i is the mass of waste, on a total weight basis, disposed in the ith year [Mg], and t_{ij} is the age of the jth portion of M_i of waste disposed in the ith year.

In the present work, the default data of the conventional CAA category were used; because, do not exist reported data on the actual composition of the wastes deposited in the landfill. The potential methane generation capacity suggested is: $L_0 = 170$ m^3 Mg^{-1}, the methane generation rate, $k = 0.050$ $year^{-1}$; and the concentration of NMVOCs, 4000 ppmv. The carbon dioxide and methane content were 44.01%v/v and 55.99%v/v of total landfill biogas respectively.

2.3. Greenhouse gas emissions

Landfill operation and supply operation are treated in this work considering that the GHG contributions are accounted for a conventional landfill without flaring of collected landfill gas (LFG). However, landfill operator accounts for 100% of GHG emissions from the operations under own controls. This approach involves the quantification of direct and indirect GHG emissions from their own operations, by direct GHG emissions resulting from the main activity of the landfill during degradation waste processes, and from combustion of fossil fuels in equipment machinery, and vehicles, which are controlled by Mulenvos Landfill operator. While indirect GHG emissions result also from landfill activity nevertheless are emitted from facilities or vehicles owned by third parties, such as electricity consumption, and fuel for vehicles whose emissions from its generation are responsibility of third parties.

The Landfill GHG emission sources and activity data collection consider:

(1) Emissions inherent of the steady combustion sources.

The electric power generator constitutes the only one steady combustion source. The contribution of emissions by electricity consumptions depends on the fuel, and technology used to generate.

(2) Emissions inherent of the mobile combustion sources and electricity.

Table 3. Data describing fuel and electricity consumption in landfill process.

Activity	Description
Excavation, reloading and trampling of soil	Fuel-diesel, without leakage during operation
Coverage layers	Welding warming machine fuelled-diesel (L $h^{-1)}$
Waste compaction	Waste compaction density, efficiency – 300 m^3 h^{-1}
	Fuel — diesel, consumption 15 L h^{-1}
Waste moving	Fuel — diesel, consumption 13 L h^{-1}
Leachate recirculation irrigation	Fuel — diesel consumption 7 L h^{-1}
LFG collection system	Electricity, fuel — diesel consumption 3 L h^{-1}
Transportation vehicles	Fuel — diesel consumption 7 L h^{-1}

Table 4. Biogas and methane estimation by LandGEM in 2017, associated to landfill GHG emissions and activity data collection.

	Biogas [m^3 $year^{-1}$]	Methane [m^3 $year^{-1}$]	Carbon dioxide [m^3 $year^{-1}$]
LandGEM	207,477,036	116,166,393	91,310,643
Gas content by in situ measurement [%]	100	55.99	44.01

Table 5. Emissions factors associated to electricity consumption [16].

Activity	Emission factor	Reference
Diesel generator	0.35 $kgCO_2eq/kWh$	DEFRA [16]
Excavation, waste movement, compaction machinery	2.67 $kgCO_2eq/kWh$	DEFRA [16]
Electricity consumption	0.35 kg CO_2eq/kWh	DEFRA [16]

Fuel consumption of waste collection trucks, and associated to unloading at landfill is not included in this study because it does not depend on the landfill operator company (Table 3).

The fuel consumption at the landfill site depends on the degree of compaction and the amount of soil that is excavated and moved for daily cover [15].

(3) Emissions associated to biological process.

The landfill involves very complex processes where anaerobic microorganisms degrade the organic matter into compounds producing biogas; a mixture of mainly CO_2 and CH_4; a powerful GHG gas. Table 4 shows the annual generation of CO_2 and CH_4 gases both estimated by the LandGEM model. In 2017, the methane content represents 55.99% of the total LFG while the carbon dioxide content corresponds to 44.01%.

Emission factors selection

Emission factors referred to direct and indirect emissions of the GHG as result of landfill activity. The DEFRA [16] data base suggests EF values as shown in Table 5.

Using the emission factor EF, the annual GHG emission is calculated by Eq. (2):

$$CO_2\, emissions = Activity\, data \times Emission\ Factor \tag{2}$$

3. Results and discussion

The main GHG from landfill is the LFG. The global warming contributions of the LFG depends of the conversion of CH_4 to CO_2 by combustion in flares, gas engines or by microbial oxidation in the soil top cover of the landfill, because the CH_4 converted to CO_2 does not account to GWP. The landfill has CO_2 as direct GHG emissions from fuel consumption, diffuse CH_4 emissions and CH_4 from net collection however released to atmosphere. Mulenvos Landfill has contributed to the global warming with over 2 million Mg of CO_2eq along 2017, as shown in Table 6. Considering that in each barrel of crude oil produces an average a minimum of 317 kg of CO_2 when consumed. This result represents more than 8 million of barrels of crude over the year [16].

Thus, carbon offsetting should be seen as a complementary tool to efforts to reduce GHG emissions, towards reducing the impact of human activities on climate change.

The methodology adopted in this assessment of GHG emissions, even being wide world accepted, involves many sources of uncertainty. The LandGEM model 3.02 (2005) has as main disadvantages the assumption of only one type of wastes materials, unless the composition of unsorted wastes.

Table 6. Emissions of GHG in 2017.

Activity	Emissions kgCO_2eq year^{-1}
Diesel generator	518,142
Fuel consumption of diesel vehicles	6,322,899
Methane generation	2,439,494,244
Total	2,446,335,285

4. Conclusions

The evaluation of carbon footprint associated to MSW management in Angola was not done before this work. However, Mulenvos Landfill located in Luanda has been operating since late of 2007 receiving the MSW collected in Luanda province. Based on the guidelines of the IPCC and the GHG Protocol of GHG emissions, associated with MSW anaerobic decomposition, over 2 million Mg of CO_2eq was produced in 2017, only at Mulenvos landfill. Due to the economic crisis, the construction of new landfills in other provinces is delayed and MSW are still deposited in dumps.

The evaluation of carbon footprint associated to MSW management in Angola, should be used as a tool to push the government to improve environmental development and to monitor the activities of the several companies operating in this sector. Nevertheless, the high costs demanded on the terms of know-how, a better attention must to be taken to those emissions of carbon in their referred activities.

Opportunities

(1) To identify the steps of MSW management to reduce carbon emissions; (2) Carbon emissions use as an additional criterion for deciding the technological applications for landfill, and biogas energy conversion operations; (3) To improve the reputation of companies vis-à-vis the population and policy makers; (4) Training and qualification of technical personnel in this activity.

Challenges

(1) To avoid the increasing of the amount of GHG generated with MSW management systems in Angola; (2) To introduce methodologies worldwide accepted to the evaluation and accounting of footprint; (3) To carry out local studies and compare results; (4) To extend methodologies to monitor the industrial activities impacts.

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