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# Supporting waste management in a Brazilian city using life cycle assessment: a case study of Uberlândia

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**ABSTRACT**

Life cycle assessment (LCA) applications in solid waste management are often used to analyse environmental impacts. In Brazil, however, LCA approach is still not disseminated and its applications remain limited. So, this paper aims to provide the results of a case study involving the LCA application in waste management in Uberlândia a Brazilian city. Four waste management scenarios were assessed and compared, including the current waste management system configuration of Uberlândia. The results of this paper show the benefits of LCA applications in waste management to support decision making process. Indeed, LCA allows quantifying environmental impacts related to each waste management strategy analysed. Among the scenarios considered, the one based on recycling and incineration, Scenario 4, presented the best performance in terms of environmental impacts. On the other hand, the existing waste management system of Uberlândia presented the worst result in three of the six impact categories analysed, indicating an urgent need to change the current SWM strategy in this city.

*Keywords:* Waste management; Life cycle assessment; Environmental assessment

## 1. Introduction

According to a study by Hoornweg and Bhada-Tata [1] about 1.3 billion tonnes of solid waste are generated annually. It is estimated that this amount will increase to 2.2 billion tonnes by 2025. On the other hand, waste management has gained importance because solid waste disposal generates several impacts to the environment. So, waste management becomes crucial to achieve sustainability because when its steps are properly executed they contribute to reducing environmental liabilities and decreasing natural resources requirements including fossil fuels and water [2]. In addition, according to United States Environmental Protection Agency [3], the major objective of technologies and policies for solid waste management (SWM) is to protect the environment and human health by reducing the negative impacts and finding ways to reuse them to provide benefits to society. Several studies have presented the benefits from waste management to sustainability.

The latter means a balance between economic efficiency, social equity and environmental protection. Moreover the first definition of this term provided by the World Commission on Environment and Development (WCED) in 1991, sustainable development consists in a development that meets the needs of the present without compromising the ability of future generations to meet their own needs [4].

Indeed, a crucial aspect to achieve urban sustainability is an affordable, effective and truly sustainable waste

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management [5]. Concerning developing countries, municipal solid waste becomes an important issue for cities in emerging economies due to the costs associated with its management and the absence of knowledge to correctly understanding and planning all stages of waste management [6].

Among the methodologies used to evaluate environmental impacts of waste management strategies, LCA presents several features that make it one of the most largely used approaches to this purpose [7]. LCA is a holistic method, that is, it assesses the environmental impact of products or processes from the beginning, as raw material, through production and use to disposal [8]. According to International Standardization Organization [9], LCA is a technique to assess environmental impacts based on the evaluation of potential environmental impacts associated with an inventory of inputs and outputs of a system. For European Commission [10], LCA is a structured, comprehensive and internationally standardised method designed to quantify relevant environmental and health impacts and resource depletion. In addition, LCA helps to evaluate and implement opportunities for environmental improvements [11].

The life cycle thinking approaches offer a science-based tool to support sustainable waste management [12,13]. So, LCA is applied in SWM context to support decision-making process and in strategy planning [14]. Actually, LCA studies in SWM are largely used in the assessment of environmental effects of waste management scenarios [15,16]. Indeed, in the last decades, environmental impacts from waste management systems have been frequently assessed by life cycle assessment [17]. In the study by Ikhlayel [18], LCA was applied to assess waste management scenarios in Lebanon. The latter highlights the importance to consider country specificities in the study. From the study by Vossberg et al. [19], which carried out a LCA study involving waste management in South Africa, it is noted that the simple adoption of the waste management hierarchy without a previous analysis not necessarily results in the best environmental solution. Moreover, Bisinella et al. [20] assess the influence of waste composition in LCA studies and concluded that the adoption of local waste composition data is essential to the reliability of LCA results. Detailed reviews of LCA studies applied to waste management are provided in the studies by Laurent et al. [21], Khandelwal et al. [22], and Yadav and Samadder [23].

According to the study by Laurent et al. [21], there is no decisive agreement about a generalized optimum waste treatment strategy because LCA results depend on context and local characteristics. In addition, the same author reported that the huge majority of LCA studies in SWM are addressed to developed countries. Based on these findings and in the current difficulty of emerging economies in handling solid waste [6], it is noted a need for LCA studies to support SWM strategies in such countries. In Brazil, for example, LCA approach is still not disseminated and its applications remain limited.

Actually, LCA studies involving waste management context are mostly concentrated to Europian and Asian countries, as reported by Khandelwal et al. [22]. A few number of LCA studies in waste management were carried out in Brazilian context, such as studies by Soares and Martins [24] and Angelo et al. [25]. In the study by Soares and Martins [24], LCA was used to assess waste management strategies in São Paulo. In the study by Angelo et al. [25], in turn, LCA and multicriteria analysis were adopted to select strategies to manage food waste in Rio de Janeiro. So, this paper aims to provide the results of a case study involving the LCA application in waste management in Uberlândia, a Brazilian city.

## 2. Materials and methods

### *2.1. Description of the area in study*

Uberlândia is a city located in the southeast of Brazil in the state of Minas Gerais. This city presents an urban area of 219 km² and a population of 602.359 inhabitants [26]. Waste generation and characterization for Uberlândia are presented in Table 1. The climate is tropical, the average temperature is 22°C and the average rainfall rate is 1,400 mm/year [27].

### *2.2. Life cycle assessment*

#### *2.2.1. General aspects*

This LCA study was performed according to the following steps [9,10]: goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA) and interpretation of results. LCA study was carried out based on LCA-IWM methodology [29], which has been applied in several studies worldwide [8,30–34]. It is important to note that LCA-IWM was specially designed to support authorities in cities where waste management planning was still not properly established [31,35], as for the city under study. Moreover, characterization factors of LCA-IWM were updated according to the last version of CML database provided in [36]. The LCA-IWM was adapted to the Brazilian waste context and to the local characteristics, which include waste composition, electricity mix and national regulations. The annual amount of MSW generated in Uberlândia was the functional unit adopted in this study.

#### *2.2.2. Scenarios considered*

The LCA was carried out for four waste management scenarios for the city of Uberlândia, one representing the current municipal SWM in this city and three new scenarios. Scenario 1 corresponds to the existing situation of the waste management system in Uberlândia. Indeed, nowadays the

Table 1
Municipal solid waste generated in Uberlândia in 2013 [28]

| Waste fraction | Waste generation (kg/year) | Portion of total waste (%) |
|---|---|---|
| Glass | 12,259.5 | 6.8% |
| Metal | 5,769.2 | 3.2% |
| Paper | 12,800.3 | 7.1% |
| Plastic | 23,076.6 | 12.8% |
| Organics | 105,827.9 | 58.7% |
| Others | 20,552.6 | 11.4% |

most part of waste in this city is sent to landfill and only 0.7% of wastes are sent to recycling plants.

In Scenario 2 composting of 50% of organic waste fraction were considered whereas current recycling rates were maintained. Scenario 3 is similar to Scenario 2, but 50% of organic waste were sent to anaerobic digestion and not to composting. In Scenario 4, in turn, waste management strategy was based on recycling and incineration. In this scenario organics and others fractions were sent to incinerations as well as 50% of recyclables. The remaining 50% of recyclables were sent to recycling plants. Table 2 presents the waste inputs for each scenario.

### *2.2.3. Goal and scope*

The goal of this LCA study is to assess waste management strategies to Uberlândia. Concerning scope, the boundary conditions of the study are treatment and disposal facilities. Temporary storage, collection and transport of waste were not considered in the analysis.

### *2.2.4. Life cycle inventory*

LCI was carried out based on the LCA-IWM methodology described in the study by Den Boer et al. [29]. Data sets used to quantify emissions of pollutants and consumption of resources for each waste treatment technology were also provided by the aforementioned methodology.

Regarding electricity generation, data based on the Brazilian power generation mix were used, as provided in the study by Brazilian Ministry of Mines and Energy [37]. The electricity mix of this country comprises 4.8% of coal, 5.1% of fuel oil, 13% of natural gas, 2.5% of nuclear power, 67.4 % of hydropower, 5.2% of biomass, 2% of wind and 0.003% of solar source.

### *2.2.5. Life cycle impact assessment*

LCIA was carried out based on the LCA-IWM methodology described in the study by Den Boer et al. [29], which follows the CML 2001 method [38]. The following LCA impact categories were considered based on LCA-IWM model [29,33–35]: abiotic depletion (kg Sbeq), acidification (kg $SO_2$eq), eutrophication (kg $PO_4$eq), global warming (kg $CO_2$eq), human toxicity (kg 1.4-dichlorobenzeneeq) and photochemical oxidation (kg $C_2H_4$eq).

Table 2
Waste inputs for each scenario

| | Waste inputs by treatment technology (ton/year) | | | | |
|---|---|---|---|---|---|
| Scenario | Comp | Diges | Recy | Inci | Land |
| 1 | 0 | 0 | 1,279.2 | 0 | 180,161.8 |
| 2 | 52,913.9 | 0 | 1,279.2 | 0 | 127,247.8 |
| 3 | 0 | 52,913.9 | 1,279.2 | 0 | 127,247.8 |
| 4 | 0 | 0 | 26,952.7 | 153,333.3 | 0 |

*Note*: Composting (Comp), anaerobic digestion (Diges), recycling (Recy), incineration (Inci), landfill (Land).

### *2.2.6. Interpretation of results*

No weighting step was carried out for impact category results. Furthermore, results were assessed by comparing the impact category values among scenarios. In addition, scenarios were classified according to the results of each impact category. Moreover, the impact categories were normalized and aggregated to facilitate a global analysis of each scenario. Table 3 presents the normalization factors adopted. They are related to the world emissions in 2000. The aggregation was carried out for each scenario by the summation of the normalized results of all impact categories. A contribution analysis was also performed. The latter consists in decomposing the LCA results of a system into its individual process contributions.

## 3. Results and discussion

LCIA results divided by treatment technology for all scenarios are provided in Table 4. It is important to note that a negative value means an environmental benefit/credit whereas a positive value indicates an environmental burden. Fig. 1, in turn, presents the normalized result for each scenario in all impact categories.

For abiotic depletion, it is noted that Scenario 1 presented the worst result. Indeed, in Scenario 1 materials recovery represents less than 1% of waste destination and the most part of waste is landfilled, consequently resource consumption is superior to recovery. On the other hand, for Scenarios 2–4 a significant amount of waste is allocated in recycling, composting or incineration facilities avoiding the consumption of virgin materials, resulting in environmental benefits.

Concerning acidification, Scenarios 2 and 3, which presents a high waste composting rate, presented an adverse impact from the release of nitrogen and sulphur compounds. So, environmental burdens observed in these scenarios are mainly related to compost production and usage. On the contrary, recycling was an important alternative to prevent impacts in this category as this practice allows avoiding the emissions from the production of paper and plastics by virgin materials. Scenario 4 presents the best result for this impact category. Indeed, net environmental benefits were achieved in this scenario because it recovers higher amounts of material than the previous ones.

Eutrophication resulted in burden effects for all scenarios. It is noted that Scenarios 2 and 3, which include biological

Table 3
Environmental impact categories and normalization factors related to world emissions in 2000 presented in terms of Inhabitants Equivalent (adapted from [36,38,39])

| Impact category | Normalization factor |
|---|---|
| Abiotic depletion, $kgSb_{eq}$/y.cap | 2.63E + 01 |
| Acidification, $kgSO_{2eq}$/y.cap | 3.93E + 01 |
| Eutrophication, $kgPO_{4eq}$/y.cap | 3.37E + 01 |
| Global warming, $kgCO_{2eq}$/y.cap | 6.94E + 03 |
| Human toxicity, kg1.4-$C_6H_4Cl_{2eq}$/y.cap | 1.46E + 03 |
| Photochemical oxidation, $kgC_2H_{4eq}$/y.cap | 6.05E + 00 |

Table 4
LCIA results for each scenario

| Scenario | Environmental impact category | | | | | |
|---|---|---|---|---|---|---|
| | AbDe ($kgSb_{eq}$) | GloWar ($kgCO_{2eq}$) | HuTo ($kg1.4\text{-}C_6H_4Cl_{2eq}$) | PhOx ($kgC_2H_{4eq}$) | Acid ($kgSO_{2eq}$) | Eutro ($kgPO_{4eq}$) |
| 1 | –15.4 | 6,572.9 | 456.4 | 1,596.2 | 109.3 | 608.9 |
| 2 | –435.9 | –4,999.5 | –1,518.6 | 1,360.8 | 2,293.2 | 2,017.2 |
| 3 | –472.6 | –8,800.9 | –2,126.5 | 1,388.3 | 1,239.6 | 2,192.4 |
| 4 | –10,359.4 | –3,075.7 | 53,080.9 | –1,836.1 | –3,877.8 | 894.1 |

*Note*: Abiotic depletion (AbDe), global warming (GloWar), human toxicity (HuTo), photochemical oxidation (PhOx), acidification (Acid), eutrophication (Eutro).

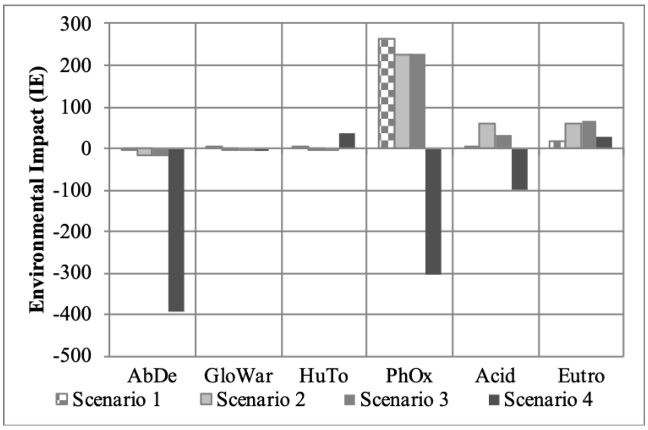


Fig. 1. Impact category results for each scenario.

treatment of the waste organic fraction, presented the worse scores in this category due to the release of micronutrients to the environment.

For global warming, Scenario 1 was the only one that presented environmental burdens for this category. Indeed, waste materials recovered in Scenarios 2 to 4 prevent greenhouse gases emissions from waste landfilled or virgin materials extraction, resulting in environmental benefits.

Referring to human toxicity, the impacts are higher for the alternative based on incineration (Scenario 4). The best results were obtained by Scenarios 2 and 3 due to composting. In addition, it is noted that Scenario 3 presented better results than Scenario 2, because the latter has no electricity production, whereas the former generates energy from anaerobic digestion.

Regarding photochemical oxidation, air emissions from landfill were the most important source of environmental burden in this category for all scenarios. On the other hand, material recovery was the main process to avoid environmental burdens.

Thus, the net environmental benefits obtained by Scenario 4 were obtained due to the focus on material recovery, which reduces the quantities of waste landfilled. Actually, this scenario presented the best results for this category, thanks to material recycling associated with incineration, reducing the amount of waste landfilled. Scenario 1, in turn, which focuses on waste landfilling, presented the worst result for this impact category.

From the results, it is noted that the current waste management strategy in Uberlândia presented the worse scores for most part of impact categories, indicating the need for improvements in the existing waste management system. Indeed, in Table 5, scenarios were classified according to the results of each impact category. It is noted that Scenario 1 was the only one to achieve the last position (fourth) in three impact categories. Scenario 4, in turn, obtained the first position for three categories.

Fig. 2 presents the results for each scenario considering the aggregation of normalized impacts of all categories. From Fig. 1, it is noted that global environmental impacts are very similar from Scenarios 1 to 3, all of them resulting in net environmental burdens. On the contrary, for Scenario

Table 5
Classification of scenarios according to impact category results

| Scenario | Environmental impact category classification | | | | | |
|---|---|---|---|---|---|---|
| | AbDe | GloWar | HuTo | PhOx | Acid | Eutro |
| 1 | 4 | 4 | 3 | 4 | 2 | 1 |
| 2 | 3 | 2 | 2 | 2 | 4 | 3 |
| 3 | 2 | 1 | 1 | 3 | 3 | 4 |
| 4 | 1 | 3 | 4 | 1 | 1 | 2 |

*Note*: Abiotic depletion (AbDe), global warming (GloWar), human toxicity (HuTo), photochemical oxidation (PhOx), acidification (Acid), eutrophication (Eutro).

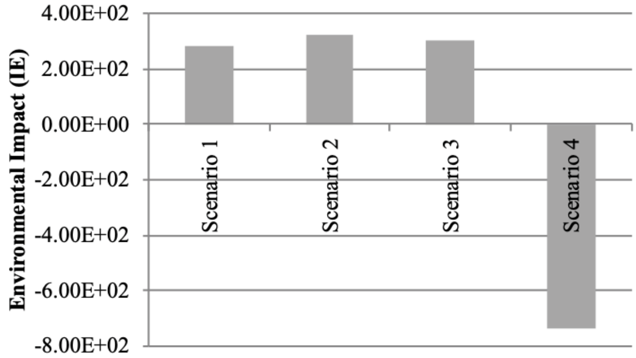


Fig. 2. Aggregated LCA impact results for each scenario in terms of inhabitant equivalent (IE).

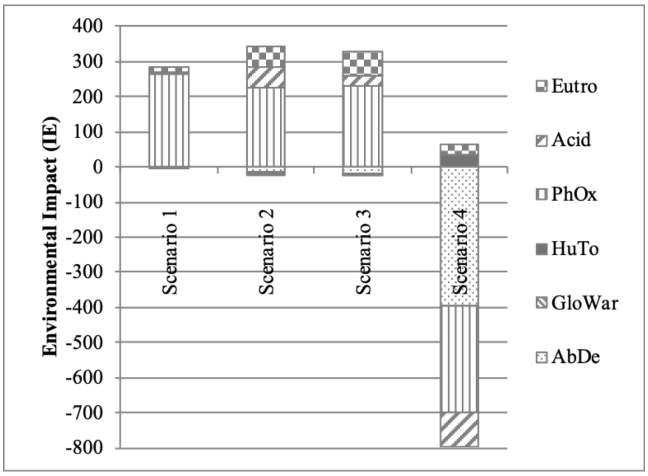


Fig. 3. Contribution analysis for normalized LCA results.

4 it was observed a negative global result, which indicates a net environmental benefit. So, despite the significant differences among scenarios when they are compared for each impact category, global results indicate relevant differences only for Scenario 4. However, is important to note that results of the aggregation of normalized impact categories must be considered with parsimony as the determination of normalization factors is a complex task which could directly affect the conclusions. Anyway, both aggregated and individual results show that Scenario 4 focused in recycling and incineration showed to be the best strategy among the scenarios considered.

Fig. 3 shows the contribution of each impact category to the global result. It could be observed from Fig. 3 that scenarios in which the net results indicate an environmental burden, Scenarios 1 to 3, present the highest environmental impact linked to photochemical oxidation. From Fig. 3, it is also noted that in Scenario 4, the only one presenting net environmental benefits, the most important impact category to the final result is the depletion of abiotic resources followed by photochemical oxidation. So, in terms of global analysis, photochemical oxidation was the most impacting category considered, influencing both positive and negative results.

## 4. Conclusions

This paper provides a case study of LCA in waste management in Brazilian context. The results of this paper show the benefits of LCA applications in waste management to support decision making process. Indeed, LCA allows quantifying environmental impacts related to each waste management strategy analysed. The existing waste management system of Uberlândia presented the worst result in three of the six impact categories analysed, indicating an urgent need to change the current SWM strategy in this city.

Among the scenarios considered, the one based on recycling and incineration presented the best performance in terms of environmental impacts. However, this result needs to be analysed with parsimony, as only four scenarios were assessed. In future works, the consideration of a larger number of scenarios can provide a broader vision of the best waste management strategies.

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