Chapter 131

Life cycle assessment for municipal solid waste management scenarios in Humaitá, state of Amazonas: the impact of including collection in indigenous areas

Crossref doi https://doi.org/10.56238/devopinterscie-131

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ABSTRACT
In the Amazon, around 80% of the municipalities dispose of their waste in open-air dumps, challenging government agencies to find alternatives for its management. In this context, the Life Cycle Assessment (LCA) methodology has been used to analyze the environmental impact of municipal solid waste (MSW) management system scenarios. The objective of this chapter was to analyze municipal solid waste management scenarios, based on the LCA methodology, in the municipality of Humaitá, state of Amazonas, including the collection of waste from indigenous communities. This study included secondary data from articles published by a research partnership between the São Paulo State University (Unesp) and the Federal University of Amazonas (UFAM). The LCA followed the model proposed by ISO 14040 and 14044 and was performed using the Simapro software. The environmental impact category assessed corresponded to greenhouse gas (GHG) emissions, expressed in kgCO2eq. Three scenarios were evaluated: a) Base scenario (CB): which corresponded to the collection of waste from the urban area of Humaitá, transport, and disposal in a sanitary landfill; b) Scenario 1 (C1): which corresponded to CB with the inclusion of the collection of waste generated in indigenous areas; c) Scenario 2 (C2): corresponded to C1, excluding organic waste, which would be destined for composting. The analysis of the inventories of each scenario led to the conclusion that including the collection of solid waste from indigenous reserves would increase GHG emissions by 4%.

1 INTRODUCTION

The increase in global production rates of municipal solid waste (MSW) has increased the environmental problems of contemporary society, such as pollution of surface and groundwater, soil, and air, increasing risks to human health (PAES et al., 2014).

In Brazil, the National Solid Waste Policy (PNRS) (Federal Law No. 12,305/2010) provides for shared responsibility for the life cycle of products with manufacturers, distributors, traders, consumers, city halls, and governments (BRASIL, 2010). Another important guideline of this policy was to establish a hierarchy in MSW management, prioritizing generation reduction, waste treatment, and, as a last option, adequate final disposal (PAES et al., 2020b). Despite the priority given to the reduction and recovery of

MSW by Brazilian legislation, its main destination is sanitary landfills (60%), followed by dumps and controlled landfills (25%), with only 2.2% being recovered in sorting structures (MANCINI et al., 2021). However, the worst indicators of solid waste management in Brazil are observed in the Amazon, as more than 80% of the municipalities in this region dispose of MSW in open dumps and controlled landfills (OLIVEIRA & MEDEIROS, 2019).

Several aspects justify this panorama in the Amazon, highlighting the territorial and demographic ones, such as the low population density, the precarious logistics, and the incipient industrial park, in addition to the rainfall regime that limits, in this region, the implementation of alternatives for integrated MSW management (OLIVEIRA et al., 2021).

The isolation of the Amazon, both in Brazil and in other South American countries, is also reflected in the scarce literature produced on MSW management in this important region of the planet, according to a survey carried out by Oliveira & Medeiros (2020). This reality raises challenges for decision-making in the management of MSW in the Amazon, due to the complexity of the environmental, social, cultural, and political impacts involved.

In this context, the LCA can be understood as the compilation and evaluation of inputs and outputs of matter and energy, and the potential environmental impacts of a product system throughout its life cycle (PAES et al, 2020a). This approach has been used to model and quantify environmental impacts generated by different scenarios for MSW management, from the cradle (extraction of raw materials) to the grave (final disposal) (PAES et al., 2020a).

LCA studies related to solid waste management have been disseminated in different regions of Brazil, predominantly in the Southeast (PAES et al., 2020a; PAES et al., 2020b) and South (MERSONI & REICHERT, 2017). However, studies related to the Amazon are rare, with emphasis on Oliveira et al. (2022).

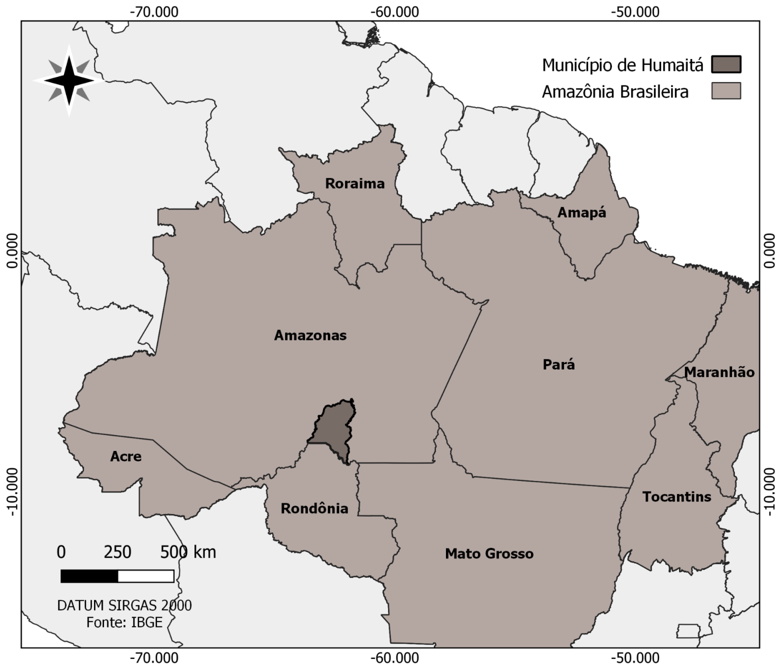
Thus, the present work aimed to analyze municipal solid waste management scenarios in the Amazon, based on the Life Cycle Assessment technique, through a case study in the municipality of Humaitá, state of Amazonas.

2 METHODOLOGY

2.1 SOCIAL, ENVIRONMENTAL AND ECONOMIC CHARACTERIZATION OF HUMAITÁ

The climate of the state of Amazonas corresponds to the humid equatorial, with an average annual temperature ranging from 26 to 28 ºC and precipitation exceeding 2,000 mm.year-1 (DALAGNOL et al., 2017). The municipality of Humaitá (Figure 1), on the banks of the Madeira River, is 700 km from the metropolitan region of Manaus, at coordinates 07° 30' 22'' S and 63° 01' 15'' W and 90 m above sea level. from the sea (BRASIL, 2021a). Its population was estimated at 56,144 inhabitants in 2020, distributed over 33,144 km² or 1.70 inhabitants.km-2, and had a gross domestic product of US$ 2,200.00 (IBGE, 2020).

Figure 1 - Municipality of Humaitá, in the state of Amazonas, Brazil.



According to Oliveira et al (2022), the low demographic density still presents significant differences when analyzing the urban, rural and indigenous populations. In all its extension, around 38,700 inhabitants live in the urban area (4.5 inhab.km-2). In rural areas lived about 17,400 inhabitants (0.98 inhab.km-2) and in the indigenous reserves approximately 2,231 inhabitants (0.14 inhab.km-2), in 2014, according to data from the Special Secretariat for Indigenous Health (Sesai) made available by the Instituto Socioambiental (ISA) (ISA, 2020).

2.2 PROPOSED SCENARIOS FOR THE MANAGEMENT OF MUNICIPAL SOLID WASTE IN HUMAITÁ

The scenarios proposed in this chapter, for the management of MSW in Humaitá, followed the recommendations of specialists, in previous research carried out by Oliveira et al. (2021). The three scenarios are described below:

2.3.1 Base scenario (CB)

In this scenario, the MSW management system practiced in Humaitá was modeled, replacing disposal in a controlled landfill with a sanitary landfill. In this scenario, the collection reaches 5,412 t.year-1 of MSW (dry and organic), without prior separation, using two 5 m³ compactor trucks. The collection covers only the urban area of the municipality, with a frequency of 6 days a week in residential areas, and every day in commercial areas.

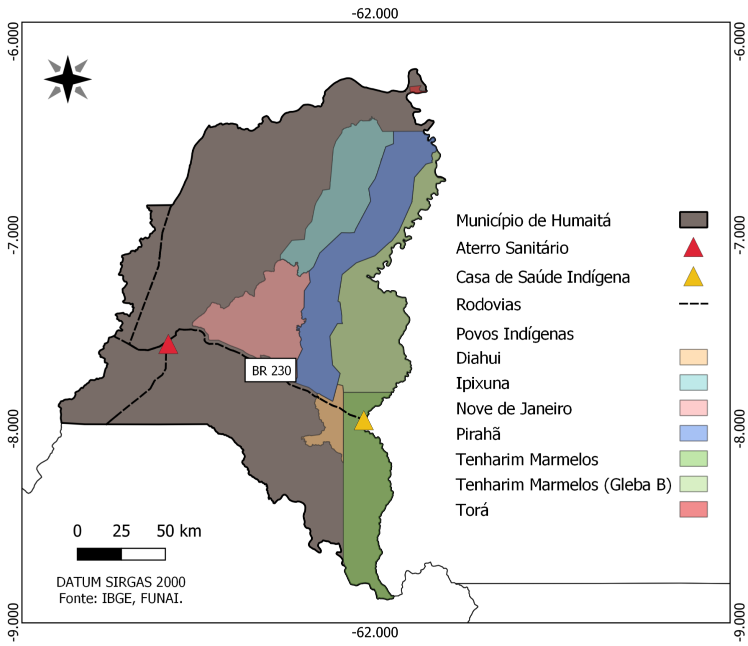
2.3.2 Scenario 1 (C1)

This scenario corresponded to the CB with the inclusion of the collection of MSW generated in indigenous areas, and subsequent disposal in the landfill. The estimate of waste generation in the indigenous area was based on the research by Vélez et al. (2019), carried out in the Ecuadorian Amazon, as there is no record in the Humaitá region.

The areas considered corresponded to the territories occupied by the Diahui (115 indigenous peoples), Ipixuna (64 indigenous peoples), Nove de Janeiro (206 indigenous peoples), Pirahã (592 indigenous peoples), Tenterins Marmelos (535 indigenous peoples), Tenterins (393 indigenous peoples) and Torá (326 indigenous people), based on data from the National Indian Foundation (FUNAI) (BRASIL, 2021b).

The Casa de Saúde Indígena was selected for the collection of waste generated in indigenous areas (Figure 2), 150 km from the urban area of Humaitá and inserted in the territory of the Tenterim people. This post serves individuals from various ethnic groups in the surrounding area and, naturally, is a place of influx of indigenous people from the region. The low demographic density, precarious logistical infrastructure, and spatial dispersion of people residing in the municipality led to the definition of one collection per week.

Figure 2 - Indigenous lands in Humaitá, location of landfill and MSW collection point in the indigenous area, called Casa de Saúde Indígena.



2.3.3 Scenario 2

In scenario 2, the C1 collection system is repeated, however, only dry solid waste from indigenous areas would be sent to the landfill, while the organic part would be sent to home composting.

2.4 LIFE CYCLE ASSESSMENT (LCA)

The present study followed the model proposed by ISO 14040 and 14044, consisting of the following phases: objective and scope definition, inventory analysis, impact assessment and, finally, the interpretation of results. The LCA simulation of the proposed scenarios was performed using SimaPro software, version 9.2.

2.4.1 Goal Definition

The study aimed to evaluate the CO2eq emissions caused by the proposed MSW management scenarios in Humaitá.

2.4.2 Scope Definition

The scope covered all stages of management of MSW from Humaitá: collection, transport and final disposal.

2.4.3 Function and Functional Unit

The function of the system follows the proposal of managing the activities necessary for the collection, transport and final disposal of 5,412 t year-1 of MSW generated in Humaitá, state of Amazonas, Brazil.

2.4.4 System Boundaries

The system frontier corresponded to the cradle-to-grave model, composed of the collection, transport and final disposal phases, associated with leachate generation, fuel consumption and atmospheric emissions.

2.4.5 Life Cycle Inventory (LCI)

The Life Cycle Inventory (LCI) was prepared based on the Ecoinvent 3 database and secondary data obtained from a research partnership between the São Paulo State University (Unesp) and the Federal University of Amazonas (UFAM). These data included the main inputs (fuel, electricity, solid waste generated in the urban area and indigenous lands) of the scenarios of the Humaitá MSW management system.

Information on transportation and collection, the route and distances traveled by trucks were collected by Souza et al. (2018). Four routes were established by the municipality's cleaning service provider, using two compactor trucks, the first with a capacity of 5.5 t and the second with 4.5 t. The average distance covered by each truck reached 50 km per day. These vehicles were supplied weekly with 260 L of diesel oil, corresponding to an average yield of 1.34 km.L-1, or consumption of 46.3 t per year.

The regular waste collection covered the entire urban area of the city, however, the rural and indigenous population was not contemplated due to the distances involved, distribution and road conditions. Another characteristic that influences the collection and management of solid waste refers to the occupation of the territory since approximately 46% of the municipality is formed by indigenous lands, with forests and low population density, in addition to specific legal and environmental restrictions (DOURADO et al. , 2017). For the reasons presented, about 31% of the population of Humaitá does not have access to MSW collection (OLIVEIRA et al., 2021).

Based on the analysis of the truck routes, the aspects and impacts associated with the collection and transport of MSW, until its final disposal, were determined. The dimensioning of impacts followed the methodology described by Oliveira et al. (2022) with secondary data from the Air Pollution Control Program for Motor Vehicles (Proconve).

The gravimetric composition of MSW was raised by Oliveira et al. (2022). According to these authors, Humaitá generated 14.83 t.day-1 of RSM (5,412 t.year-1) or 0.4 kg.day-1 per capita. Organic matter predominated (44%), followed by plastic materials (16%) and cardboard (10%), corroborating the results compiled from other regions of the Amazon, such as Bolivia, Ecuador, Peru, and Suriname (OLIVEIRA et al., 2021). In indigenous lands, a daily generation of 0.26 kg.inhabitants-1 was assumed, based on research carried out with communities in the Ecuadorian Amazon (VÉLEZ et al., 2019). In these areas, around 75% of the waste is organic, and 18% is considered reusable, such as metals, plastics, and cardboard.

2.4.6 Avaliação dos Impactos do Ciclo de Vida

Na avaliação dos impactos do ciclo de vida foi estimada a categoria de impacto ambiental emissões de gases de efeito estufa, expressa em CO_2eq, conforme WRI (2015). Nos cenários avaliados utilizou-se o conjunto de dados presente no software Simapro, Ecoinvent, com a realidade mais próxima de um aterro sanitário brasileiro *(Municipal waste collection service by 21 metric ton lorry {GLO}| processing e Sanitary landfill facility {CH}| construction).*

Na base de dados tem-se as entradas e saídas comumente utilizadas para a construção e operação do aterro, como a escavação, o transporte e compactação dos resíduos por meio de tratores.

3 RESULTS AND DISCUSSION

3.1 ICV COMPONENTS AND IMPACTS OF SCENARIOS EVALUATED

Table 1 presents the input flows of materials and energy used in the LCA of the evaluated scenarios, and includes data from the collection and transport of MSW. Table 2 shows a comparison of the three evaluated scenarios, considering CO2eq emissions.

Waste generated annually in indigenous lands was estimated at 180.8 t, based on the estimate by Vélez et al (2019). According to the same authors, 18.1% correspond to dry waste, leading to an estimated

32.7 t generated in the indigenous lands of Humaitá. The inclusion of collection in indigenous areas increased annual diesel consumption by 11.7% for scenarios C1 and C2, as the collection and transport system has the same route for both scenarios. However, in scenario C2, only dry solid waste generated by indigenous communities was disposed of in landfills.

Table 1 - Life Cycle Inventory of the scenarios evaluated in Humaitá, state of Amazonas

	Base Scenario		
	Waste collection and logistics	Unit	Amount
Entrance	Diesel Oil Consumption	t diesel/year	46,3
	Transport	t.km/year	270.100
	Waste	t/year	5.412
	landfill disposal	Unit	Amount
Entrance	Diesel Oil Consumption	t/year	16,6*
	Electricity	kWh/year	7.200
	Waste	t/year	5.412
	Scenario 1		
	Waste collection and logistics	Unit	Amount
Entrance	Diesel Oil Consumption	t/year	51,7
	Transport	t.km/year	301.733,5
	Waste	t/year	5.622
	landfill disposal	Unit	Amount
Entrance	Diesel Oil Consumption	t/year	16,6
	Electricity	kWh/year	7.200
	Waste	t/year	5.622
	Scenario 2		
	Waste collection and logistics	Unit	Amount
Entrance	Diesel Oil Consumption	t./year	51,67
	Transport	t.km	278.193
	Waste	t/year	5.465
	Waste disposal in landfill	Unit	Amount
Entrance	Diesel Oil Consumption	t.diesel/year	16,6
	Electricity	kWh/year	7.200
	Waste	t/year	5.465

* The annual diesel consumption for landfill disposal includes 14.76 t for landfill operation activities and 1.84 t for landfill lighting (OLIVEIRA et al., 2022).

Table 2 – Annual greenhouse gas (GHG) emissions in municipal solid waste management scenarios in Humaitá, state of Amazonas.

Scenarios	Unit	Issuance
CB	kg CO_2eq	1.537.130
C1	kg CO_2eq	1.601.340
C2	kg CO_2eq	1.555.780

Scenario C1 had the highest GHG emissions, as waste collection from indigenous areas caused an annual increase in the distance traveled by 14,400 km and, consequently, in fuel consumption (5.37 t of diesel oil), compared to scenario C1 CB. This phenomenon led to a 4% increase in greenhouse gas emissions. However, it should be considered that there would be a reduction in direct emissions caused by burning waste, a practice commonly used in indigenous communities.

When comparing scenarios C1 and C2, there is a reduction of 2.85% in CO2eq emissions. Given the gravimetric composition of waste generated in urban areas and in indigenous lands, whose share of organic waste is 44% and 75%, respectively, an alternative would be composting. This recommendation is based on a consultation carried out with specialists by Oliveira et al. (2021). According to these authors, around 70% of specialists considered composting a potential alternative for the treatment of MSW in the Amazon. However, the low levels of waste separation, the need for maintenance and operation of composting units, the absence of a market, and the lack of investments limit large-scale composting (ALFAIA et al., 2017).

4 CONCLUSION

The implementation of composting systems, collective or individual, can be a viable alternative for reducing the volume of waste disposed of in landfills, the volumes transported by the collection system, and, consequently, the emissions of greenhouse gases. The inclusion of waste collection from indigenous areas, despite the increase in CO2eq emissions, reduces the environmental vulnerability of these populations.

ACKNOWLEDGMENT

The authors would like to thank CNPq for granting a scientific initiation scholarship to the first author of the chapter.

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