

Final Disposal of Urban Solid Waste and the Generation of Greenhouse Gases in the State of Pará.

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ABSTRACT

This paper presents the a study about the emission of greenhouse gases - GHG resulting from the final disposal of urban solid waste - USW in the State of Pará. The research was qualitative and quantitative, applied in nature and with exploratory and descriptive objectives, having as object of study the solid waste sector in the State of Pará. The activities carried out were divided into 3 stages, with the verification of the amount of GHG emissions in the State of Pará (Stage 1), the contribution of the sectors responsible for the state's emissions (Stage 2) and the analysis of GHG emissions in the USW sector (Stage 3). The survey results show that Pará is the state that emits the most GHG in Brazil (447,927,368 tons of CO₂e). Although the USW sector accounts for only 1% of GHG, it was found that 138 of the 144 municipalities in Pará still send USW to dumps and controlled landfills. With the research, it was verified the need to adapt the environmentally-appropriate final destination of USW, as an alternative to reduce GHG emissions in the State of Pará.

Key Words: Urbanization. Solid Waste. Greenhouse Gases.

1 INTRODUCTION

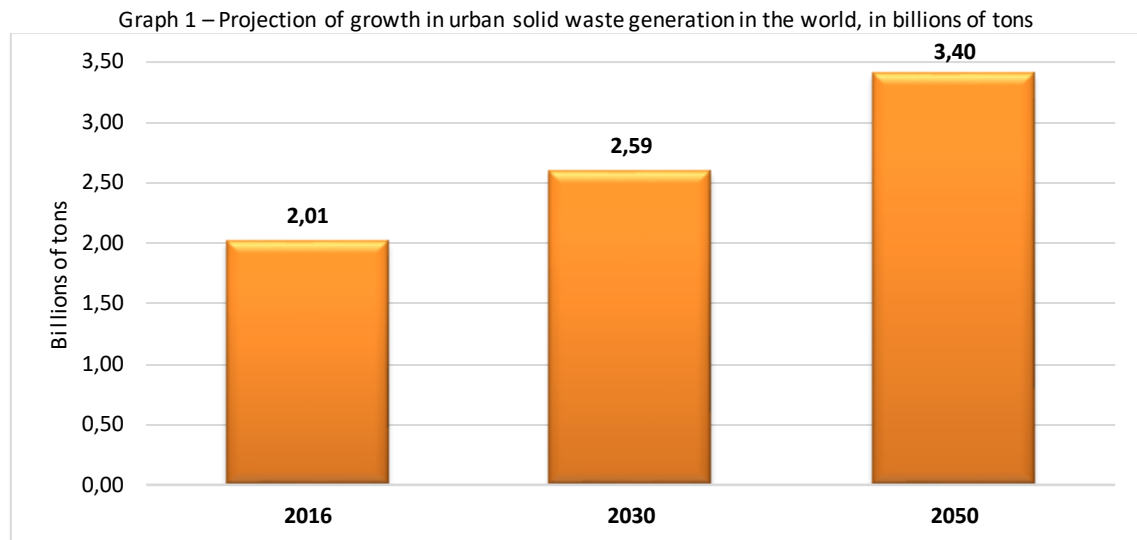
Urbanization and the development of cities have been accompanied by an increase in the generation of Greenhouse Gases (GHG), such as carbon dioxide (CO₂), methane gas (CH₄) and nitrous oxide (N₂O). These gases have a significant impact on the quality of life of the population, with consequences for human health and the environment. An example is the increase in urban temperature, through the intensification of the phenomenon known as heat islands, which can reach levels of up to 10°C above average temperatures, with harmful effects to children and elders (BARROS, 2020).

On a global scale, cities are the source of 70% of anthropogenic GHG emissions, with inadequate final disposal of Urban Solid Waste (USW) being one of the main sources of emissions, especially methane gas (ICLEI, 2021). However, urbanization drives the consumption and production of goods and services, which leads to an increase in waste generation and GHG emissions during the process of decomposition and/or burning of solid waste.

Currently, the management of solid waste is one of the great global challenges to be overcome by humanity, appearing in the UN Sustainable Development Goals (SDGs), more specifically in SDG 11 (sustainable cities and communities) and 12 (sustainable consumption and production) (MDR, 2021). In addition to these, SDG 13 (action against global climate change) has also been gaining more prominence in the solid waste sector due to GHG emissions from the final disposal of waste.

World projections point to growth both in product consumption and population in the following years, which, despite being less intense than in past decades, still prospects for a scenario of ascension. This situation warns of the consequent increase in the generation of solid waste, especially in underdeveloped and developing countries, which tend to have greater difficulty in ensuring the sustainability of the integrated management of solid waste and, consequently, disposing of it in an environmentally appropriate manner (TISI, 2019).

According to the report "What a Waste 2.0" prepared by the World Bank (2018), it is estimated that approximately two billion tons of USW are generated every year in the world and with a perspective of growth of this value to more than three billion by 2050, as represented in Graph 1.



Source: Banco Mundial (2018).

With the growth of waste generation in the following years, there is also an increasing concern about the need for an environmentally-appropriate final destination of waste and an environmentally appropriate final disposal of waste, as established in Brazil by the National Solid Waste Policy (PNRS). These activities are translated into treatments based on the reuse of solid waste and the controlled decomposition of waste, through the installation of sanitary landfills, mitigating environmental impacts such as GHG emissions.

The sanitary landfill, according to Souto and Povinelli (2013, p. 577, our translation), “[...] is an engineering work that enables the safe confinement of waste, avoiding risks to public health and minimizing negative environmental impacts”¹. This facility includes environmental safety measures that prevent the leakage of polluting substances from the decomposition of waste (slurry and gases), such as waterproofed disposal area, drainage system for percolated liquids, and a gas drainage system (ABNT, 1992).

In Brazil, from the institution of the PNRS with the enactment of Law n° 12.305/2010, several provisions began to regulate the management of waste in the national territory. However, it is noted that after a decade, many guidelines have not yet achieved the expected effect, as is the case of shared responsibility for the life cycle of products, the implementation of reverse logistics and the guideline that establishes the order priority of non-generation, reuse, recycling, treatment of solid waste and environmentally appropriate final disposal (BRASIL, 2010).

In this sense, the municipal management of Brazilian solid waste has prioritized final disposal and neglected the explicit need in the PNRS for prior treatment of the different types of waste generated before the materials are grounded, a behavior that has been mostly taken by municipalities only to comply with the deadlines established said the aforementioned policy (PRATES, PIMENTA E RIBEIRO, 2019).

Regarding the Brazilian Amazon, the impacts and GHG emissions caused by deforestation and forest burning are widely discussed, but they end up overshadowing the importance of discussions about emissions caused by urban activities in Amazonian cities and

¹ “[...] é uma obra de engenharia que possibilita o confinamento seguro dos resíduos, evitando riscos à saúde pública e minimizando os impactos ambientais negativos”.

metropolises, such as poor management of solid waste and the lack of environmentally appropriate final destinations in this region.

The generation of GHG in cities is a complex problem that requires integrated actions for its mitigation. Among these is compliance with the provisions of Article 9 regarding the order of priority in waste management, which involves actions to reduce waste generation, recycling, composting and, finally, environmentally appropriate final disposal. Thus, the adoption of sustainable practices, such as integrated urban planning and the correct management of urban solid waste, can help to minimize the impacts of urbanization on climate change.

Given this scenario, determining/acknowledging the sources of GHG emissions in cities is essential for the adoption of effective measures to control and mitigate these emissions. Scientific research on the topic is essential for innovation and the creation of effective solutions for smart cities, which seek sustainable development and improve the quality of life of the population.

2 OBJECTIVE

Verifying the contribution of the urban solid waste sector of the municipalities of Pará in the generation of Greenhouse Gases (GHG), comparing with the values of Carbon Dioxide Equivalent (CO₂e) emission by other sectors of activities.

3 METHOD

The research method was divided into three stages, in order to quantify the total GHG generated in the State of Pará (stage 1), identify the main sectors responsible for emissions with their respective contribution levels (stage 2) and, finally, analyze how the solid waste sector interferes with GHG emissions (step 3).

Thus, the methodological classification of the research can be considered as qualitative and quantitative, of an applied nature and with an exploratory and descriptive purpose, according to the definitions addressed in Silveira and Córdova (2009) and Nascimento and Souza (2016).

The methodological steps established for achieving the research objective are detailed below:

- Step 1: Survey of the total amount of GHG generated in the State of Pará;

The quantitative survey of GHG emitted in the state was extracted from secondary data on the System of Estimates of Emissions and Removals of Greenhouse Gases (SEEG), regarding the total emissions of the state in tons of Carbon Dioxide Equivalent (CO₂e), which is the unit adopted for normalizing the amount of GHG emitted by different sources in terms of their global warming potential, making them equivalent to the emission of Carbon Dioxide (CO₂). This normalization is necessary because the different GHGs have different global warming potentials, that is, with different capacities to heat the atmosphere. Thus, CO₂ is the gas used as a reference point for measuring other GHG emissions, assigning it a value of 1.

Therefore, the GHG emission in CO₂e of the State of Pará was compared with that of other Brazilian states, in order to evaluate the degree of contribution of the State of Pará in the

national scenario of emissions, as well as ranking the 10 municipalities in Pará that most contributed to the state's total emissions in 2021.

- Step 2: Contribution of the main sectors responsible for GHG emissions.

In addition to the amount of GHG emitted in the State of Pará, data were also extracted on the specific emissions of the main gas emitting sectors in the state, which were also conceptually detailed. In addition to the SEEG, data from the National Emissions Registry System (SIRENE), linked to the Ministry of Science, Technology and Innovation (MCTI) was also used with complementary purposes, as they also provide specific data regarding GHG emissions by sectors and human activities.

The mentioned emitting sectors analyzed and with estimated data available in SEEG and SIRENE refer to Agricultural activities; Energy; Land Use Change and Forestry, and Waste/Effluent treatment. Therefore, the emissions in tons of CO₂e from these sectors and their percentage in relation to the total emitted by the state were analyzed.

- Step 3: Analysis of the USW sector in the State of Pará regarding GHG emissions.

The subjects that make up the diagnosis of the current situation of the USW sector in the State of Pará in terms of GHG emissions, in order to reach stage 3, are composed by the quantitative analysis of waste collection and the survey of the types of final disposal applied in the state.

Based on data from the National Sanitation Information System (SNIS), the mass of urban solid waste (household waste + public cleaning waste) collected in 2021 in the municipalities of Pará was quantified by 3 levels of population scales, being 0 to 50,000 inhabitants, 50,000 to 100,000 inhabitants and more than 100,000 inhabitants. This quantitative was intended to analyze the per capita collection of the municipalities of Pará and the contribution of these municipalities, included in the aforementioned population scales, in the total mass of waste sent for final disposal in the state.

Then, still with data extracted from the SNIS, a quantitative and qualitative survey of the final provisions applied in the municipalities of Pará was carried out to analyze the types of facilities used in the State of Pará and classify them in Environmentally Adequate Final Disposition (EAFD) such as landfills, and Inadequate Final Disposal (IFD) which includes dumps and controlled landfills.

In addition, the amount of USW sent to the three types of final disposal facilities studied, "dumps", "controlled landfill" and "sanitary landfill", was also accounted for in order to relate this quantity to the consequent GHG emissions intrinsic to the development of these activities.

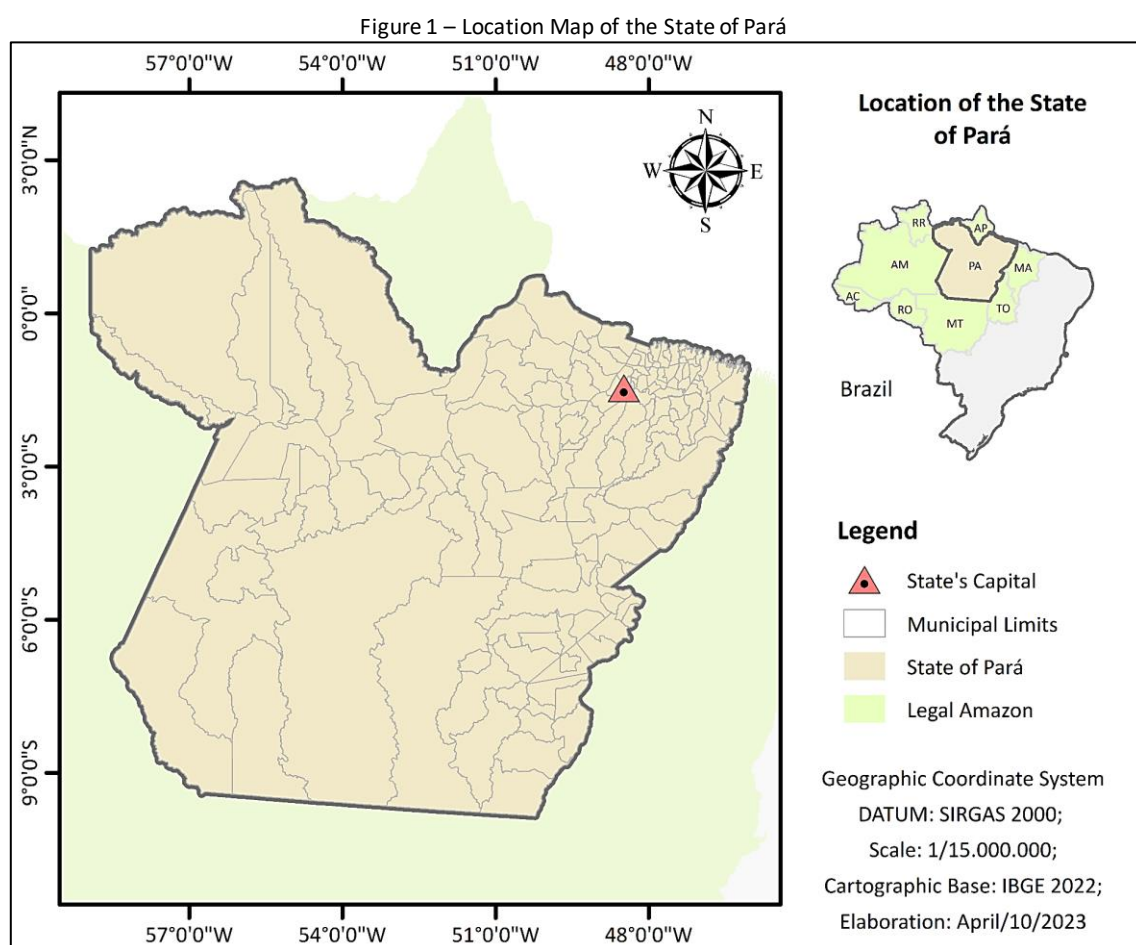
Data on the types of final disposal applied by the municipalities of Pará and the amount of USW collected, as already mentioned, were extracted from the SNIS, more specifically from the annual report referring to 2021. The SNIS is linked to the Ministry of Development and Regional Integration and fed annually by Brazilian municipal administrations.

Municipalities that did not respond to the SNIS in 2021 were considered IFD users after a confirmatory survey on the websites and official documents of municipal governments. The amount of waste collection sent to final disposal assumed the average per capita collection value

corresponding to the population scale of the municipality, according to the result obtained in step 2.

3.1 Study area

The State of Pará is the second largest federative unit in Brazil in extension and is located in the North region of the country, integrating the composition of the nine states that constitute the Legal Amazon and bordering with six: Amapá to the North, Amazonas and Roraima to the East, Mato Grosso to the South, and Maranhão and Tocantins to the West. The Map in Figure 1 represents the location of the state inserted in the national territory and in the Legal Amazon region, as well as the identification of the point where the state capital is located, the municipality of Belém.



Source: Author (2023).

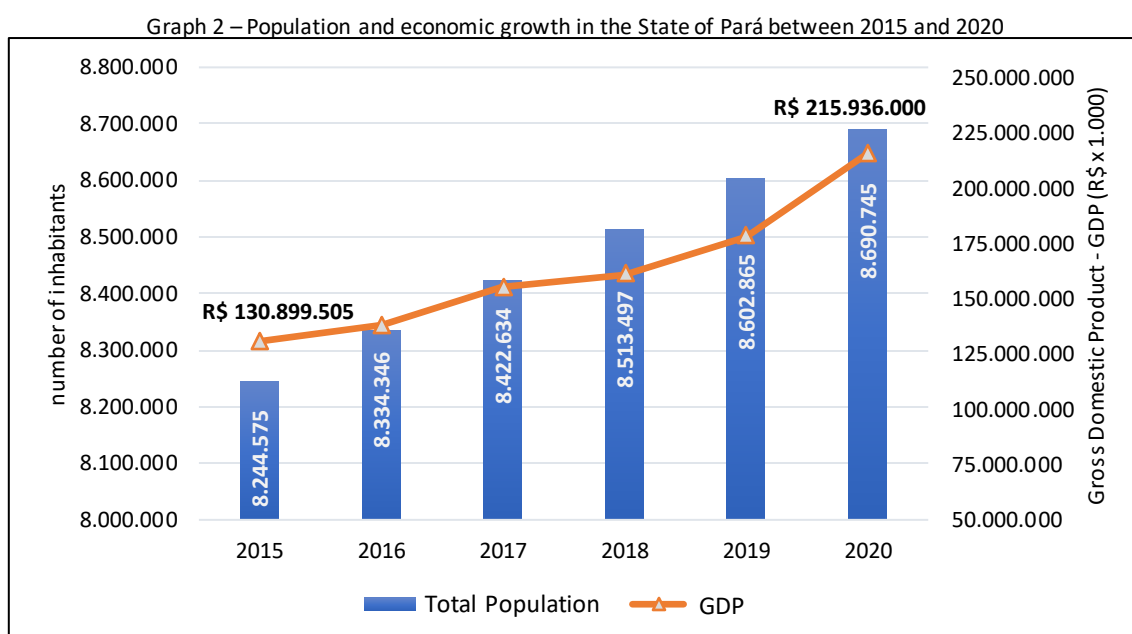
The State of Pará, as part of the Legal Amazon, has received increased attention from the federal and state governments for the preservation of forest biomass, being the target of several programs for the conservation of natural resources and creation of environmental protection areas.

According to data from the Fundação Amazônia de Amparo a Estudos e Pesquisas (FAPESPA), the State of Pará occupies an area of 1,245,870.7 km² with 54 indigenous lands and 116 conservation units of full protection and sustainable use between federal and state

administrations. Additionally, 93 environmental protection areas are also included in the territory of Pará, this time, between federal, state and municipal administrations (FAPESPA, 2022).

With regard to the population of the State of Pará, the Brazilian Institute of Geography and Statistics (IBGE) estimated a population of 8,777,124 inhabitants in 2021, which is equivalent to approximately 7 inhab./km², classifying Pará as the most populous state in the North region (IBGE, 2023). In addition, the state also has the largest number of municipalities in the North region, a total of 144, and the average population is divided into 70% urban and 30% rural (SNIS, 2022).

The economic development and the improvement of the quality of life over the years in the state led to the proportional and continuous growth of the population, as represented in Graph 2.



Source: FAPESPA (2022).

There was an increase of 446,170 inhabitants in five years (2015 to 2020), adding R\$ 85,036,495,000.00 to the Gross Domestic Product (GDP). In the Brazilian socioeconomic context, the State of Pará has the 10th largest GDP in the country, with a value of approximately 216 billion reais in 2020 (FAPESPA, 2022).

The industry of Pará in 2019 represented 34.3% of the state's GDP, consisting of several segments, including mining (58.3%), public utilities such as energy and sanitation (18.2%), civil construction (13.6%), food and beverages (3.9%), metallurgy (2.8%), wood and furniture (0.8%), among others. Some of the main industrial projects in the state are installed in the municipalities of Barcarena (bauxite refining and cement production), Belém and Castanhal (food, beverages and others), Capanema and Primavera (cement production) (CNI, 2021; FAPESPA, 2022).

The service sector, in turn, is also of great importance in the state's economy, with emphasis on trade, transport, tourism, telecommunications, financial services, education, and health activities. The great commercial and services center of the state is in the capital Belém, with the largest number of workers in this sector. The state's trade balance has grown

progressively since 2017, reaching an approximate value of 28 billion dollars in 2021 (FAPESPA, 2022).

Finally, the information presented about the study area is intended to contextualize the spatial, environmental, and economic scenario of the State of Pará in relation to the regional characteristics of the state.

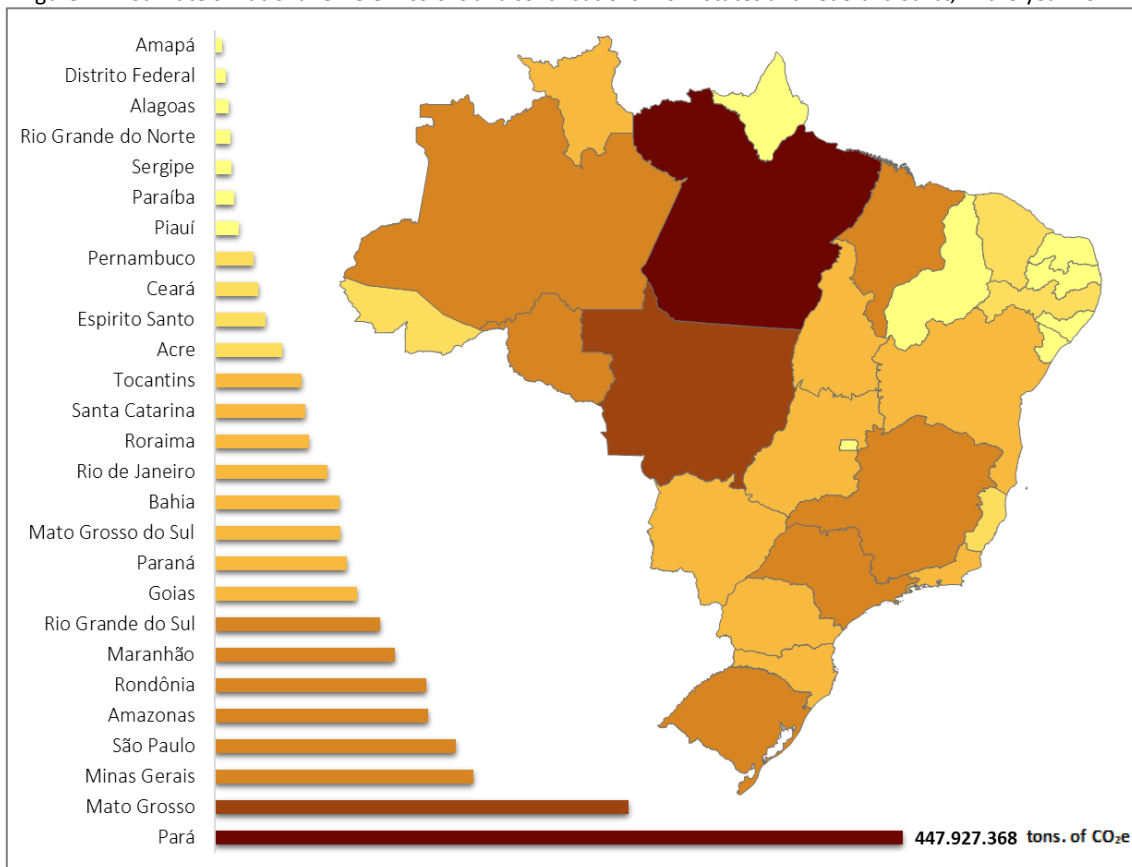
4 RESULTS

The research results were organized according to the stages of activities established in the research method, starting with the survey of the total quantity of GHG generated in the State of Pará, the contribution of the sectors responsible for the emission of GHG in the State of Pará and, lastly, by the analysis of the USW sector of the state and municipalities of Pará regarding GHG emissions.

4.1 Survey on the quantitative of GHG emitted in the State of Pará

Currently, the State of Pará is the largest emitter of GHG among all Brazilian states, with the total emissions of 447,927,368 ton. of CO₂e, as indicated in the illustration in Figure 2.

Figure 2 – Estimate of national GHG emissions and contributions from states and federal district, in the year 2021



Source: SEEG (2022).

As noted, the value of GHG emissions in the State of Pará is much higher than the other Brazilian states, so that the 2nd state with the highest emissions (Mato Grosso) is equivalent to

approximately 2/3 of Pará's emissions. Additionally, emissions from 13 states (AP, AL, RN, SE, PB, PI, PE, CE, ES, AC, TO, SC and RR) and the federal district, if added up, are equivalent to 84% of emissions from Pará.

The high value of GHG emissions in the State of Pará is due to the polluting activities carried out by the municipalities. In this scenario, the 10 municipalities in Pará that most contributed to the amount of GHG emissions in the state in 2021 are listed in Table 1.

Table 1 – Pará municipalities with the highest GHG contributions, in the year 2021

Ranking	Municipalities	Emission (tons of CO ₂ e)	%
1°	Altamira	35.247.300	7,9
2°	São Félix do Xingu	28.894.968	6,4
3°	Pacajá	16.180.604	3,6
4°	Novo Progresso	14.934.730	3,3
5°	Novo Repartimento	11.919.144	2,7
6°	Itaituba	11.716.481	2,6
7°	Portel	9.873.782	2,2
8°	Senador José Porfírio	9.670.093	2,2
9°	Anapú	8.511.721	1,9
10°	Marabá	6.910.396	1,5
-	Subtotal	153.859.219	34,4
11° a 144°	-	294.068.149	65,6
	TOTAL	447.927.368	100

Source: SEEG (2022)

With data on municipal emissions, it is evident that Altamira and São Félix do Xingu altogether represent approximately 15% of all emissions in the state. These same municipalities are also those with the highest deforestation increments, in the State of Pará, in 2021, indicating a relationship with these values (INPE, 2022). The sum of the emissions of the 10 most emitting municipalities is equivalent to close to 35% of the state's total emissions.

Thus, for the correct analysis of GHG emissions, it is important that the sectors responsible for GHG emitting activities are duly identified for control and inspection by the public authorities.

4.2 Contribution of sectors responsible for GHG emissions

The SEEG points out four sectors as the main GHG emitting activities in the State of Pará, which are: Agriculture, Energy, Land Use Change and Forestry, and Waste/Effluent Treatment.

The sector related to agriculture and livestock is what gathers GHG emissions from animal and vegetable production activities, and CH₄ and N₂O emissions can be released in these activities.

The energy sector refers to the consumption of electricity in public buildings, residences and productive activities present in the State of Pará that are directly responsible for the demand for electricity generated in the plants of the national electrical system. Although Brazilian electricity is mostly produced from renewable sources, a greater demand for electricity can lead to greater thermoelectric generation, emitting more GHG (SEEG, 2022);

Land use change and forestry is the sector responsible for most deforestation and burning, a factor that makes it one of the main sources of CO₂e emissions into the atmosphere, along with forest degradation that can result in CH₄ and N₂O emissions. In addition, the aforementioned activities cause the interruption of carbon sequestration carried out by plant matter, which contributes to the concentration of gases in the atmosphere.

The waste and effluent sector represents CO₂, CH₄ and N₂O emissions from intermediate treatment and final disposal of USW, sludge from effluent treatment stations, incineration of health care waste, open-air burning of solid waste, and treatment and disposal of domestic and industrial liquid effluents (SEEG, 2022). Emissions from this sector are mainly related to the biochemical reactions of the decomposition of organic matter.

Therefore, when observing the GHG emissions of the sectors mentioned above, the most relevant ones are the Change in Land Use and Forests, which has a great occurrence in the Amazon region, and the emissions from Agriculture and Livestock, together totaling 96% of all emissions in the State of Pará. In Table 2, the contributions of each sector to the estimated total GHG generation in the state are presented in more detail.

Table 2 – Contribution of the main sectors of GHG emitting activities in the State of Pará, in 2021

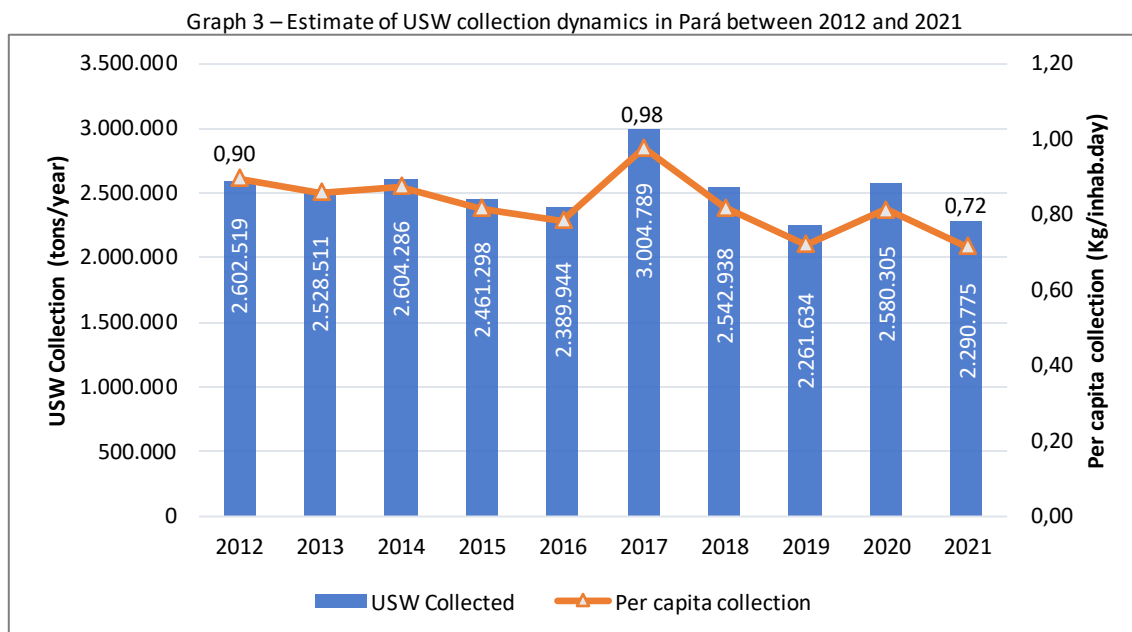
Ranking	Sector	Emission (tons of CO ₂ e)	%
1°	Mudança de uso da terra e florestas	380.738.262,8	85
2°	Agropecuária	49.272.010,6	11
3°	Energia	13.437.821,0	3
4°	Resíduos/Efluentes	4.479.273,8	1
	TOTAL	447.927.368,00	100

Source: SEEG (2022).

In this way, it is clear that due to the great forest extension of the State of Pará, the emissions resulting from deforestation and fires are still intensely more representative than the emissions arising from the treatment of solid waste and effluents, whereas, in the scale of management cities, emissions from the solid waste sector, especially from the final disposal stage, become much more significant.

4.3 Analysis of the USW sector in the State of Pará regarding GHG emissions

In the State of Pará, despite the population growth and economic development demonstrated by the state in recent years (Graph 2), there was a reduction in the mass of USW collected between 2012 and 2021, thus reducing per capita collection, as can be seen in Graph 3.



Source: Adapted from SNIS (2022).

In the last 10 years, the reduction in the mass of USW collected was around 12% between 2012 and 2021, reducing the average per capita collection of Pará municipalities from 0.90 to 0.72 kg/person.day. This behavior can be explained, among others, due to the advancement of municipal management in the management of USW, as well as a greater awareness of the environmental problem by the population.

More specifically, through the population scales of these municipalities, it is possible to analyze the contribution of the mass collected from small, medium and large municipalities, represented by population scales in inhabitants of up to 50,000, 50,000 to 100,000 and more than 100,000, respectively. Table 3 presents the collection data of the 117 municipalities that responded to the SNIS in 2021.

Table 3 - Analysis of the USW collected in the municipalities of Pará, based on population scales, in 2021

Population Scales (inhabitant)	Number of municipalities	Sum of inhabitants	USW collection in ton./year	Collection per capita (kg/person.day)
0 - 50.000	76	1.867.382	366.077	0,54
50.000 - 100.000	23	1.498.303	450.640	0,82
mais de 100.000	18	4.566.677	1.253.580	0,75
TOTAL	117	7.932.362	2.070.298	0,72

Source: SNIS (2022).

As it is possible to highlight from the information presented, most municipalities in the State of Pará analyzed by the SNIS in 2021 are considered small, that is, with a population of 0 to 50,000 inhabitants. Although this category represents the majority of municipalities in the state, it is the one that least contributes to the mass of waste collected and destined for final disposal, featuring approximately 17.7% of the total collected.

The 23 medium-sized municipalities (50,000 to 100,000 inhab.) were the ones with the highest per capita collection value among the three analyzed categories, and despite being

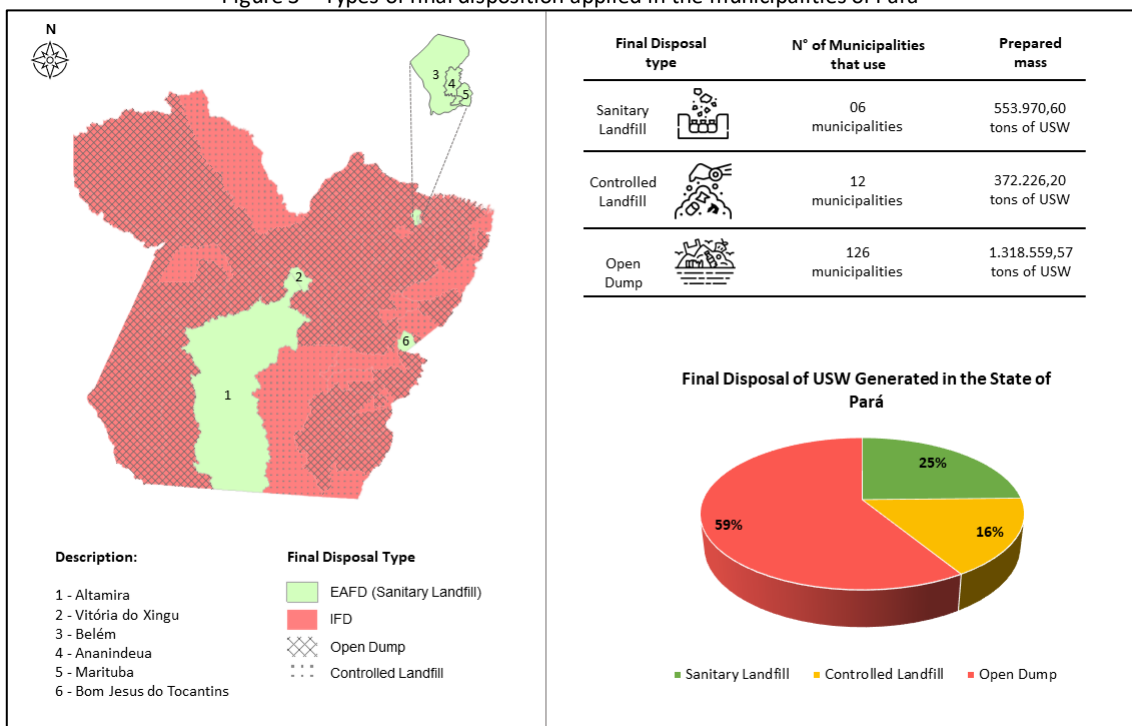
equivalent to just under 1/3 of the number of small municipalities (76), send more USW (84,563 ton.) to final dispositions than municipalities with up to 50,000 inhabitants.

Finally, it was also possible to verify that the 18 municipalities categorized as large were the ones that most contributed to the sending of USW collected for final disposal, representing about 61% of the total collected in the state, with a per capita collection mass value of 0.75 kg/person.day.

In general, with regard to the final disposal of waste and rejects, the management of the urban cleaning service and USW management has made little progress in the municipalities of Pará, prioritizing the final disposal without segregation and/or previous treatments such as recycling and composting, which still have incipient values.

Figure 3 shows the situation of the 144 municipalities in Pará regarding the type of final disposal adopted in the management of USW, classified as EAFD the municipalities that have a sanitary landfill and IFD the municipalities that still do not comply with the provisions of the PNRS and use controlled landfills and /or landfills as the main final destination for waste.

Figure 3 – Types of final disposition applied in the municipalities of Pará



Source: SNIS (2022).

In 2021, a total mass of 2,244,756.37 ton was disposed in the State of Pará. of USW. Out of the 144 municipalities in Pará, only six adopted sanitary landfills as their final disposal practice (Figure 3), that is, the final disposal considered as environmentally appropriate in the PNRS, adding up to 553,970.60 tons for this type of final disposal of USW. The other municipalities, on the other hand, adopted practices considered irregular, most of them being represented by dumps that received 1,318,559.57 tons. of USW and, to a lesser extent, the controlled landfills in which 372,226.20 tons were disposed. of USW.

The municipalities that use sanitary landfills as final disposal are: Altamira, Ananindeua, Belém, Bom Jesus do Tocantins, Marituba and Vitória do Xingu. Thus, since the

institution of the PNRS in 2010, which determined the obligation of the EAFD and the eradication of dumps, only six municipalities in the State of Pará comply with this determination (BRASIL, 2022).

Among the main reasons that explain the difficulty of Pará municipalities in complying with the PNRS are: poor infrastructure, lack of financial resources, low environmental education, non-existent or inefficient regulation, lack of planning and ineffective public policies.

Many municipalities in Brazil do not have the infrastructure to install adequate treatments and final disposal to deal with USW, including the lack of selective collection, waste treatment units and landfills. Added to this, the lack of financial resources can make USW management unfeasible when there are no economic conditions to maintain services or invest in infrastructure and management programs.

Another point of extreme importance is the education and environmental awareness of society about the need for proper USW management, aiming at engaging communities and other generators in cooperation with the implemented waste management programs. At the same time, only regulation and well-applied inspection can allow municipalities to stop operating dumps and controlled landfills, through the penalties provided for by law.

In this way, the planning and proper management of the USW management service can avoid problems during the execution of the management steps and provide more efficient methods of collection, treatment and final disposal. In addition, it allows public policies to become effective through the creation of incentive programs and the implementation of good practices in USW management.

However, it is possible to observe that most municipalities in the state of Pará are not following the guidelines established by the PNRS regarding the order of priority for the management of solid waste. As a result, there is no separation of materials and few treatments are carried out before final disposal. This reality can be considered an environmental crime in cases where municipalities do not have at least the EAFD, which occurs in 138 municipalities that still do not have landfills for the final disposal of waste.

5 CONCLUSION / FINAL CONSIDERATIONS

In the vast majority of the State of Pará, solid waste is still disposed of improperly, that is, without any control of water, soil and atmospheric pollutants. In addition to this, the international urgency that has been given to climate issues has pressured countries to adopt practices that are less harmful to the climate, encouraging the reduction of GHG emissions in all human activities, in accordance with the provisions of SDG N^o. 13, which aims to: "Take urgent action to combat climate change and its impacts".

The high amount of GHG emissions in the State of Pará is due to the polluting activities carried out, especially the deforestation and burning of the Amazon forest, which, in addition to releasing millions of tons of CO₂, inhibits the recovery of this gas by the natural process of photosynthesis of plants. However, urban activities such as the final disposal of USW can also contribute to the amount of emissions, especially when coming from dumps and controlled landfills.

Based on the results of the research, it is possible to conclude that the inadequate disposal of USW in dumps and controlled landfills in 96% of the municipalities of Pará has been

a major contributing factor to the emission of GHG in cities, as it releases a value of GHG higher than recommended in practical with environmentally sound alternatives.

Therefore, it is imperative that public policies and effective actions are implemented in the municipalities of Pará, for the adoption of sustainable and environmentally correct practices in the management of USW, especially regarding the final destination of USW, aiming at reducing GHG emissions and, consequently, contributing to improve the environmental conditions and the quality of life of the population of Pará.

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