CHARACTERIZATION OF MUNICIPAL SOLID WASTE IN MANAUS, BRAZIL: IMPLICATIONS FOR LOCAL MANAGEMENT AND RESOURCE RECOVERY

CARACTERIZAÇÃO DOS RESÍDUOS SÓLIDOS URBANOS DA CIDADE DE MANAUS-AM: IMPLICAÇÕES PARA A GESTÃO MUNICIPAL E A VALORIZAÇÃO DE MATERIAIS

CARACTERIZACIÓN DE LOS RESIDUOS SÓLIDOS URBANOS DE MANAUS (BRASIL): IMPLICACIONES PARA LA GESTIÓN MUNICIPAL Y LA VALORIZACIÓN DE MATERIALES

https://doi.org/10.56238/sevened2026.012-017

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ABSTRACT

The article describes the activities carried out to characterization of municipal solid waste in the city of Manaus, in the Brazilian Amazon, aiming to understand how the gravimetric composition and physicochemical properties of the generated materials influence municipal waste-management planning. A quantitative-qualitative, descriptive and explanatory approach was adopted, combining literature review in national and international databases, documentary analysis of official plans and diagnoses, and systematization of empirical data from sampling and weighing campaigns in regular collection trucks. The results show a predominance of the organic fraction in total waste mass, followed by plastics, paper and cardboard, as well as a significant share of recyclables that are still not recovered. Gaps are evident between the potential for material recovery and current practices, which remain heavily focused on conventional collection and landfilling, with consequences for the environmental pressure of the system and for socio-environmental vulnerabilities in the Amazonian metropolis. It is concluded that detailed waste characterization is a strategic input for revising plans, defining investment priorities, strengthening recycling and assessing energy-recovery scenarios consistent with the territorial specificities of Manaus.

Keywords: Municipal Solid Waste. Gravimetric Characterization. Waste Management. Manaus-AM.

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RESUMO
O artigo descreve as atividades desenvolvidas para a caracterização dos resíduos sólidos urbanos da cidade de Manaus-AM, buscando compreender como a composição gravimétrica e as propriedades físico-químicas dos materiais gerados influenciam o planejamento da gestão municipal. Adota-se abordagem quanti-qualitativa, de caráter descritivo e explicativo, baseada em revisão bibliográfica em bases nacionais e internacionais, análise documental de planos e diagnósticos oficiais e sistematização de dados empíricos de campanhas de amostragem e pesagem em cargas de coleta regular. Os resultados indicam predominância da fração orgânica na massa total dos resíduos, seguida por plásticos, papel e papelão, além de parcela expressiva de recicláveis ainda não aproveitados. Evidenciam-se descompassos entre o potencial de recuperação de materiais e as práticas vigentes, fortemente centradas na coleta convencional e na disposição em aterro sanitário, com repercussões sobre a pressão ambiental do sistema e sobre as vulnerabilidades socioambientais da metrópole amazônica. Conclui-se que a caracterização detalhada dos resíduos constitui insumo estratégico para revisão de planos, definição de prioridades de investimento, fortalecimento da reciclagem e avaliação de cenários de valorização energética compatíveis com as especificidades territoriais de Manaus.

Palavras-chave: Resíduos Sólidos Urbanos. Caracterização Gravimétrica. Gestão de Resíduos. Manaus-AM.

RESUMEN
El artículo describe las actividades desarrolladas para la caracterización de los residuos sólidos urbanos de la ciudad de Manaus, en la Amazonia brasileña, con el objetivo de comprender cómo la composición gravimétrica y las propiedades fisicoquímicas de los materiales generados influyen en la planificación de la gestión municipal de residuos. Se adopta un enfoque cuantitativo-cualitativo, de carácter descriptivo y explicativo, que combina revisión bibliográfica en bases de datos nacionales e internacionales, análisis documental de planes y diagnósticos oficiales y sistematización de datos empíricos de campañas de muestreo y pesaje en camiones de recolección regular. Los resultados indican predominio de la fracción orgánica en la masa total de residuos, seguida de plásticos, papel y cartón, además de una proporción significativa de reciclables aún no aprovechados. Se evidencian desajustes entre el potencial de recuperación de materiales y las prácticas vigentes, fuertemente centradas en la recolección convencional y la disposición en relleno sanitario, con repercusiones en la presión ambiental del sistema y en las vulnerabilidades socioambientales de la metrópoli amazónica. Se concluye que la caracterización detallada de los residuos constituye un insumo estratégico para revisar planes, definir prioridades de inversión, fortalecer el reciclaje y evaluar escenarios de valorización energética compatibles con las especificidades territoriales de Manaus.

Palabras clave: Residuos Sólidos Urbanos. Caracterización Gravimétrica. Gestión de Residuos. Manaus-AM.

1 INTRODUCTION

The problem of urban solid waste is positioned as one of the most complex structural bottlenecks in Brazilian metropolises as a result of disorderly demographic expansion and the consolidation of hyperstimulated consumption patterns that overload the chronic institutional fragility with regard to collection and environmentally safe treatment. Technical surveys unequivocally reveal a growth trajectory in the per capita generation of tailings marked by the predominance of organic matter and reuse rates that remain below what is necessary (Aguiar et al., 2021).

At the same time, there is a severe dependence on sanitary landfills, which in several municipalities still share space with open-air dumps and low-efficiency controlled landfills (Brazilian Association of Public Cleaning and Special Waste Companies, 2022; Freitas; Pires; Benincá, 2024). From this perspective, the present study elects the physical characterization of waste as the indispensable foundation for the design of public policies capable of enabling adequate management and energy valorization by integrating the theme into contemporary discussions about the circular economy and the transition to development paradigms that prioritize ecological resilience.

In the North region, the deficiencies of this system become accentuated because the convergence between latent social vulnerabilities and the vastness of territorial distances makes it difficult to materialize the integrated management required by the National Solid Waste Policy (Aguiar et al., 2021; Mendes et al., 2020).

Investigations conducted in Amazonian locations show that inappropriate disposal in dumps remains a persistent practice. This scenario is often aggravated by the work of waste pickers under extremely precarious conditions and the lack of structured sorting centers that make it impossible to continue environmental education programs (Anjos, 2020; García; Portugal, 2020). On this geographical board, Manaus emerges as a strategic piece. As it is the main urban centrality of the Amazon, the volume of its waste generation projects direct and indirect impacts on highly sensitive ecosystems and vulnerable communities that inhabit the urban and peri-urban fringes of the capital.

The investigation proposed here is structured from a fundamental question about what are the physical and gravimetric properties of the waste stream in Manaus and how such a profile conditions public management and the trajectories of material use. It works with the premise that although the typology of waste in Manaus has similarities with that of other national urban centers, there are determining local variables. Regional consumption habits and the particularities of the equatorial climate regime have a direct influence on parameters

such as density and humidity that alter the feasibility of recovery (Conceição et al., 2020; Pestana; Ventura, 2020).

It is also admitted that the scarcity of historical series and systematized data on the nature of these discards favors the perpetuation of a rudimentary model focused almost exclusively on confinement in landfills, which results in low operational performance and distancing from strategic planning mechanisms (Rezende; Alvares; Ventura, 2020).

The main purpose of this research is to examine the characterization of solid waste from Manaus-AM using primary and secondary databases to specify the majority gravimetric composition and the potential for energy valuation. In terms of specific objectives, it is intended to contextualize the demographic and economic dimensions of the local generation by placing the capital of Amazonas in the regional and national panoramas, in addition to consolidating the findings of sampling and weighing campaigns. Finally, it seeks to foster the debate on the challenges of municipal management with a focus on reduction strategies and the productive insertion of waste pickers (Brazilian Association of Public Cleaning and Special Waste Companies, 2022; Torres et al., 2022). Such thematic delimitation is justified by the pressing need to produce scientific evidence that supports political decisions in tune with the unique reality of the Amazon biome.

As for the methodological path, the article adopts a quantitative-qualitative logic of a descriptive nature and exploratory character, operating on two complementary fronts. The theoretical approach is based on a rigorous bibliographic review in repositories such as SciELO and CAPES Journal Portal, covering the national and international literature on waste management and valuation, with an emphasis on studies applied to the context of the North region (Mendoza et al., 2023; Costa et al., 2020).

The empirical stage is dedicated to the treatment and interpretation of data obtained in field campaigns carried out in Manaus. This process includes the measurement of gravimetry and the calculation of per capita generation under the rigor of protocols established by sanitary engineering (Rodrigues et al., 2024; Pereira et al., 2020). The resulting indicators are confronted with the current information on the urban cleaning system and the final destination, evidencing the distances between daily practices and the Brazilian normative framework.

2 THEORETICAL FRAMEWORK

The discussion around urban solid waste is anchored in the premise that such materials from domestic or commercial waste require rigorous management strategies to avoid sanitary collapses. In the Brazilian scenario, although the National Solid Waste Policy

has established pillars such as non-generation and shared responsibility, current diagnoses persist in pointing to an excessive use of dumps accompanied by still incipient material recovery rates. Contemporary academic thinking reinforces that the management of these tailings should not be isolated. It needs to be understood as a vital arm of urban policy directly articulated with economic regulation mechanisms and planning instruments (Freitas; Pires; Benincá, 2024).

The growth of populations and the physical expansion of metropolises increase the volume of discards. This exerts disproportionate pressure on cleaning systems that as a rule lack institutional robustness. In the North region, specifically, it is noted that urban densification added to income disparities generates heterogeneous waste flows marked by a massive presence of organic fractions and underused recyclable materials (Conceição et al., 2020). Such particularities call for regionalized diagnoses that respect territorial singularities. It is necessary to avoid reproducing management models designed for totally different geographical realities (Aguiar et al., 2021).

The technical literature emphasizes that the examination of management systems must consider the triad between production, consumption and environmental preservation. In studies focused on the Amazon, it is noted that the amalgam between rapid urbanization and deficient infrastructure culminates in scenarios of severe socio-environmental fragility (Conceição et al., 2020). In these circumstances, negligence in relation to long-term planning usually imprisons municipalities in palliative solutions for collection and final disposal. This ignores technological routes aimed at recycling and energy recovery (Mendes et al., 2020).

The historical analysis of the problem reveals the permanence of harmful practices such as disposal in sensitive ecosystems that still shape the configuration of urban cleaning in Brazil. In Cachoeiras de Macacu, for example, the cross-referencing of documentary data made it possible to map the evolution of the forms of garbage disposal, showing how specific advances coexist with the recurrence of emergency measures (García; Portugal, 2020). This historical lens is fundamental. It helps to unravel how political coalitions and institutional arrangements determine the effectiveness of the solutions adopted.

From a legal perspective, the implementation of national guidelines still faces severe obstacles in the monitoring of municipal integrated management plans. Evidence collected in Paraíba shows that many of these plans were conceived without effective social participation, resulting in goals disconnected from the operational capacity of the municipalities (Mendes et al., 2020). In addition, the use of quality tools in medium-sized cities reveals a critical lack of process standardization, which weakens the integration between the environmental and urban planning sectors (Rezende; Alvares; Ventura, 2020).

The impacts of inadequate disposal on public health and the environment form the core of concern in the specialized literature, especially in territories marked by inequalities. Research in watersheds proves that landfills severely degrade water quality, compromising aquatic biodiversity and the multiple uses of water resources (Pereira et al., 2020). In the urban fabric, the accumulation of waste in vacant areas fosters the proliferation of vectors and aggravates floods. Thus, a cycle of vulnerability is fed that affects the lower income social strata (Anjos, 2020).

The multifaceted nature of waste requires strategies that consider its specific properties, from household waste to healthcare waste. In Eirunepé, in the interior of Amazonas, it was found that the hospital flow had critical failures in storage and transport, increasing the risks of biological contamination for workers (Menezes; Situba, 2020). These findings reiterate that integrated management is imperative to ensure safety in municipalities with difficult logistics.

The evaluation of municipal performance has used, with increasing frequency, quantitative methods that refine logistics routes and monitor impacts on the environment. In Ribeirão Preto, for example, researchers have identified that certain obstacles in participatory governance end up hindering the real transition to sustainability models (Rezende; Alvares; Ventura, 2020). Other research fronts prefer to focus on areas of urban expansion. The objective is to decipher disposal patterns and, based on this, guide inspection actions or environmental pedagogy (Pestana; Ventura, 2020).

In this sense, the adoption of robust indicators — such as the ecological footprint — has allowed for a much more sophisticated reading of sustainability in cities. In Recife, the use of this metric showed that waste generation varies according to the socioeconomic profile of the neighborhoods, which exposes deep inequalities in waste production (Costa et al., 2020). This approach makes undeniable the fact that lifestyle acts as a central determinant in the pressure exerted on the ecosystem and on cleaning services.

On a global scale, the technical literature points to an inseparable link between economic development and increased disposal, with a faster jump in emerging countries. Analysis of international data shows that as progress indicators improve, waste volumes tend to grow. This requires sophisticated management policies so that there is no unsustainable intensification of environmental impacts (Mendoza et al., 2023). This finding reinforces the urgency for developing nations to structure preventive strategies and valorization technologies; otherwise, they will only reproduce flawed trajectories observed in industrialized countries.

In the Brazilian scenario, reports indicate that, despite the advances in the replacement of dumps by sanitary landfills, there is still a high number of municipalities with inadequate disposal. In addition, there is a chronic difficulty in expanding recycling or composting. The recent panorama highlights that the organic fraction is still predominant in urban waste and that selective collection covers only limited portions of the territory, presenting a very uneven performance between regions (Brazilian Association of Public Cleaning and Special Waste Companies, 2022). This information is essential to guide local characterization studies, such as the one outlined for Manaus.

Gravimetric characterization — and the definition of physicochemical properties — appears in the literature as a mandatory step for the design of resource treatment and recovery systems. In the specific case of Manaus, surveys carried out sampling and weighing campaigns to identify fractions, apparent density, and energy potential, constituting a solid basis for the analysis of technological scenarios (Rodrigues et al., 2024). Studies with this rigor make it possible to evaluate the real feasibility of routes such as composting, recycling of dry goods and the thermal use of the tailings fraction.

The discussion about energy recovery has gained momentum, especially in metropolises where the availability of areas for new landfills is scarce and transportation costs are prohibitive. Analyses of co-processing in cement kilns indicate that there is potential to reduce the volume destined for landfills, replacing fossil fuels and mitigating greenhouse gas emissions (Torres et al., 2022). However, the authors warn: the adoption of these technologies needs to be preceded by a rigorous characterization and a deep assessment of the social impacts involved.

Within the Amazonian context, studies suggest that the particularities of the climate, the vastness of the forest, and river logistics directly influence the organization of services. Studies in the North region show the coexistence of capitals with intense consumption and small municipalities with low revenue, which generates a complex mosaic of institutional arrangements (Aguiar et al., 2021). Under these conditions, defining strategies for Manaus requires analyses that integrate the specific territorial and environmental aspects of the region (Conceição et al., 2020).

The body of evidence reveals that the characterization of the residues transcends pure technique; It is linked to historical and socioeconomic processes that shape the planning capacity of cities. Studies converge on the idea that the increase in generation goes hand in hand with GDP, but the damage can be mitigated with integrated prevention policies (Mendoza et al., 2023). This perspective reinforces why empirical research in specific

contexts is so vital to provide reliable parameters for local decision-making (Costa et al., 2020).

Thus, the theoretical framework of this study combines the relationship between urban growth and vulnerability with performance evaluation approaches and technological alternatives. The literature is clear: detailed diagnoses of the composition of garbage are the necessary condition for any strategy, from environmental education to energy recovery (Rodrigues et al., 2024). In this context, characterizing Manaus waste is a strategic step to support management models compatible with the law and the Amazonian reality (Freitas; Pires; Benincá, 2024).

3 METHODOLOGY

The investigative strategy of this work is anchored in a quantitative-qualitative approach of a descriptive and explanatory nature. The study articulates techniques of bibliographic survey, documentary analysis and processing of empirical data on the characterization of urban solid waste. The bibliographic research was carried out in databases such as SciELO, LILACS and CAPES Journal Portal, prioritizing publications published between 2020 and 2025 that deal with the management and composition of discards in Brazilian and Amazonian contexts. This effort allowed the support of the theoretical framework presented previously (Freitas; Pires; Benincá, 2024; Mendoza et al., 2023). In addition, a detailed examination of case studies in municipalities in the North region and investigations that discuss institutional and operational aspects were carried out. The central objective was to situate the city of Manaus in a broader panorama of logistical challenges and management strategies (Conceição et al., 2020; Aguiar et al., 2021).

The documentary research focused on the scrutiny of plans, reports and official diagnoses, as well as academic theses that portray the reality of various Brazilian municipalities. Documents related to integrated management were evaluated under categories such as the type of final destination, the coverage of the collection and the effective participation of waste pickers. Procedures similar to those used in investigations in Paraíba and other Brazilian regions were adopted (Mendes et al., 2020; Rezende; Alvares; Ventura, 2020). This stage sought to understand the current institutional framework. At the same time, we sought to identify informational gaps that reinforce the pressing need for studies focused on the physical characterization of materials.

The empirical dimension consisted of the systematization of gravimetric characterization data and physicochemical properties of urban solid waste in the city of Manaus - AM. These indicators were extracted from previous academic research and

sampling campaigns carried out at strategic points of municipal collection. The classic sampling procedure was used in loads of compactor trucks with manual segregation of fractions and rigorous weighing by categories of materials, following the practices consolidated in sanitary engineering (Costa et al., 2020). The results of these campaigns, published in a specific study on local gravimetry, served as the primary source for calculating percentages in mass and apparent density (Rodrigues et al., 2024). Such metrics are essential to identify the fractions with the greatest potential for energy recovery.

The data obtained were organized in spreadsheets and submitted to descriptive statistical treatments. Means, deviations and intervals of variation were calculated for the different fractions, evidencing the typical composition of the Manaus residues. Whenever relevant, the findings were compared with values reported in studies from other urban centers. This made it possible to assess convergences regarding the predominance of organic matter and tailings (Brazilian Association of Public Cleaning and Special Waste Companies, 2022; Torres et al., 2022). This comparison was decisive to situate the local scenario in front of the national panorama, helping in the discussion on the sizing of treatment technologies and final disposal.

The integrated analysis of the data was interpretative. We sought to articulate the physical characterization of the waste to the socioeconomic and institutional conditions of the capital of Amazonas. The triangulation between field results, official information and evidence from the literature made it possible to identify tensions between the generation profile in Manaus and the management strategies currently underway (Pestana; Ventura, 2020; Pereira et al., 2020). This methodological option aimed to ensure robustness to the final conclusions. By combining the depth of qualitative analysis with the objectivity of quantitative indicators, the study delivers a systemic view of the Amazonian reality.

4 DISCUSSION AND RESULTS

The results obtained in the characterization of urban solid waste in Manaus reveal a profile that, in general, is similar to that of other Brazilian metropolises, although it is deeply crossed by the territorial and socioeconomic specificities of the Amazon. It is noted that the organic fraction exerts a clear hegemony in the total mass of the waste. This is followed by plastics, paper and cardboard, while metals, glass and various waste have a proportionally lower share. Such a configuration confirms the centrality of household waste and food services in the regular flow of the municipality (Brazilian Association of Public Cleaning and Special Waste Companies, 2022). This pattern reinforces the urgency of debating integrated strategies that include source reduction, composting and biodigestion, in addition to the

necessary improvement in segregation systems in line with the consumption behavior of the local population (Freitas; Pires; Benincá, 2024).

To refine the interpretation of these findings, the discussion was structured in analytical axes that seek to articulate the physical composition of the materials to the socio-environmental conditions and the performance of the institutions. Table 1 summarizes these axes, relating the observations collected in Manaus to the reference sources that guide this study. The pedagogical intention of this organization is to make explicit how empirical data converse with national diagnoses and Amazonian case studies, as well as global analyses on the relationship between development and tailings generation (Conceição et al., 2020; Mendoza et al., 2023). In this way, a more robust view is built on the strategic role that the capital of Amazonas occupies in this contemporary debate.

Table 1

Analytical axes of the discussion of the results for Manaus-AM

Analytical axis	Summary of findings for Manaus	General Source
Gravimetric composition and dominant fractions	Predominance of organic fraction, followed by plastics, paper/cardboard and a significant portion of unused recyclables.	Rodrigues et al. (2024); Brazilian Association of Public Cleaning and Special Waste Companies (2022)
Per capita generation and upward trends	Specific generation compatible with large centers of middle-income countries, with a growth trend associated with urbanization and consumption.	Conceição et al. (2020); Mendoza et al. (2023)
Socio-environmental vulnerabilities in the Amazonian context	Pressure on floodplain areas, streams and urban peripheries, with risks of contamination and worsening of territorial inequalities.	Angels (2020); Aguiar et al. (2021)
Impacts on water bodies and environmental health	Irregular releases and inadequate management contribute to the degradation of water quality and increased health risks.	Pereira et al. (2020); Menezes; Situba (2020)
Institutional performance and management planning	Mismatch between diagnoses, plan goals and effective use of field data in decision making.	Mendes et al. (2020); Rezende; Alvares; Ventura (2020)
Disposal patterns and urban dynamics	Evidence of diffuse disposal in areas of urban expansion and in areas with less infrastructure for inspection and cleaning.	Pestana; Ventura (2020); García; Portugal (2020)
Ecological footprint and environmental pressure of the waste system	High environmental load associated with current management, especially due to the disposal of the organic fraction to landfills.	Costa et al. (2020)
Energy recovery potential of the tailings fraction	Presence of materials with relevant calorific value, with technical feasibility for co-processing routes, conditioned to environmental criteria.	Torres et al. (2022); Rodrigues et al. (2024)

Source: Authors.

The predominance of the organic fraction — a central element in the gravimetric composition of Manaus — imposes severe operational and environmental bottlenecks on the public management system. When this material is sent untreated to landfills, it accelerates leachate production and methane emissions, which overwhelms leachate drainage and requires complex atmospheric monitoring systems. At the same time, this same critical mass reveals remarkable potential for composting and anaerobic digestion. Such routes, however, depend on source segregation programs and environmental education that dialogues with the ecological footprint of consumption (Costa et al., 2020). The fact that organic matter in Manaus remains mostly unprocessed ratifies the urgency of integrating this variable into planning strategies (Brazilian Association of Public Cleaning and Special Waste Companies, 2022).

With regard to per capita generation, the data from Manaus are close to the rates recorded in large metropolises of emerging nations. This trend confirms the nexus between economic growth and the intensification of disposal flows. International evidence suggests that improvements in development indicators tend to increase the volume of waste, requiring sophisticated prevention and recovery policies (Mendoza et al., 2023). In the context of the North region, this phenomenon is aggravated by socioeconomic abysses and by an institutional structure that is still in formation. The result is reactive management systems, which operate with a low density of technical diagnoses (Conceição et al., 2020).

The socio-environmental vulnerabilities typical of the Amazonian scenario become evident when observing the occupation of the territory. Local investigations denounce the persistence of disposal on river banks, floodplain areas, and vacant lots — practices umbilically linked to urban poverty and the discontinuity of cleaning services (Anjos, 2020). In the states of the Amazon, the combination of complex logistics and low inspection capacity exposes vulnerable populations to accentuated environmental risks. Manaus, as a metropolis that drains regional flows, synthesizes these challenges (Aguiar et al., 2021).

The degradation of water bodies and the impacts on public health gain prominence in cities crossed by streams. Research in Brazilian basins shows that the release of solids and effluents compromises water quality, affecting everything from supply to leisure and fishing (Pereira et al., 2020). In the interior of Amazonas, studies on health waste have revealed critical flaws in segregation and storage, increasing the danger of contamination for workers and riverside communities (Menezes; Situba, 2020). Such findings reinforce the need to connect waste management in Manaus to water resources protection policies and environmental surveillance.

On the institutional axis, the confrontation between field data and formal instruments exposes profound mismatches. Evaluations of municipal plans indicate incomplete diagnoses and goals that rarely get off the ground (Mendes et al., 2020). In medium-sized cities, the absence of consolidated indicators and the fragile integration between the urban planning and environmental sectors limit evidence-based decisions (Rezende; Alvares; Ventura, 2020). The experience of Manaus suggests that, although there are data on gravimetry and physicochemical properties, their systematic incorporation into political decision-making is still a horizon to be reached.

The urban dynamics reveal the coexistence of assisted areas and expansion zones marked by diffuse disposal, especially in the peripheries and recent occupations. Studies in cities in São Paulo show that stretches with less presence of the State tend to concentrate garbage sources on public roads, generating degradation and social conflicts (Pestana; Ventura, 2020). The historical analysis of cases such as that of Cachoeiras de Macacu helps to understand how political choices and economic crises shape the current system, inserting Manaus in a trajectory of disputes over land use (García; Portugal, 2020).

As for environmental pressure, the model based on conventional collection and total grounding generates a heavy ecological load. In Recife, for example, the ecological footprint analysis showed that neighborhoods with high waste generation and inefficient management severely pressure natural resources (Costa et al., 2020). The results from Manaus indicate that, without prevention policies and prior treatment, the capital tends to reproduce this significant footprint.

The potential for energy recovery of the tailings fraction shows that, although the priority is recycling, there is material with viable calorific value for thermal routes. The use of fuels derived from waste in cement kilns can reduce the burning of fossils and the volume in landfills, provided that strict emission criteria are respected (Torres et al., 2022). For Manaus, this possibility is technically plausible, but it depends on planning that does not cannibalize recycling opportunities or the treatment of organic matter (Rodrigues et al., 2024). In short, the axes discussed show that characterizing Manaus waste is the strategic foundation for a transition towards more sustainable models (Freitas; Pires; Benincá, 2024; Conceição et al., 2020).

5 FINAL CONSIDERATIONS

The final considerations of this article demonstrate that the objective of characterizing the urban solid waste of Manaus was fully achieved. The description of the predominant gravimetric composition — added to the analysis of the specific generation and the

physicochemical properties — offered the necessary basis for the strategic planning of the municipal management. The data confirmed the hegemony of the organic fraction in the total mass, accompanied by plastics, paper and cardboard, while metals and glass registered a reduced participation. Such a scenario ratifies the centrality of household waste and the food sector in the capital's waste stream. In view of this, it is imperative to face the bottlenecks of segregation at source and reduction of generation, seeking a destination that is, in fact, environmentally balanced.

The articulation between the empirical findings and the specialized literature allowed us to interpret the results through the lens of socio-environmental vulnerabilities and institutional limitations in the region. It was observed that the management model of Manaus is still anchored, almost exclusively, in conventional collection and burial in sanitary landfills. The use of recyclables and the biological treatment of organic matter remain at restricted levels. In addition, critical mismatches were identified between the available technical diagnoses and the effective political decisions, which reveals a significant margin for the improvement of public administration based on scientific evidence.

From the methodological point of view, the combination between the quantitative-qualitative approach and the analysis of gravimetric data proved to be effective in capturing both the coldness of the numbers and the structural complexity of the problem in Manaus. The organization of the discussion into analytical axes — ranging from the physical composition to the potential for energy recovery — gave clarity to the exposition of local challenges. This methodological arrangement reinforces how characterization studies are vital inputs for the review of plural plans, the definition of investment priorities, and the design of policies for the socio-productive inclusion of waste pickers.

Although the study is based on a solid empirical basis, it is recognized that further field surveys would be opportune. More extensive time series and detailed spatial cutouts by neighborhoods could broaden the understanding of seasonal variations and changes in the population's consumption habits. Future investigations that integrate the modeling of economic scenarios and the active participation of local actors have the potential to deepen the evaluation of technological routes. Such efforts are essential to support choices aligned with the logistical particularities of the Amazon and the sustainability requirements that the twenty-first century imposes on the region's metropolises.

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