

Diagnosis of Solid and Semi-Solid Waste Management in Recycling Companies at the Manaus Industrial Pole

Diagnóstico do Gerenciamento de Resíduos Sólidos e Semissólidos em Empresas de Reciclagem do Polo Industrial de Manaus

Diagnóstico de la Gestión de Residuos Sólidos y Semisólidos en Empresas de Reciclaje del Polo Industrial de Manaus

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Abstract: Throughout history, anthropogenic activities have caused significant impacts on socio-environmental dynamics, often resulting in irreversible changes in natural ecosystems. In this context, various strategies have been implemented to mitigate such impacts and promote sustainable development. In the business sector, there is a growing strengthening of corporate socio-environmental responsibility, evidenced by the adoption of environmentally appropriate practices and the valorization of sustainable production processes. In this scenario, this study aimed to characterize the waste management process and the development of practices related to solid and semi-solid waste in recycling companies located in the Manaus Industrial Pole, with emphasis on the analysis of final disposal practices, aiming to identify weaknesses, compliance aspects, and potentialities in waste management within the Amazonian context. The research was conducted using a case study approach, based on secondary data, documentary analysis, and field data collection instruments, including environmental checklists and semi-structured interviews with managers, environmental management system personnel, and operators of the selected companies. The results indicated that most of the analyzed companies do not have a structured Solid Waste Management Plan or, when present, it is not integrated into operational routines. A lack of continuous training, limited intersectoral communication, and insufficient infrastructure for waste storage and sorting were also observed. It is concluded that there are weaknesses and potentialities in the management processes, highlighting the need for operational standardization, strengthening of internal control, improved knowledge of environmental legislation, and continuous training of employees, particularly within the Amazonian context, contributing to the strengthening of environmentally responsible and sustainable corporate practices.

Keywords: Manaus Industrial Hub, Environmental Management, Circular Economy.

Resumo: Ao longo da história, as atividades antrópicas têm provocado impactos significativos nas dinâmicas socioambientais, frequentemente resultando em alterações irreversíveis nos ecossistemas naturais. Diante desse cenário, diferentes estratégias vêm sendo implementadas com a finalidade de mitigar tais impactos e promover o desenvolvimento

sustentável. No âmbito empresarial, observa-se o fortalecimento da responsabilidade socioambiental das indústrias, evidenciado pela incorporação de práticas ambientalmente adequadas e pela valorização de processos produtivos sustentáveis. Nesse contexto, o presente estudo teve como objetivo caracterizar o processo de gerenciamento e o desenvolvimento das práticas relacionadas aos resíduos sólidos e semissólidos em empresas de reciclagem do Polo Industrial de Manaus, com ênfase na análise das ações de disposição final adotadas, visando identificar fragilidades, conformidades e potencialidades na gestão de resíduos no contexto amazônico. A pesquisa foi conduzida por meio do método de estudo de caso, utilizando dados secundários, análise documental e instrumentos de levantamento de campo, incluindo checklist ambiental e entrevistas semiestruturadas realizadas com gestores, responsáveis pelo Sistema de Gestão Ambiental (SGA) e operadores das empresas selecionadas. Os resultados indicaram que a maioria das empresas analisadas não dispõe de Plano de Gerenciamento de Resíduos Sólidos (PGRS) estruturado ou, quando existente, este não se encontra plenamente integrado às rotinas operacionais. Observou-se, ainda, ausência de capacitação contínua, comunicação limitada entre setores e insuficiência de infraestrutura destinada ao armazenamento e à triagem dos resíduos. Conclui-se que as empresas investigadas apresentam tanto fragilidades quanto potencialidades relacionadas aos processos de gestão ambiental, evidenciando a necessidade de padronização operacional, fortalecimento do controle interno, ampliação do conhecimento sobre a legislação ambiental e capacitação contínua dos colaboradores, contribuindo para o fortalecimento de práticas corporativas ambientalmente responsáveis e sustentáveis no contexto amazônico.

Palavras-Chave: Polo Industrial de Manaus, Gestão Ambiental, Economia Circular.

Resumen: A lo largo de la historia, las actividades antrópicas han provocado impactos significativos en las dinámicas socioambientales, resultando frecuentemente en alteraciones irreversibles en los ecosistemas naturales. Ante este escenario, diversas estrategias han sido implementadas con el fin de mitigar dichos impactos y promover el desarrollo sostenible. En el ámbito empresarial, se observa un fortalecimiento de la responsabilidad socioambiental de las industrias, evidenciado por la adopción de prácticas ambientalmente adecuadas y la valorización de procesos productivos sostenibles. En este contexto, el presente estudio tuvo como objetivo caracterizar el proceso de gestión y el desarrollo de las prácticas relacionadas con los residuos sólidos y semisólidos en empresas de reciclaje del Polo Industrial de Manaus, con énfasis en el análisis de las prácticas de disposición final adoptadas, con el fin de identificar fragilidades, conformidades y potencialidades en la gestión de residuos en el contexto amazónico. La investigación se desarrolló mediante el método de estudio de caso, utilizando datos secundarios, análisis documentales e instrumentos de levantamiento de campo, incluyendo listas de verificación ambiental y entrevistas semiestructuradas con gestores, responsables del sistema de gestión ambiental y operadores de las empresas seleccionadas. Los resultados evidenciaron que la mayoría de las empresas analizadas no dispone de un Plan de Gestión de Residuos Sólidos estructurado o, cuando existe, no está integrado a las rutinas operativas. Asimismo, se observó la ausencia de capacitación continua, comunicación limitada entre sectores y la insuficiencia de infraestructura para el almacenamiento y la clasificación de residuos. Se concluye que existen fragilidades y potencialidades en los procesos de gestión, lo que evidencia la necesidad de estandarización operativa, fortalecimiento del control interno, ampliación del conocimiento de la legislación ambiental y capacitación continua de los colaboradores, en el contexto amazónico y en el fortalecimiento de prácticas corporativas ambientalmente responsables y sostenibles.

Palabras Clave: Centro industrial de Manaos, gestión ambiental, economía circular.

Introduction

The generation of solid and semi-solid waste has intensified throughout history due to technological advances, urbanization, and contemporary production and consumption models. Since the Industrial Revolution, the increase in mass production and the complexity of industrial processes have significantly expanded the environmental impacts associated with waste generation, making its management one of the primary environmental challenges today (Silva & Ramos, 2021; Dias, 2022).

In Brazil, the National Environmental Policy (PNMA), established by Law No. 6.938/1981, and later the National Solid Waste Policy (PNRS), Law No. 12.305/2010, set guidelines for

integrated management and environmentally appropriate management of solid waste, reinforcing principles such as shared responsibility and the "polluter pays" principle.

Despite regulatory progress, studies indicate that industrial waste management still faces challenges related to the effectiveness of monitoring systems, the integration of environmental practices into business routines, and the consolidation of preventive management strategies (Andrade, 2020; Conceição, 2022). Among these wastes, semi-solid wastes stand out, often associated with industrial sludge and by-products with high moisture content, whose management requires specialized technical control and remains under-explored in scientific literature (Oliveira & Souza, 2022; Freitas, 2023).

In the Amazonian context, these challenges become even more complex due to the region's environmental sensitivity and the high generation of waste from industrial activities at the Manaus Industrial Pole (PIM). Although the PIM represents one of the main industrial hubs in the Northern Region, there is a lack of applied studies on the management practices adopted by recycling companies, especially regarding the final disposal stages and the integration of these practices into operational routines.

In addition to the limitation of updated institutional data, evidenced by the last consolidated survey by SUFRAMA (2015), a scientific gap is identified related to the understanding of solid and semi-solid waste management practices in recycling companies within the Amazonian context.

Given this scenario, this research seeks to answer the following question: how is the solid and semi-solid waste management process characterized in recycling companies in the Manaus Industrial Pole, especially regarding the final disposal practices adopted?

Thus, this article aims to characterize the management process of solid and semi-solid waste in recycling companies in the Manaus Industrial Pole, with an emphasis on final disposal practices and the identification of weaknesses, compliance, and potentialities related to Amazonian industrial environmental management.

Theoretical Framework

Industrial Solid Waste Management and Corporate Sustainability

Industrial advancement and the growth of consumption patterns intensified after the Industrial Revolution contributed significantly to the increase in waste generation and the environmental impacts associated with productive activities. The expansion of large-scale production, combined with the intensive exploitation of natural resources, resulted in relevant changes in the quality of soil, water, and air, making environmental management a strategic element for industrial organizations.

In this context, environmental concern has become part of business strategies, especially in the face of strengthening environmental legislation and society's demands for more sustainable production practices. According to Barbieri (2018), corporate environmental management represents a set of guidelines and instruments aimed at reducing environmental impacts from productive activities, allowing for a greater balance between economic development and environmental preservation.

The National Solid Waste Policy (PNRS), established by Law No. 12.305/2010, consolidated important guidelines for environmentally appropriate management in Brazil, establishing

principles such as prevention, shared responsibility, and reverse logistics. The legislation assigns responsibility to generators for the handling, packaging, transport, and environmentally appropriate final disposal of waste, strengthening the role of companies in mitigating environmental impacts.

In addition to meeting legal requirements, proper management has become a competitive differentiator. According to Oliveira and Gomes (2012), adopting environmental practices contributes to improving institutional image, optimizing production processes, and reducing waste, favoring greater operational efficiency.

In the industrial context, industrial solid waste (ISW) comprises materials resulting from production processes, which may have different physical, chemical, and biological characteristics according to the raw material used. The Brazilian Association of Technical Standards (ABNT), through NBR 10004:2004, classifies waste according to its hazardousness into Class I (hazardous) and Class II (non-hazardous), the latter subdivided into Class II-A (non-inert) and Class II-B (inert). Class I waste presents characteristics such as flammability, corrosivity, toxicity, reactivity, or pathogenicity, demanding rigorous environmental control procedures. On the other hand, Class II waste, although considered non-hazardous, also requires proper management to avoid environmental impacts and risks to public health.

The efficient management of this waste involves actions related to segregation, storage, transport, treatment, and environmentally appropriate final disposal. According to Mattos (2009), waste management constitutes an organizational system aimed at implementing practices and procedures destined for the minimization of environmental impacts and the reuse of materials.

Semi-solid Waste and Industrial Management Challenges

Semi-solid wastes constitute an intermediate category between solid and liquid wastes, characterized by high moisture and a pasty consistency, making storage and conventional treatment difficult. These are often generated in industrial processes, effluent treatment systems, and recycling processes.

According to ABNT NBR 10004:2004, waste can be classified by physical state as solid, semi-solid, liquid, and gaseous. Semi-solid waste has a distinct physical behavior, requiring specific infrastructure for packaging and treatment, such as pressing and dehydration systems.

Among the main examples of industrial semi-solid waste, industrial sludge, oily sludge, fibrous waste, filter cakes, and materials from effluent treatment stand out. When improperly managed, these wastes can cause soil and groundwater contamination, in addition to the emission of odors and the proliferation of vectors.

According to Dias (2022), the management of semi-solid waste represents one of the primary environmental challenges faced by Brazilian industries, especially in environmentally sensitive regions such as the Amazon. Therefore, the proper handling of these wastes becomes essential to reduce environmental liabilities and ensure compliance with current legislation.

In addition to environmentally appropriate final disposal, strategies such as energy recovery, industrial composting, and recycling have been discussed as sustainable alternatives for the management of these materials.

Environmental Management Systems (EMS) and ISO 14001

The Environmental Management System (EMS) constitutes a set of administrative and operational practices aimed at identifying, controlling, and mitigating the environmental impacts resulting from business activities. According to Mazzer (2004), the EMS allows organizations to incorporate sustainable practices into their production processes, promoting greater environmental control and continuous improvement of organizational performance.

Among the main frameworks used by companies, ISO 14001 stands out, an international standard that establishes requirements for the implementation of environmental management systems. ISO 14001 certification assists organizations in defining environmental policies, monitoring risks, waste control, and compliance with environmental legislation.

The adoption of the EMS and ISO 14001 is directly related to the pursuit of industrial eco-efficiency, waste reduction, and the strengthening of business competitiveness. According to Barbieri (2018), organizations that incorporate structured environmental practices tend to show a greater capacity to adapt to regulatory requirements and contemporary socio-environmental demands.

In the context of the Manaus Industrial Pole (PIM), the implementation of environmental management systems plays a relevant role given the high volume of waste generated by industrial activities and the need for compliance with legal instruments for environmental control.

Circular economy, reverse logistics, and shared responsibility

Recent studies demonstrate that the circular economy has been widely incorporated into sustainable industrial strategies, especially in sectors with high waste generation. According to Geissdoerfer et al. (2020), the circular economy contributes to the reduction of natural resource extraction and the strengthening of production efficiency, promoting greater integration between economic development and environmental sustainability.

Research developed by Kirchherr, Reike, and Hekkert (2021) points out that circularity practices, such as reuse, recycling, and energy recovery, have consolidated as relevant mechanisms for reducing industrial environmental liabilities. In the Brazilian context, recent studies indicate that the implementation of the circular economy still faces challenges related to infrastructure, waste traceability, and integration between actors in the productive chain.

Furthermore, Silva et al. (2021) highlight that corporate sustainability has taken on a strategic position in industrial organizations, especially in the face of regulatory requirements, market pressures, and the strengthening of global environmental agendas. In this scenario, practices related to reverse logistics and efficient solid waste management become fundamental for expanding business competitiveness and improving environmental performance.

The circular economy emerges as an alternative to the traditional linear model of production and consumption, based on the logic of extraction, use, and disposal of natural resources. This model seeks to promote the reuse of materials, reduction of waste generation, and the reinsertion of products and inputs into productive cycles.

According to the Ellen MacArthur Foundation (2015), the circular economy proposes maintaining the value of products, materials, and resources for as long as possible, reducing losses and environmental impacts associated with improper disposal.

In this context, reverse logistics constitutes one of the main instruments provided for by the National Solid Waste Policy, allowing the return of waste to the productive sector for reuse, recycling, or environmentally appropriate disposal. Shared responsibility for the product life

cycle involves manufacturers, distributors, merchants, consumers, and companies responsible for the final disposal of waste.

The adoption of these mechanisms contributes to the reduction of environmental impacts, the strengthening of corporate sustainability, and the stimulation of the reuse of recyclable materials. For recycling companies, the circular economy represents an important instrument for the valuation of waste and the optimization of environmental management.

Solid waste management in the Manaus Industrial Pole

The Manaus Industrial Pole (PIM) holds a significant share in the regional and national economy, concentrating companies from various industrial segments, such as electronics, metallurgy, chemical, plastics, and two-wheeled vehicles. However, the high volume of industrial production also results in significant generation of solid and semi-solid waste.

Studies conducted on waste management in the PIM demonstrate that challenges related to segregation, traceability, storage, and environmentally appropriate final disposal of industrial waste still persist. Furthermore, operational failures and structural limitations can compromise the efficiency of environmental management programs.

The Superintendency of the Manaus Free Trade Zone (SUFRAMA), in partnership with national and international institutions, has developed initiatives aimed at improving industrial waste management in the PIM, seeking to stimulate recycling practices, reuse of materials, and the strengthening of industrial sustainability.

Despite the observed advances, studies point out that many companies still present difficulties in the effective implementation of waste management programs, especially regarding environmental monitoring, technical training, and the integration of sustainable practices into production processes. Thus, understanding the management of solid and semi-solid waste in the context of the PIM becomes relevant for identifying operational limitations, evaluating the environmental practices adopted by companies, and analyzing strategies related to industrial sustainability.

Methodological foundation of the case study

The present study is characterized as qualitative, descriptive, and exploratory research, conducted through a multiple case study. According to Yin (2015), the case study consists of a methodological strategy suitable for investigations that seek to understand contemporary phenomena embedded in real contexts, especially when the boundaries between phenomenon and context are not clearly defined.

For Eisenhardt (1989), multiple case studies enable greater analytical robustness and contribute to theoretical construction based on comparisons between different units of analysis. This approach favors a deep understanding of complex organizational processes, allowing for the identification of patterns, similarities, and specificities among the investigated cases.

In the Brazilian context, Godoy and Bandeira-de-Mello (2010) highlight that qualitative research in organizational studies makes it possible to interpret social and environmental phenomena based on the reality experienced by participants, contributing to contextualized and

in-depth analyses.

Thus, the use of a multiple case study proved to be suitable for analyzing solid and semi-solid waste management in recycling companies within the Manaus Industrial Pole, allowing for an understanding of environmental practices, operational limitations, and strategies related to industrial waste management.

Methodological elements of the research

Research Design

The research is characterized as qualitative, descriptive, and exploratory, conducted through a multiple case study. According to Yin (2015), this methodological strategy is indicated for investigations seeking to understand contemporary phenomena in their real-life contexts. Complementarily, Eisenhardt (1989) highlights that multiple case studies favor greater analytical robustness through the comparison between different units of analysis.

The investigation was also based on a bibliographic review conducted in the CAPES Journal Portal, SciELO, Scopus, and Google Scholar databases, using descriptors related to industrial solid waste management, semi-solid waste, circular economy, reverse logistics, corporate sustainability, and Environmental Management Systems (EMS). Priority was given to scientific articles, legislation, and technical documents published between 2020 and 2025, in addition to environmental and institutional standards related to waste management.

Study Area and Selection of Companies

The research was developed at the Manaus Industrial Pole (PIM), located in the city of Manaus, Amazonas. The study included seven companies operating in the segments of recycling and treatment of solid and semi-solid waste.

The selection of cases occurred in an intentional and non-probabilistic manner, considering criteria of sectoral representativeness, diversity of treated waste, and the companies' environmental regularity. Only organizations licensed by the Amazonas Environmental Protection Institute (IPAAM) were included, with an Operating License valid for the year 2023 and activities directly related to the collection, recycling, or treatment of Class I and II industrial waste.

Companies from distinct segments, such as the hospital, agro-industrial, and food sectors, were excluded to avoid analytical dispersion and ensure greater homogeneity among the investigated cases.

Research Participants

A total of 56 collaborators participated in the research, distributed across different hierarchical levels of the seven investigated companies. The sample consisted of 7 managers or technical leads, 14 professionals linked to environmental management, and 35 operational workers directly involved in waste handling, collection, transport, and disposal.

The inclusion of different professional profiles allowed for the understanding of multiple perceptions regarding the solid and semi-solid waste management practices adopted by the

organizations.

Data Collection Instruments

Data collection took place in two complementary stages. In the first stage, a technical environmental compliance checklist was applied, consisting of 18 items structured based on the National Solid Waste Policy (Law No. 12,305/2010), ABNT NBR ISO 14001:2015, and criteria related to current environmental licensing.

The checklist covered aspects related to storage, segregation, transport, traceability, final disposal, environmental monitoring, and the companies' documentary regularity, allowing for a preliminary diagnosis of the organizations' environmental performance. The checklist used is available in Appendix A.

In the second stage, semi-structured interviews were conducted, and questionnaires containing six open and closed questions were administered to the company managers. The script was developed based on the research objectives and studies on industrial waste management and corporate Sustainability.

The questions addressed themes related to waste management, environmental practices, reverse logistics, professional training, and the operational flows of solid and semi-solid waste. The interview script used is available in Appendix B.

Complementarily, the flow-map tool was used for the visual representation of operational waste flows within the companies, allowing for the identification of production stages, internal movements, storage points, and final disposal. The developed operational flow maps contributed to the comparative analysis between the investigated companies, making it possible to identify operational differences related to segregation, temporary storage, internal transport, and the final disposal of solid and semi-solid waste.

Data Analysis Procedures

The obtained data were analyzed using a descriptive and interpretative approach, utilizing triangulation between interviews, questionnaires, technical checklists, field observations, and documentary analysis.

The collected information was organized into analytical categories related to environmental compliance, operational management, sustainability, and waste management.

The use of multiple collection instruments allowed for greater reliability of the results, favoring the comparison between the investigated cases and the integrated interpretation of the environmental practices developed by the companies.

Ethical Aspects

The research respected the ethical principles applicable to scientific investigations involving human participants. The project was submitted to and approved by the Research Ethics Committee (CEP) through Plataforma Brasil, under the Certificate of Presentation for Ethical Appreciation (CAAE) No. 85372924.7.0000.5020, meeting the guidelines established by Resolution CNS No. 466/2012.

The participating companies provided institutional authorization for the study, and the

participants were previously informed about the research objectives, ensuring the confidentiality of strategic information and the use of data exclusively for academic purposes. All participants voluntarily agreed to participate in the research by signing the Informed Consent Form (ICF).

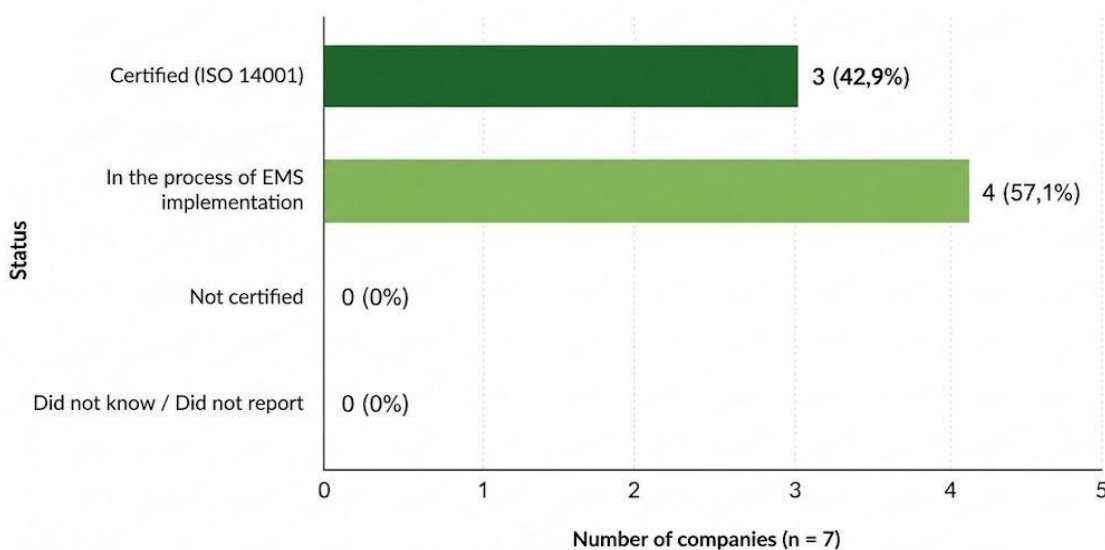
Results and Discussion

Environmental Structure and Company Compliance

The investigated companies presented similar operational structures, consisting of areas for receiving, sorting, processing, and temporary storage of solid and semi-solid waste. Despite operating in different segments of the recycling chain in the Manaus Industrial Pole (PIM), a relative standardization was observed regarding the operational stages related to waste management, evidencing the adoption of minimum practices aimed at meeting the legal and operational requirements of the sector.

The analysis allowed for the identification of different levels of environmental maturity among the organizations analyzed. Some of the companies held ISO 14001 certification, while others were in the process of implementing an Environmental Management System (EMS). The certified companies showed greater systematization of environmental procedures, especially regarding operational monitoring, waste traceability, and the formalization of environmental policies.

Figure 1 – Status of companies regarding ISO 14001 certification and implementation of the Environmental Management System (EMS)



Source: Research data (2025).

These results corroborate Barbieri (2018), who states that Environmental Management Systems contribute directly to the strengthening of legal compliance, continuous improvement of industrial processes, and the expansion of corporate environmental control. Similar results were

observed by Oliveira et al. (2022) in a study conducted with industrial recycling companies in Southeast Brazil, where certified organizations presented greater operational control and a lower incidence of environmental liabilities compared to companies without formalized certification.

Additionally, it was found that companies with greater environmental structuring showed better integration between operational procedures and environmental management strategies, demonstrating that the formalization of processes tends to favor the monitoring of potentially polluting activities and the reduction of environmental risks.

However, weaknesses related to operational infrastructure were also identified, especially regarding the existence of adequate areas for temporary storage, waste segregation, and the control of hazardous materials. Such limitations represent potential risks of environmental non-compliance, particularly in activities involving waste classified as hazardous.

In the Amazonian context, these weaknesses take on greater relevance due to the proximity between industrial areas, water resources, and forest remnants, increasing the potential for environmental impacts resulting from inadequate waste management. Thus, the results reinforce the need to strengthen preventive strategies and continuous environmental monitoring in activities related to industrial recycling in the Amazon.

Operational Weaknesses and Environmental Management

The results showed that, although some of the companies have formal procedures aimed at assessing environmental aspects and impacts, there are still gaps related to internal communication, technical training, and the dissemination of environmental policies among different organizational levels.

A significant portion of the operational workers demonstrated a lack of knowledge regarding procedures related to the assessment of environmental risks, environmental liabilities, and citations linked to the activities developed by the companies themselves. These findings suggest weaknesses in the integration between the technical-managerial and operational sectors, compromising the consolidation of an organizational culture focused on sustainability.

Similar results were identified by Santos et al. (2021) when analyzing companies in the industrial recycling sector in the state of São Paulo, observing difficulties related to the integration of environmental policies among different organizational sectors. According to the authors, the absence of collective participation in environmental management processes reduces the effectiveness of preventive actions and makes it difficult to strengthen the corporate environmental culture.

In this context, Leff (2006) highlights that corporate sustainability does not depend exclusively on the adoption of technologies or environmental certifications, but also on the internalization of environmental principles by different institutional actors. Thus, the results of this study show that the effectiveness of environmental practices is directly associated with the strengthening of technical training and corporate environmental education actions.

Another relevant aspect refers to the inadequate segregation of waste received by the companies, especially mixed or contaminated materials, making the stages of sorting, reuse, and environmentally appropriate final disposal difficult. According to Dias (2021), failures in segregation directly compromise the operational efficiency of recycling chains and amplify the environmental risks associated with the inadequate management of industrial waste.

Although some companies conduct periodic training, the adoption of sporadic and non-systematized actions predominated, highlighting the need for continuous training programs aimed at strengthening environmental management practices.

Sustainability, Reverse Logistics, and Circular Economy

The investigated companies presented different levels of incorporation of practices related to sustainability and the circular economy. Initiatives focused on industrial waste recycling, material reuse, and reverse logistics stood out, especially in the segments of electro-electronic waste, plastics, and hazardous waste.

The results demonstrated that companies with a higher level of organizational structuring presented practices more aligned with the principles of the circular economy, including waste

reuse, reduction of final disposal, and the valorization of industrial byproducts. These practices reinforce the strategic role of recycling companies in reinserting waste into the production cycle, as established by the National Solid Waste Policy (Law No. 12,305/2010).

Similar results were observed by Geissdoerfer et al. (2020), as they highlight that the circular economy depends on the integration of technological innovation, material reuse, and the strengthening of sustainable production chains. The authors emphasize that companies with a greater capacity for environmental integration tend to present better indicators related to sustainability and operational efficiency.

However, it was observed that the implementation of programs focused on reducing the consumption of natural resources and adopting sustainable technologies still occurs on a limited basis in some of the investigated companies. The main obstacles reported involved high operational costs, structural limitations, and difficulties related to the technological modernization of production processes.

Even in the face of these limitations, some companies demonstrated increasing concern with sustainable practices, including the use of renewable energy, energy recovery from waste, and the development of regional technologies focused on the treatment and valorization of recyclable materials. These results demonstrate important advances in strengthening corporate environmental strategies in the Amazonian context.

Technical and Institutional Challenges

Among the main challenges identified by the companies were the complexity of environmental legislation, high costs associated with waste management, and difficulties related to inspection and technical institutional support.

Managers reported limitations related to the interpretation of legal requirements and the operationalization of environmental obligations, especially in activities involving hazardous waste, control of environmental liabilities, and compliance with current environmental standards.

Similar results were observed by Silva et al. (2021), as they identified that companies in the recycling sector frequently face difficulties related to adapting to legal requirements and the absence of specialized technical support, especially in regions on the periphery of major industrial centers.

Furthermore, difficulties related to the environmental awareness of suppliers, customers, and the population regarding the segregation and appropriate disposal of waste were mentioned, showing that challenges related to environmental management go beyond the organizations' internal environment. Another relevant aspect refers to the dependence on outsourced companies to perform certain stages of environmental management, a factor that can weaken control and monitoring mechanisms when there are no audits and systematic follow-up procedures.

In this sense, the results demonstrate that solid and semi-solid waste management in the Amazonian context goes beyond exclusively technical issues, also involving institutional, economic, and operational limitations that directly impact the effectiveness of the environmental practices developed by organizations.

Operational Flows and Waste Management

The operational flows observed in the investigated companies presented a similar structure,

involving stages of receiving, segregation, classification, temporary storage, processing, and final disposal of waste.

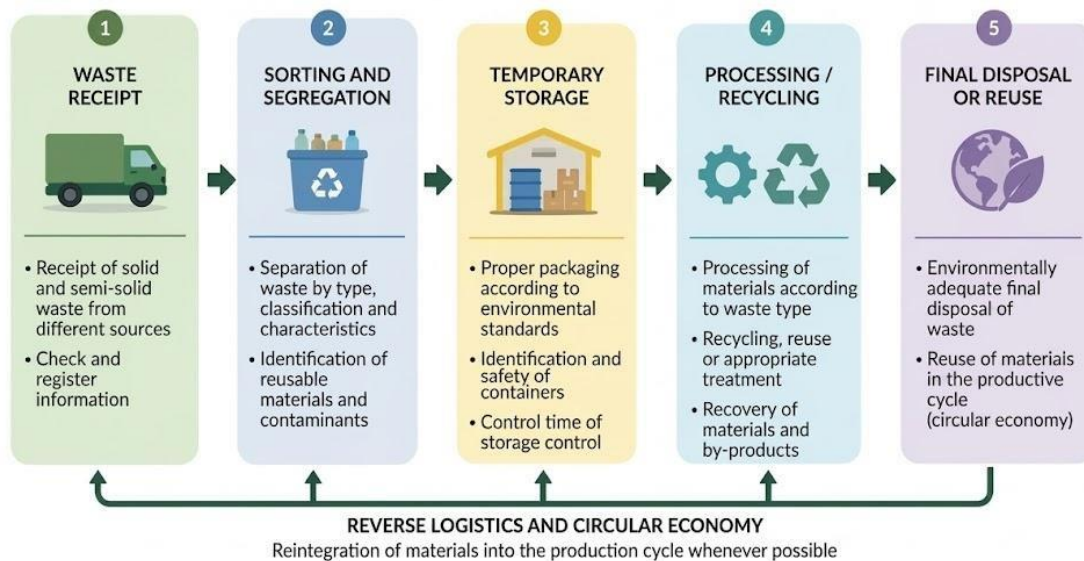
The use of the flow map allowed identifying relevant differences regarding the internal organization of processes, especially in relation to waste segregation, control of hazardous materials, and reuse of industrial byproducts. Companies with a higher level of environmental structuring presented more organized operational flows that were integrated with environmental management practices, while less structured organizations demonstrated greater dependence on informal operational processes.

The results also evidenced the adoption of strategies related to reverse logistics and the circular economy, including the reuse of industrial waste, recycling of electro-electronic components, and energy recovery from materials previously destined for disposal.

Unlike strictly descriptive approaches, the integrated analysis of operational flows allowed the identification of recurring patterns of environmental weaknesses and potentials across the different segments evaluated, contributing to a broader understanding of the relationships between waste management, industrial sustainability, and operational organization in the Amazonian context.

Figure 2 – Synthesis of operational flows related to the management of waste

Common stages identified among the companies investigated



Source: Prepared by the author based on research data (2025).

Synthesis of Environmental Conformities and Weaknesses

The application of the environmental checklist allowed the identification of important conformities, such as regular environmental licensing, the existence of basic waste management procedures, and the partial adoption of practices aimed at sustainability in some of the companies analyzed.

Table 1 – Synthesis of main compliances and weaknesses identified in the investigated companies

ASPECTS ASSESSED	IDENTIFIED COMPLIANCES	IDENTIFIED WEAKNESSES
 1. Environmental management	 Existence of Environmental Management Systems (EMS), valid environmental licensing, and partial formalization of environmental procedures.	 Low integration between operational and environmental sectors and limitations in the dissemination of environmental policies.
 2. Operationalization of management	 Execution of segregation, temporary storage, and basic disposal of waste.	 Failures in storage, operational monitoring, and segregation of contaminated waste.
 3. Sustainability and circular economy	 Development of recycling practices, reverse logistics, and material reuse.	 Structural and technological limitations for expanding sustainable practices.
 4. Environmental training and awareness	 Partial execution of training and operational guidance.	 Sporadic training and low involvement of some employees in environmental actions.
 5. Environmental control and monitoring	 Existence of operational monitoring in part of the investigated companies.	 Weaknesses in traceability, documentary control, and follow-up of generated waste.

Source: Elaborated by the author based on research data (2025).

However, weaknesses were also observed related to operational infrastructure, environmental monitoring, technical training, and the dissemination of environmental policies among workers. Generally, the results demonstrate that the investigated companies present significant advances in the adoption of environmental practices aimed at the management of solid and semi-solid waste, especially regarding industrial recycling, material reuse, and compliance with legal requirements. Yet, challenges persist related to the consolidation of more integrated Environmental Management Systems, the expansion of technical training actions, and the strengthening of preventive strategies aimed at industrial sustainability.

The findings of this research contribute to broadening discussions on industrial waste management in the Amazonian context, especially in recycling companies linked to the Manaus Industrial Pole, a segment still little explored by national scientific literature. Furthermore, the study highlights that the challenges faced by companies in the region are not restricted to operational infrastructure, also involving institutional, economic, and organizational factors that directly influence the effectiveness of environmental practices developed in the Amazonian industrial context.

Final Considerations

This study allowed for the analysis of solid and semi-solid waste management in recycling companies located in the Manaus Industrial Pole (PIM), highlighting advances related to environmental compliance and the adoption of sustainability-oriented practices, as well as

structural, operational, and institutional limitations that still compromise the effectiveness of environmental management in these organizations.

The results demonstrated that, although some companies have regular environmental licensing, initiatives related to the implementation of Environmental Management Systems (EMS), and use control instruments such as the Waste Transport Manifesto (MTR), weaknesses persist regarding the standardization of procedures, proper waste segregation, integration between sectors, and the dissemination of environmental policies among workers. Additionally, it was found that a significant portion of the companies do not have a fully structured Solid Waste Management Plan (PGRS) or one integrated into the operational routine, evidencing limitations related to the planning and continuous monitoring of environmental practices.

It was further observed that companies with a higher level of environmental structuring—especially those with ISO 14001 certification or in the process of implementing an EMS—presented greater operational organization, waste traceability, and integration of environmental practices into production processes. These results reinforce the importance of adopting formal environmental management instruments as mechanisms capable of strengthening operational control and reducing environmental risks associated with industrial recycling activities.

In the Amazonian context, the identified challenges become even more relevant due to the proximity between industrial areas, water resources, and forest remnants, making inadequate waste management a potential factor for regional environmental impact. Thus, the study highlights that challenges related to solid waste management in the Manaus Industrial Pole go beyond exclusively technical issues, also involving institutional, economic, and organizational limitations.

As an applied contribution, the research supported the development of educational material for corporate environmental education, built from the weaknesses identified during the study, particularly those related to waste segregation, internal communication, and the strengthening of environmental practices among operational workers. Furthermore, the findings contribute to broadening discussions on industrial waste management and corporate sustainability in the Amazonian context, a segment still little explored by national scientific literature.

However, the research has limitations related to the geographic scope restricted to the Manaus Industrial Pole, the selection of companies based on accessibility criteria, and the absence of longitudinal follow-up of the investigated environmental practices, preventing generalizations to other industrial contexts.

In view of this, it is recommended that future research develop comparative studies between different industrial poles in the North region, as well as investigations aimed at monitoring the evolution of environmental management practices, the implementation of Solid Waste Management Plans (PGRS), and the effectiveness of reverse logistics strategies in the Amazonian context.

In general, it is concluded that the study achieved its objective by characterizing the practices, limitations, and challenges related to the management of solid and semi-solid waste in recycling companies in the Manaus Industrial Pole, in addition to proposing strategies to support corporate environmental education based on the research findings. In this sense, the study reinforces the need to strengthen corporate environmental management policies and expands discussions on industrial sustainability and waste management in the Amazonian context.

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