

Pathways to Urban Sustainability: An Investigation of the Economic Potential of Untreated Household Solid Waste (HSW) in the City of São Paulo

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Abstract: The depletion of natural resources, the useful life of landfill sites, and the amount of garbage accumulating all challenge public policy to manage urban solid waste. We identified the economic potential for unused solid waste (HSW) in São Paulo in 2018 to be USD 637,633,836.04 through descriptive quantitative research and documentary analysis in the collected data. This amount comes from five sources, with the majority coming from internalizing private cost credits (45.58%), followed by recycling (42.21%), carbon credits (5.46%), refuse-derived fuel (3.77%), and organic compounds (2.98%). This potential assumes the implantation of waste sorting plants that generate jobs, reduce public expenses, and provide environmental benefits such as forest protection, water, and minerals. The environmentally adequate final destination of HSW constitutes an economic and socio-environmental measure that enables the reverse logistics of the business sector and urban sustainability. Consequently, the economic potential of HSW, generated from its sorting and marketing, could provide a positive contribution with the mitigation of environmental impacts, in addition to income generation and social inclusion.

Keywords: urban sustainability; household solid waste; economic potential; gravimetry; São Paulo; Brazil; National Solid Waste Policy (NSWP)

1. Introduction

Environmental degradation is one of the main challenges for public environmental policies and has become a permanent agenda for many companies. The state, civil society, and organizations have all become increasingly aware when adopting actions based on environmentally responsible behavior [1]. The impact that solid waste production has on the environment was the object of research developed by Slomski et al. [2] (p. 1), whose results indicated that the company at the center of their study “generated 1,068,317 kilos of by-products. From this total, 902,289 kilos were recycled, and only 166,028 kilos of solid waste were disposed of in an eco-friendly manner.” With the implementation of reverse logistics, as foreseen by the National Solid Waste Policy (NSWP) [3], the company mitigated environmental impacts such as toxic gases, occupation of space in dumps, and extraction of raw material for the manufacture of new parts, “giving rise to financial-economic gains of USD 2,371,144.65” [2] (p. 1). In other words, the company assumed its responsibility in post-consumption and included costs of treating the products and packaging at the end of their useful lives into the costs of production.

The study by Kassai et al. [4] on the Current Account Balance warns that the planet will not be able to support the size of its population if the current models of extraction, production, distribution, consumption, and disposal continue, based on the beliefs and values adopted during the 20th century. The circular cycle adopted by the economies of companies in the last century held the assumption that resources were abundant and inexhaustible and, in some way, would be renewed. However, the by-products generated by current products and services do not always return to the state of raw materials, showing that society has broken the cycles of nature [1]. The authors concluded that, at one end, natural and non-renewable resources were being depleted and, at the other end, there is no solution for what to do with the solid waste that accumulates.

According to Romeiro [5] (p. 66), it is necessary for the “economic agents ‘to internalize’ the costs of the degradation they cause” and, in this regard, implementing actions based on environmentally responsible behavior becomes a fundamental issue, not only for the survival of companies but also for the planet, which has more than 7.7 billion inhabitants [6]. This statement means that companies need to adopt environmental management models that consider the entire life cycle of the product and include the costs of treating, disposing, and packaging it at the end of its useful life into the cost of cleaner production [7].

The abovementioned ideas highlight the fact that the essential environmental challenge faced by cities today is “the exhaustion of landfill space, the presence of waste collectors in dumps, the scarcity of areas available for the creation of additional landfill sites, and environmental impacts” [8] (p. 1). In this study, “landfills” are classified as repositories of projected and controlled solid waste and, “dumps” are classified as repositories of discarded solid waste without any criteria or control. Following this, the studies by Aryampa et al. [9] and Carlos et al. [10] declare that, in addition to economic costs, public expenses, and environmental impacts, the model of solid waste management, based on the collection and disposal of waste in landfills and dumps, disregards income generation, employability, and urban sustainability. This study aims to demonstrate that household solid waste is a source of income. The valuation of the economic potential generated by its sorting, and subsequent marketing, contribute to the mitigation of environmental impacts, encouraging income generation, and social inclusion. This understanding was the motivation for this research and led to the formulation of the following question: What was the economic potential of untreated household solid waste in the city of São Paulo in 2018?

In search of an answer to this question, this study’s general objective was to investigate the economic potential of untreated household solid waste in the city of São Paulo in 2018. This research will demonstrate that the screening and reuse of domestic solid waste, still ignored by municipal governments, is a socio-environmental and economically viable measure that could mitigate environmental impacts and have positive effects in terms of income generation, jobs, and social inclusion. It demonstrates that domestic solid waste is a source of income and that the commercialization and valorization of its economic power is an alternative way to improve domestic solid waste management practices in municipalities and, thus, lead to the development of a more sustainable culture.

2. Sustainable Economic Development

The terms “economic development” and “sustainability” are involved, unclear, and diffuse, and it is necessary to clarify the point of view that this study defends. For Slomski et al. [1] (p. 280), “countries, today considered developed, have degraded their rivers and decimated their flora and fauna”; however, today it is these same countries that advocate sustainable development. The environmental issue is the current agenda of European countries that, in the past, placed a high value on economic stability with no concern for environmental degradation. In this context, this study considers that externalities resulting from the effects caused by productive activity must be the responsibility of all (industry, commerce, consumers, and the state), and defends sustainability as the “capacity to satisfy the needs of the present in an equal way, without compromising the possibilities of survival and prosperity of future generations” [11] (p. 117).

Environmental degradation has been one of the significant challenges of so-called environmental economics. The studies by Mcneill [12] and Gao et al. [13] discuss the current economic development model and, in it, the issues related to sustainability as being the model that derives from production chains in order to develop themselves and adopt nature protection measures, considering its constant renewal with “concerns that range from the extraction of the raw material to the final destination of the product or its packaging, in other words, to be economically viable, being socially ethical and fair” [1] (p. 280). In this way, productive chains with the ability to preserve the environment to ensure the rights of present and future generations consider the interdependence between economic development and quality of life, since there is no way to talk about economic development without having ecological sustainability as an assumption [14].

The problems caused to the environment stem from the indiscriminate use of natural resources. However, there is a perception that, if these sources of wealth are not preserved, the survival of future generations may be compromised. This reality made the economic theory rethink its concept. Thus, there is an urgent need to redirect the entire logic of economic thought towards long-term planning that contemplates social and environmental aspects as part of the strategy of human existence [15]. From this point of view, sustainability directly influences the companies’ behavior, which faces economic and social and environmental problems [1,16,17]. From this perspective, the concept of sustainability, defended by this study, concerns: “A production chain that, to develop itself, does not degrade the environment but considers its sustainability, and the possibility of its constant renewal. Has concerns that range from the extraction of the raw material to the final destination of the product or its packaging, in other words, to be economically viable, being socially ethical and fair” [1] (p. 280).

In the scope of discussions on sustainability, the topic of urban solid waste plays a fundamental role, primarily due to the volume produced, the dangerousness of some waste, the problems related to inadequate management, and the lack of areas for the final disposal of such waste. Due to this set of aspects, solid waste has gained space on the agendas of companies, researches, governments, and legislature. Slomski et al. [1] (p. 276) warn of the fact that, for the production of goods and services, companies must use resources and strategies that consider sustainability; in this way, they must consider the entire life cycle of the product and, in this context, “understand where their industrial costs start and end.”

2.1. An Overview of Urban Solid Waste in Brazil

The Brazilian Standard—NBR 10,004 (a standard of Brazilian Association of Technical Standards or ABNT in Portuguese, which establishes the criteria solid waste classification in terms of its potential risks to the environment and human health) [18], classifies solid waste according to solid and semi-solid states, resulting from the community’s industrial, domestic, hospital, commercial, agricultural, services, and sweeping activities. Included in this definition are sludges from water treatment systems, those generated in pollution control equipment and installations, as well as certain liquids whose particularities make their launch into the public sewage system or bodies of water unfeasible, or requirements for this are technically and economically unviable solutions given the best available technology.

This definition is in line with what the NSWP—Law 12,305 of 2010 [3]—proposes in its article 3, item XVI, which defines solid waste as a material, substance, object or good discarded, resulting from human activities in society, whose final destination proceeded, proposed to proceed or is obliged to proceed, in solid or semi-solid states, as well as gases contained in containers and liquids whose particularities make its discharge into the public sewage system or bodies of water unfeasible, or requirements for this are technically or economically unviable solutions because of the best available technology. This characterization highlights the need for attention and specialized care for all objects and/or bodies when disposing of them. The standard classifies solid waste into two classes: Class I—Hazardous and Class II, represented by two subclasses: A—Non-inert and B—Inert.

Among the types of existing solid waste, there is urban waste, composed of household waste and those from urban cleaning. Thus, urban solid waste can be more broadly defined as being a complex set of solid waste generated in homes and commercial establishments and service providers,

as well as those resulting from cleaning activities (sweeping, weeding, pruning) of public roads and places, except health services, hazardous industrial wastes, and the waste from ports and airports, due to the risks of soil contamination and improper handling, if they are discharged in “dumps” [19,20].

The search for solutions capable of containing the disproportionate increase in waste accumulated in the environment has led government agencies to establish rules for its identification and storage, giving rise to techniques for handling this waste. These rules include collection, transportation, packaging, treatment, and final disposal actions. Among the possible classifications of these wastes, the most adequate to the objective pursued here is that which considers the moment in which it is generated. There are two categories: that of post-industrial waste, generated as burr of the production processes, either as maintenance scraps or as obsolescence of machinery and equipment, and the category of a post-consumption waste result of the disposal of leftovers when consuming goods or services. Household waste is an example of the latter category.

Current sources such as the annual report entitled “Panorama of Solid Waste in Brazil”, published by the Brazilian Association of Public Cleaning and Special Waste Companies, demonstrated that, in 2017, 78.4 million tons of solid waste were produced in Brazil [21]. However, of this collected amount, 29 million tons were deposited in controlled landfills and dumps distributed in 3352 cities. This report also shows that the urban cleaning market generated around 337 thousand jobs and mobilized BRL 28.5 billion. The cost of these services consumed approximately BRL 10.37 per inhabitant/month from public coffers [21] (p. 14). According to Adeodato Filho [22], short-term measures are adopted by public managers because of the problem of solid waste to the detriment of prioritizing more assertive decision-making in the solid waste management system in cities. Such decisions are due to the cost of selective collection and the installation of sorting sheds. However, disregarded are the environmental/social benefits and the economic potential of solid waste. This perspective makes use of immediate measures: when considering only the ratio between revenues and expenses, it ends up hampering an eco-friendly and potentially beneficial practice for the natural resources, the productive sector, and public costs.

For the Business Commitment to Recycling (Compromisso Empresarial para Reciclagem—CEMPRE) [23], different factors interfere in the generation of waste, from consumer preferences and habits and customs, seasonal and climatic variations, demographic density, specific laws, and regulations. In accordance with these factors, research data carried out by the Institute for Applied Economic Research [24] indicate that the composition of household waste in Brazil, in 2010, presents the following gravimetric composition: (a) organic matter (51.4%); (b) plastic (13.5%); (c) paper/cardboard/long-life packages (13.1%); (d) glass (2.4%); (e) ferrous metals (2.3%); (f) aluminum (0.6%); and (g) others (16.7%). Of these materials, paper/cardboard, plastic, glass, aluminum, and ferrous material stand out most, adding up to 31.9%. Calderoni [25] warns about the economic, environmental, and social potential of recycling urban waste and highlights the viability of this economic activity by estimating the value of recyclable waste inappropriately wasted/disposed in dumps and sanitary landfills at over one billion reais. With this approach, Freitas and Damasio [26] calculated the revenue that the State of Bahia failed to obtain in 2003, due to not treating urban waste, at more than 700 million. On the other hand, the Institute for Applied Economic Research (IPEA) estimated the potential benefits of recycling in Brazil at BRL 8 billion annually [24].

2.2. National Solid Waste Policy in Brazil (NSWP)

The sustainability of production systems requires manufacturers to design products with the principles of sustainability, such as reducing waste generation, reusing and recycling, where reverse logistics is a way of adding value to the product in an increasingly competitive market [27]. In its legal framework, Brazil is ahead of other countries by establishing that the ecologically balanced environment is a constitutional right and, because it is in everyday use by the people, it is the duty of the Public Power and the community to defend and preserve it (article 225 of the Brazilian Federal Constitution) [28]. As a result of this article, the duty arises to create infra-constitutional instruments and tools that deal with the means to achieve the objective of preservation, as well as determining who are the parties responsible for repairing any damage caused to the environment.

In this framework, the National Environment Policy (Law 6938/1981) [29] deals with the social and legal responsibilities of all parties responsible for preserving, improving, and restoring environmental quality, in a way that guarantees right living conditions. Following this same logical line, article 4, item VII, of Law 6938/81, determines “the imposition, on the polluter and the predator, of the obligation to recover and compensate the damages caused, and to the user, of contribution for the use of environmental resources for economic purposes” [29], which, like article 225 of the Brazilian Federal Constitution [28], provides for the ‘polluter pays’ principle.

The National Solid Waste Policy (NSWP), instituted by Law 12,305/2010 [3], has principles, objectives, instruments, guidelines, goals and actions that seek to ensure greater efficiency in the disposal and recycling of waste. Its importance lies in post-consumer accountability directly related to the idea of environmental preservation throughout the product’s life cycle. Thus, one of the main instruments of application of the regulatory mark is reverse logistics, since its actions, procedures, and means seek to “enable the collection and return of solid waste to the business sector, for reuse, in its cycle or other productive cycles, or other eco-friendly final destination” (article 3, item XII, Law 12,305/2010) [3]. According to Leite, Reverse Logistics is “the business logistics area that plans, operates and controls the flow and corresponding logistical information, from the return of post-sale and post-consumer goods to the business cycle or the production cycle, through reverse distribution channels, adding the value of different kinds: economic, ecological, legal, logistical, of corporate image, among others” [30] (pp. 16–17).

These measures for returning the product to its origins have become a legal requirement that requires importers, distributors, manufacturers, or traders of specific products (recyclable products) to compose a logistical structure. This structure provides the return of the generated products to their starting point so that it can be reused in the production cycle (raw material), for the generation of another product or, only, for proper disposal [27]. When studying solid waste management in the metropolitan region of São Paulo, Castro Neto and Guimarães [31] observed that domestic waste management was a problem arising from legal inaccuracy in the Brazilian Constitutional Law when it did not specify the responsibility of federative entities. This gap in the legislation was filled by article 10 of Law 12,305/2010 [3]. According to the Law, the Federal District and the cities are responsible for managing solid waste generated in their territories. NSWP [3] has become an essential instrument for harmonizing economic development and environmental preservation, and its guidelines encourage a sustainable, productive system guided by integrated management and accountability in post-consumption.

2.3. Urban Solid Waste Management and Administration Practices

According to NSWP [3], item X of article 3, solid waste management and administration practices are considered the set of actions exercised, directly or indirectly, in the stages of eco-friendly collecting, transporting, transshipment, treatment, final disposal of solid waste and final eco-friendly disposal of residues, following with the municipal plan for the integrated management of solid waste or with the plan for the management of solid waste, required under this law. Additionally, this same law highlights, using article 9, as a priority in the management and administration of solid waste, the observation of the items in the following order: “non-generation, reduction, reuse, recycling, treatment of solid waste and final eco-friendly disposal of residues” [3]. Araujo and Altro [32] (p. 312) say that it will be necessary to adopt integrated management practices for “society, collectors and collectors’ cooperatives, generators and consumers of waste, in addition to universities, which are proponents of methodologies and disseminators of knowledge about the challenges at hand.”

Regarding the elements of solid waste management best practices listed by Law 12,305/2010 [3], environmental management has essential tools that must be used according to the municipal plan’s instructions for integrated management of solid waste or any management plan for solid waste. From then on, this waste follows a path until its cycle is renewed or extinguished. Regardless of its “destination”, the waste begins its trajectory from the collection. Depending on how this material is carried out, it will be reintroduced or not to the productive environment. After being collected, both the waste from the selective collection and the conventional collection are transported to sanitary

landfills, open dumps, or, in the best case, are taken to the solid waste treatment centers. According to Campos [33], waste recovery activities are carried out in these places, such as “receiving and storage, separation of bulky, hazardous, food wastes, pressing, baling, marketing, disposal of waste (fuel residues without market value) such as Refuse Derived Fuel (RDF) or for final disposal in sanitary landfill” [33] (p. 34).

Based on item X, article 3, of the Law 12,305/2010 [3], the types of treatment and final destination that can be applied to household waste are discussed. According to Souto and Povinelli [34], the treatment of solid waste comprises the use of tools that allow the volume of waste to stabilize or even be reduced, thus contributing to increase the usable space of landfills.

These abovementioned waste utilization techniques can be inserted in some industrial and agricultural production processes or even in the energy generation process. Upon reaching the waste sorting plants, the waste is subjected to separating recyclable and non-recyclable materials. The so-called recyclable materials are subsequently reintroduced into the production system and contribute to the generation of new products. In parallel, non-recyclable ones, mostly organic matter, are submitted to recovery processes, such as, for example, composting and RDF manufacturing [33], ([35], pp. 53–54).

The waste separation process may include from the most primitive form, which is the manual collecting or separation, to modern equipment with various levels of technology. Even so, whether the plants have little or much technology in their processes, manual sorting is essential at some stage of the process [33] (p. 37). After sorting the materials, other operational resources can be applied to promote their use. In this logic, recycling is one of the ways to use it.

According to Law 12,305/2010, in its item XIV of article 3 [3], recycling is understood as the process of transformation of solid waste that involves changing its physical, physical-chemical or biological properties, with a view of transforming it into inputs or new products, subject to the conditions and standards established by the competent bodies of the National Environment System (NES) and, if applicable, the National Health Surveillance System (NHSS) and the Unified Agricultural Health Care System (UAHCS) [3]. Recycling is defined by Souto and Povinelli [34] (p. 584) as “the reuse of waste in some production process.” According to these authors, the type of material to be recycled determines whether it will be crushed or ground. This procedure facilitates the process of transport, storage, and processing of these materials. As benefits and importance, Besen et al. [36] (p. 259) highlight that “the selective collection and recycling of recyclable waste are activities that contribute to urban sustainability with impacts on environmental and human health.”

Composting, on the other hand, uses solid organic waste, being defined by Bidone and Povinelli [37] as an aerobic biological treatment process that transforms organic waste into a stabilized material, which results in what is called compound or humus. In addition to recycling and composting, the HSW can also be subjected to the incineration process. This process is classified according to the type of system used, which is defined based on the occurrence or not of preliminary treatment. Gripp [38] (p. 9) classifies incineration into two types: I—Direct Burning Incineration and II—Refuse-Derived Fuel Incineration. The difference between them is that, in the direct burning incineration, the residues do not undergo any kind of prior separation before being sent to the combustion chamber.

In contrast, in the incineration by RDF, the residues are previously separated, and only that fraction said without economic value for recycling is crushed and transformed into RDF. With the generation of heat from the burning of waste, it is possible to carry out energy recycling. According to Souto and Povinelli: “Energy recycling can be direct or indirect. In direct recycling, the residues are used directly as the energy source and may go through some simple treatment processes such as fragmentation or grinding. In indirect recycling, waste is converted, chemically or biologically, into other materials, which are used as a source of energy” [34] (p. 583).

With the adoption of eco-friendly measures, such as the sorting and reuse of solid waste, the productive sector, the society, and the cities can collaborate to minimize problems with the exhaustion of the landfill’s space, the presence of waste collectors in the dumps and the scarcity of areas available for the creation of other landfills. On the other hand, are instigated benefits such as job creation, social inclusion of waste collectors, and mitigation of impacts on the environment.

2.4. Internalizing Private Costs Credit (IPCC): An Alternative Way to Reverse Logistics

The commercialization of IPCC is an essential tool for the industry to meet the requirements of the NSWP. The legal mark obliges the production chains to implement reverse logistics (RL) systems to proceed with the eco-friendly destination of products and packaging in post-consumption. That is, to treat and correctly dispose of the solid waste generated because of its economic activity. The purchase of IPCC serves as an alternative to the reverse logistics that the industry should proceed with. According to the NSWP [3] proposal, the industry must take responsibility for the generated solid waste, proceeding with the treatment and the correct final destination of its products and/or packaging in post-consumption. However, it has been noticed that the public authorities are responsible for the collection and final destination of solid waste generated in the cities, maximizing their public spending and minimizing the costs of the industry that, although generating waste, maximizes its profits, since it does not include the treatment and final destination of what it produces [39].

For the industry, setting up a reverse logistics chain is exceptionally costly, not to mention that it would be a different field. This gap, which the public authorities fill today and impacts their budget, should be the industry's responsibility to adopt measures to meet what the NSWP determines. These ideas are corroborated by Slomski et al. [40], as they consider the creation of a Waste Final Disposal Industry (WFDI), remunerated by companies when they acquire IPCC. The WFDI was conceived by the authors Slomski et al. [1] and allowed the industry to acquire credits that replace the reverse logistics operation of the solid waste produced by it. The authors classify the IPCC as a way of internalizing business costs and define them as: "a title to be sold, in a competitive market, whose objective is to facilitate the process of collection and final disposal of all household waste in cities, with the full participation of all the companies that contributed to its generation, either by packaging or by the product itself. The IPCC will be issued by concessionaires accredited in the waste final destination chain, according to the volume of daily production" [1] (p. 285).

This alternative to reverse logistics with the acquisition of IPCC assumes that development and sustainability impose environmental management concepts and best practices that consider the entire life cycle of the product, from its design to its disposal. This model of solid waste management is defended by NSWP [3], which requires the production chain to proceed with reverse logistics, with this instrument being the flagship of the regulatory mark. In this way, the Cost Accounting must internalize the expenses with the treatment and final destination of the product and/or packaging to the production costs and/or with the acquisition of the IPCC.

In the current scenario, most of the Brazilian industry has not yet proceeded to reverse logistics and, thus, does not internalize the costs of treatment of the packaging and/or product to the costs of production. However, industries need to "internalize as a cost of production the collection and disposal of what is their responsibility, to become sustainable" [1] (p. 286). From this point of view, Slomski et al. [1] present a proposal for the internalization of IPCC, in which a cost of at least BRL 1.00 is attributed to each kilogram of material used with the potential to generate solid waste. The authors exemplify the following: in monthly production of soft drinks with the use of tons of PET bottles, with the acquisition of 1000 IPCC at BRL 1.00, we have the following situations:

First case (Without IPCC-current): Finished Product Cost (BRL 100,000) + Internalizing Private Cost Credits (BRL 0.00) = Total Finished Product Cost (BRL 100,000). Second case (With IPCC-future): Finished Product Cost (BRL 100,000) + Internalizing Private Cost Credits (BRL 1000.00) = Total Finished Product Cost (BRL 101,000) [1] (p. 286).

These examples show that the industry would be held responsible and the WFDI would make it feasible, so that the total cost of the product would be considered, in which "the cost of the IPCC would increase the cost of the finished product and the entire production process would be under the responsibility of the industry, without producing negative externalities" [1] (p. 286), in which the industry would not need to implement reverse logistics processes. However, "all production costs

will be internalized, without the industry having to create instruments to collect their packaging” [1] (p. 286).

In line with the abovementioned, this research highlights the application of the models proposed by Braz [41] and Slomski et al. [1] on environmental management practices, in which the reverse logistics of the product includes the collection, treatment, reuse and eco-friendly disposal of the product at the end of its useful life. The authors Slomski et al. [2] (p. 85) proved the viability of this logic and reinforced the need to implement the WFDI, as the industries “must dedicate themselves to the development of their products, leaving to the WFDI the process of reverse logistics and eco-friendly disposal of products at the end of their useful life.”

3. Research Methodology

Considering that the objective of this research was to highlight the economic potential of untreated household solid waste in the city of São Paulo in 2018, we chose to conduct descriptive-quantitative research. The descriptive research, according to Gil [42] (p. 28), aims “the description of the characteristics of a given population or phenomenon, or the establishment of relationships between variables.” Martins and Theóphilo [43] (p. 107) add that descriptive research aims to “organize, summarize, characterize and interpret the collected numerical data.”

The field of this study was the Municipal Department of Urban Development of the city of São Paulo. This department has an Interministerial Committee for the Municipal Solid Waste Policy, composed of the Municipal Authority for Urban Cleaning and the Secretariat for the Environment of State of São Paulo. The managers of these municipal departments provided the data, and the companies were contracted for the collection of urban garbage. The choice for the city of São Paulo was because it is the largest Brazilian city, and it has the most significant number of inhabitants, thus producing a large daily amount of solid household waste.

3.1. Methods, Techniques and Instruments for Data Collection

As a Data Collection Technique, Document Analysis was used based on the instrumental basis of this research. According to Martins and Theóphilo [43] (p. 53), this technique is used by “studies that use documents as a source of data, information, and evidence.” Considering that the field research began in 2018, the documents of the year 2017 were taken as a historical date to determine the composition of gravimetry. Technical visits to the Municipal Departments of Urban Cleaning, and meetings with managers of the companies responsible for the collection of household waste were held in the city of São Paulo to identify the documents that would answer the research question.

The documents used for data collection consisted of seven main reports: (a) Reports “Quantitative, waste collected in the city of São Paulo (2013 to 2019)”, meets the objective of identifying the volume of untreated household solid waste (destined to landfills) in the city of São Paulo in 2018; (b) Quarterly reports on the gravimetric composition of household solid waste for 2017, sent by the concessionaires that collect garbage in the municipality. Excel spreadsheets were created for these reports and applied the mathematical formula of arithmetic mean to obtain gravimetry by four months and year 2017; (c) Report for the pricing of recyclable materials, obtained on the website of the Business Commitment for Recycling (CEMPRE) [23]; (d) Quotation report to estimate the commercialization of carbon credits, obtained on the website Investing.com [44]. The value for the commercialization of carbon credits was obtained from the following procedure conversion of the value from euros (EUR) to reais (BRL) using the conversion platform of the Central Bank of Brazil (<https://www.bcb.gov.br/conversao>). On July 26th, 2019, the euro closed trading for R \$4.1958; report of equivalence of ton of recycled material to calculate the reduction of CO₂ emissions, obtained on the IPEA website (https://www.mma.gov.br/estruturas/253/_arquivos/estudo_do_ipea_253.pdf, p. 17), recovered on July 28th, 2019); (e) Study by Mamede [45] (p. 48) was extracted value for the commercialization of Waste Derived Fuel (CDR); (f) Report “Technical Data Sheets-Organic Compound” for pricing the value of organic compost, obtained on the website of the Business Commitment for Recycling (CEMPRE) (<http://cempre.org.br/artigo-publicacao/ficha-tecnica/id/10/composto-urbano>, retrieved on 3 July 2019). The following procedures were performed: (a)

identification of the values for the commercialization of the organic compound; (b) calculation of the arithmetic mean of these values; (g) Study by Slomski et al. [1] (p. 286) from where the value for the marketing of IPCC was extracted; estimates for the Marketing of Internalizing Private Costs Credit (IPCC): An Alternative Way to Reverse Logistics (RL).

Development of Data Collection Instruments

The data collection instrument was composed of seven parts, namely: (a) Part 1 identifies the volume of untreated household solid waste (HSW) (destined to landfills) in the city of São Paulo in 2018 (Table 1); (b) Part 2 determines the gravimetric composition of household solid waste in the city of São Paulo in 2017 and has variables such as types of materials, gravimetric composition, quantity produced in the month and year 2017 (Table 2); (c) Part 3 estimates the market potential of household solid waste that can be continuously recycled from the untreated volume in 2018, from the gravimetry of 2017. The following variables are the gravimetric composition of household solid waste in the city of São Paulo in 2017 that could be recycled, the volume of untreated household solid waste (destined to landfills), the market value per kilo and ton of recycled material (Table 3); (d) Part 4 estimates the market potential for the marketing of carbon credit (CC) based on the total recycling materials contained in the untreated volume in 2018. The variables are volume of untreated household solid waste (destined to landfills) that can be recycled, an index equivalent to tons of CO₂ not released into the atmosphere due to recycling (Table 4); (e) Part 5 estimates the market potential in the marketing of Waste Derived Fuel (CDR), based on the total non-recycling materials contained in the untreated amount in 2018. The variables are: household solid waste that cannot be recycled, the volume conversion rate of the material at the end of the process and the market value per ton of CDR (Table 5); (f) Part 6 estimates the marketing of Organic Compound (OC). The variables are: household solid waste not subject to recycling, the conversion rate of the material volume at the end of the process, and market value per ton of organic compound (Table 6); (g) Part 7 estimates the trade of Internalizing Private Costs Credit (IPCC). To estimate another source of income, such as reverse logistics credits or IPCC, the values attributed by Slomski et al. [1] (p. 286) were used, who converted an IPCC to one kilo of the material. Having made this equivalence, they determined that each IPCC should be sold for a price of BRL 1.00 (one real), given the socio-environmental impact that solid waste from production activities causes to the environment and the public coffers. Thus, Table 7 provides a demonstration of the economic potential that HSW in the city of São Paulo can offer to the Waste IDF, considering the price of one real (BRL 1.00) or (USD 0.2581) per treated kilo.

Table 1. Untreated household waste in the city of São Paulo in 2018.

	Average (Tons/Month)	Total (Tons/Year)	%
Amount of waste collected	314,181.75	3,770,181	100.00
Amount from selective collection	7,326.75	87,921	2.33
Amount of untreated household waste	306,855.00	3,682,260	97.67

Source: Research data.

Table 2. Gravimetric Composition, based 2017—city of São Paulo.

Material Types	%	Tons/Month	Tons/Year
Aluminum	0.43	1,319.48	15,833.72
Rubber	0.34	1,043.31	12,519.68
Miscellaneous	0.87	2,669.64	32,035.66
Long-life package	0.76	2,332.10	27,985.18
PET package	1.04	3,191.29	38,295.50
Foam	0.29	889.88	10,678.55
Diapers and tampons	6.34	19,454.61	233,455.28
Styrofoam	0.27	828.51	9,942.10
Electronic waste	-	-	-
Wood	1.3	3,989.12	47,869.38
Organic matter	53.16	163,124.12	1,957,489.42
Ferrous metals	0.92	2,823.07	33,876.79
Paper, cardboard, and newspaper	10.83	33,232.40	398,788.76
Batteries	-	-	-
Hard plastic	5.55	17,030.45	204,365.43
Soft plastic	8.99	27,586.26	331,035.17
Earth and stone	0.67	2,055.93	24,671.14
Rags and cloths	5.73	17,582.79	210,993.50
Glass	1.94	5,952.99	71,435.84
Subtotal	99.43	305,105.93	3,661,271.12
Process losses	0.57	1,749.07	20,988.88
Total	100	306,855.00	3,682,260.00

Source: Research data.

Table 3. Estimate for the recycling potential.

Gravimetric Composition By Material Type/Household Solid Waste (HSW)	%	Estimated Tons Volume/Year/HSW	Value	Amount Ton	Estimated Total Sales Value
			USD/KG	USD/TON	USD/TOTAL
			A	B = (c * 1000)	E = (b * d)
Aluminum	0.43	15,897.74	1.0323	1,032.2600	16,410,570.32
Long-life package	0.76	28,098.32	0.0645	64.5161	1,812,794.84
PET package	1.04	38,450.34	0.6968	696.7700	26,791,204.65
Ferrous metals	0.92	34,013.76	0.1548	154.8387	5,266,646.71
Paper, cardboard, and newspaper	10.83	400,401.13	0.1652	165.1613	66,130,767.28
Hard plastic	5.55	205,191.71	0.4774	477.4200	97,962,493.81
Soft plastic	8.99	332,373.61	0.1548	154.8387	51,464,300.90
Glass	1.94	71,724.67	0.0465	46.4516	3,331,726.61
Total	30.46	1,126,151.28			269,170,505.11

Source: Research data.

Table 4. Estimate for the marketing of carbon credits (CC).

Material Types	Physical Quantity HSW	Carbon Credit Recycling Benefits (CC)	Total Carbon Credit	Market Value of Ton of Carbon Credit	Potential Sales Value of Carbon Credit
	TON	CC/TON	CC/TOTAL	USD/TON/CC	USD/TOTAL
	A	B	C = (a * b)	D	E = (c * d)
Aluminum	15,897.74	5.08	80,760.52	30.60	2,471,167.68
Ferrous metals	34,013.76	1.44	48,979.81	30.60	1,498,719.12
Paper, cardboard, and newspaper	400,401.13	0.27	108,108.31	30.60	3,307,974.64
Plastic (hard, soft, PET)	576,015.66	1.53	881,303.96	30.60	26,966,764.00
Glass	71,724.67	0.25	17,931.17	30.60	548,670.59
Total	1,098,052.96		1,137,083.77		34,793,296.03

Source: Research data.

Table 5. Estimate for the marketing of Refuse-Derived Fuel (RDF).

Gravimetric Composition By Material Type/Household Solid Waste (HSW)	%	Estimated Tons Volume/Year/HSW	Useful Conversion Rate/HSW	Amount Ton	Estimated Total Sales Value
				USD/TON	USD/TOTAL
	A	B	C = (b * 0,30)	D	E = (c * d)
Rubber	0.34	12,570.30	3,771.09	143.1019	539,650.14
Miscellaneous	0.87	32,165.19	9,649.56	143.1019	1,380,870.37
Foam	0.29	10,721.73	3,216.52	143.1019	460,290.12
Diapers and tampons	6.34	234,399.18	70,319.75	143.1019	10,062,889.83
Styrofoam	0.27	9,982.30	2,994.69	143.1019	428,545.83
Wood	1.3	48,062.92	14,418.88	143.1019	2,063,369.12
Rags and cloths	5.73	211,846.58	63,553.97	143.1019	9,094,693.86
Total	15.14	559,748.21	167,924.46		24,030,309.28

Source: Research data.

Table 6. Estimate for the marketing of organic compound (OC).

Gravimetric Composition by Material Type/Household Solid Waste (HSW)	%	Estimated Tons Volume/Year/HSW	Conversion Rate HSW	Amount Ton	Estimated Total Sales Value
				USD/TON	USD/TOTAL
	A	B	C = (b * 0.30)	D	E = (c * d)
Organic matter	53.16	1,965,403.88	589,621.16	32.2581	19,020,034.76
Total	53.16	1,965,403.88	589,621.16		19,020,034.76

Source: Research data.

Table 7. Marketing of Internalizing Private Costs Credit (IPCC).

Gravimetric Composition By Material Type/Household Solid Waste (HSW)	Estimated Tons Volume/Year/HSW	Volume/Year/HSW	Amount Ton	Estimated Total Sales Value
			USD/TON	USD/TOTAL
	A	B = (a * 1000)	C	D = (b * c)
Aluminum	15,897.74	15,897,740	0.2581	4,102,642.58
Long-life package	28,098.32	28,098,320	0.2581	7,251,179.35
PET package	38,450.34	38,450,340	0.2581	9,922,668.39
Ferrous metals	34,013.76	34,013,760	0.2581	8,777,744.52
Paper, cardboard, and newspaper	400,401.13	400,401,130	0.2581	103,329,323.87
Hard plastic	205,191.71	205,191,710	0.2581	52,952,699.35
Soft plastic	332,373.61	332,373,610	0.2581	85,773,834.84
Glass	71,724.67	71,724,670	0.2581	18,509,592.26
Total	1,126,151.28	1,126,151,280		290,619,685.16

Source: Research data.

For Data Analysis, mathematical calculations were used, with basic rules of multiplication, division, sum, and subtraction, with Excel spreadsheets, specially prepared for this research. According to Richardson [46] (p. 70), in the measurement, “the data are translated by numbers, quantities, relations, and parallels according to the rules of mathematics.”

4. Results and Discussions

In this section, results and discussions are presented with the theoretical foundations.

4.1. Untreated Household Solid Waste (HSW) and their Environmental Impacts

Based on the Quantitative Reports of Household Waste collected in the city of São Paulo in 2018, it was possible to update data on the amount of waste disposed of in landfills. According to the methodology used in Table 1, it was found that on this historic date, 3,697,148 tons of household waste were not used, equivalent to 308,095.67 tons/month. Consequently, such waste did not have a final eco-friendly destination going directly to landfills.

These results indicate that the amount of HSW treated in the city is meager; the 3,682,260 tons of household waste, equivalent to 306,855 tons/month, impacted the environment, and generated expenses for the city. On the other hand, cooperatives also failed to promote recycling, obtain revenues, and reduce use of natural resources. While there is no way to overcome the problems caused by the disposal of collected solid waste, the city continues to suffer from the daily implications imposed by a management that is limited almost exclusively to the collection, transport, and landing of household solid waste generated by the city, while ignoring the economic potential and benefits that waste sorting generates [47].

4.2. Gravimetric Composition

The data in Table 2 show that the gravimetric composition of the HSW for the year 2017 in the City of São Paulo, based on the untreated volume of 3,682,260 tons, was composed of 53.16% of organic matter, 30.46% of recyclable materials, followed by 16.38% of residues.

These data indicate that the city's expensive management model does not solve the environmental and social problem, as it continues an unsustainable system that discards raw materials. Equally, this does not reduce greenhouse gases (GHG) emissions, it does not promote the social inclusion of waste collectors, and it does not yet use waste to generate revenue from energy and materials marketing. In this way, it generates environmental impacts and expenses to the city, and the cooperatives also fail to promote recycling, obtain revenues and reduce the use of natural resources.

Thus, the high percentage of waste (97.96%) that failed to receive adequate treatment confirms what Besen et al. [36] concluded in their study, when they declared that cities in the metropolitan region of São Paulo give little priority in the public agenda for the selective collection. Following that, Paschoalin Filho et al. [48] and Venanzi et al. [47] consider that the low level of the selective collection in the city is due to the low adhesion in separating the residues in the generating source. According to Venanzi et al. [47], in addition to health problems, separation doubles the sorting work, as it makes it more detailed. For Almeida et al. [49], the answer to explain this reality is that there is a certain distance between the citizens' speech and the practice in supporting selective collection and recycling processes.

4.3. Estimate for the Marketing of Recyclable Materials

Based on the gravimetry of 2017 and the amount discharged in the year 2018 (3,697,148 tons/year), the recycling potential was estimated this year. According to Table 3, the total of solid household waste collected in 2018 with recycling potential was 1,126,151.28 tons. Of this total, 30.46% of the materials were recyclable, and was disposed of almost a third in landfills.

The economic potential that the HSW discarded by the city of São Paulo has from their recycling corroborates the study by Souza et al. [50], which also identified an amount equivalent to R 80 and 104 million wasted annually, in the city of Porto Alegre/RS. Therefore, large Brazilian cities despise the economic potential that HSW can offer.

These results demonstrate that the solid waste management model adopted by the studied city is incompatible with urban sustainability. It improperly discards the collected solid waste, not complying with the provisions of the NSWP (Law 12,305/2010) [3] regarding the treatment and eco-

friendly disposal of the collected waste. This view is supported by authors such as Foladori [11], Löwy [51] and Slomski et al. [40] regarding the search for an economic model that makes sustainable use of natural resources. This scenario of wasting income, raw materials and natural resources with the disposal of materials that can be recycled is by the point of view of Gouveia [52]. The author emphasizes that recycling is a tool with the potential to mitigate environmental impacts and generate benefits, such as job and income opportunities, the return of materials to the production cycle, energy savings, raw materials, and reduction of materials destined to landfills.

4.3.1. Estimate for the Marketing of Carbon Credits (CC)

The waste that can be recycled, except for a long-life package, was listed in Table 4 to be converted and priced according to the quotation for its sale. The price of the carbon credit on July 26th 2019 was traded on the London Stock Exchange for € 28.26 per ton of equivalent carbon, converted to the value of the euro quoted on the same date for BRL 4.1958, and resulted in BRL 118.57 for each carbon credit.

The marketing of carbon credits from recycling can be considered as a sustainable alternative for generating revenues. In accord with that, Slomski et al. [1,40] also considered the marketing of carbon credits as a revenue source for the operation of the Waste Final Disposal Industry. Thus, the recycling of HSW has the potential to raise revenue [41,50,53–55]. Besides, Besen et al. [36] stated that the recycling of materials contributes to urban sustainability with effects on environmental and human health.

4.3.2. Estimate for the Marketing of Refuse-Derived Fuel (RDF)

To estimate RDF's economic potential, we excluded waste that can be recycled (Table 1), organic matter, earth and stone. Mamede [45], in his study, outlines routes for energy use from urban solid waste, namely, those with fuel bias with anaerobic digestion and production of RDF, or electricity generation bias using anaerobic digestion and incineration. This proposal is corroborated by Sampaio [56], when he argues that the production of RDF has benefits. He says that "the equipment is cheaper because there is no need to burn 100% of RDF" and he points out, as an example, "the combined combustion of sugarcane bagasse and RDF" [56] (p. 49).

According to the estimate made, the RDF produced at the Sorting Factories can be used as an auxiliary fuel in industrial ovens of cement factories and also in alcohol and sugar factories. According to Sampaio [56], considering only the State of São Paulo, there were approximately 170 alcohol and sugar factories that make use of RDF. Using the RDF, these factories will spend less on other more expensive fuels and, consequently, contribute to the reduction of waste deposition in landfills, now close to saturation.

4.4. Estimate for the Marketing of the Organic Compound (OC)

For the results in Table 6, it was necessary to take into account that, according to CEMPRE [57], the price of the organic compound, also called fertilizer, varies between BRL 100.00 and BRL 150.00 and, in this case, the average of these values was used to price the ton of the compound. Another thing that also needs further explanation is that, during the composting process, organic matter undergoes biological mutations that culminate in weight and volume loss. Therefore, the conversion rate of 30% from organic matter to compound was used. According to Table 6, the amount of HSW produced in the city of São Paulo was susceptible to composting.

These results, keeping the production proportions for each year, corroborate with Culi and Contrera [58], who also studied the HSW of the city of São Paulo, and demonstrated, based on the amount of organic matter of that year, that it was possible, depending on the composting technology, to obtain between 3237.21 and 1618.61 tons/day of the compound. Although there are other ways of using organic matter, such as the capture of methane in landfills or biodigester use, composting presents itself as a low investment and maintenance technology is considered. Its results allow to

reduce GHG emissions and obtain a high-quality organic compound for agricultural use and, also, to be subject to marketing [59] (p. 20).

The studies by Aprilia et al. [60] and Harir et al. [61] highlight composting as an alternative for waste management and revenue generation. Composting meets the requirements of the NSWP (Law 12,305/2010) [3] and generates benefits for the environment. Finally, it should be noted that the implementation of composting will comply with the provisions of article 36, item V, of Law 12,305/2010 [3]. The law states that it will be up to the holder of public services for urban cleaning and solid waste management, with the municipal plan for integrated management of solid waste, to implement a composting system for organic solid waste, as well as articulate, with the economic and social agents, the ways of using this compound.

4.5. Estimate for the Marketing of Internalizing Private Costs Credit (IPCC): An Alternative Way to Reverse Logistics (RL)

To estimate another source of income, such as reverse logistics credits or IPCC, the values attributed by Slomski et al. [1] (p. 286) were used, who converted an IPCC to one kilo of the material. Having made this equivalence, they determined that each IPCC should be sold for a price of BRL 1.00 (one real), given the socio-environmental impact that solid waste from production activities causes to the environment and the public coffers. Thus, Table 7 provides a demonstration of the economic potential that HSW in the city of São Paulo can offer to the Waste IDF, considering the price of one real (BRL 1.00) or (USD 0.2581) per treated kilo.

This result was highlighted in the proposal by Slomski et al. [1] when it foresees the implantation of the WFDI as an alternative to adjusting the household waste management system. The authors discuss the format of these factories, in such a way that they aim at a change in what is understood and practiced, until now, as a solid waste management model. According to the authors, it “will be part of this new industry—the Waste Final Disposal Industry—the concessionaire companies who will purchase, through bidding, the waste from cities (unlike the current situation in which cities pay companies to collect the waste), and who will hire companies/people to sort the waste, destining it for recycling or incineration” [1] (p. 285).

With the creation of the WFDI, in addition to complying with the current legislation, “the company manager, aware of the corporate responsibilities with the final destination, acquires IPCC shares to internalize the costs that are the company’s responsibility to its products or packaging [and] do not impact on the sustainability of the planet” [1] (p. 286). As can be seen in Table 7, the revenue of USD 290,619,685.16 for the WFDI, with the marketing of IPCC, could be part of the revenue of cities and/or cooperatives, which could charge polluting companies, because of what the ‘polluter pays’ principle provides, practiced in developed countries like Germany, as demonstrated in the study by Nelles et al. [55]. In other words, companies should pay for the reverse logistics of solid waste that they generate with their production activities. Thus, it is believed that companies’ culture would make them develop products that are less harmful to the environment.

With the creation of WFDI, the city will adopt more sustainable management of HSW, in which it will no longer impact the budget and the environment with the lack of treatment and with a final eco-friendly destination. This paradigm shift will require a new culture, in which investments result in benefits, not expenses.

4.6. Economic Potential of Solid Household Waste in the City of São Paulo in 2018

Data from Figure 1 shows estimated disclosures of the economic potential of untreated household solid waste (HSW) in the city of São Paulo in 2018 from five sources of income.

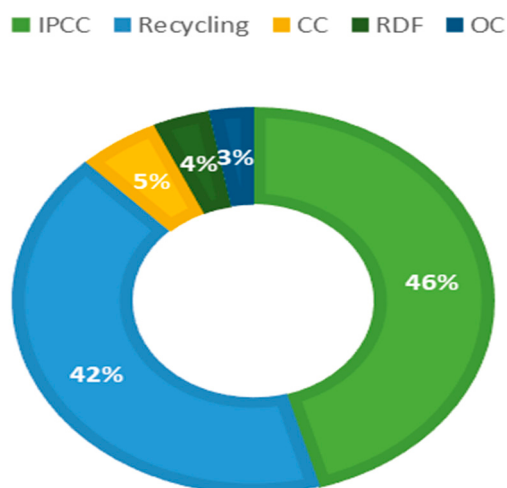


Figure 1. Economic potential of untreated household solid waste (HSW) in the City of São Paulo in 2018. Source: Research data.

According to Figure 1, the commercialization of IPCC with revenues of USD 290,619,685.16 (45.58%) has greater prominence, followed by Recycling with revenue of USD 269,170,505.11 (42.21%); the marketing of CC with revenue of USD 34,793,296.03 (5.46%); the sale of RDF with revenue of USD 24,030,309.28 (3.77%); and the marketing of OC with revenue of USD 19,020,034.76 (2.98%). These results are corroborated by Slomski et al. [1], when they say that with the appropriate treatment and final destination, the WFDI would have a potential revenue of USD 637,633,830.04; however, this was discarded by the city of São Paulo in 2018.

These identified potential HSW revenues from the implementation of screening centers contribute to job creation and social inclusion. Regarding the benefits that could have been generated to the environment, the saving of water, minerals, and the protection of the forest are estimated. If the city had treated the produced HSW correctly, it would have avoided part of the expense with collection and disposal in landfills and, consequently, environmental impacts and annual expenses, being able to invest in other areas, such as education, health, and safety.

5. Conclusion and Implications

This research aimed to disclose the economic potential of untreated household solid waste in São Paulo in 2018, based on the gravimetry of 2017. The city of São Paulo, in 2018, failed to give proper waste treatment, sending 97.96% of the household solid waste produced to landfills, which corresponded to a total of 3,697,148 tons discarded. An economic potential from HSW was identified of USD 637,633,836.04 in São Paulo with implanting the WFDI. This amount comes from five sources, with emphasis on Internalizing Private Costs Credit with 45.58%, followed by Recycling with 42.21%, Carbon Credits with 5.46%, Refuse-Derived Fuel with 3.77%, and Organic Compounds with 2.98%. These findings indicate that environmental benefits used are intrinsic to economic benefits since they are recycled materials. These contribute significantly to reducing of public expenses and the extraction of raw materials and processing of energy, water, and other inputs.

A sustainable production model must parameterize the production system. It will also require changes in beliefs and values, which will require the productive sector to face and overcome environmental problems, adopting a concept of sustainability, in which the production chain does not degrade nature to develop itself, but in which it develops itself considering the sustainability of the planet and the possibility of constant renewal of nature. Its concerns will range from the extraction of the raw material to the final destination of the product or its packaging; in other words, to be economically viable, and socially ethical and fair. This perspective will provide an opportunity for the planet to recover from the damage caused by the predatory extraction of its natural resources, emission of polluting gases into the atmosphere, and degradation of the environment caused by the irresponsible disposal of waste. It is a fact that non-renewable resources already show signs of

scarcity in some parts of the planet, like oil and minerals such as coal, bauxite and iron. This research contributes to society and the planet, demonstrating the potential economic benefits in mitigation of the effects of environmental degradation from the sorting of HSW.

This study may also contribute to the implementation of a sustainable management policy for household solid waste capable of reducing public spending. At the same time, it presents an alternative path to the reverse logistics of the business sector, which will be able to buy IPCCs, which will become a source of income for WFDI. From this point of view is presented the implementation of sorting stations for the environmentally correct treatment and final destination of domestic solid waste as a social, environmental and economically viable measure to achieve urban sustainability and best practices for the management of household waste in the city.

Given these findings, it is concluded that the final environmentally appropriate destination of the HSW constitutes an economic and socio-environmental measure that enables the reverse logistics of the business sector and urban sustainability. Consequently, the economic potential of the HSW, generated with its screening and commercialization, contributes to the mitigation of environmental impacts, in addition to income generation and social inclusion. It is suggested, as future research, the replication of this study in other cities, as well as the study of the feasibility of implanting the WFDI as a way to enable the integrated management of solid waste with the full participation of companies, (observing the logic of the polluter payer), society and public authorities.

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