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Journal of Material Cycles and Waste Management
Official Journal of the Japan Society of Material Cycles and Waste Management (JSMCWM) and the Korea Society of Waste Management (KSWM)

ISSN 1438-4957

J Mater Cycles Waste Manag
DOI 10.1007/s10163-020-01070-x

Springer

Journal of Material Cycles and Waste Management
https://doi.org/10.1007/s10163-020-01070-x

ORIGINAL ARTICLE

Monetary losses caused by the absence of packaging reverse logistics: environmental and economic impacts

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Received: 21 December 2019 / Accepted: 31 May 2020

Abstract

Reverse logistics systems are one of the instruments brought by the Brazilian National Solid Waste Policy (PNRS), to improve waste management in the country. Packaging materials play a big part on waste generation and present a high recovery potential. In 2017, after 7 years of the PNRS' issue, the Public Ministry of the state of Mato Grosso do Sul funded a project to valuate the monetary losses due to the absence of packaging reverse logistics systems in the state. Packaging waste generation, collection and final disposal were estimated to assess the monetary losses to the environment and the public coffers. The results show a total monetary environmental loss of $ 2,961,089.50 and a total loss to the public funds of $ 21,779,781.89. Paper and cardboard presented the highest representativeness of all packaging sectors, followed by plastics. The findings show that the monetary losses are high and should be minimized as it impacts the entire local population.

Keywords Waste management · Sustainability · Recovery · Public budget · Environment

Introduction

The United Nations Conference on Environment and Development, held in 1992 in the city of Rio de Janeiro, became known worldwide as Rio-92 or Eco-92, incorporated priorities for sustainable management of solid waste worldwide, which represented a change in paradigms that guided the actions of governments, society and industry [1]. Abramovay et al. [2] argue that the intensity of solid waste generation in economic activities, which can be characterized between the growth of the Gross Domestic Product (GDP) and the volume of waste generated, increased in low and middle income countries and decreased in countries of high income. There is an expectation that the generation of solid waste will more than double in the next 20 years in low-income countries, and the cost for solid waste management will increase by more than five times [3]. Thus, many low- and middle-income countries face the challenge of reversing the prevailing logistics and investing more and more in reducing excessive production and waste. To this end, seeking this inversion, public policies are developed, such as, for example, the National Solid Waste Policy (PNRS) in Brazil [1].

The Brazilian PNRS was established by Federal Law n. 12,305, in August 2nd, 2010, and it determines as one of its instruments, the reverse logistics systems, defined as a set of actions and procedures established to enable the collection and return of solid waste to the business sector, represented by manufacturers, importers, distributors and traders, for reuse, in their cycle or in other production cycles, ensuring the environmentally appropriate final destination [4]. Implementing reverse logistics systems help to ensure the sustainable development of the industries involved, as it recovers the value of waste, or promotes the correct final destination [5, 6].

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s10163-020-01070-x) contains supplementary material, which is available to authorized users.

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Published online: 07 June 2020

The Federal Decree n. 7,404 of December 23, 2010, which regulates the PNRS, defines that reverse logistics systems should be implemented and operationalized through sectoral agreements, regulations issued by the Government or terms of commitment. In its 17th article, it mentions that reverse logistics systems should be extended to plastic, metallic (steel and aluminum) and glass packaging, and to other products and packaging (paper, cardboard, multilayer, among others), considering the impacts on public health and the environment [7]. Considering the life cycle of waste management systems, the implementation of reverse logistics systems would increase the recycling rates, the appropriate final disposal, and the diversion of recyclables from landfills, which individually already decreases the environmental impacts of the systems, and combined can potentialize the environmental savings in all impact categories [8].

Another important aspect defined in the PNRS is that only rejects, that is, that portion of solid waste remaining after exhausting all possibilities of treatment and recovery, can be landfilled at environmentally sound disposal sites[1] [4]. In this sense, it can be understood that the implementation of the reverse logistics system of general packaging is an essential action to achieve the goal of reducing dry waste in sanitary landfills, disposing only the rejects in the sites. Consequently, in November of 2015, the Brazilian sectoral agreement to implement the reverse logistics system of packaging was signed [9]. This agreement defined several responsibilities for companies, manufacturers, importers, distributors and traders and, under the shared responsibility for the product's life cycle, to the public urban cleaning and solid waste management services holders, consumers and waste pickers' organizations to the effectiveness of actions.

Mato Grosso do Sul (MS) is the 6th largest Brazilian state in terms of territorial extension, with 357,145.532 km^2 and 2,449,024 inhabitants [10]. The sectoral agreement did not cover in its first implementation phase this state, which, in the vast majority of its municipalities, end up sending a large portion of packaging waste to improper disposal sites[2] or to the few sanitary landfills in the state, despite the legal recommendations [11]. In this regard, when the actions that make packaging recovery viable in the 79 municipalities of Mato Grosso do Sul do not occur, the environmental benefits that could be generated by recycling end up becoming environmental and social damage due to the failure to implement the packaging reverse logistics system. Further, when reverse logistics is absent, the costs for the management of this waste fraction are wrongly assumed by the Government, and as such should be valued. Thus, the Public Ministry of the state of Mato Grosso do Sul (MPE-MS) acting as inspector of the law on urban cleaning and solid waste management systems, concerned with the compliance with the reverse logistics system, hired a specialized company to value the environmental damage and, also, the damage to public coffers arising from the non-application of reverse logistics in the packaging sector in all municipalities of the state [12, 13].

The proposed valuation has not been found in the literature, and to the authors' knowledge, this type of assumption and calculations have not been performed before. The environmental and economic advantages of glass reverse logistics was verified by Oliveira Neto et al. [6], as costs savings from plastic incineration versus recycling were assessed by Lea [14]; and Axion [15] performed a financial assessment of recycling, which fits as cost assessments of specific sectors and industries but not such a broad valuation as proposed in this work. Environmental and public funding losses affect the entire population, since it can decrease the quality of life in a diversity of ways. Therefore, the goal of this research was to value the monetary damages to the environment and to the public finances arising from the failure to implement general packaging reverse logistics in the State of Mato Grosso do Sul, Brazil.

Methods

The methodology of this work was divided in three: contextualization, packaging estimates and cost assessments, which are all described next.

Contextualization

Initially, we performed a general and locational characterization of the state of Mato Grosso do Sul and defined the timeframe of the study. The state is located in west central Brazil with territorial boundaries with the states of Goiás (northeast), Minas Gerais and São Paulo (east), Mato Grosso (north), Paraná (southeast), and it has also international borders with Paraguay and Bolivia (both west of the state). Formed by 79 municipalities and 86 districts, Mato Grosso do Sul has as its capital the municipality of Campo Grande, located about 1,075 km from Brasilia, capital of Brazil. The population distribution in the state is defined by high population concentration in the municipalities of Campo Grande, Dourados, Corumbá and Três Lagoas (> 100,000 inhabitants), and by the dispersion of the remaining population in dozens of small urban centers. Thus, Fig. 1 illustrates the main information of the State of Mato Grosso do Sul, as well as its location in relation to Brazil.

[1] Waste destination that includes reuse, recycling, composting, recovery and energy recovery, including the final disposal in sanitary landfills.

[2] According to the Brazilian reality, these sites are characterized by open dumps and controlled landfills.

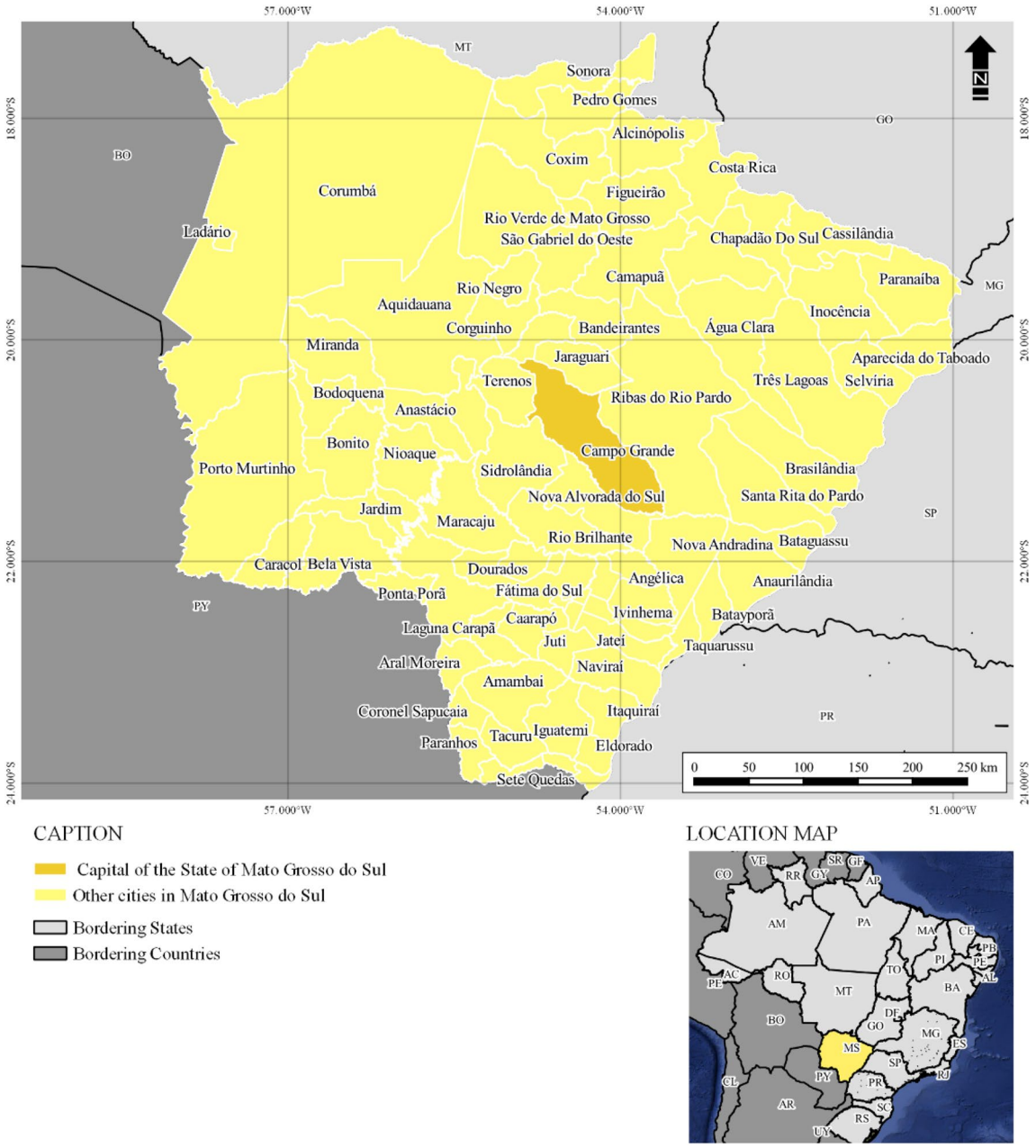

Fig. 1 Illustrated characterization of the state of Mato Grosso do Sul, Brazil. Source: Prepared by the authors

The timeframe was defined considering a literature review, the legal precepts and principles, the publication of the Brazilian Federal Law No. 12,305/2010 (the PNRS) and the official start date of the State Public Ministry's (MPE-MS) project. Therefore, the time horizon dates from August 3rd, 2010 (day after the PNRS was published), until April 10th, 2017 (when the project officially started), totaling 6 years, 8 months and 7 days. Hence, all estimates of packaging generation, recovery and final disposal are within this period, and the values will be shown annually.

Packaging estimates

The second step of the study involved all the estimations needed for the cost assessments: generated and recovered packaging, packaging collected and disposed by public services, which are described in the following topics.

Table 1 Generation of packaging and other recyclables contained in the dry recyclable fraction of HHW representativeness in Brazil in 2010. Source: Adapted from LCA; E2 (2012)

Material	Dry recyclable fraction HHW (t/day)	Representativeness (t/day)		Representativeness (%)	
		Packaging	Other durable goods	Packaging	Other durable goods
Plastics	22,856	2,769	20,087	12.10	87.89
Paper/Cardboard	22,178	9,577	12,601	43.20	56.82
Glass	4,063	2,852	1,211	70.20	29.81
Steel	3,894	1,655	2,239	42.50	57.50
Aluminum	1,016	693	323	68.20	31.79
Total	54,007	17,546	36,461	32.49	67.51

Estimation of generated and recovered packaging waste

This step of the methodology was divided into two: estimation of Household Waste (HHW) generated and estimation of packaging generated. For the estimation then, we consulted secondary information regarding population projections, per capita generation, gravimetric composition of HHW available in waste management planning instruments (e.g., the state plan, intermunicipal and municipal integrated waste management plans, sanitation[3] plans, as well as selective collection plans, when available) and literature review. However, when information from secondary sources was inconsistent, we decided to pursue primary data by inquiries to the municipal administrations. From this information, the estimation of the generation of HHW in each municipality of Mato Grosso do Sul was possible, as well as the quantification of the total dry recyclable fraction and its various typologies in the period from August, 2010 to April, 2017.

Considering the emphasis that is given to the packaging contained in the dry fraction of HHW, for estimating packaging generation in the municipalities, secondary information was used from the economic report by LCA & E2 [16], which consolidated the Annex VI of the sectoral agreement for the implementation of the reverse logistics of general packaging [9]. This document presents information on total daily generation of the dry recyclable fraction of HHW and packaging in Brazil for 2010 as presented in Table 1.

The table shows that, from the total amount of plastics generated by Brazilians, 12.10% are packaging, as 43.20% is paper/cardboard and so on. Therefore, the present study contemplated the qualitative reality regarding the gravimetric composition of each municipality in the state, when primary data were not available, the state's average was adopted as a rule. Thus, the percentage of packaging present in the dry fraction (Table 1), and also in the total mass of HHW was recalculated considering the maintenance of the packaging indices for each typology of recyclable (i.e., plastic, paper/cardboard, glass, steel and aluminum) in each municipality, according to Table 1.

For the estimation of recovered packaging, the recovery rate in relation to the total generated is 61.71% [16]. This index was calculated based on information provided by the industries in each sector regarding the volume of recycled solid waste and by official government data on the amount of recyclable waste generated and properly collected in 2010. Therefore, the amount was estimated considering the packaging generated and the recovery rate presented.

Calculation of packaging collected through the public selective collection service

Selective collection is the differentiated collection of waste that was previously separated according to its constitution or composition. In Brazil, it is usually performed by the municipality in two different ways: door-to-door and through points of voluntary delivery (LEVs in Portuguese). Door-to-door selective waste collection refers to the pickup of the separated waste in front of the residents' doors, and in LEVs the residents take their recyclables to these places located conveniently, such as in supermarkets, pharmacies and schools.

To calculate the amount of packaging collected, we first obtained historical data on the quantities of solid waste selectively collected considering the start date of services for each municipality that have the public selective collection service. Given the lack of a historical information series, the most recent data found were adopted. The data were obtained in SEMAGRO [17], municipal solid waste, sanitation or selective collection plans, and through primary data obtained at municipal administrations. Given the lack of primary and/or secondary data on the quantity selectively collected, based on CEMPRE [18], it was estimated the average quantity collected based on the reality of other municipalities around the country (such as Belo Horizonte/MG, Brasilia/DF, Campinas/SP, Curitiba/PR, Florianopolis/SC, Goiânia/GO, São Paulo/SP, among others).

[3] In Brazil, according to Federal Law n. 11,445/2007, sanitation refers to water supply systems, sewage systems, urban drainage and rainwater management, urban cleaning and solid waste management.

In addition, qualitative data in terms of the gravimetric composition of solid waste collected through the public service of selective collection were needed and obtained. In the absence of local data, the gravimetric composition from the state's capital was employed [19]. In Campo Grande, sectoral and statistically treated samples indicated that of the total collected by the public selective collection service, about 76.43% are recyclable, i.e., plastics, paper/cardboard, glass, aluminum and steel. The other 23.57% is waste that due to its physical or chemical characteristics make recycling impossible and can be considered as "rejects", such as organic, hazardous, sanitary, contaminated recyclable waste and other unclassified waste. Therefore, we adopted that Campo Grande's reality is applicable to the other municipalities of Mato Grosso do Sul. For the establishment of each typology representativeness in the dry recyclable fraction, adjustments were made considering the local gravimetric composition of each municipality and the identified representativeness of the recyclable dry fraction in the state capital (76.43%).

Regarding the percentage of packaging within the dry recyclable fraction collected by the public selective collection service, due to the lack of local data, the information provided by LCA & E2 [16] was used. With that information to estimate the percentage of packaging representativeness in relation to the total dry recyclable waste recovered by type of material (plastic, paper/cardboard, glass, steel and aluminum) was possible.

Calculation of packaging destined to final disposal

Complementary to the information regarding recovery (or recycling), for each municipality of the state, the amount of general packaging that was not recovered should be specified to estimate what was collected by regular collection and/or transported to the solid waste disposal site, i.e., landfills and municipal open dumps.[4] Figure 2 illustrates the current situation of final disposal in the municipalities of the state: municipal open dumps, as well as those municipalities that perform the operation of transshipment of waste followed by transportation and final disposal in landfills located in other municipalities, and local landfills. From the 79 municipalities of the state, only 7 have landfills in operation and 11 transship and dispose their solid waste in the existing landfills in the state. The remaining 61 municipalities currently dispose of their waste in inadequate disposal sites, i.e., municipal open dumps [11], as presented in Fig. 2.

The most recent information on the final disposal practice was not enough, therefore we also considered the history of final disposal of each municipality since the publication of the PNRS until April 2017. After that, the total packaging material sent to final disposal sites was quantified, from the estimated difference of generated and recovered packaging previously calculated.

Cost assessment of environmental damage resulting from the non-application of reverse logistics legislation in the packaging sector

Environmental benefit, in this study, refers to the economic savings arising from the non-production of raw material due to recycling, i.e., avoiding the production of virgin matter and consequently reducing energy consumption and greenhouse gas emissions, as well as the preservation of biodiversity and resources [16, 20]. In Mato Grosso do Sul, although part of the packaging that composes the HHW dry fraction is recovered, most of these materials still end up being sent to final disposal sites.

One of the biggest challenges in the environmental law field is the economic quantification of environmental damage as it involves scientific, social, economic and environmental criteria. However, in this specific case, the methodology and values specified by the business sector were adopted, therefore it is inferred that the values presented as benefits related to the use of recyclable waste in the production process of steel, aluminum, cellulose, plastic and glass were used for the valuation of the damage caused by the reverse logistics failure [16]. On the other hand, given the nonoccurrence of recycling, the "environmental damage" is a loss to the society as a whole and its value needs to be measured to create incentives for the establishment of actions aimed at the implementation of reverse logistics systems.

In summary, "environmental damage" is defined in this paper as the environmental cost arising from the absence of the benefit/savings that would be obtained from the use of recyclable materials in the steel, aluminum, cellulose, plastic and glass production processes. Therefore, it is assumed that when the packaging reverse logistics systems are not implemented, the environmental benefit that would result from recycling ends up becoming an environmental damage in the respective monetary value. Figure 3 shows a graphic representation of the calculations taken to estimate the environmental damage costs, considering all the information already presented.

Based on information from IPEA [20], the environmental damages corrected to April, 2017 through the General Market Price Index (IGP-M)[5] and converted to American dollars with the price from April, 2017 as well, were 27.49 $/ton for plastics, 11.78 $/ton for paper/cardboard, 5.40 $/ton for glass, 36.3 $/ton for steel, and 166.42 $/ton for aluminum.

[4] Municipal open dumps refer to official municipal disposal sites characterized by open-air dump areas.

[5] As this is a market-driven monetary value.

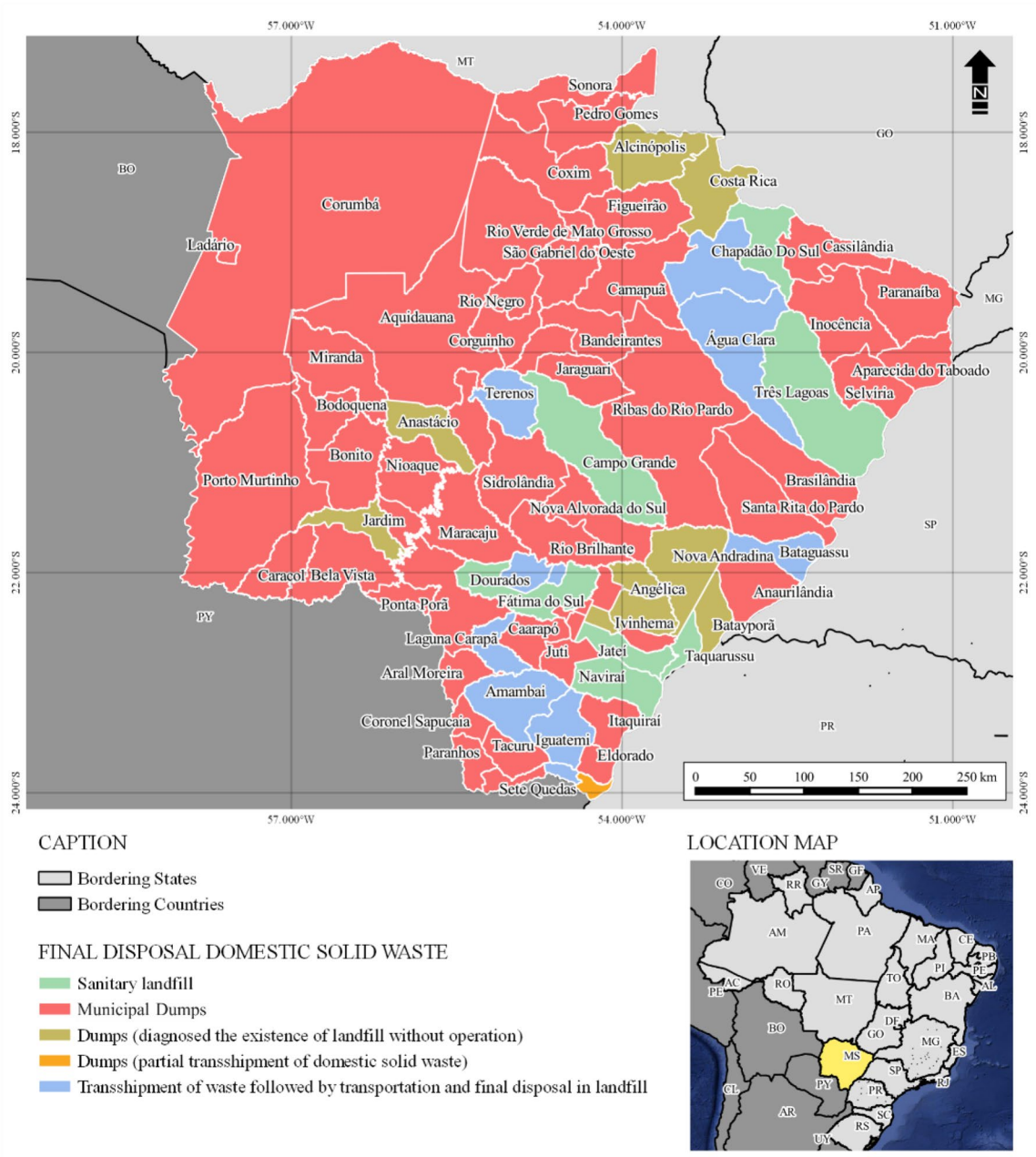

Fig. 2 Latest published information on final disposal of household solid waste in the state of Mato Grosso do Sul. Source: Adapted from TCE-MS (2016)

Cost assessment of damage to the public finances due to non-application of reverse logistics legislation in the packaging sector

According to the Brazilian Federal Constitution, municipalities are the public services holders for handling solid waste, having the obligation to offer them to citizens. However, they are not obliged to the waste share that is legally a private responsibility—as is the case with packaging. Accordingly, the lack of packaging recycling actions from the business sector also generates damage to the municipalities' funds, as this waste ends up being managed by the public sector, demanding infrastructures investments and operating costs resulting from collection, transportation and final disposal services. Therefore, it is important to quantify the economic amounts spent by the Government in these services and the costs necessary for the environmental liabilities' recovery caused by improper waste disposal in open dumps.

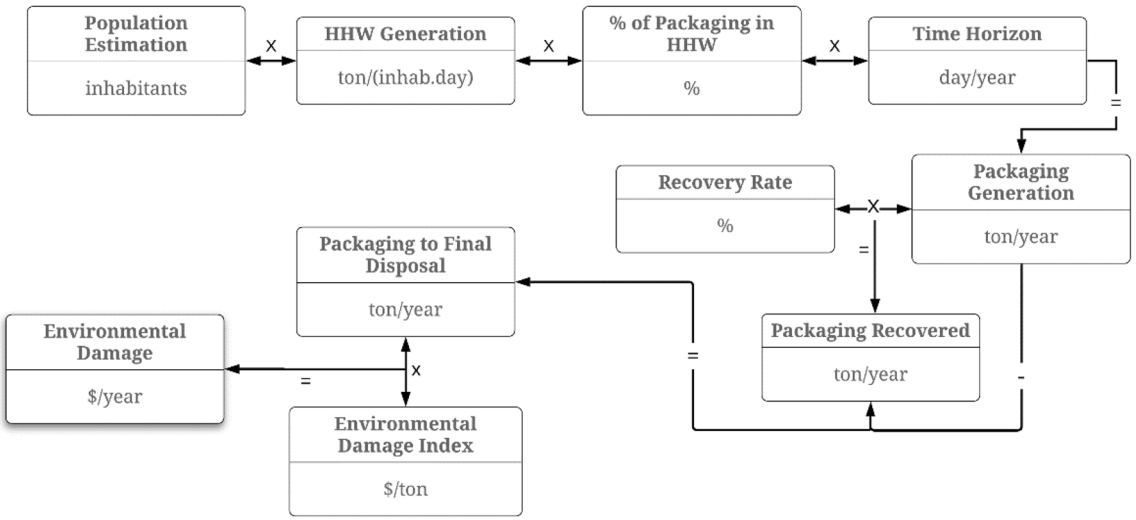

Fig. 3 Illustrated methodology of the environmental damage cost assessment. Source: Prepared by the authors

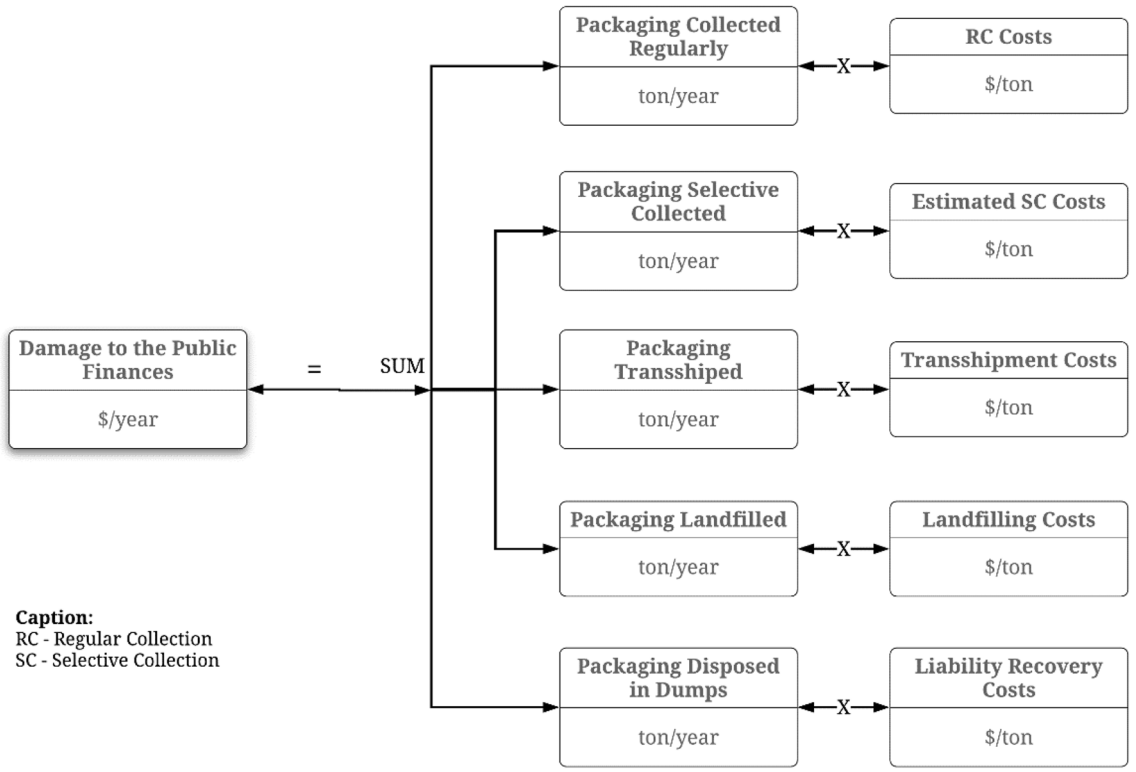

Fig. 4 Illustrated methodology of the damage to the public finances cost assessment. Source: Prepared by the authors

We want to point out that the costs related to the operation of sorting plants when existing in the municipalities were not estimated due to the lack of reliable official data. Consequently, the damage to the public capital calculated did not consider the costs involving the implementation and operation of these plants, so the actual damages are certainly higher than the estimated ones. Accordingly, the valuation of damage to the treasure is based on real values for those municipalities that perform the operations under a service contract with solid waste management companies [11]. The calculation's methodology is presented in Fig. 4.

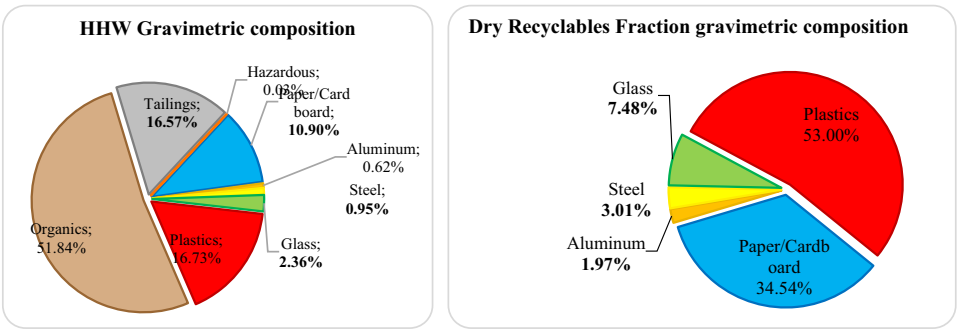

Fig. 5 Gravimetric composition of HHW and dry recyclables fraction from Mato Grosso do Sul State, based on the consolidation from the 79 municipalities. Source: Prepared by the authors

In the absence of reliable official data on the cost per ton landfilled, the cost of final disposal of $37.25 per ton (R$ 130.00, converted at R$3.49 as it was the average price for 2016, year of the report) was adopted [11]. Given the absence or inconsistency of data regarding transshipment of HHW, the values were technically estimated based on vehicles freight, metallic container rental and the actual distances traveled to transport the waste to the landfill. And for the regular collection costs, when the real practiced values were not available, information was retrieved from the report by TCE-MS [11], which presents the values by number of inhabitants: 59.23$/ton until 10,000 inhab., 46.99$/ton from 10,000 to 55,000 inhab., and 48.70$/ton for municipalities with 55,000 or more inhabitants.

For the valuation of selective collection (when existing), in the absence of official data, the cost was considered as 4.3 times higher than the cost of regular collection [18].

The calculated values involving the final disposal in dumps considered the costs for recovery of environmental liabilities caused by the final disposal of packaging. Considering the complexity of obtaining primary data, the authors estimated based on the costs of disposed waste removal, site rehabilitation and environmentally appropriate final disposal in a landfill. This estimate was performed using the National System of Costs Survey and Indexes of Construction (SINAPI) from January, 2017, as detailed on Table S1 in the Supplementary Material (SM).

Thus, to estimate the environmental liabilities' recovery, a few parameters were adopted: average height of 3.0 m of waste disposed in open dumps; specific mass of 250 kg/m^3 or 0.25 ton/m^3; and 1.0 ton of waste disposed in open dumps, which represents an area of 1.33 m^2 and a volume of 4.0 m^3. The parameters were used based on the total quantities of packaging destined for inadequate final disposal sites (i.e., open dumps and controlled landfills). We considered that the costs for the recovery of environmental liabilities would involve the costs of equipment, machines, vehicles and teams to handle the quantity of packaging disposed in an inappropriate place, through removal service by mechanical excavation and subsequent loading and transportation of this mass to a landfill. Also, there was a need to insert the Budget Difference Income (BDI) index, as such services involve the performance of private companies. It was calculated as 22.12%, totaling an approximate cost of R$ 279.07 per ton (88.90 dollars[6]) for environmental liabilities' recovery.

Results

From the methodology, the household solid waste generation, packaging generation and recovery, as well as the quantities of packaging collected through the public selective collection service and destined for final disposal sites were estimated. All these data were used to value the damages (environmental and to the public treasure) from the non-implementation of packaging reverse logistics. The next topics also present general information about household solid waste management in the municipalities of Mato Grosso do Sul.

Waste generation: HHW and packaging

Regarding the qualitative data, from the reality identified in the municipalities of the state and informed in the existing planning instruments at municipal, intercity and/or state level, the reference value of the gravimetric composition in terms of mass of HHW and of the recyclable dry fraction generated in Mato Grosso do Sul were found and are shown in Fig. 5.

By analyzing the gravimetric composition of the HHW, 31.56% are characterized as "dry recyclables", with the following composition: plastic (16.73%), paper/cardboard (10.90%), glass (2.36%), steel (0.95%) and aluminum (0.62%). This means that there is a quite high recycling potential in the waste generated in the state. Furthermore, the "organic" fraction represented 51.84%, while "rejects", consisting of sanitary and other unclassified wastes, totaled 16.57%.

[6] Dollar at R$ 3.14 as in April 2017.

Table 2 Estimated household solid waste generation and packaging generated in Mato Grosso do Sul

YEAR	2010	2011	2012	2013	2014	2015	2016	2017	TOTAL	A. A	A. M	A. D
Generation estimate (ton/year)												
HHW	265,022.1	656,404.5	667,967.7	680,553.1	692,505.8	706,058.4	719,718.1	199,412.7	4,587,642.4	684,722.7	57,345.5	1,878.6
Dry recyclable	83,545.4	206,951.9	210,623.8	214,894.7	218,687.5	222,925.7	227,195.3	62,956.7	1,447,781.0	216,086.7	18,097.3	592.9
Plastics	44,303.9	109,750.0	111,699.8	113,874.9	115,883.1	118,112.7	120,357.2	33,349.7	767,331.4	114,527.1	9,591.6	314.2
Paper/cardboard	28,835.4	71,421.3	72,681.3	74,279.9	75,582.0	77,040.0	78,508.8	21,753.8	500,102.6	74,642.2	6,251.3	204.8
Glass	6,250.5	15,485.9	15,763.7	16,044.5	16,332.8	16,656.3	16,982.8	4,707.6	108,224.1	16,152.8	1,352.8	44.3
Steel	2,511.9	6,222.4	6,333.6	6,464.2	6,581.4	6,718.5	6,857.3	1,901.0	43,590.2	6,506.0	544.9	17.9
Aluminum	1,643.7	4,072.2	4,145.4	4,231.2	4,308.2	4,398.2	4,489.2	1,244.6	28,532.7	4,258.6	356.7	11.7
Packaging generation estimate (ton/year)												
General packaging	24,395.6	60,430.4	61,502.9	62,767.8	63,878.1	65,124.6	66,381.0	18,395.6	422,875.9	63,115.8	5,285.9	173.2
Plastics	5,367.3	13,296.0	13,532.2	13,795.7	14,039.0	14,309.1	14,581.0	4,040.3	92,960.7	13,874.7	1,162.0	38.1
Paper/cardboard	12,452.1	30,842.1	31,386.2	32,076.5	32,638.8	33,268.5	33,902.7	9,394.0	215,960.9	32,233.0	2,699.5	88.4
Glass	4,387.2	10,869.5	11,064.5	11,261.6	11,463.9	11,691.0	11,920.2	3,304.2	75,962.0	11,337.6	949.5	31.1
Steel	1,067.6	2,644.7	2,691.9	2,747.4	2,797.2	2,855.5	2,914.5	808.0	18,526.8	2,765.2	231.6	7.6
Aluminum	1,121.3	2,778.1	2,828.0	2,886.6	2,939.1	3,000.5	3,062.6	849.1	19,465.4	2,905.3	243.3	8.0

"A." corresponds to the average in tonnes, per year (A.A.), month (A.M.) and day (A.D.) based on the time horizon defined

Evaluating only the HHW dry recyclable fraction, also shown in Fig. 5, the following composition could be determined: plastics (53.00%), paper/cardboard (34.54%), glass (7.48%), steel (3.01%) and aluminum (1.97%). Given the above, seeking to present generation information, in quali-quantitative terms of the dry recyclable fraction, Table 2 shows the estimated generation of each component material in the time horizon of the study (from August 3rd, 2010 to April 10th, 2017).

From Table 2, it is observed that the estimated HHW generation in the state increased, except for 2010 and 2017 which considered partial results for 5 and 3 months, respectively. Considering the generation of 2011 and 2016 (656,404.5 and 719,718.1 tons, respectively) there was a growth of about 9.65%. This increase is justified by the urban population growth, as well as by the per capita generation increase of HHW, as indicated by the municipal estimates. The monthly and daily averages measured in the whole period were 57,345.5 t/month and 1,878.6 t/day, respectively. Thus, in the recyclable material generation, the largest typologies represented were plastics and paper/cardboard with daily averages of 314.2 and 204.8 t/day, respectively. The amount of glass waste generated is also considerable, with an average of 44.3 t/day. Lastly, the average generation of metals totaled 29.6 t/day, steel 17.9 t/day and aluminum 11.7 t/day.

We understand that the dry fraction of HHW consists of packaging and other durable goods, such as parts of appliances, parts in general, utensils, among others that are also discarded by the population and, later, can be recycled. However, as recommended by the PNRS, packaging contained in the dry fraction of HHW should be object of the reverse logistics system, therefore there was a necessity to highlight its generation estimate. In this regard, based on consumption data provided by the production sector in 2010 [16], and on generation and gravimetric composition data presented in the detailed municipal reports, the packaging generation in the state was calculated, as presented also in Table 2.

From Table 1, it can be verified that the recyclable materials that have a considerable representativeness as packaging are glass (70.20%) and aluminum (68.20%), followed by paper/cardboard (43.20%) and steel (42.50%). On the other hand, plastic waste as packaging, represents only 12.1% of the total generated plastics [16]. In quantitative terms, it is observed that the highest averages of packaging refer to paper/cardboard with 88.4 tons daily and plastics with 38.1 t/day. Glass, aluminum and steel packaging accounted for 31.1 t/day, 8.0 t/day and 7.6 t/day, respectively. Analyzing the total generation of packaging in the period, it is estimated a quantity of 422,875.9 tons, which represents an average daily generation of 173.2 tons. In the SM, Table S2 summarizes the generation of general packaging, and its typology categories (plastic, paper/

cardboard, glass, steel and aluminum) for all municipalities of Mato Grosso do Sul.

Packaging collected and recovered

Packaging recovered was estimated using the previously mentioned recovery rate and the results are presented in Table 3. As for collection, based on primary and secondary data collected in various municipal and intermunicipal planning instruments, the availability of public selective collection services was verified in 36.71% of the municipalities, that is, in 29 of the 79 administrative divisions of the state. Thus, for these 29 municipalities, the quantity of packaging collected through the selective collection public service was measured. In this respect, from the total generated from 2010 to 2017, it is assumed that around 5.57% of the generated packaging were collected through public selective collection, according to what is presented in Table 3.

Table 3 shows the worthiness of the selective collection of paper/cardboard packaging in the period, totaling 10,063.3 tons, representing 4.66% of the total of paper/cardboard packaging generated in the state. Also noteworthy was the collection of plastic and glass packaging, with 7,201.1 and 4,566.0 tons in the period, respectively, followed by steel (912.5 tons) and aluminum (873.8 tons) packaging. Further, the total packaging collected by the public selective collection service in Mato Grosso do Sul reached 23,537.5 tons, representing 5.57% of the total packaging generated in the state. Additionally, Table S3 in the SM presents the data on the selective collection public services in the State of Mato Grosso do Sul, showing the start date and mode of operation by municipality, that presents the service. Furthermore, Table S4 in the SM summarizes the information regarding the quantity of packaging in the plastic, paper/cardboard, glass, steel and aluminum sectors selectively collected in the municipalities of Mato Grosso do Sul, considering the time horizon of this study.

Packaging to final disposal

Figure 2 already presented the final disposal situation in the state, and in addition, a retrospective of the final disposition adopted in each of the 79 municipalities of Mato Grosso do Sul is presented in Table S5 in the SM, regarding the use of local landfills and landfills in other municipalities through transshipment operation in the time horizon of the study.

Currently (in the studied period) only 18 municipalities (22.78%) of the state dispose of their HHW in environmentally sound disposal sites (i.e., sanitary landfill). Out of these, 11 municipalities carry out transshipment operation, destining solid waste generated to landfills in other municipalities and 7 have local sanitary landfills, namely: Campo Grande, Dourados, Três Lagoas, Chapadão do Sul, Jateí, Naviraí and Taquarussu. It is important to highlight that nine municipalities of the total have non-operating landfills, which means that they are still under construction and/or licensing process, or had its useful life exhausted [11].

Regarding general packaging that were not recovered and were eventually collected by the regular collection service, transshipped and sent to final disposal sites in the state, Table 3 shows the details of total quantity that was collected. According to SEMAGRO [17], regular collection in the state covers 100% of the urban areas in all municipalities, except in Bela Vista that indicated 70% coverage.

Analyzing Table 3, it is observed the increasing quantity of packaging that was regularly collected over the studied horizon, except in 2010 and 2017 which considered partial results. The amount collected through regular collection totaled 172,533.4 tons of packaging in the period representing 40.80% of the total packaging generated. Considering the time horizon, it is interpreted that, on average, 70.7 tons of packaging per day are collected in the state through the regular collection service. Table 4 shows the quantities of packaging that were estimated to have been transshipped in the state of Mato Grosso do Sul.

From analyzing Table 4, it can be noted that the beginning of the transshipment operation of HHW in Mato Grosso do Sul was in 2014, when the MPE-MS started reinforcing the legislation, and it reached 155.4 tons. This amount increased in 2015 and 2016, totaling, respectively, 852.8 and 1,542.1 tons, which may be justified by the increase in the number of municipalities that began to perform this operation aiming at the environmentally appropriate disposal of waste in landfills. Moreover, the majority of municipalities that transship HHW in the state destine it to privately owned landfills, and Table 4 also details the quantities of packaging that were sent for final disposal in environmentally appropriate landfills in the state and in municipal open dumps.

It is observed then, the increasing quantity (except for 2010 and 2017 that show partial results) of packaging disposed in environmentally appropriate disposal sites, especially between 2012 and 2013, when the sanitary landfill was opened in Campo Grande. This increase in the amount of landfilled packaging demonstrates an improvement in the environmental aspect, due to the closure of municipal open dumps within this period, but it also shows that the absence of reverse logistics systems contributes to a 78,529.9 tons of potentially recyclable waste that has not yet been diverted from landfill, which is a considerable amount. Table 4 on the other hand, shows a remarkable quantity of packaging disposed in inappropriate places (municipal open dumps), adding to 94,705.9 tons in the period. Considering the annual totals, there is a decrease over the horizon, justified by the

Table 3 Estimate of packaging waste collected through the selective collection public service and through regular collection service, and total packaging waste recovered in the state of Mato Grosso do Sul

Year	2010	2011	2012	2013	2014	2015	2016	2017	Total	A. A. [B]	A. M. [B]	A. D. [B]
General packaging waste collected by selective collection (tons)												
Plastics	74.8	553.6	611.5	652.2	1,044.7	1,625.7	2,077.2	561.4	7,201.1	1,074.8	90.0	2.9
Paper/cardboard	126.2	797.6	889.8	964.5	1,339.5	2,255.5	2,895.1	795.0	10,063.3	1,502.0	125.8	4.1
Glass	29.3	398.2	461.8	491.8	625.0	939.7	1,273.0	347.3	4,566.0	681.5	57.1	1.9
Steel	18.9	85.6	91.4	96.9	133.9	190.1	232.7	62.9	912.5	136.2	11.4	0.4
Aluminum	12.0	74.2	80.1	86.4	128.4	189.4	238.8	64.4	873.8	130.4	10.9	0.4
TOTAL	182.0	1,909.3	2,134.6	2,291.7	3,271.6	5,200.3	6,716.9	1,831.0	23,537.5	3,513.1	294.2	9.6
Regularly collected packaging (tons)												
Plastics	2,603.9	6,450.4	6,565.2	6,690.7	6,780.1	6,872.4	6,988.0	1.935.3	44,885.9	6,699.4	561.1	18.4
Paper/cardboard	4,330.0	10,720.5	10,905.8	11,133.8	11,209.6	11,261.7	11,442.0	3,165.3	74,168.7	11,070.0	927.1	30.4
Glass	2,416.8	5,988.5	6,096.5	6,202.4	6,285.5	6,368.2	6,482.0	1,796.7	41,636.6	6,214.4	520.5	17.1
Steel	605.2	1,498.8	1,525.0	1,554.1	1,570.8	1,593.5	1,624.5	450.1	10,422.0	1,555.5	130.3	4.3
Aluminum	93.4	230.2	233.1	232.5	211.4	193.6	193.2	52.9	1,440.2	215.0	18.0	0.6
TOTAL	10,049.3	24,888.4	25,325.5	25,813.4	26,057.4	26,289.4	26,729.7	7,400.2	172,553.4	25,754.2	2,156.9	70.7
Total packaging waste recovered (tons)												
Plastics	2,754.2	6,822.7	6,943.9	7,081.8	7,235.4	7,412.9	7,568.9	2,098.4	47,918.2	7,152.0	599.0	19.6
Paper/cardboard	8,107.7	20,086.4	20,445.0	20,907.0	21,393.0	21,970.2	22,423.6	6,218.6	141,551.7	21,127.1	1,769.4	58.0
Glass	1,957.0	4,848.3	4,935.1	5,026.0	5,144.8	5,288.7	5,403.7	1,498.0	34,101.6	5,089.8	426.3	14.0
Steel	461.1	1,142.9	1,163.8	1,190.3	1,223.3	1,258.9	1,286.8	357.0	8,084.2	1,206.6	101.1	3.3
Aluminum	1,027.6	2,547.1	2,594.1	2,653.2	2,726.8	2,806.0	2,868.5	795.9	18,019.2	2,689.4	225.2	7.4
Total	14,307.7	35,447.3	36,082.0	36,858.3	37,723.4	38,736.7	39,551.6	10,967.9	249,674.8	37,264.9	3,120.9	102.2

"A." corresponds to the average in tonnes, per year (A.A.), month (A.M.) and day (A.D.) based on the time horizon defined

[A] Percentage of the collection calculated from the total packaging generated by type in the municipality

[B] The average values were calculated from the time horizon defined in this report

increase of recovery actions in the municipalities and the implementation and use of landfills by part of the municipalities studied. It is important to emphasize that the use of open dumps generates environmental liabilities due to improper disposal of waste that should be recovered, burdening the public urban cleaning and solid waste management services' holders.

In the SM, Table S6 summarizes the information regarding the quantity of packaging regularly collected, transshipped and sent to appropriate and inadequate disposal sites in the 79 municipalities of Mato Grosso do Sul, considering the time horizon of this study.

Environmental damage from the non-implementation of reverse logistics

Considering the quantity in unrecovered tons (or recycled) of the various types of packaging and the costs listed above and the environmental damages presented in 2.3, the total monetary loss to the State of Mato Grosso do Sul was measured, to expose the damage resulting from the non-implementation of reverse logistics over the horizon of the present study as shown in Table 5. As mentioned previously, the environmental damage (or loss) represents the monetary value arising from the absence of the benefit or savings that would come from the recycling of packaging materials.

Analyzing Table 5, it can be observed that, for the studied period, the non-implementation of reverse logistics systems for the packaging sector, caused a considerable environmental loss to Mato Grosso do Sul, totaling about $ 2.961.089,50 (R$ 9,192,884.39). From the packaging typologies, it is observed that the largest amount corresponds to the plastic sector with approximately $ 1.238.198,49 (R$ 3,882,111.40), followed by the paper/cardboard sector which totaled $ 876.771,77 (R$ 2,748,935.42). Steel, aluminum and glass sectors totaled: $ 379.367,90, $ 240.691,51 and $ 226.059,83, respectively (R$ 1,189,428.55, R$ 754,645.83 and R$ 708,763.19). In addition, Table S7 in the SM shows the environmental damage calculated for each of the 79 municipalities, in which the lowest value was measured in Japorã with $ 1,267.79 (R$ 3,974.52) while the highest value occurred in the state capital, Campo Grande, totaling $ 1,154,242.07 (R$ 3,618,548.89).

Table 4 Estimated quantity of transshipped packaging waste, packaging waste sent to environmentally sound disposal sites and to municipal open dumps in the state of Mato Grosso do Sul

Year	2010	2011	2012	2013	2014	2015	2016	2017	TOTAL	(%)[A]	A. A. [B]	A. M.[B]	A. D. [B]
General packaging transshipped (tons)													
Plastics	–	–	–	–	38.01	211.19	405.99	85.30	740.49	0.80%	110.5	9.3	0.30
Paper/cardboard	–	–	–	–	54.06	319.96	574.38	121.17	1,069.58	0.50%	159.6	13.4	0.44
Glass	–	–	–	–	55.36	263.04	435.92	77.25	831.57	1.09%	124.1	10.4	0.34
Steel	–	–	–	–	6.15	48.04	102.72	25.72	182.63	0.99%	27.3	2.3	0.07
Alumínio	–	–	–	–	1.80	10.60	23.13	5.60	41.13	0.21%	6.1	0.5	0.02
TOTAL	–	–	–	–	155.38	852.84	1,542.14	315.04	2,865.41	0.68%	427.7	35.8	1.17
General packaging sent to landfill (tons)													
Plastics	372.4	925.2	1,461.6	4,157.5	4,260.2	4,499.4	4,747.0	1,317.4	21,740.6	23.39%	3,244.9	271.8	8.9
Paper/cardboard	719.2	1,789.5	2,588.3	6,536.0	6,662.7	6,978.7	7,270.5	2,017.9	34,562.7	16.00%	5,158.6	432.0	14.2
Glass	317.2	788.6	1,228.3	3,433.1	3.542.8	3,811.7	4,006.1	1,112.7	18,240.5	24.01%	2,722.5	228.0	7.5
Steel	105.6	262.9	326.3	624.8	646.7	719.7	755.2	210.2	3,651.4	19.71%	545.0	45.6	1.5
Aluminum	17.2	43.0	46.4	57.3	52.2	45.0	57.3	16.1	334.6	1.72%	49.9	4.2	0.1
Total	1,531.6	3,809.2	5,650.9	14,808.7	15,164.7	16,054.5	16,836.1	4,674.3	78,529.9	18.57%	11,720.9	981.6	32.2
General packaging sent to municipal open dumps (tons)													
Plastics	2,247.6	5,548.1	5,126.7	2,556.4	2,543.4	2,396.8	2,265.1	624.5	23,308.6	25.07%	3,478.9	291.4	9.5
Paper/cardboard	3,643.7	8,966.2	8,352.9	4,633.5	4,583.0	4,319.6	4,208.6	1,157.6	39,865.1	18.46%	5,950.0	498.3	16.3
Glass	2,117.4	5,232.6	4,901.1	2,802.5	2,776.3	2,590.6	2,510.4	693.5	23,624.3	31.10%	3,526.0	295.3	9.7
Steel	502.4	1,238.9	1,201.8	932.3	927.2	877.0	872.4	240.8	6,792.8	36.66%	1,013.8	84.9	2.8
Aluminum	79.9	188.0	187.6	176.1	160.1	149.5	136.9	37.0	1,115.1	5.73%	166.4	13.9	0.5
Total	8,591.0	21,173.8	19,770.0	11,100.8	10,990.1	10,333.4	9,993.4	2,753.4	94,705.9	22.40%	14,135.2	1,183.8	38.8

"A." corresponds to the average in tonnes, per year (A.A.), month (A.M.) and day (A.D.) based on the time horizon defined

[A] Percentage of the collection calculated from the total packaging generated by type in the municipality

[B] The average values were calculated from the time horizon defined in this report

Table 5 Estimation of environmental damage caused by failure to implement reverse packaging logistics in the state of Mato Grosso do Sul

YEAR	Environmental damage ($)					
	Plastics	Paper/cardboard	Glass	Steel	Aluminum	TOTAL
2010	71.833,27	51.190,34	13.123,86	22.033,42	15.598,10	173.778,99
2011	177,948.93	126,735.11	32,516.43	54,558.62	38,454.24	430,213.33
2012	181,109.00	128,921.00	33,100.73	55,512.87	38,936.58	437,580.17
2013	184,562.38	131,611.42	33,674.15	56,568.83	38,840.16	445,256.94
2014	187,028.48	132,509.88	34,125.38	57,178.13	35,332.39	446,174.25
2015	189,574.00	133,128.35	34,574.30	58,004.29	32,372.95	447,653.88
2016	192,760.36	135,259.19	35,190.96	59,130.22	32,309.57	454,650.30
2017	53,382.07	37,416.48	9,754.02	16,381.52	8,847.52	125,781.61
TOTAL	1.238.198,49	876.771,77	226.059,83	379.367,90	240.691,51	2.961.089,50
A. A. [A]	184.805,74	130.861,46	33.740,27	56.622,07	35.924,11	441.953,66
A. M. [A]	15.477,48	10.959,65	2.825,75	4.742,10	3.008,64	37.013,62
A. D. [A]	507,04	359,04	92,57	155,35	98,56	1.212,57

"A." corresponds to the average in tonnes, per year (A.A.), month (A.M.) and day (A.D.) based on the time horizon defined

[A] The average values were calculated from the time horizon defined in this report

The values were converted from Brazilian reais to US dollars, according to the Central Bank average price for each year

Monetary loss to the public treasure from the non-implementation of reverse logistics

The damage to the treasure (monetary loss) corresponds to the amounts invested by the government for managing and taking care of the dry recyclable fraction (i.e., selective collection services, operation of sorting plants, regular collection, transshipment and final disposal in landfills), as well as the recovery of the environmental liability caused by waste disposed in open dumps. Thus, to present a summary of the unit costs for the operation of regular collection, selective collection, transshipment, final disposal and open dumps recovery in the 79 administrative divisions of the state, Table S8 is presented in the SM.

Given the presented data, we obtained the total damage to the public treasure calculated for the general packaging sector in Mato Grosso do Sul, according to Table 6. These values were summarized, considering the sum of the damage to the purse calculated for each of the 79 municipalities, which involved the packaging quantities managed by public service holders through regular collection, selective collection, transshipment and environmentally appropriate final disposal and the unit costs listed in Table S8. As already mentioned, the costs involving the recovery of environmental liabilities, was estimated based on the recovery of municipal open dumps, regarding the removal of packaging disposed in the wrong place, site recovery and environmentally appropriate final disposal in a nearby landfill.

Analyzing Table 6, we can observe that, for the listed period, the non-implementation of reverse logistics systems for the packaging sector, caused a considerable loss to the treasure in Mato Grosso do Sul, totaling about $ 21,779,781.89 (R$ 68,279,616.20). The cost of $ 8,427,398.75 (R$ 26,419,895.09) for the recovery of environmental liabilities is highlighted due to the final disposal of packaging in municipal open dumps, and for collection and transportation of packaging through the regular collection service, the costs were $ 6,695,692.19 (R$ 20,990,995.04). On the other hand, the investments demanded by the service holders by offering the public collection service also involving the collection of packaging totaled $ 3,639,055.34 (R$ 11,408,438.51). It is important to note that the offer of this service enables the destination of these packaging to sorting plants for processing and subsequent recycling, that is, in practice the burden is even greater.

Public financial resources invested in environmentally sound disposal of packaging in the state of Mato Grosso do Sul totaled $ 2,949,379.23 (R$ 9,246,303.88) in the period. The increase in values over the horizon demonstrates an improvement in the environmental aspect in the state, related to the closure of part of the open dumps and the beginning of landfills' operation, but evidencing the increasing disposal of potentially recyclable packaging in these locations. Another important fact refers to the beginning of public transshipment services of waste in the state from 2014, demanding capital invested by service holders for the proper disposal of unrecovered packaging to the environmentally appropriate disposal site, totaling a damage to the treasure of $ 68,256.36 (R$ 213,983.69). Lastly, Table S9 in the SM systematizes the information regarding the damage to the treasure in all 79 municipalities of Mato Grosso do Sul. From the table,

Table 6 Estimated damage to the treasury caused by the packaging sector in the state of Mato Grosso do Sul

YEAR	Damage to the treasury—general packaging ($)					
	Regular collection	Selective collection	Transshipment	Final disposal	Liability recovery	TOTAL
2010	390,033.10	55,615.76	–	52,037.27	761,662.88	1,259,349.01
2011	965,757.74	253,982.28	–	129,876.42	1,884,841.29	3,234,457.74
2012	982,519.40	348,406.87	–	201,229.96	1,759,874.86	3,292,031.10
2013	1,002,726.67	372,941.59	–	551,424.20	988,168.91	2,915,261.37
2014	1,011,128.64	497,710.00	4,826.96	569,830.51	978,308.32	3,061,804.42
2015	1,019,729.39	774,947.30	22,649.09	616,680.78	919,858.09	3,353,864.64
2016	1,036,804.72	1,036,089.37	34,962.54	650,252.06	889,586.77	3,647,695.46
2017	286,992.53	299,362.18	5,817.76	178,048.04	245,097.63	1,015,318.14
TOTAL	6,695,692.19	3,639,055.34	68,256.36	2,949,379.23	8,427,398.75	21,779,781.89
A. A. [A]	999,357.04	543,142.59	10,187.52	440,205.86	1,257,820.71	3,250,713.71
A. M. [A]	83,696.15	45,488.19	853.20	36,867.24	105,342.48	272,247.27
A. D. [A]	2,741.89	1,490.19	27.95	1,207.77	3,451.02	8,918.83

"A." corresponds to the average in tonnes, per year (A.A.), month (A.M.) and day (A.D.) based on the time horizon defined

[A] The average values were calculated from the time horizon defined in this report

The values were converted from Brazilian reais to US dollars, according to the Central Bank average price for each year

it can be stated that the five largest values occurred in the municipalities of Campo Grande, Três Lagoas, Paranaíba, Dourados and Nova Andradina, which totaled, respectively, $ 7,216,501.33 (R$ 22,623,731.67); $ 973,897.22 (R$ 3,053,167.77); $ 956,915.38 (R$ 2,999,929.72); $ 951,845.03 (R$ 2,984,034.18) and $ 646,679.08 (R$ 2,027,338.92).

Discussion

The key factor considered to justify the damage assessed in the present study is the failure to comply with the recommendations contained in the federal legislation (PNRS) from the entities responsible for the effectiveness of reverse logistics. Article 33 of the aforementioned law states that manufacturers, importers, distributors and traders of products and their packaging, are obliged to structure and implement reverse logistics systems, by returning the products after use by the consumer, independently of the public service of urban cleaning and solid waste management [4]. In practice, this premise has not been fulfilled for years. Problems of this type are common in the Brazilian reality, given that government programs are unable to guarantee the execution, inspection and correct accountability for non-compliance with legal premises. It is observed that culturally accommodation and a sense of impunity are common due to the fact that in practice the deadlines established in the legal framework tend to be successively extended or almost always breached under the argument that the scarcity of resources leads to the need to prioritize some areas at the expense of others.

Therefore, estimates of the total costs due to the non-application of packaging reverse logistics systems in Mato Grosso do Sul, were compiled, segregated and measured by economic sector (plastic, paper/cardboard, glass, steel and aluminum), considering both the environment and the public coffers. Thus, Table 7 presents the consolidation of the total loss and by economic sector generated by the non-implementation of packaging reverse logistics in Mato Grosso do Sul and Table S10 in the SM details the total damage in all 79 municipalities.

The total economic damage obtained was $ 24,712,121.40, this value represents a daily average of $ 10,119.62, which is quite high for a developing country that has a lot of social and economic needs. Given the difficulty of public management in the state, this amount is sufficient to pay for the final disposal of 244.33 t/day of waste, which represents the waste generation of 286,406 people (0.85 kg/day), or 45 municipalities with population < 15,000 inhabitants. The biggest contributor to the total damage was the paper and cardboard sector, representing 41.2%, followed by the plastics sector (28.1%). Considering that paper and cardboard represent 10.9% of the total waste generated in the state, and 34.53% of the recyclable fraction, it urges for actions towards recovering these materials and avoiding further monetary and environmental losses to the population. The plastic sector ($ 6,943,052.40) and glass ($ 5,326,418.69) held second and third positions, and together they are responsible for 19.09% of the total waste generation and 60.48% of the recyclables.

Table 7 Summary of the damage caused by packaging sector in Mato Grosso do Sul

YEAR	Total economic damage ($)					
	Plastics	Paper/cardboard	Glass	Steel	Aluminum	TOTAL
2010	397,719.28	593,511.36	312,059.18	100,093.43	30,021.90	1,404,378.04
2011	1,019,756.87	1,510,146.55	804,021.97	252,003.24	78,742.45	3,664,671.07
2012	1,037,666.09	1,532,297.38	821,481.61	255,874.56	82,291.63	3,729,611.28
2013	926,352.95	1,376,793.97	727,920.41	246,736.68	82,714.28	3,360,518.30
2014	987,887.59	1,431,064.63	753,303.20	253,533.81	82,189.45	3,507,978.67
2015	1,086,510.84	1,559,550.07	803,757.39	264,538.55	87,161.68	3,801,518.53
2016	1,162,350.31	1,703,803.78	865,459.69	275,951.40	94,780.57	4,102,345.76
2017	324,808.47	474,355.60	238,415.22	76,842.93	26,677.52	1,141,099.75
TOTAL	6,943,052.40	10,181,523.35	5,326,418.69	1,725,574.60	564,579.48	24,712,121.40
A. A. [A]	1,036,276.48	1,519,630.35	794,987.86	257,548.45	84,265.59	3,688,376.33
A. M. [A]	86,788.15	127,269.04	66,580.23	21,569.68	7,057.24	308,901.52
A. D. [A]	2,843.18	4,169.34	2,181.17	706.62	231.20	10,119.62

"A." corresponds to the average in tonnes, per year (A.A.), month (A.M.) and day (A.D.) based on the time horizon defined

[A] The average values were calculated from the time horizon defined in this report

The values were converted from Brazilian reais to US dollars, according to the Central Bank average price for each year

According to Bottani et al. [21] the highest costs of food reverse logistics systems are from the transportation services, i.e., collection and transportation to storage, which corresponds to 280.00 €/ton. Considering that every reverse logistics system is somewhat similar, similar costs for other types of waste could be considered. As the maximum environmental damage obtained by this study was $ 166.41 per ton of waste, we understood why these types of systems are still not yet much developed. It is almost two times more expensive to implement and run the systems than to deal with the "damages" from not having them. However, it needs to be clarified and spread to the public that these losses go far beyond monetary costs, the environmental impacts on global warming and eutrophication for example have consequent impacts on public health and in the natural resources availability for future generations [21, 22].

Therefore, the present study is important in the Brazilian context as it demonstrates the importance of promoting the production chain and the associated responsibilities, promoting the production of less waste and the effective implementation of actions based on the recovery and recycling of solid waste. The developed methodology can be extended to other Brazilian cities and states, and to other low- and middle-income countries with similar conditions, as it was based on primary data, which can be consulted with the municipal administrations, responsible for public services of urban cleaning and solid waste management; and secondary data that can be obtained from official sources from the respective state's agencies, such as MPE—MS, SEMAGRO (State's Environmental Agency) and TCE—MS (State's Court of Auditors). Moreover, the pace of adaptation of each municipality to the legal determinations in recent years interferes in the damage valuation estimates, since different techniques were used to value each of the services offered and/or demanded by the local reality. For example, there is an evident change in the pattern and value of damages in a municipality that in a certain part of the time horizon started to use sanitary landfill, instead of municipal open dump, as determined by federal law. It limited the costs for the remediation of the liabilities from the open dump and started to have the costs of disposing in a sanitary landfill.

The main goal of reverse logistics is to reduce environmental pollution and waste of resources, as well as to increase reuse and recycling of products [23]. This research shows the monetary effects to the public of non-implementing it, however, there are far more advantages to these types of systems, such as the profits possibilities and the improvement of the local population's quality of life. One of the motivating drivers of reverse logistics are the economic factors, due to the possibility of profits from recycling and reducing the expenses with raw materials [22], nonetheless, the industries have not been taken advantage of this aspect as much as they could, resulting in not only their own monetary loss, but to the entire population as well.

The economic benefit of recycling a particular type of waste refers to the savings in the costs of inputs and energy resulting from production from recyclable material compared to primary production through virgin matter [16, 20]. The study presented by IPEA [20] showed that when comparing the advantages and disadvantages of producing raw material from recyclable solid waste, recovery or recycling

generates economic benefits for the productive sector and environmental benefits for society as a whole. Accordingly, it is not overstated to assume environmental losses to the population when not implementing reverse logistics systems, as waste management Life Cycle Assessment studies show that the absence of recycling, and consequently incorrect final disposal of dry waste, bring burdens to the environment and human health [8, 24–27].

In Mato Grosso do Sul, although part of the packaging from the HHW dry fraction is recovered by processes that culminate in recycling, most of these materials still end up being sent to final disposal sites. There are two very important aspects that need to be considered in this situation and have been assessed in the study. First, when monetary resources from taxes and fees payed by the population are misused and mistakenly employed where it should not, such as in handling solid waste that should be recovered and handled by private companies, the public loses a great deal from other investments that could be made (for example in the health system and public transportation). Second, when dry recyclable waste is not recovered, it generates environmental impacts that could easily be avoided, which are magnified in a country the size of Brazil. Therefore, even though the authors here exposed one perception of the losses from the absence of reverse logistics, there are several other aspects that could and should be addressed in the future, like the environmental impacts of the current situation and the impacts (social and monetary) to the waste pickers that play a big role in the solid waste management chain in Brazil.

Further, through correlations and comparative methods, the results obtained between different Brazilian states and municipalities can be analyzed in future research. For example, seeking to elucidate whether those in the southeastern and southern regions of Brazil, which are more advanced in reverse packaging logistics systems, present more favorable results compared to those in which the effective execution of the PNRS has not yet become a priority in its entirety, such as the State of Mato Grosso do Sul. A similar methodology can be employed to value the performance of recyclable material collectors in recovering the portion of packaging contained in the dry fraction of urban solid waste. In the Brazilian reality, it is understood that the non-occurrence of the reverse logistics of the packaging sector commits to the dependence of the activity of organizations of waste pickers, when existing, to enable recycling of the recovered waste in the municipal scope.

No less important is to show that, based on this valuation study, the Brazilian authorities will have, as did those in Mato Grosso do Sul, greater practical foundation from the perspective of the financial representativeness of the non-implementation of the legislation. This will lead, optimistically, to discussions and greater demand in the revision of the Sectorial Agreement for the Implementation of the Reverse Logistics System for General Packaging (signed in 2015 and under review). In addition, after reviewing it, it is also necessary to continue this line of research, valuing its effectiveness in reducing losses to the treasury after implementation.

Conclusions

The monetary and environmental damages arising from the failure to implement general packaging reverse logistics in the state of Mato Grosso do Sul, Brazil were assessed in the present study. The cost assessment showed a total environmental damage of $ 2,961,089.50 and a total loss to the public funds of $ 21,779,781.89, for the time horizon from 03/08/2010 to 10/04/2017. Therefore, it is concluded that the losses represented in monetary values are high, especially when considering it is the population's property that end up being sacrificed.

The paper and cardboard sector was the one that obtained the highest total economic damage, $ 10,181,523.40 for the period, representing 41.2% of the total costs. The second biggest contributor was the plastic sector ($ 6,943,052.40) and glass ($ 5,326,418.69), calling for special attention for these fractions of recyclable wastes.

The results of environmental damage due to the failure to implement reverse packaging logistics in the State of Mato Grosso do Sul can be used as a guide for other studies involving implementing solutions for environmentally appropriate final disposal of urban solid waste.

It is known that these systems also have impacts in the society, especially on waste pickers that play an important role in the recycling chain, as addressed by the State Prosecutor. Therefore, it is recommended that further studies are developed considering these types of social aspects to measure the waste pickers' economic losses as well, for example.

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