Transition to circular economy in Brazil

A look at the municipal solid waste management in the state of São Paulo

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Abstract

Purpose – The purpose of this paper is to evaluate how improvements in municipal solid waste management systems (MSWMS) can contribute to a transition toward circular economy (CE) in urban areas, outlining actions and guidelines for public policies.

Design/methodology/approach – The research was carried out in three municipalities located in the state of São Paulo in terms of: diagnosis; elaboration of more positive scenarios in terms of CE and scaling of economic and environmental benefits; and outline actions and guidelines for public policies of MSWMS.

Findings – In developing countries like Brazil, MSWMS can contribute to a transition toward a CE through new public policies and management practices, or even through the improvement of those that already exist. Examples of this are the integration of the informal sector of the recycling chain and service sector related to repairs of clothing, shoes, furniture and electronics as well as composting at the food production site. This could be strengthened by legal and financial mechanisms, training and carbon credit projects. Moreover, there is a need for integration of public policies between different levels of governments and sectoral policies.

Originality/value – This paper developed a methodology to examine the potential for a transition toward a CE through the MSWMS in different scenarios and cities. This methodology allows to advance the implementation of the concept of CE in urban areas of developing countries and generating co-benefits to the local economy and the global environment.

Keywords Municipal solid waste, Circular economy, Public policies

Paper type Research paper

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1. Introduction: circular economy principles applied to solid waste management (SWM)

Significant technological and management innovations in waste management have emerged in the last decade in order to face the growing demand for materials and to confront the increasing ecological and social impact of the disposable consumer economy. Although some guidelines aim at reforming and improving traditional waste management frameworks, others are fundamentally designed to reconceptualize and reformulate them completely (DjuricIlic *et al.*, 2018; Lauridsen and Jørgensen, 2010).

For the year 2016, official estimates (SNIS, 2018) indicate a daily average generation of 161,400 t municipal solid waste (MSW) in Brazil, where 59 percent were disposed in landfills, 19.9 percent were dumped in soil without any treatment, 3.4 percent were treated and recovered in sorting, composting and recycling units and 17.7 percent were without information.

In some European Union (EU) countries, such as Germany, Austria, Belgium, Denmark, the Netherlands and Sweden, public policies have raised the rates of reusing, recycling and incineration with energy recovery and/or composting to 95 percent (Eurostat, 2014; World Bank, 2013). Even having other destination technologies, sending MSW to landfills is still a major practice in the USA. In 2015, this option was used for 52.5 percent of the solid waste, followed by incineration with energy recovery (12.8 percent), recycling (25.8 percent) and composting (8.9 percent) (EPA, 2016).

In this context, the concept of circular economy (CE) emerges as an alternative response to the desire for sustainable development. However, the economy is still operating predominantly on a linear model basis of extraction, production, use and elimination/disposal, whereby all products will inevitably reach their end of life (European Union, 2012; UNEP, 2011; Stahel, 2016; Mangla *et al.*, 2018).

According to Suavé *et al.* (2016) environmental science, sustainable development and CE are, in fact, important issues for conceptualizing solutions to a complex environment. In this way, CE models can be subdivided into two groups: those that promote reuse and extend the useful life of the waste or goods through repairing, fixing, remanufacturing, upgrading and reforming; and those that transform old goods into new resources through recycling and materials and waste treatment (Suavé *et al.*, 2016). In this way, Geissdoerfer *et al.* (2017) define CE as a regenerative system, in which the inputs and outputs of the system (resources and waste, emissions and energy) may be minimized through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing and recycling.

In some locations, such as San Francisco (USA), Flanders (Belgium) and Japan, there are already experiences of MSW management integration through CE. Of these, stands-out regulations to divert waste from landfills, by means of a significant increase in the waste valorization through remanufacturing, recycling and composting (Geng *et al.*, 2013; Silva *et al.*, 2017). However, Tisserant *et al.* (2017) emphasized that the EU would need to increase recycling by approximately 100 Mt/year and reduce landfilling by approximately 35 Mt/year by 2030 in order to achieve the targets set by the CE actions.

In a study by Kirchherr *et al.* (2017), which analyzed 114 CE concepts and applications, it was detected that only 30 percent took into account the waste hierarchy, considered for this case as 4 R's – reduce, reuse, recycle and recovery – while 79 percent used only recycling, claiming that this is an integral part of the CE. The study also evaluated that only 40 percent conceptualized the CE based on systems theory, which considers the supporting capacity limits (providing resources and receiving waste disposal) of the planet ecosystems as fundamental to, for example, review the current patterns of production and consumption (Kirchherr *et al.*, 2017). McDowall *et al.* (2017) evaluated further that the actions and strategies adopted by China have been broader than those of the EU, considering all ecosystem capacity, not just waste and/or material management and social benefits.

In this way, understanding CE as a concept and tool that must, in fact, integrate ecosystem capacity within the waste management hierarchy poses a great challenge for society, governments and productive sectors. This hurdle, however, is especially great for developing countries, where infrastructure availability and waste valorization rates are lower than those observed in developed countries. Therefore, the CE concept and its implementation in industry and country level is an approach to minimize and manage waste effectively and efficiently, especially in emerging economies (Agyemang *et al.*, 2019).

There are huge co-benefits for improving the various urban sectors, generating a series of co-benefits to the local population and the global environment (Doll and Puppim de Oliveira, 2017). However, despite the growing understanding about the social, economic and environmental benefits of the CE, barriers have been cited by different authors regarding their dissemination and implementation in developing countries. These barriers include cultural, political and economic aspects, such as the utilitarian buying behavior, and anthropocentric attitude toward waste disposal (Gaur *et al.*, 2019), unawareness of the customers and entrepreneurs (Agyemang *et al.*, 2019; Sharma *et al.*, 2019); lack of technology, techniques and expertize (Agyemang *et al.*, 2019; Sharma *et al.*, 2019; Mangla *et al.*, 2018), cost and financial constraint (Agyemang *et al.*, 2019; Mangla *et al.*, 2018), lack of industry incentives for "greener" activities (Mangla *et al.*, 2018), lack of environmental laws and regulations (Mangla *et al.*, 2018).

In Brazil the CE is still incipient, with a small number of studies published in scientific journals involving its application to the productive and governmental sectors (Oliveira *et al.*, 2018; Silva *et al.*, 2019). The adoption of the CE to municipal solid waste management (SWM) is emphasized in the National Solid Waste Policy, in which recycling and strategies to minimize disposal in landfills are recommended (Oliveira *et al.*, 2018; Silva *et al.*, 2019). However, there is a significant scarcity of studies in this country that allow us to evaluate the potential of SWM as a tool to promote the transition toward a CE, and which policies, strategies and actions could be developed and applied. Improvements in MSWMS using the concept of CE in urban areas can generate a series co-benefits to the local economy and the global environment.

2. Objectives

This work aims to develop and test a methodology to evaluate the co-benefits when improving the MSW management systems in order to promote transitions to the CE in a developing country. The methodology is tested by analyzing the main opportunities to advance MSWMS using the case of Brazil, particularly in three cities in the São Paulo State. The paper is an effort to analyze MSW system scenarios to promote a transition to the CE, considering environmental and economic aspects of urban areas in a developing country.

The contribution to the literature include an integrated cost and environmental analysis of MSW management, considering municipalities with different social and economic profiles; the analysis is based in positive MSW management scenarios with environmental impacts simulated and costs surveyed from studies performed in Brazil; this research provides an methodological approach to identify and reflect on the main structural barriers, challenges and opportunities for the transition to CE.

3. Methodology

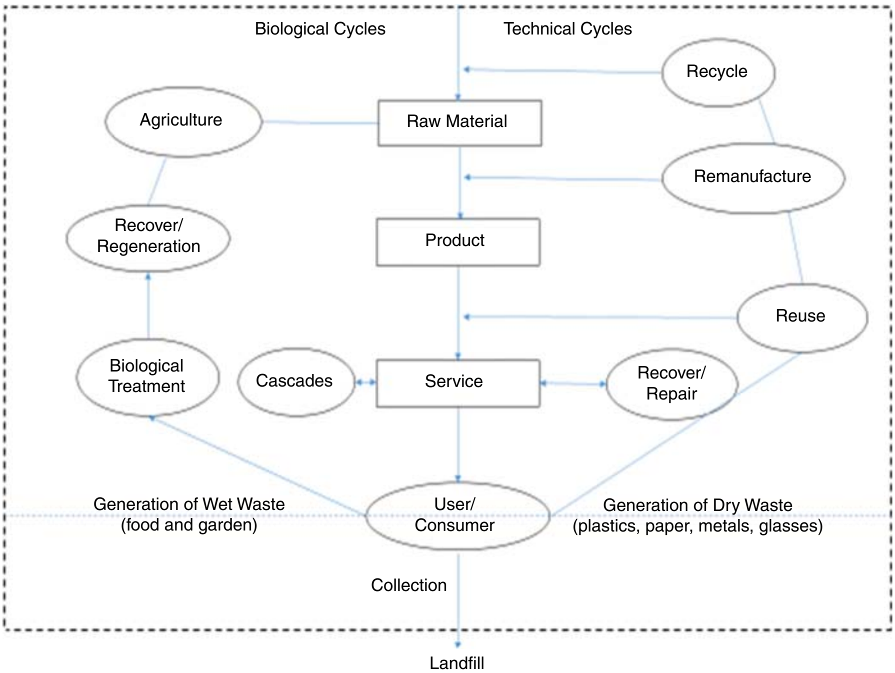
The research started with a diagnosis of the MSW composition and management system. Based on the analysis of these results, allied with work on literature review about the main concepts of CE, we analyzed the barriers, challenges and opportunities for MSWMS improvement and how they can contribute to actions transitioning to the CE (DjuricIlic *et al.*, 2018) and to obtain economic benefits in MSW management policies.

We collected data and information on the MSWMS of the three cities: São Paulo, Sorocaba and Piedade. Since the year 2014, a series of semi-structured interviews with city officials in the area of SWM were carried out in the three municipalities. Data from São Paulo were obtained through interviews and questionnaires and through its waste management plan (PMSP, 2014). The data from Piedade and Sorocaba were also obtained through interviews, questionnaires and participation in public processes to elaborate their waste plans (PMP, 2011; PMS, 2014), as well as input and output data of the systems (such as characterization of waste and environmental aspects and impacts) through scientific publications (Paes *et al.*, 2014, 2018; Paes, 2018). For Brazil, the main information were obtained through official publications on SWM of the Ministry of Environment (Brasil, 2011) and Ministry of Cities (SNIS, 2018).

The data concerning the value of the dollar for Brazil (US$1 = R$2.4 on 2014) and the systems economic costs refer to 2014 operations. In the cities of São Paulo and Sorocaba were obtained through official publications (PMS, 2014; PMSP, 2014; Paes, 2018). In the city of Piedade the estimated costs were obtained through interviews. The management average final cost (transportation, sorting and final disposal) for the cities of São Paulo, Sorocaba and Piedade was US$178.00, US$139.00 and US$92.00 per ton of waste, respectively.

Based on this information, two hypothetical scenarios with reuse targets of 10 and 40 percent of the residues (dry and humid) were carried out, considering that they would not enter the public collection, transportation and final disposal systems. Thus, they would be reused by independent systems linked to CE, as it can be understood in Figure 1.

Additionally, the study performed the calculation for CO_2eq emissions and its carbon credit generating potential for the three cities and scenarios. The emissions of CO_2eq were determined through the CO2ZW software, developed by the SosteniPra research group of the Universitát Autònoma de Barcelona (Sevigne Itoiz *et al.*, 2013). CO2ZW enables the estimation, monitoring and inventory of greenhouse gas (GHG) emissions from the MSW management system, according to the guidelines of the Intergovernmental Panel on Climate Change (IPCC, 2006), and applying the life-cycle perspective. This methodology also allows



Source: Adapted from Pan *et al*. (2015) and EMF (2015)

Figure 1.
Interaction between MSWMS and CE concepts

the evaluation of scenarios for the management of MSW, from municipal to national coverage, with a small amount of input data (Sevigne Itoiz *et al.*, 2013).

The CO2ZW was adapted to the Brazilian conditions and tested to brazilian municipalities (Paes *et al.*, 2017). In the GHG estimation, the following parameters were considered: annual average amount MSW disposed in the landfill, its gravimetric characterization and landfill operation time.

For the carbon credit potential economic values calculation aiming the Clean Development Mechanism (CDM) projects, it was used the updated market values of the emissions permit for 1 t of carbon equivalent, expressed in t.CO_2eq. The average value of the estimated price for ton of CO_2 avoided – or other GHGs calculated as equivalent tons of CO_2 according to their climate change potential – was €7.0/t.CO_2eq for the year 2014, equivalent to US$9.1/t.$CO_2$eq and R$21.84/t.CO_2eq (EEA, 2016).

4. Case studies presentation: municipal solid waste management systems (MSWMS) in Brazil

4.1 Background

The focus of the present study was the state of São Paulo, which presents a gross domestic product (GDP) of US$774bn, corresponding to 30 percent of the Brazilian GDP, with the country's second highest annual income per capita (US$18,206.00). The state has approximately 3 percent of the national territory area and 20 percent of the population (IBGE, 2010). São Paulo state also presents the best Brazilian indicators of waste management. According official data, in state of São Paulo, 97 percent of waste generated is adequately disposed by 98.8 percent of its municipalities (SNIS, 2018). In addition, São Paulo has also a more favorable situation in relation to the existence of infrastructure and enterprises, such as highways, recycling and reverse remanufacturing industries, as well as a stronger institutional framework, which can contribute to promote CE (State of São Paulo, 2015).

In Brazil, as in other countries, municipalities are legally responsible for MSW management. In total, 3 of the 645 municipalities of São Paulo state were selected for the present study, seeking cases that present different sizes and socioeconomic realities in order to test the principles of CE in SWM in different contexts. For this reason, the municipalities of the capital city of São Paulo (considered to be large), Sorocaba (classified as medium sized and with industrial vocation) and Piedade (small municipality and agricultural vocation) were selected.

The municipality of São Paulo is considered the financial capital of the country. It has approximately 11.2m inhabitants – distributed in 1,523 km^2. It has the tenth largest GDP in the world among cities, accounting for 10.7 percent of all Brazilian GDP and 36 percent of all goods production and services in the state of São Paulo, being the headquarters of 63 percent of multinationals established in Brazil (IBGE, 2010, 2017).

Sorocaba is a municipality located in the interior of São Paulo state, in a distance of 90 km away from the capital. Its area reaches 456 km^2 with approximately 616,000 inhabitants, having an economy based on industrial production (IBGE, 2010, 2017).

Piedade is located in the southeast portion of the state of São Paulo, about 100 km from the capital São Paulo, and bordering the municipality of Sorocaba. This municipality has a population of 52,000 inhabitants, distributed in a territory of approximately 746 km^2, having predominantly an agricultural economy (IBGE, 2010, 2017).

4.2 Management systems

Generally, a typical MSWMS in Brazil is structured through the operations of ordinary and selective collection, plus sorting/recycling and final disposal in landfill (Brasil, 2011), as can be observed in Figure 2.

It is worth noting that of the approximately 58.9m t.MSW/year generated in Brazil, estimated for the year 2016, only 3.4 percent (2m t) was being reused and destined to the sorting, recycling

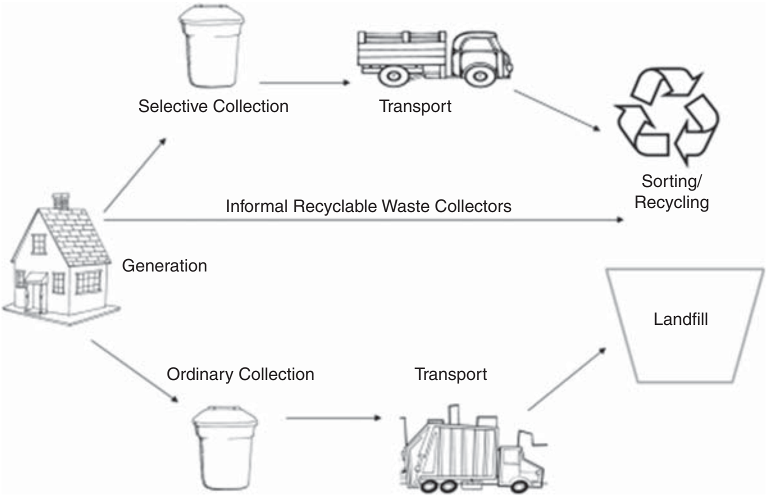


Figure 2.
Activities that commonly make up the MSWMS in Brazil

and composting units, and 96.6 percent (56.9m t per year) was landfilled (SNIS, 2018). In the city of Piedade, 2.9 percent (445 t) was being sent to the sorting and recycling units, while 97.1 percent (14,958 t) were sent to landfill without any treatment (PMP, 2011). In the city of Sorocaba, 3.4 percent (6,205 t) was sent for sorting and recycling and 96.6 percent (178,303 t) to the landfill (PMS, 2014), while in the city of São Paulo only 1.6 percent (71,905 t) of the waste was sorted and recycled, while 98.4 percent (4,425,625 t) was sent to landfill (PMSP, 2014).

The gravimetric compositions of MSW in Brazil and of São Paulo, Sorocaba and Piedade are shown in Table I.

It should be noted that Piedade, a city with a predominantly agricultural economy, presents the largest amount of organic matters in the waste, while Sorocaba, a city with an industrial profile in its economy, presents the least amount of organic waste. São Paulo and Brazil presented gravimetric results with very similar characteristics. It is also worth mentioning the average of approximately 3 percent of metals present in MSW can be considered low (in relation to plastics and papers), and it can be attributed to the formal and informal collectors work, which contribute to the diversion of these materials in Brazil (Lima and Mancini, 2017).

A simple average of the four realities presented in Table I, 51 percent of the MSW were characterized as organic matter (food waste and garden waste, with potential for reutilization via

Table I.
Gravimetric composition of MSW for Brazil and the cities of São Paulo, Sorocaba and Piedade

Wastes	Brazil[a] (%)	São Paulo[b] (%)	Sorocaba[c] (%)	Piedade[d] (%)
Organic matter	51.4	51.2	48.0	53.7
Papers	13.1	13.1	17.0	9.2
Plastic	13.5	13.5	9.5	9.9
Glasses	2.4	2.4	5.4	1.9
Metals	2.9	2.9	3.5	2.8
Inerts and woods	NI[e]	NI[e]	2.1	3.9
Textiles	NI[e]	NI[e]	3.3	6.1
Rubber and leather	NI[e]	NI[e]	0.0	0.0
Others	16.7	16.9	11.2	12.5
Total	100.0	100.0	100.0	100.0

Sources: [a]Brasil (2011), [b]PMSP (2014), [c]PMS (2014), [d]PMP (2011), [e]No information biological treatments such as composting and/or anaerobic digestion); 31 percent as recyclable (plastic, glass, paper and metal, with potential for recycling); and 18 percent as wastes (fractions where characteristics make commercialization and/or recycling unfeasible, at least at the moment, such as metallized plastics, some types of glass, rubbers, visually contaminated paper, thermosets, diapers, printed circuit boards, animal feces and toilet waste) (Brasil, 2011; Mantovani *et al.*, 2016; Lima and Mancini, 2017; Paes, 2018; PMS, 2014; PMSP, 2014; PMP, 2011).

5. Casestudy analysis: transition to circular economy

5.1 Estimations of the gains with a circular economy approach to SWM

Based on field survey data, derived from the MSW gravimetric characterization and its management systems, one can estimate the potential economic benefits that some CE actions could generate for the three cities. The costs were calculated for the scenarios in which they were in operation in the year 2014 and still considering reuse targets of 10 percent and 40 percent, through the multiplication of the economic values obtained (US$/t), by the annual quantity of waste generated, transported and treated (t/year) by the public systems of waste management, as it can be seen in Table II.

Wastes	São Paulo		Sorocaba		Piedade	
	t/year	US$/year	t/year	US$/year	t/year	US$/year
Current scenario						
Organic matter	2,302,735.36	410,654,472.53	88,563.84	12,325,134.40	8,271.41	758,212.68
Papers	589,176.43	105,069,796.68	31,366.36	4,365,151.77	1,417.08	129,898.63
Plastic	607,166.55	108,278,034.75	17,528.26	2,439,349.52	1,524.90	139,782.23
Glasses	107,940.72	19,249,428.40	9,963.43	1,386,577.62	292.66	26,826.89
Metals	130,428.37	23,259,725.98	6,457.78	898,707.72	431.28	39,534.37
Inerts and woods	0.00	0.00	3,874.67	539,224.63	600.72	55,065.73
Textiles	0.00	0.00	6,088.76	847,352.99	939.58	86,128.44
Rubber and leather	0.00	0.00	0.00	0.00	0.00	0.00
Others	760,082.57	135,548,058.32	20,664.90	2,875,864.69	1,925.38	177,904.65
Total	4,497,530.00	*802,059,516.67*	184,508.00	*25,677,363.33*	15,403.00	*1,413,353.61*
Scenario of 10% deviation of waste to reuse						
Organic matter	2,072,461.82	369,589,025.28	79,707.46	11,092,620.96	7,444.27	682,391.41
Papers	530,258.79	94,562,817.02	28,229.72	3,928,636.59	1,275.37	116,908.77
Plastic	546,449.90	97,450,231.28	15,775.43	2,195,414.57	1,372.41	125,804.00
Glasses	97,146.65	17,324,485.56	8,967.09	1,247,919.86	263.39	24,144.20
Metals	117,385.53	20,933,753.39	5,812.00	808,836.95	388.16	35,580.93
Inerts and woods	0.00	0.00	3,487.20	485,302.17	540.65	49,559.15
Textiles	0.00	0.00	5,479.89	762,617.69	845.62	77,515.60
Rubber and leather	0.00	0.00	0.00	0.00	0.00	0.00
Others	760,082.57	135,548,058.32	20,664.90	2,875,864.69	1,925.38	177,904.65
Total	4,123,785.26	*735,408,370.83*	168,123.69	*23,397,213.47*	14,055.24	*1,289,808.71*
Scenario of 40% deviation of waste to reuse						
Organic matter	1,381,641.22	246,392,683.52	53,138.30	7,395,080.64	4,962.85	454,927.61
Papers	353,505.86	63,041,878.01	18,819.82	2,619,091.06	850.25	77,939.18
Plastic	364,299.93	64,966,820.85	10,516.96	1,463,609.71	914.94	83,869.34
Glasses	64,764.43	11,549,657.04	5,978.06	831,946.57	175.59	16,096.14
Metals	78,257.02	13,955,835.59	3,874.67	539,224.63	258.77	23,720.62
Inerts and woods	0.00	0.00	2,324.80	323,534.78	360.43	33,039.44
Textiles	0.00	0.00	3,653.26	508,411.79	563.75	51,677.07
Rubber and leather	0.00	0.00	0.00	0.00	0.00	0.00
Others	760,082.57	135,548,058.32	20,664.90	2,875,864.69	1,925.38	177,904.65
Total	3,002,551.03	*535,454,933.33*	118,970.76	*16,556,763.88*	10,011.95	*919,174.03*

Table II. Distinct scenarios for waste reuse and operational costs for the three locations for the year 2014

Based on the "current" realities (2014) of the volume of municipal waste and public expenditures, there is a need for investments in actions that can increase the capacity of reusing organic and recyclable waste in the three municipalities. Assessing the potential of cost reduction (all compared to operating scenarios in 2014), if it would be possible to divert only 10 percent of these materials, the municipal public expenditures would be reduce in approximately US$66.7m (8 percent) in the city of São Paulo, US$2.3m (9 percent) in Sorocaba and US$123,500 (9 percent) in Piedade. With reutilization/recycling targets reaching 40 percent (of all dry and wet residues) the savings could reach US$266.6m (33 percent) in São Paulo, US$9.1m (36 percent) in Sorocaba and US$494,200 (35 percent) in the city of Piedade. These values do not include the costs of implementing the actions of the CE, although some cities already have a collection system for recyclable materials (we will just assume that the volume will be reduced through autonomous and independent systems of the CE).

By also analyzing the potential for reducing methane emissions from landfill disposal systems – expressed in CO_2eq using CO2ZW software – it could also, aiming the implementation of CDM projects, obtain the following economic benefits, as presented in Table III. The carbon value was US$9.1/t.$CO_2$eq in 2014 (EEA, 2016).

Consequently, emissions reductions and possible economic gains can be observed in the two established scenarios, where the city of Piedade, with reuse/recycling rates of 10 percent, could generate annual gains in the order of US$5,700 and, with 40 percent, US$53,100. Sorocaba could gain, via possible projects similar to CDM projects, US$338,100 and US$898,900, with the 10 and 40 percent reuse/recycling goals, respectively. While the city of São Paulo, the municipality with the largest volume of waste, could generate benefits between US$2.9 and US$16.8m with reuse goals of 10 and 40 percent, respectively.

If combined with the potential economic benefits of saving municipal public resources (Table II) with the possibility of CO2 credits (Table III), the city of Piedade could obtain annual economic gains of 9 percent or US$129,300 with a 10 percent reuse/recycling and up to 39 percent or US$547,300 with 40 percent reuse/recycling; Sorocaba from 10 percent or US $2.6m to 39 percent or US$10.0m; São Paulo from 9 percent or US$69.5m up to 35 percent or US$283.3m, respectively. Through these analyzes, it was also possible to understand that, in the average of the three locations and scenarios, more than 90 percent of the economic gains could come from the savings in operating costs and the rest of the potential gains from CDM and carbon credit projects.

Table III. CO_2eq emissions and the potential to reduce these emissions and obtain economic benefits via carbon credits for the scenarios and three municipalities

	Current	10%	40%
Piedade			
Generated emissions – t.CO_2	19,502.73	18,874.07	13,662.48
Emission reductions – t.CO_2	0.00	628.65	5,840.25
Economic benefits – US$	0.00	5,720.73	53,146.28
Sorocaba			
Generated emissions – t.CO_2	273,629.17	236,474.70	174,845.14
Emission reductions – t.CO_2		37,154.46	98,784.03
Economic benefits – US$		338,105.63	898,934.66
São Paulo			
Generated emissions – t.CO_2	5,466,766.17	5,150,889.64	3,624,073.76
Emission reductions – t.CO_2		315,876.52	1,842,692.41
Economic benefits – US$		2,874,476.38	16,768,500.90

5.2 Alternatives and opportunities to divert waste in the state of São Paulo

Based on the best practices and studies related to the theme, it was possible to understand that actions and guidelines that promote reduction, such as: composting at the generation sites (schools, public buildings, residences, neighborhoods and condominiums), home composting (as a project under development in the city of São Paulo) (PMSP, 2014) and installation of voluntary delivery points in strategic locations of cities (where the population can deliver materials that can be reused, repaired, remanufactured and recycled). These are presented as fundamental actions to diversify the material flows of public waste collection and treatment systems and thus promote decentralized local initiatives that can contribute to the reduction of costs and environmental impacts of the MSWMS (Blanco *et al.*, 2010; Cleary, 2010, 2014; Nessi *et al.*, 2013; Paes *et al.*, 2018; Puppim de Oliveira, 2017).

In addition, a comprehensive diagnosis and registration of informal recyclable waste collectors (who are not acting in a legal manner according to national laws), recyclable materials and scrap trade, recycling companies, as well as the repair activities of electrical and electronic goods, household appliances (stoves, refrigerators, microwaves, etc.), clothes, shoes, furniture, among others, could be promoted and integrated by the studied cities and others that present similar characteristics. The intention of this is to formalize (if necessary), encourage and stimulate such initiatives that can contribute to the activities of reusing, repairing, recovering, remanufacturing and recycling.

Through the Figure 1, it is possible to understand how this interaction between the MSWMS activities and the CE can act, subdivided through technical and biological cycles. It can be seen how consumers and public authorities can contribute to recover materials to production cycles, avoiding its end of life and its removal by the ordinary collection system and subsequent disposal in a landfill.

In biological cycles, wastes can be reused in "ripple effect" through, for example, organic matter deriving from gardening wastes that can be applied directly to the covering of green areas, like squares, parks and gardens, such as what is already started in the city of Sorocaba, with wastes generated in conservation activities (PMS, 2014). In the biological treatment, there is the option of producing compost for the recovery of degraded areas and application in agriculture. The technical cycles follow the concepts of the waste hierarchy, where it must first be reduced, and then recovered/repaired/extended, reused, remanufactured and recycled.

It is also worth noting that for the results to have effect, some management actions and guidelines should be considered in public policies, which:

- The use of the economic instruments planned in the Municipal, State and National Policies of Climate Change and Waste (Brasil, 2009; Brasil, 2010; State of São Paulo, 2009; PMS, 2016; PMSP, 2009). The objective is promoting, through financing and activities that reduce GEE and operational costs, such as the energetic use of methane in the landfill and sales of carbon credits in voluntary markets (Paes, 2018; Winans *et al.*, 2017). Other objective is to stimulate the entire recycling chain and reverse logistics and the treatment of organic waste by means of composting at the generation site (Paes, 2018; Paes *et al.*, 2018). It should be emphasized that this item could be theme and subject to be discussed by the municipalities at the national and state levels of government, seeking the integration of projects and actions for financing, training and incentive to these initiatives throughout the country (Puppim de Oliveira, 2017; Winans *et al.*, 2017).
- As established by the Municipal, State and National Policies of Climate Change and Waste (Brasil, 2009, 2010; State of São Paulo, 2009; PMS, 2016; PMSP, 2009), these ventures of high concentration – such as residential and commercial condominiums, shopping malls, retail centers, among other agglomerates – require the preparation of

their waste management plans, linking to the certificate of completion, license or operating permit. It would even be possible to establish gradual incentives for those who present local alternatives for waste management and/or treatment, such as the reduction and/or exemption of the "waste tax" for condominiums and lots that implement, in addition to selective collection, composting *in loco*. These mechanisms have been revealed to be fundamental for the reduction of environmental impacts and of operational and investment costs, as shown in Tables II and III.

- Implement extended-producer responsibility strategies, or similar programs as already foreseen by the National Solid Waste Policy, in order to both ensure proper collection and destination (reuse or recycling whenever possible) of recyclable material from products and packaging; and the transfer of costs and responsibilities for part of MSW management from municipalities to producers, as recommended by Ribeiro (2015).

In this context, another important aspect would be the development of more local and decentralized management alternatives in urban centers, cities and metropolitan regions. Examples include maximized measures to reduce waste sent to public collection and transport systems and treatment, and final disposal, such as installation of voluntary delivery points (for recyclable materials with reusing, repairing and recovery potential) and community and residential composting combined with prevention, reduction and non-generation (Blanco, 2010; Cleary, 2010, 2014; Nessi *et al.*, 2013).

Finally, it should be pointed out that such actions and guidelines could only be proposed through studies of the wastes composition and characteristics, infrastructure knowledge and installations of each stage that makes up the MSWMS and evaluation of environmental and economic aspects of the studied municipalities. Such guidelines can only be adopted in realities similar to the ones studied or in other places that carry out the same studies developed by this one.

6. Conclusions

Based on the methods and results, this work presented a methodology to assess MSWMS (composed of generation, collection, transportation, sorting, treatment and final disposal stages) and how actions and local public policies (of municipalities) could contribute to a transition to a more CE in a developing country, Brazil.

Through the proposed objectives of evaluating how MSW management can contribute for the policy transition in a CE, it was possible to highlight actions and guidelines that can be implemented through the municipal public policies of MSW management. That could still generate savings to the municipality and therefore be reverted in policies and actions to stimulate more practices of the CE. Thus, based on the methods and results (proposed actions and guidelines), the study identified and highlighted the main challenges: the need for integration in the conduct of public policies among different governmental levels (municipalities, states and unions) and sectoral levels (such as environmental education, economic development, urban and environmental planning); the need for evaluation the impacts on the change of productive patterns; and the need for the population awareness. It is also emphasized that without actions that increase the awareness of the population on these issues and transitions, little of this can have effect and result.

The main opportunities that were indentified are: the flow of material deviation from public waste management systems, thus avoiding and reducing the environmental impacts and public expenditure (between 9 percent and up to 39 percent) on collection, treatment and final disposal systems; the population participation in a more circular, active and sustainable economy. The main structural barriers that could be highlighted are: population awareness and participation; infrastructure that interconnects citizens, public power and private initiative/productive sector (through points of voluntary delivery and strengthening on repairing, recovering, reusing and recycling activities); use of economic tools to stimulate environmental improvement (such as taxes and/or fees that discourage the use of polluting activities and stimulate best practices related to CE concepts) and local and regional infrastructure (such as roads, recycling industries and reverse manufacturing and consumer market).

The study also presented a method for diagnosing the characteristics of MSWMS – including the waste composition and each management stage infrastructures and facilities – and local and regional realities. Allied to the concepts of CE as a tool for other localities, it is possible to evaluate their realities in order to contribute to the implementation of actions and guidelines for the transition in CE.

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