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The role of a socio-integrated recycling system in implementing a circular economy – The case of Belo Horizonte, Brazil

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ABSTRACT

Waste pickers (WPs) are considered a strong suggestion to become practical mediators of the circular economy (CE) in emerging economies. This new recommendation intends to strengthen WPs' role in household solid waste management while supporting the establishment of CE. Municipalities often do not recognize WPs as service providers and frequently discriminate against them. In such a challenging situation, could a socio-integrated recycling system with integrated WPs be a robust strategy to boost a CE? Belo Horizonte is a learning platform to answer this research question because this Brazilian city has a long-term commitment to social integration. The work applies the combination of participatory observation, multi-year material flow analysis (MFA), and structural agent analysis (SAA) to identify allocative resources, legitimation, and cultural values that are fundamental to operationalizing CE. The MFA results show a significant increase in waste generation, but not more than 4% of recyclable waste generated could be collected as input for WP cooperatives. The number of WPs registered in cooperatives, the market price of recyclables, and regulatory legislation for packaging products are classified as barriers for the successful extension of a socio-integrated recycling system identified in the SAA. This study suggests that knowing the target group (e.g., city hall and industries) brings opportunities for WPs to disclose niches (based on a small network of agents with expectations and visions) and can potentially create socio-technical regimes to implement a conscious and sustainable CE.

1. Introduction

The practice of circular economy (CE) is a topic of debate in scientific and non-scientific circles (Kalmykova et al., 2018; Kirchherr et al., 2017; Laurenti et al., 2018; Suárez-Eiroa et al., 2019). The conceptual approach of circularity has opened different interpretations, understandings, and thoughts to complement the economic and business orientation for industries that are aimed at the continual use of resources while eliminating waste (Foundation, 2019). One challenge is to embed socio-economic practices in CE initiatives at city levels (Kirchherr et al., 2017; Laurenti et al., 2018; Suárez-Eiroa et al., 2019).

Many cities are pushed to restructure their household solid waste (HSW) management systems to a circular view (Ghosh and Agamuthu, 2018; Haupt et al., 2017). European legislation, for example, claims phasing out the disposal of recyclable HSW (e.g., paper, plastic, glass, metal), preventing its generation, and/or transforming it into new resources (Commission, 2019). This circularity view is expanding worldwide (Ghosh and Agamuthu, 2018; Kirchherr et al., 2017). However, emerging economies often face a different situation. They generally follow basic sanitation policies without giving priorities or restrictions to HSW sorting and treatment systems (Gutberlet et al., 2017; Hartmann, 2018; Welivita et al., 2015). The novelty is to create a frame to embed waste pickers (WPs) as mediators of the circular economy (Gutberlet, 2018; Gutberlet et al., 2017; Rutkowski and Rutkowski, 2017; Velis, 2017). Waste picking is either a predominant or a prominent part of recovering recyclable resources in countries with "financial constraints," "institutional failure," and "undeveloped treatment systems" (Velis, 2017). Many citizens in those countries live under conditions of poverty and unstructured life; for the mismanagement of HSW, i.e., open dumpings and landfilling with mixed waste, they find a profitable solution to meet socio-economic needs (Ferronato and Torretta, 2019; Guerrero et al., 2013).

The embeddedness of WPs creates an unconventional reflection of the principles and aims of the circular economy. Municipalities often do not recognize WPs as service providers and frequently discriminate against them (Azevedo et al., 2019; Chen et al., 2018;

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Hartmann, 2018; Rateau and Tovar, 2019). In such a challenging situation, could a socio-integrated recycling system with integrated WPs be a robust strategy to boost a CE?

Transparency regarding the definition (and understanding) of the CE concept and socio-integrated recycling system is needed to answer the research question. According to Kirchherr et al. (2017), *"The circularity approach seeks for an economic system that replaces the 'end-of-life' concept by reducing, alternatively reusing, recycling and recovering materials in production, distribution and consumption processes within the aim to accomplish sustainable development"*. Rutkowski and Rutkowski (2015) considered a socio-integrated recycling system, i.e., "*the procedure of combining informal sectors in urban services by giving WPs socio-economic opportunities whereby the operational costs and environmental impacts of landfilling can be minimised*". Benefits exist in favor of a socio-integrated recycling system, but economic prosperity is still the primary aim of the CE and might imply tradeoffs in terms of economic growth (Kirchherr et al., 2017). Kirchherr et al. (2017) have correlated CE as an approach toward sustainability to bring the perspective that is considered in this study, and which stands for creating *environmental quality, economic prosperity and social equity, to the benefit of current and future generations simultaneously*".

The integration of WPs in circularity initiatives is an issue to be analyzed on a local scale. The situation of WPs can differ among countries or cities because of, for example, legal issues, social behavior, and culture. Belo Horizonte is a learning platform to answer the research question mentioned above. Belo Horizonte is Brazil's fourth economic axis and a reliable reference for the organizational structure of WPs into cooperatives worldwide (Alfaia et al., 2017; Campos, 2014; IBGE, 2018; Tirado-Soto and Zamberlan, 2013; UN-HABITAT, 2014). Through the study case, this paper aims to analyze the socio-integration development of individual groups that directly execute or influence an action in HSW management and to discuss the barriers that WP communities face towards the circular economy's purposes.

The work applies the combination of participant observation (Kawulich, 2005), material flow analysis (MFA), and structural agent analysis (SAA) developed by Binder (Binder, 2007a, b). The methodological approach brings the focus on the role of agents seldom studied in HSW management and is fundamental for operationalizing CE (Bugge et al., 2019; Marshall and Farahbakhsh, 2013).

This paper is structured as follows. Section 2 describes the background information of Belo Horizonte's case study. Section 3 outlines the methodological framework and the respective research steps carried out in this study. Section 4 presents the results of the case study and the discussion. Sections 5 and 6 summarize the conclusions.

2. A literature review about the situation of Belo Horizonte

Belo Horizonte, the capital of Minas Gerais' state, is located in southeast Brazil with a population of about 2.5 million (2014) and an average growth rate of 0.6% per year since 2001 (IBGE, 2018). The mainstays of its economy range over all three economic sectors, with iron and steel mining industries, packaging, food, biotechnology, business, and tourism jewelry as the main branches.

Belo Horizonte is characterized by high social inequalities, with a Gini coefficient of 0.60 (IBGE, 2018). This socio-economic situation is reflected by the high relevance of informal collecting and sorting of HSW (Varella, 2011). Belo Horizonte launched its Municipal Solid Waste Plan in 2017, after three years of the target having been defined by the Brazilian National Policy on Solid Waste (NPSW) (HORIZONTE, 2017). NPSW is a political action for municipalities to pay attention to the mismanagement of HSW and the integration of WP cooperatives (Brazil 2010).

The plan is based on the *status quo* of Belo Horizonte's HSW management in 2014 (HORIZONTE, 2017). Belo Horizonte presents an advantage regarding the integration of WP cooperatives in comparison to other Brazilian cities. Belo Horizonte had the first political initiative to recognize waste pickers as agents of HSW management in the 1990s (Campos 2014; Jacobi and Teixeira 1997). The political initiative demonstrated the working value of WPs, who were often confused as being part of the marginalized groups of that time, and caused a social and political movement nationally and internationally (Campos 2014). Campos (2014) described how Belo Horizonte's political initiative opened opportunities in line with Eco 92 and helped to establish social and governmental programs such as "Garbage and Citizenship" and the "National Forum Garbage and Citizenship". Both programs aimed to promote campaigns against child labor in dumpsites and participative dialogue between governments and WPs funded by the United Nations Children's Funds and the Brazilian government in 1997 and 2000, respectively (Campos 2014).

No technological treatment takes place in Belo Horizonte, as shown in Fig. 1. The conventional system relies on landfilling after HSW is reloaded into larger vehicles at the transfer station (SLU, 2014). Consequently, the long-term collection of mixed waste motivated social interventions in HSW management activities accompanied by constant popular movements (Rutkowski, 2008; Varella, 2011). The recycling network system started with CataUnidos in 2004. The recycling network systems promote joint action for marketing and technical support to reduce the influences of the informal sector (Tirado-Soto and Zamberlan, 2013; Varella, 2011). As shown in Fig. 1, the formal and the informal waste sectors still run in parallel in Belo Horizonte. The informal sector helps small and medium-sized middlemen businesses by creating the opportunity to generate fast income by selling recyclable waste at the lowest market prices (Varella, 2011).

The difference between the formal (registered) WP cooperatives and the informal sector is the services that formal WP cooperatives provide for the city hall of Belo Horizonte. They perform door-to-door collection followed by sorting of recyclables at working sheds (Varella, 2011). Thus, for formal WPs, not only the economic aspect of waste collecting and sorting is of relevance, but also their position in the society as service providers for the city (Rutkowski, 2008; Rutkowski and Rutkowski, 2015; Varella, 2011).

It is due to a significant gap regarding the efficiency of the socio-integrated recycling system that many decision-makers consider the Belo Horizonte HSW management to be stagnating (HORIZONTE, 2017). New perspectives from industries bring hope for WP cooperatives to create best practices for the socio-integrated system in the context of a circular economy (Ometto et al., 2018). Although the socio-integrated system is part of the national policy (BRAZIL, 2010b), industries and Belo Horizonte's city council remain locked in a stalemate when it comes to investing in HSW management.

3. Research method and data

3.1. Overview

This study carried out three main stages that enable an in-depth analysis of the dynamics of a real-life setting of the case study chosen, as displayed in Fig. 2.

The first stage aimed to disclose the characteristics of the system under review in-depth and to gather primary data. This step followed the qualitative method approach of participatory

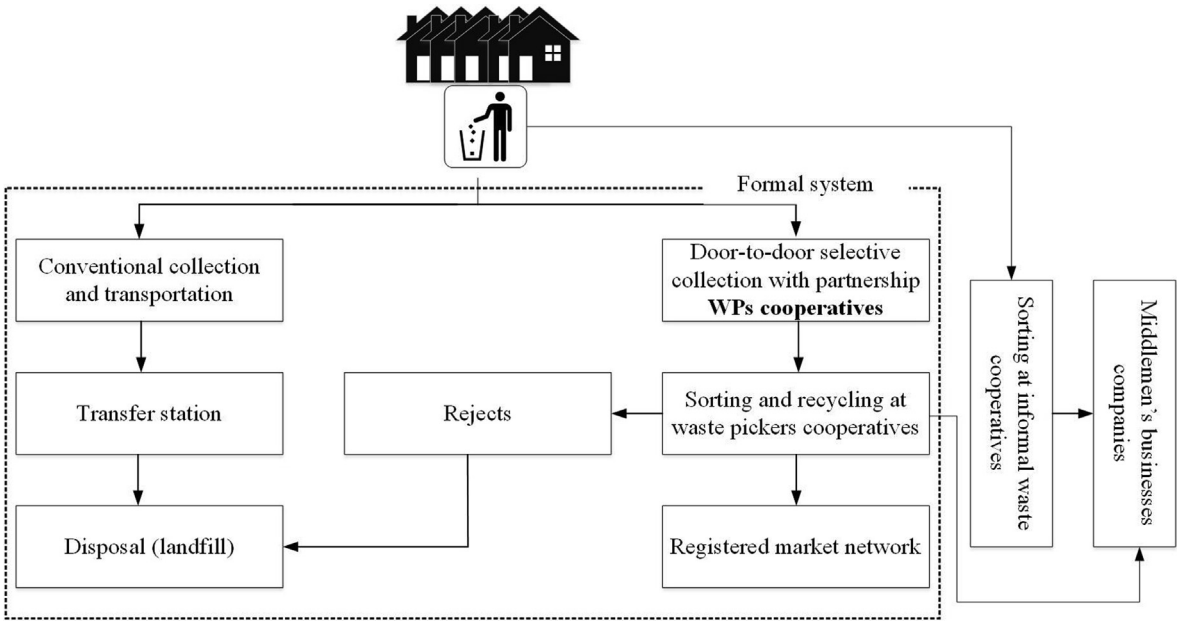

Fig. 1. Belo Horizonte's HSW management in 2014. Processes are part of the descriptions presented in Varella (2011) and SLU (2018).

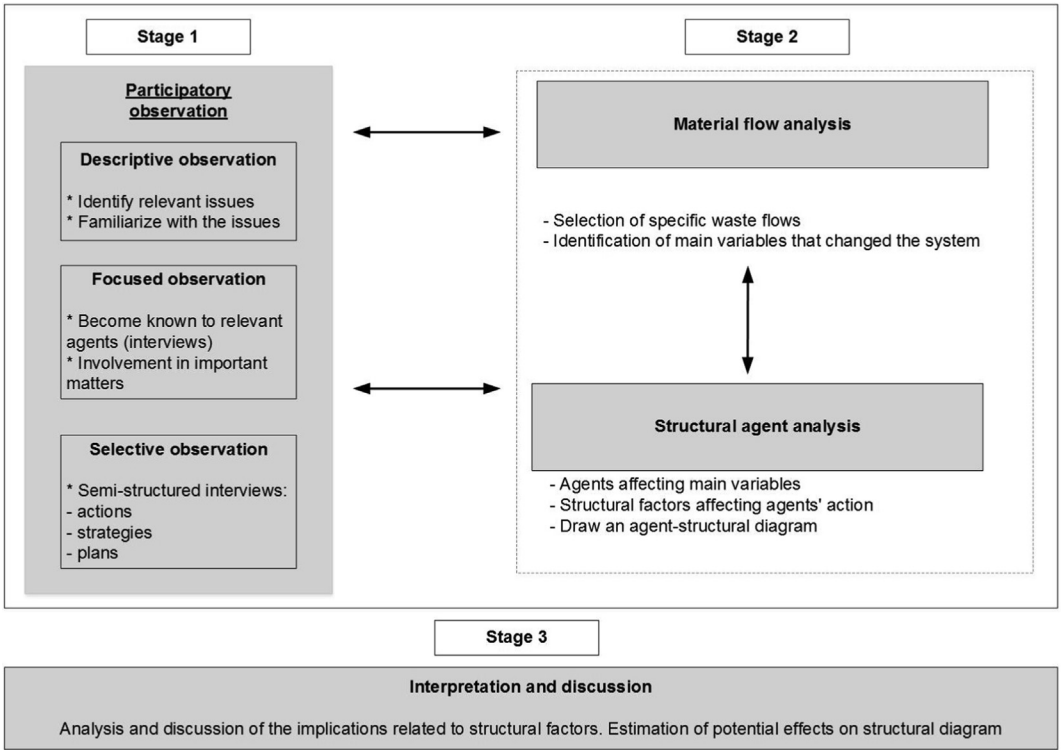

Fig. 2. Research method stages based on a combination of participatory observation and MFA-SAA. Stages adapted from (Binder, 2007b; Kawulich, 2005).

observation (Kawulich, 2005) to obtain an understanding and direct contact with the *status quo* of Belo Horizonte's city and its HSW management. The analysis started with prolonged fieldwork done in 2014 carried out by one of the researchers (an observer) and supported by a native researcher. The first method approach (Stage 1) helped the team to confront information from the literature review (see Section 2) and the different views of a native from an observer of the situation. It enabled the authors to identify issues and agents and to familiarize themselves with the formal and informal activities and interactions, such as unplanned activities. Mainly, WPs were observed as to how they were acting during day-to-day activities. Their historical backgrounds and beliefs were taken into account in interviews. The producers of household solid wastes were also investigated. Different parts of the city were visited to find out mainly how the society acts regarding waste generation, integration of WPs, and satisfaction with the current HSW management situation. The study's first stage was documented through

pictures and recorded videos to be used in the subsequent research processes.

One of the researchers of the study (the one who conducted the participatory observation) became integrated in the Waste and Citizenship Forum of Belo Horizonte. His involvement lead to the establishment of a platform of communication with about 34 agents of Belo Horizonte. This platform was essential for developing structural agent analysis (SAA). Direct contact with local agents enabled us to gain access to historical annual reports done by the city hall and WP cooperatives. These reports helped to build a data platform of a multi-year material flow analysis (MFA). This study analyzed a time range of 10 years. It considered the transition before the implementation of recycling networks (2004) and the reference year (2014) of the Municipal Solid Waste Plan (see Section 2). The targets presented in the Municipal Solid Waste Plan and the semi-structured interviews with the agents supplemented the interpretation of MFA-SAA to provide an up-to-date discussion of the findings (Stage 3).

3.2. Detailed characterization of MFA-SAA

While MFA is well established in the field of waste management, agent analysis is a common tool in the field of sociology (Binder, 2007a; Graedel, 2019; Long, 2004; Moriguchi and Hashimoto, 2016). This paper is related to the combined issues identified in recyclable materials flow analysis, and the social impacts of urban systems predominated by WPs. Thus, it is neither a single analytical analysis (MFA) nor a sociological analysis (SAA) *per se*. The application of MFA-SAA helped to investigate the relationship between agents and structural mechanisms by recognizing conflicts driven by economic, sociological, and psychological issues. Especially regarding the development of cities, decision-makers have problems in understanding the physical results provided by an MFA because the results are derived from conflicts of actions by agents (Binder, 2007a). Thus, MFA-SAA was developed to overcome the need to integrate the impact of social structures (e.g., legislation, culture, and economic systems) on human actions to assist decision-makers in understanding, in a practical manner, the systematic assessment of MFA (Binder, 2007a, b; Brunner and Rechberger, 2004).

One challenge identified in analyzing the city of Belo Horizonte is that there are no precise system boundaries when taking into account the circularity approach of recyclable materials. The scope of this study entailed that each agent corresponded to a "physical system", according to the conceptual framework for MFA-SAA (Binder, 2007a). However, the society of Belo Horizonte is exposed to all products available at the national level, i.e., the modeling approach focused on various consumer packaging products. This approach provided an in-depth analysis of the material flow sector, legislation, and market regarding the product value chain.

At the city level, MFA follows Belo Horizonte's recyclable HSW management (see Fig. 1), which allows quantifying recyclable waste generation, sorting routes, treatment, and disposal. Sorting rates follow the split into closed- and open-loop collection rates following the recommendations of ISO 14044 (2006) and reported in Haupt et al. (2017). Closed-loop recycling pursues recyclables that can still substitute original resources for the traditional processing industry while recyclables from open-loop recycling aim at a different type of resources for any other undefined industrial process (Haupt et al., 2017). From the participatory observation (Stage 1) and MFA results, three major steps constituted the SAA (Binder, 2007a) in this study:

I. Classification of the relevant agents, i.e., integration of outcomes from the participatory observation according to their impact on the variables driving the MFA system. For example, WPs are already pre-defined agents of this study. The sorting processes of recyclable materials relate directly to them, affecting, for example, the aluminum can flows;
II. Breakdown of structural factors into allocative resources (economics and market- related interactions for recyclables), legitimation (e.g., legislation for collectivism, production of packaging materials, recycling), and cultural values (e.g., significance of traditions the WPs live in). At the level of WP cooperatives, the drivers and motivators for the behavior model of the socio-recycling system are investigated. Following behavioral economics, the psychological approach that drives WPs was analyzed and interpreted (Hoff and Walsh, 2018; Madrian, 2014);
III. Visualization of the SAA outcomes through the agent-structure diagram. The diagram shows the structural factors driving agents' actions and interactions.

Details of the MFA-SAA modeling framework can be found in the supporting information S1.

3.3. Data management

The application of MFA-SAA requires two types of data, and, thus, two types of data gathering. Local reports are the background data to build the HSW management system for Belo Horizonte. Additionally, national reports provided secondary data for recyclable packaging production for food industries.

This study followed the MFA principle that total production in mass matches the total consumption demand (availability), while total consumption must correspond to the total post-consumption (accumulation and discard) (Brunner and Rechberger, 2004). Thereby, the transformation of packaging categories (*ex-ante*) into waste products (*ex-post*) moves across the system and vice versa. The disaggregation procedures applied the same reasonable hypothesis based on the technique introduced by Courtonne et al. (2015p. 69): "consumption is almost proportional to the population growth". For instance, the consumption of glass (U) at a local scale would be:

$$U_i = U * \frac{k_i}{k} \quad (1)$$

where U_i stands for consumption of a product, here glass, in region i in tons, U for nationwide consumption of the product in tons, k_i for the population of the corresponding region i, and k stands for the total population of the country under investigation, here of Brazil. The index i stands for Belo Horizonte.

Likewise, a relatively high data uncertainty is identified when the mass balance model is developed for both the years of 2004 and 2014. This study pays attention to this drawback by analyzing the uncertainties of the data input for MFA. The methodological approach follows the method presented by Laner and colleagues (Laner et al., 2016), which combines data classification and exponential-type uncertainty characterization functions. The MFA models for 2004 and 2014 are built using the free platform subSTance flow ANalysis (STAN) (Cencic and Rechberger, 2008). Table 1 sums up the primary data sources used for MFA. All equations and process descriptions are available in the supplementary material.

The SAA follows the qualitative approach based on semi-structured interviews and secondary data to determine the allocative resources, legitimation, and cultural values. The output of participatory observation helped to fulfill the first and second steps of SAA (see Section 3.2). For example, after the fieldwork, semi-structured interviews were often conducted with NGOs, public authorities, waste pickers, local recycling industries, and local HSW researchers to analyze the prolonged individual relationships

Table 1
Data source for MFA.

MFA			
Data demand	Data type	Data source	Scale identified
Physical supply of packaging materials produced in Brazil	Annual report and database	Brazilian Association of Packaging and Brazilian Institute of Statistics (ABRE, 2015; IBGE, 2015)	national
Trade of packaging materials (import and export)	Annual reports	Brazilian Association of Packaging (ABRE, 2015)	national
Consumption of packaging materials	Annual reports	Brazilian Associations: Metals (ABEACO), PET-Plastic (ABIPET), Glass (ABIVIDRO), Paper (ANAP, SINPACEL, BRACELPA, ABPO), Plastic (PlastiVida), Aluminium cans (ABRALATAS)	national
Waste collection and treatment	Empirical data	Superintendence of Urban Cleaning of Belo Horizonte (SLU, 2018)	local
Waste sorting	Empirical data	Waste pickers' cooperatives records	local
Recycling indexes	Annual report	Brazilian Associations (see above) and local recycling industries	local/national
Socio-economic entries (population, GDP, income)	Statistics	Brazilian Institute of Statistics ((IBGE, 2018) Secretariat for Strategic Affairs (SAE, 2014)	regional/local

Table 2
Data source for SAA.

SAA		
Issues discussed	Method	Involved agents
Recyclable waste collected in the sheds, sorting preferences, the ratio of recyclables rejected	Semi-structured interviews (face to face)	Informal waste pickers; leader of WP cooperatives; NGOs
Main problems of HSW management	Semi-structured interviews (face to face and phone	University professors; public authorities; third-party companies
The needs for a socio-integrated sorting system (15 persons)	Round table discussion Waste pickers; NGOs, PhD students; funding organizations; neighborhood representatives	
Structure of national, regional, and local regulations	Semi-structured interviews (phone and video conference)	University professors; NGOs; public authorities
Strategies for HSW management		Public authorities
Cultural values of WPs		Formal waste pickers; NGOs; university professor
Structure of market and legislation for recyclable materials		Leader of WP cooperatives; recycling industries
Market preference of recyclable materials		Leader of WP cooperatives; recycling industries
Results of agent analysis		University professors; expert in system analysis; NGOs; funding organization

with other agents within the recyclable materials chain. Regulation structures were identified according to the sorting products discussed with WP cooperatives and NGOs. The agent diagram was reviewed with experts on the field of HSW management and system analysis. Table 2 describes the main data sources used for SAA.

4. Results

The findings of the participatory observations (Stage 1) are integrated into the results of the MFA-SAA and are presented as follows. Pictures of the participatory observation and the MFA diagrams can be found in the supplementary material.

4.1. Recyclable waste flows and the impact on the circularity approach

The MFA started from the perspective to certify the amount of waste generated in Belo Horizonte by households and commercial places. Between 2004 and 2014, the total recyclable waste generation increased from about 195 kt to 260 kt, respectively, by an average growth of 2.9% each year. The main reasons for the growth are rapidly increasing incomes (about 2.7% each year), higher demands for recyclable products, and a growing population. In the same period, the net accumulation increased from 11 kt (2004) to 15 kt (2014).

The composition of the recyclable waste changed in due course (see Table 3). Although plastics, particularly PETs and PEs, are losing relevance (from a 36% (2004) share to 30% (2014) of the total generation), the growth rate of 49% is highly significant. Paper waste, in total, is outperforming the general development of waste generation (from 30% [2004] to 34% [2014]) with an annual growth of 7.2% in contrast to a 5.2% growth in plastics.

The overall collection rate of Belo Horizonte improved from 92% (2004) to 96% (2014). Therefore, not more than 4% of recyclable waste could be assigned (as input) to WP cooperatives for both years, i.e. in 2004, about 6.6 kt (±2%) and 11.3 kt (±2%) in 2014. The remaining fraction is collected together with the wet waste and disposed of in landfill sites.

The organization of the socio-cooperatives in recycling networks shows the impact of changes in the input flows on recycling processes. WP cooperatives are becoming more professionalized. Each member has assumed a labor division of collecting (selective collection), sorting (with or without the support of bells), mechanical recycling (i.e., shredding or pressing), and assisting the office staff. Their participation in selective collection has supported minimization of the impurities usually related to sand or stones used as filling to add to the weight of aluminum cans, and the communication of the quality conditions of cleanliness regarding cardboard. Such attitudes reflected that 48% of the total material sorted by WP cooperatives could be assigned to the closed-loop recycling system in 2014 (see Table 3). The largest share corresponds to aluminum cans (30%), followed by PET bottles (14%) and cardboard (4%). Both aluminum cans and cardboard always have been considered the easiest to identify recyclables and the

Table 3
Composition of Belo Horizonte recyclable waste vs. output of WPs cooperatives (t/a).

Waste product	Generation[1]		WP cooperatives[2]		Recycling path
	2004	2014	2004	2014	
PET[3]	**14 016**	**19 348**	**–**	**548**	**Closed-loop recycling**[4]
HDPE[3]	**11 346**	**15 663**	**403**	**411**	**Open-loop recycling**[5]
LDPE[3]	**25 362**	**35 011**			
PP[3]	**5 340**	**7 371**	**18**	**20**	**Open-loop recycling**
PVC[3]	**9 344**	**12 899**	**–**	**–**	
PS[3]	**101**	**106**	**–**	**–**	
EVA	**11**	**18**	**–**	**–**	
Others	**4 959**	**14 723**	**–**	**–**	
Total plastic	70 481	105 138	421	979	
Office paper	**9 404**	**15 579**	**129**	**207**	**Open-loop recycling**
Magazine and news	**3 135**	**5 193**	**43**	**69**	**Open-loop recycling**
Cardboard	**34 483**	**57 123**	**–**	**162**	**Closed-loop recycling**
Multi-material tetrapack	**3 135**	**5 193**	**–**	**–**	
Others	**8 306**	**34 173**	**–**	**–**	
Total paper	58 463	117 261	172	438	
Aluminum can	**1 567**	**2 596**	**–**	**1 235**	**Closed-loop recycling**[3]
Non-ferrous metal	**7 837**	**12 982**	**275**	**410**	**Open-loop recycling**
Ferrous metal	**4 644**	**9 548**	**673**	**468**	**Open-loop recycling**
Total metal	14 048	25 127	948	2 113	
Total Glass	23 511	38 947	–	–	
Other recyclables[6]	28 219	68 933	–	–	

[1] Uncertainties of data input vary from 15% to 31%. The most uncertain data comes from the category of metals (ferrous and non-ferrous).
[2] Uncertainties of data input vary from 22% to 45%. The most uncertain data comes from the category of metals (ferrous and non-ferrous).
[3] PET: Polyethylene terephthalate; HDPE (High-density polyethylene); LDPE (Low-density polyethylene); PP (Polypropylene); PVC (Polyvinyl chloride); PS (Polystyrene); EVA (Ethylene-vinyl acetate).
[4] Closed-loop recycling indicates the sorting process for a possible primary-purpose application (e.g., PET bottles to PET bottles).
[5] Open-loop recycling shows the sorting process for any further secondary application (e.g., use of PET bottles for textile).
[6] Any other type of recyclable materials such as rubber, textile, wood, and tinplates.

cleanest compared to any other recyclable wastes. The difference between both waste products is the strong market demand for aluminum cans, with their market price being around R$ 4.00/kg in contrast to that of cardboard of R$ 0.22/kg in 2014 (CEMPRE, 2018). PET bottles have become attractive for WP cooperatives in Belo Horizonte because of an increased generation and competition for aluminum cans within the informal sector. Wherever possible, closed-loop recycling was indicated following the recycling rates of aluminum (ABRALATAS, 2018), cardboard (ABPO, 2014), and PET associations (ABIPET, 2018). However, the recycling network systems reported the logistic challenge of trading directly with these primary production industries. In the metropolitan region of Belo Horizonte, only preprocessing recycling industries exist (e.g., smelting aluminum, shredding PET, and crushing cardboard bales), whilst the largest final product industries are located in Rio de Janeiro (450 km), Sao Paulo (580 km), and Curitiba (1000 km) (ABIPET, 2018; ABPO, 2014; ABRALATAS, 2018).

Open-loop recycling gives the opportunity for recycling networks to directly start the trade of sorted recyclables with small to medium-sized recycling companies without the intervention of middlemen, as was common in 2004. The challenge the formal WP cooperatives face is the low quality of recyclable waste received from third-party companies that are responsible for the selective collection. WP cooperatives confirmed that an average of 40% of the recyclable waste was rejected after coarse and fine sorting; there were no significant changes in the quality of waste received by service companies over the years. Therefore, after the recycling network systems, WP cooperatives discovered a new collaboration with the retail trade sector (e.g., hypermarkets and shopping centers) to obtain a better quality of recyclable waste, especially paper waste. Thus, compressed bales of sorted paper are underestimated (6% of the total) in small companies of toilet paper and tissue production that belong to the trade network of the recycling networks.

The purpose of CataUnidos started in 2014 is the mechanical transformation of colored PET, Pes, and PP into pellets. Based on the number of WPs in cooperatives and the share of metals in total waste input for the recycling networks, it is estimated that 14% of the open-loop recycling of plastics (see Table 3) were transformed into pellets and later designated to the steel industry as a substitute for coke. The remaining fraction is supposed to be commercialized with textile and unsaturated and alkyd resin industries in the metropolitan region. A specific share of plastic bales designated for each industry is unknown.

Glass waste has been considered a troublesome material. Belo Horizonte has more than 12,000 food kiosks (e.g., bars and informal food meal spots), being the largest Brazilian reference where the local population and tourists socialize (Kugel, 2007). Such commercial activities explain the growing rate of glass waste by 66% (see Table 3). Therefore, WP cooperatives who sorted glass (e.g., bottles) let the glass accumulate at their sheds because a market for such material did not exist. The crushing process to minimize the cargo volume for transportation to glass industries located in other states (Sao Paulo and Rio de Janeiro) is a barrier faced by recycling networks.

4.2. The socio-integrated recycling system in the view of SAA

The SAA results showed that HSW creates a contradicting effect, and the role of each involved agent presents fragments of significance in Belo Horizonte. For WPs who are members of a formal cooperative sorting waste brings opportunities to guarantee a better educational system for future generations. On the other hand, many citizens consider waste sorting a time-consuming task because the city hall service providers (privately or not) mix HSW during conventional collection. Nevertheless, in general, householders do not assume the responsibility of collaborating to improve the local system. There are different legislations without interconnection. This reflects how allocative resources (e.g., the market price of recyclables and the income of WPs) are controlled.

The overall responsibility of HSW management is with the city council, while formal WPs have raised the jurisdiction issue to

assume the selective collection responsibility instead of third-party companies. The agent-structure diagram (Fig. 3) provides a visualization of how Belo Horizonte's agents (depicted in ovals) interact according to the structural elements (gray boxes) identified. The arrows indicate the relationship of agents demanding services associated with flows of materials (direct agents) or technical assistance (indirect agents) such as standards, knowledge, and rights. At the same time, industries play a direct or indirect role by demanding high-quality sorting of recyclables, while leading enterprises assist with setting technical standards.

The core of the socio-integrated recycling system is the consolidation of waste pickers in HSW management, the central agent shown in the structure diagram (Fig. 3). Two pairs of regulatory structures drive agents' actions: culture & legislation (a robust local characteristic), and market mechanism & legislation (a merger of local, regional, and national rules).

The *culture & legislation mechanism* represent the merger of cultural values and legitimation. It consolidates the position of WPs today as the outcome of a long-lasting historical process symbolized by political persecution and discrimination from the Belo Horizonte' society. The Street Charity Pastoral (locally known as "*Pastoral da Rua*") substantially participated in the socio-integrated system in Belo Horizonte (Jacobi and Teixeira, 1997). The church community was primarily for providing educational awareness campaigns to minimize the marginalized view of WPs. It protected them against violent attacks (often tolerated by the city council) and intermediated the process to claim their rights more effectively among decision-makers in the 90s (Jacobi and Teixeira, 1997). Nowadays, they mediate the integration of informal WPs into legalized cooperatives together with NGOs (Fig. 3).

In 2004, no prescribed number of WPs is registered. There are eight cooperatives with about 312 WPs in Belo Horizonte registered in 2014. The formal WP cooperatives differ regarding the number of members, ranging from 20 to 100. Since then, they have all been integrated into recycling network systems, formed by two organizational structures named CataUnidos, as previously mentioned, and RedeSol. Both organizations aim to create socio-entrepreneurship induced by NGOs (CataUnidos) or are self-organized (RedeSol). They mainly act where selective collection occurs. In 2014, selective collection reached 36 of 417 neighborhoods and serviced about 15% of the total population. Table 4 summarizes the specific characteristics that differentiate between the two recycling networks' daily work performances and subsequent roles in HSW management.

The enactment of the NPSW (BRAZIL, 2010b) and the national decree for social inclusion (BRAZIL, 2006) came to regulate the socio-integrated recycling system by conceding WPs as a recognized profession determining the recycling process and giving priority to socio-entrepreneurship of WP cooperatives. Within the scope of the NPSW, different funding programs such as Pro-Collector and Cataforte and the National Secretary of Solidarity Economy opened the opportunity to consolidate the recycling network systems by giving CataUnidos, for example, the infrastructure conditions to establish a plastic pellets facility in 2014.

The integrated social system in Belo Horizonte differs from that of other Brazilian cities that failed to implement the socio-

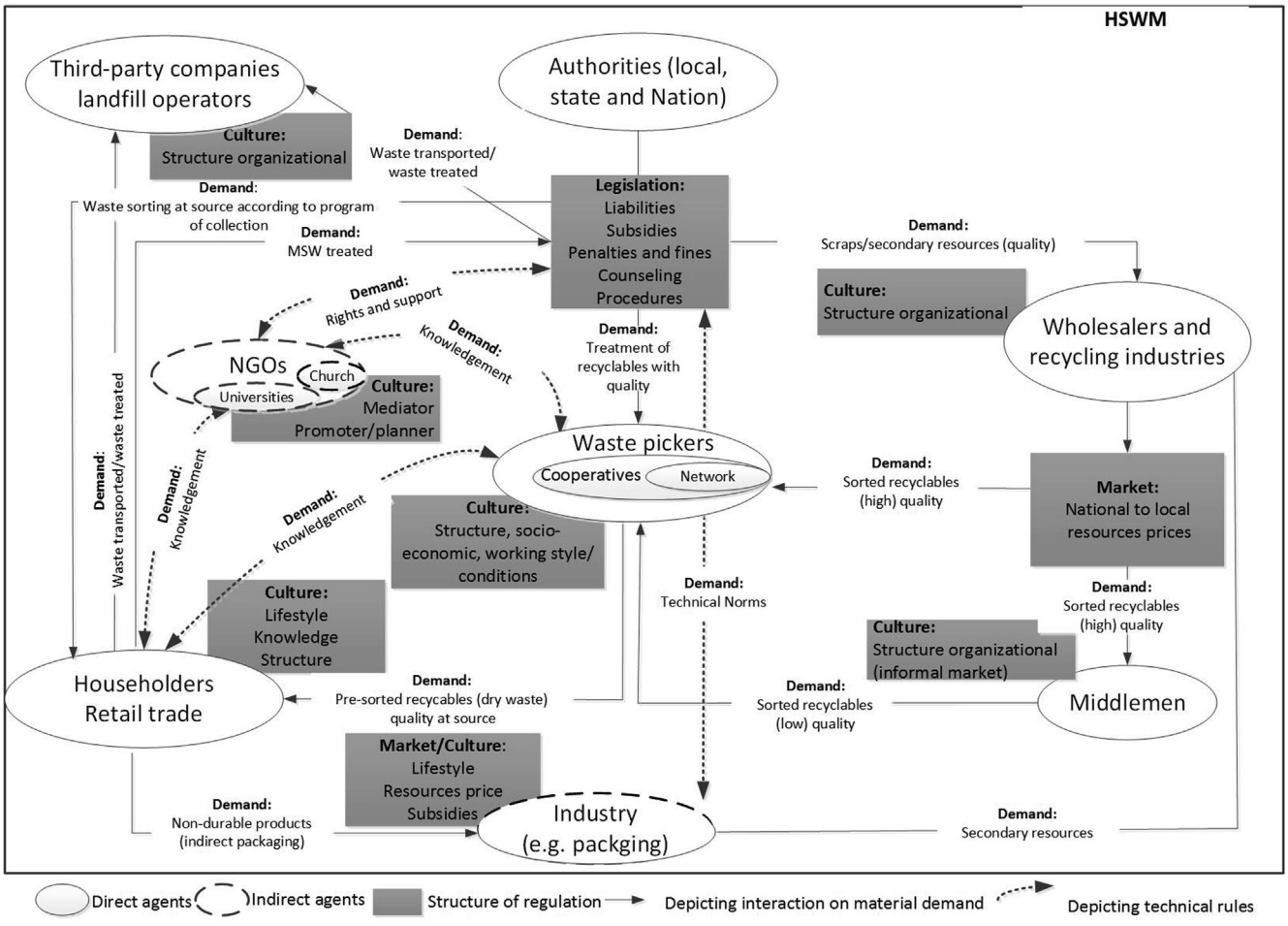

Fig. 3. Agent structure diagram within the scope of the socio-integrated recycling system. Adapted SAA diagram based on Binder (2007b).

Table 4
Organizational structure of Belo Horizonte's recycling networks.

	CataUnidos	RedeSol
Strategy of cooperatives	Expansionist	Concentrated
Function of waste pickers	Member	Service provider
Handcrafting activities	Existent	None
Interaction between cooperative	Large	Few
Performance of functionalities	Rotational	Competence
Share of income	Equitable	Weight sorted/month
Adaptation to a new technical instrument (e.g., conveyors)	Slow	Fast
Partnership with the city	yes	yes
Partnership with recycling industry	Providers of secondary material	Still under development
Foundation of 1st cooperative	Since 1992	Since 2002
Number of WP cooperatives from Belo Horizonte	1	5
Number of partner WP cooperatives from the metropolitan region	33	7

integrated model due to trust (Tirado-Soto and Zamberlan, 2013). The cultural behavior of both recycling networks reinforces the commitment of "together we can act better". The collectivism and solidarity commitment constitutes the primary internal understanding of the cooperatives' members, who assist one another through training, and support the participatory events through the external embeddedness of WP cooperatives in front of local and Brazilian societies. All members and the cooperative need to follow the normative law for a cooperative system (BRAZIL, 2010a), the statute for WPs (MNCR, 2017), and the respective amendments reported in the local union legislation. Recycling networks regulate the cooperatives while the cooperatives regulate WPs according to requirements, as follows (da Silva, 2018):

I. no child labor;
II. WPs must be registered at a cooperative;
III. legalized WP cooperative or in the process of legalization with a fixed address;
IV. equitable participation without the dictate of rules;
V. ban of trade with middlemen (considered as an action against reciprocity and commitment to collectivism);
VI. promoting physical security (equipment) and payment from the Brazilian Social Security Institute for Retirement (INSS);
VII. being approved after the application for a membership at an assembly.

The exploitation of other WPs by dictating rules and the trading outside of the market network (through middlemen) are the primary reasons that usually cancel the membership of WPs and WP cooperatives in the network systems.

The integration of informal WPs into the cooperative is considered a challenge. The profile of Belo Horizonte's informal waste pickers reflects the social identity described by Souza (2018) as the "riff-raff" class. They are extremely poor citizens, according to the national socio-economic classification (SAE, 2014). They are part of the 1.4% of Belo Horizonte's population, who have been out of the job market for a long time (IBGE, 2018; SAE, 2014). But they still hope to find moonlighting jobs and to leave the business of waste picking. These citizens are skeptical about the cooperative system due to many other social disturbances (e.g., drug use, alcoholism, and homelessness). Nevertheless, they find waste picking the last worthy chance for obtaining quick daily income rather than turning to delinquency.

Market mechanism & legislation describe the allocative resources and legitimation. They determine the recycling path, which lacks transparency among local agents because legislation is defined at the national level. Federal law imposed by the National Sanitary Surveillance Agency (ANVISA, 2016) and technical standards for industrial processes standardization (NBR, 2006) regulate packaging products for food and beverage industries (the primary source of HSW). The federal packaging legislation follows international market regulations (e.g., Mercosul and American Food and Drug Administration - FDA) to guarantee national consumption and export of packaging for goods as well as packaged food and beverage (ANVISA, 2016). For instance, the FDA permits food industries to use PP and HDPE as secondary sources from industrial processes that follow the patent technologies roadmap with a controlled supply chain (ABRE, 2015).

The supply of secondary resources cannot be ensured due to the challenge between the public sector and industry regarding the responsibilities for recycling costs. WP cooperatives are responsible for transportation and cannot afford long distances. There are patterns to follow for some recyclable products in Brazil. Closed-loop recycling is allowed for metal and glass packaging because of their high durability, mechanical resistance (without losing quality), and well-set standardized decontamination procedures (ANVISA, 1996). Paper and PET were included on the list for closed-loop recycling with some additional restrictions controlled by ANVISA in 2008 (ANVISA, 2016). For instance, multi-layers are regulated for the use of PET and paper secondary resources, where recycled PET and paper must not have direct contact with food and beverage contents (ANVISA, 2016). Under this circumstance, regulations imposed by ANVISA are seen as a bureaucracy for packaging industries that use mainly secondary resources originating from the industrial output (ABIPET, 2018; BRACELPA, 2015).

Closed-loop recycling from HSW management is a low attraction for investment for large-scale packaging industries, although the prices of primary resources (e.g., plastic resins and cellulose) are increasing (BRASKEN, 2018; Petri, 2018). An exception is the Brazilian Association for Aluminum Cans (ABRALATAS), which in the recycling process found an alternative method for minimizing energy demand and the dependence on the primary sector by investing in closed-loop recycling countrywide. Because of that, many WP cooperatives in Belo Horizonte became exclusively "aluminum can pickers" creating a highly competitive system. On the other hand, Brazil became the country worldwide leading in recycled aluminum cans (ABRALATAS, 2018). Quite the opposite happened in the case of the glass beverage industries, where returning glass bottles to the producer was stifled. Returnable glass bottles was the market strategy implemented by specific beverage brand industries that started in the 1980s and continued until 2005 (Bouças, 2017). This strategy has been lost because of substitution for plastic bottles, lack of investment into collection stations, and the decrease in prices of raw materials, which do not make recycling attractive (Bouças, 2017). Although it was a commercial strategy, returnable glass bottles were well accepted as a successful engagement of society in Belo Horizonte.

A market mechanism for open-loop recycling is growing, and new products are becoming attractive for sorting at WP cooperatives. With the interest in opening new businesses, small enterprises look for purchasing good-quality recyclables (mainly paper and plastic) from the recycling networks by sometimes offering them the transportation service as a bonus.

5. Discussion

The results of this study combined insights from bottom-up (local intervention) and top-down (at the national level) methods to discuss the approach of the research question presented in Section 1. The CE approach calls for mechanisms and policy

instruments from a top-down perspective (macro level), but actions happen at the city level (bottom-up). No agreement could consolidate these different scales, agents, and interests, for optimal development.

MFA-SAA results showed that waste generation increases in Belo Horizonte. The number of formal WPs is low. According to Table 3, each member achieved an average of sorted recyclables of 1071.78 kg/month, excluding rejects in 2014. National statistics stand that such average capacity demonstrates the low efficiency of the WP cooperatives and the need for a better infrastructure to achieve an average of 1800 kg/month based on the national standard for high efficiency (da Silva, 2018). WP cooperatives have limited support to boost their strategies because recycling networks face the challenge of the low quality of recyclable wastes received and a large number of recyclables disposed of without pre-treatment in Belo Horizonte. Local industries usually find other accessible alternatives without the involvement of HSW management. The bureaucracy and contamination constraints impede the recyclable loop from being closed.

The macro-scale perspective of the CE concept makes it a new buzzword in the discourse of integrating WPs. Recyclable HSW is becoming highly competitive because of numerous recycling options, and recycling networks can be smothered if they remain between industries and the city council due to a clash of interests. Recycling networks are built based on social values that create niches for breaking economic and technical barriers and pushing them to claim rights. The embeddedness of WPs in CE needs to consider further limitations. The infrastructure of CataUnidos and RedeSol is precarious. Working sheds are small and need refurbishment. A formal WP cooperative is usually made up of 70% women and 30% men, most from 30 to 59 years old with incomplete primary education backgrounds (ASMARE, 2015). Many women described private issues (e.g., chauvinism) that limited them from entering the market during an early stage of their lives, and recyclable waste opened new socio-economic paths.[1] The beliefs are the primary motivation to bring them together. Members of CataUnidos described their wishes to "give a prosperous future to their children far away from the marginality within a better educational perspective". Such commitment brings cultural values of collectivism and solidarity to the same work platform. Additionally, it is seen that reciprocity exists by creating attitudes of friendship between the recycling networks, although they have different organizational structures (see Table 4).

However, a CE focused on the future development of society (accomplishing sustainable development (Kirchherr et al., 2017)) could open opportunities. Recycling networks need to focus on a target group (industries or city councils) or become independent recycling companies.

Industries require a controlled supply chain of secondary resources (i.e., legitimation). CataUnidos has shown positive initiatives for urban industrial symbiosis within plastic pellet production. Plastic pellets are an alternative to fossil resources in the steel industry, which is one of the most energy-intensive industries and one of the largest CO_2 emitters in Brazil (Carvalho et al., 2015). Such an attitude is seen in this study as a positive balance of the two worlds (HSWM and industries): lower emissions from industries and less plastic landfilled. Professional assistance is needed to support WP cooperatives by identifying industrial needs or determining how to build a controlled supply chain.

The *city council* requires trustful services with low costs to assume the selective collection system. Selective collection is the most costly process, and it does not cover the entire city of Belo Horizonte (SLU, 2018). New alternatives need to be found that are not accounted for in the management plan of Belo Horizonte (HORIZONTE, 2017). For instance, door-to-door selective collection per recyclable category done by WPs could be a new regulation. Such initiative would create interventions to support society's adoption of better rules for sorting waste.

Self-sufficient recycling companies demand new products (open-loop recycling) in the market. Small enterprises start after the initiative to become WP cooperatives. Most of them are composed of handicraft persons or technicians who develop new products from waste. Such path requests more funding programs on a national scale by offering equal opportunities in both technological and capacity building.

In general, for any functioning system focused on a target group, a fair market price for recyclable waste needs to be regulated by giving value to the workload and efforts provided by WPs. Besides that, the number of waste cooperatives needs to increase. Nowadays, an average of 2412 (based on national statistics[2]) to 33,766 citizens (based on the socioeconomic classification for extremely poor citizens) could be informal WPs. The barrier of implicit discrimination requires considerable efforts to minimize psychological challenges (Hoff and Walsh, 2018).

6. Conclusion

The findings of this study confirm that a CE approach can be too broad to boost socio-integrated systems for HSW management if it is taken at a macro scale. The macro perspective of the CE concept obscures the real problem, procedures, challenges, and even targets. The application of participatory observation merged into MFA-SAA presented the dynamics of real-life settings that threaten to prevent putting into practice the CE approach in Belo Horizonte, Brazil. The MFA results showed quantitatively that the challenge starts with waste generation increasing from about 195 kt to 260 kt between 2004 and 2014. The SAA discussed the regulatory structures that encompass cultural values (grounded on collectivism, solidarity, and reciprocity), market mechanisms, and legislation constraints. The number of WPs registered in cooperatives, the market price set up by recycling companies, regulatory legislation for packing products, and new small enterprises promoting open-loop recycling are among the identified barriers that create obstacles for development of the socio-integrated system within the practice of CE.

WPs are part of society in constant development crossing cultures and behaviors from country to country, city to city, or even neighborhood to neighborhood. This study discussed suggestions that can apply to other cities. For instance, knowing the target group brings opportunities for WPs to disclose niches (based on a small network of agents with expectations and visions) and can create socio-technical regimes to implement a conscious and sustainable CE. Therefore, changes (e.g., adapting the approach close to primary industries) need to be considered along with the transformation processes. Given the growing role of waste generation in emerging economies, there is a need to develop a salubrious working environment for those people that are committed, with an aware or unaware behavior, to collaborating with a practical approach to the CE. Also, effective communication and mutual understanding of the vulnerabilities of socio-integrated recycling systems need to be further developed, and the single view on cost-saving needs to be minimized to create trends to act on sustainable and local CE.

[1] The number of women in the workforce grew from the year 2000, reaching 40% of the economically active population from 25% in Brazil in the 1980s. Andrade, A.S.C., 2004. Women in the Brazilian job market, PhD Thesis ed., Campinas.

[2] Dagnino and Johansen (2017) provide a prescription that 1 in every 1000 Brazilians is a waste picker and from each 10 waste-pickers, 7 remains in the informality.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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