2022

Sustainable options to improve household solid waste management of Belo Horizonte, Brazil

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Zur Erlangung des akademischen Grades einer

DOKTORIN DER PHILOSOPHIE (Dr. phil.)

von der KIT-Fakultät für Geistes- und Sozialwissenschaften des

Karlsruher Instituts für Technologie (KIT)

angenommene

DISSERTATION

von

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Tag der mündlichen Prüfung: 04/10/2022

This work has been made possible by the financial support from the Brazilian National Council for Scientific and Technology Development (CNPq) through the Program Science without Borders.

To my family

and special people that I met in the meantime

“Don’t wait for things to get easier, simpler and better.

Life will always be complicated.

Learn to be happy right now.

Otherwise, you will run out of time.”

(unknown author)

Abstract

The global speed of increasing household solid waste (HSW) requires new system thinking and new methods of knowledge production to assist agents involved locally (e.g., waste producers, decision-makers and NGOs), especially concerning sustainability issues in emerging economies. In emerging economies, a critical aspect is to reconcile local knowledge, social values, and preferences with a systematic understanding of worldwide technological development for HSW management in an urban situation often characterised by rapid economic growth and extreme social inequalities. This thesis addresses these complex real-life situations faced by several cities that are often neglected in transformative approaches. The Brazilian city of Belo Horizonte became a learning platform for collecting, presenting, and analysing data in a robust matter.

Belo Horizonte is one of Brazil's economic axes that ends-up with about 98% of the total HSW generated in landfill sites without any prior treatment. The remaining fraction corresponds to waste sorted by citizens from impoverished communities, i.e., waste pickers. Belo Horizonte HSW management is seen as stagnated by many decision-makers, investors, and recycling companies, although the city is a reliable reference for a social model based on the organisational structure of waste pickers into cooperatives worldwide. The case of Belo Horizonte is used as a strategy to answer three problem-oriented research questions aimed at this thesis:

I. What are the options to improve household solid waste management in Belo Horizonte?
II. Is Belo Horizonte's social model the best path example to improve household solid waste management in the Global South?
III. Why do we want to integrate waste pickers in household solid waste management in an age of accelerating and interconnected technological change?

The three research questions guide this thesis's approach to enable agents and academics to understand the nuances that require HSW management in a way to deal with waste pickers as part of a societal transition in emerging economies. For that, the tripartite transdisciplinary framework (TTF) was developed as a scientific instrument to broaden the methodological knowledge obtained through four publications developed along with the thesis. As its own name says, the TTF's structural approach is part of merged concepts taken from social sciences and

transdisciplinary research in sustainability science, such as the ideal-typical transdisciplinary research process, value-sensitive design, and historical analogies. The TTF helped to extract the knowledge of the transdisciplinary research that was conducted by indicating problems, the relationships between agents, and three possible major effects that reflect on the socio-technical future of HSW management in Belo Horizonte (research question I). The TTF also contributed the structure that was necessary to understand the resilience to answer research question II and transboundary thinking to answer research question III.

This thesis presents three options for driving the socio-technical future of HSW management in Belo Horizonte: individual, technological, and sustainability. The individual option adheres to the specific social values (respect, solidarity, fairness, responsibility and reciprocity) that are niches created to promote a local-oriented circular economy for specific recyclable HSW (e.g., aluminum cans and polyethylene terephthalate bottles). The technological development through the implementation of mechanical biological treatment draws attention to the minimisation of waste landfill and social obstacles that must be faced for a technology that is considered to be a decisive game-changer for HSW management. The sustainability option considers the envisioned view of agents regarding (among other issues) social-economic benefits to reduce poverty in the city, enhancing the recovery of materials, and the dissemination of awareness by direct contact to assist changes in social behaviour.

Although Belo Horizonte can be considered an example of cooperativism of waste pickers for other cities because of historical commitments, the transformative model designed the practice of progress, not its perfection. Belo Horizonte's lessons learned show that waste pickers symbolise the importance of intragenerational justice. Waste pickers have their own principles that are adapted or not adapted to the urban system. They create a sense of unity within the globalised issue to develop standards for a functioning HSW system. Such globalized and standardised measures deny society the option of creating a productive system based on their capabilities. This study's significance lies in the fact that it informs a problem-oriented and theoretical understanding of socio-technical approaches towards sustainability issues by introducing a focus on local problems that have hitherto been lacking.

Keywords: Transdisciplinary research; Household solid waste management; Sustainability science; Brazil; Emerging economies.

Zusammenfassung

Das weltweit zunehmende Hausmüllaufkommen erfordert ein neues Systemdenken und neue Methoden der Wissenserweiterung zur Unterstützung der lokalen Akteure (z.B. der Abfallproduzenten, Entscheidungsträger und NGOs) insbesondere im Hinblick auf Themen der Nachhaltigkeit in den Schwellenländern. In den Schwellenländern ist es entscheidend, in den häufig durch schnelles wirtschaftliches Wachstum und extreme soziale Ungerechtigkeiten gekennzeichneten städtischen Regionen lokales Wissen, soziale Werte und Präferenzen mit einem systematischen Verständnis der weltweiten technologischen Entwicklung in der Abfallwirtschaft zu vereinen. Die vorliegende Arbeit befasst sich mit den daraus resultierenden komplexen Alltagssituationen, die in einigen Städten bewältigt werden müssen und die in transformativen Ansätzen oft nicht berücksichtigt werden. Die brasilianische Stadt Belo Horizonte ist eine Lernplattform für die Erfassung, Darstellung und Analyse von Daten zu dieser umfassenden Herausforderung.

Belo Horizonte ist eine der Wirtschaftsachsen Brasiliens. Dort landen ca.98% des gesamten Hausmülls unbehandelt auf der Abfalldeponie. Der verbleibende Anteil entspricht dem von Menschen aus der armen Bevölkerung, d. h. von Müllsammlern, sortierten Abfall. Belo Horizonte ist ein verlässlicher Referenzort eines auf der Struktur der Organisation der Müllsammler in Kooperativen basierenden weltweit angewandten sozialen Modells. Dennoch wird die Stadt von vielen Entscheidungsträgern, Investoren und Wiederaufbereitungsunternehmen Stagnation attestiert. Der Fall Belo Horizonte soll als Strategie zur Beantwortung dreier problemorientierter Forschungsfragen im Rahmen dieser Arbeit verwendet werden:

I. Wie kann die Abfallwirtschaft in Belo Horizonte verbessert werden?
II. Stellt das soziale Modell von Belo Horizonte den besten Weg zur Verbesserung der Abfallwirtschaft im globalen Süden dar?
III. Was bezwecken wir in einem Zeitalter des zunehmenden und vernetzten technologischen Wandels mit dem Einbeziehen von Müllsammlern in die Abfallwirtschaft?

Die genannten Forschungsfragen sind bestimmend für den Ansatz dieser Arbeit. Wissenschaftler und Akteure sollen in die Lage versetzt werden, die Aspekte zu verstehen, derentwegen in den Schwellenländern Müllsammler im Sinne des gesellschaftlichen Wandels in die Abfallwirtschaft einbezogen werden sollten. Zur Erweiterung des methodischen Wissens, das mit Hilfe von vier im Zuge dieser

Dissertation erarbeiteter Publikationen gewonnenen werden konnte, wurde als wissenschaftliches Instrument der dreiteilige transdisziplinäre Rahmen (Tripartite Tansdisciplinary Framework - TTF) entwickelt. Wie der Name sagt, ist der strukturelle Ansatz des TTF Teil miteinander verbundener Konzepte aus den Sozialwissenschaften und der transdisziplinären Forschung in den Nachhaltigkeitswissenschaften, etwa des idealtypischen transdisziplinären Forschungsprozesses, der wertorientierten Gestaltung und der historischen Analogien. Das Instrument des TTF hat dazu beigetragen, das im Laufe der transdisziplinären Forschung akkumulierte Wissen zu extrahieren. Dieses Wissen konnte durch das Aufzeigen von Problemen, das Darstellen der Beziehungen zwischen den Akteuren und das Beleuchten dreier möglicher wesentlicher Auswirkungen auf die soziotechnische Zukunft der Abfallwirtschaft in Belo Horizonte (Forschungsfrage I) gewonnen werden.

TTF lieferte darüber hinaus die zum Verständnis der Resilienz im Zusammenhang mit der Beantwortung von Forschungsfrage II und des grenzüberschreitenden Denkens im Zusammenhang mit der Beantwortung von Forschungsfrage III erforderliche Struktur.

Um die soziotechnische Zukunft der Abfallwirtschaft in Belo Horizonte voranzutreiben, werden in der vorliegenden Arbeit drei Optionen vorgestellt: die individuelle Option, die technologische Option und die Option der Nachhaltigkeit. Die individuelle Option hält fest an den spezifischen sozialen Werten (Respekt, Solidarität, Fairness, Verantwortung und Gegenseitigkeit), d.h. den zur Förderung einer lokalen Kreislaufwirtschaft für bestimmte recyclingfähige Haushaltsabfälle (z.B. Aluminiumdosen und Flaschen aus Polyethylenterephthalat) geschaffenen Nischen. Die durch die Einführung der mechanisch-biologischen Abfallbehandlung gekennzeichnete technologische Option lenkt die Aufmerksamkeit auf die Reduzierung der Deponien und die Minimierung der sozialen Hindernisse, die eine als bahnbrechend für die Abfallwirtschaft geltenden Technologie zu bewältigen hat. Die Nachhaltigkeitsoption berücksichtigt die Vorstellungen der Akteure, u.a. hinsichtlich des sozioökonomischen Nutzens der Verringerung der Armut in der Stadt, der Verbesserung der Materialrückgewinnung und der Bewusstmachung durch direkten Kontakt zur Unterstützung von Änderungen im Sozialverhalten.

Belo Horizonte kann für andere Städte historisch gesehen als beispielhaft in Bezug auf die Kooperativität der Müllsammler betrachtet werden. Der transformative Ansatz

beschreibt jedoch die Praxis und nicht die Vollendung des Fortschritts. Die mit Belo Horizonte gemachten Erfahrungen lassen die Müllsammler als Symbol der Bedeutung intragenerationeller Gerechtigkeit erscheinen. Die Müllsammler haben ihre eigenen, an das städtische System angepassten oder nicht angepassten Prinzipien. Im Sinne des Entwickelns von Regeln für eine funktionierende Abfallwirtschaft stellen sie innerhalb der globalen Problematik ein Gefühl des Zusammenhalts und der Einigkeit her. Derartige globalisierte und standardisierte Maßnahmen nehmen der Gesellschaft die Möglichkeit, ein produktives System auf Grundlage ihres Potenzials und ihrer Fähigkeiten zu schaffen. Diese Arbeit vermittelt ein problemorientiertes und theoretisches Verständnis soziotechnischer Ansätze im Hinblick auf Nachhaltigkeitsfragen und legt den Fokus dabei auf bisher nicht berücksichtigte lokale Probleme.

Keywords: Transdisziplinäre Forschung; Brasilien; Schwellenländer; Abfallwirtschaft; Nachhaltigkeitswissenschaft;.

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1. Introduction

When speaking about sustainable household solid waste management or sustainable options for household solid waste management, the term “sustainable” often echoes in my mind. If we stop for a second and pay attention to our waste bin at home every day, we see noteworthy changes in some days and weeks. The contents of our waste bin change according to our daily consumption wishes. Sometimes, the contents change based on our mood or to take away some products (e.g., beverage bottles or journals) to make a handcraft. It can surprise us when we invite a certain number of guests for dinner or even how they were satisfied with our invitation. At a particular time, we do not feel comfortable with our waste bin and leave it outside of our house, allowing the encharged authority of the city empties it. The disturbing contents are away from our view. It is, therefore, time to fill it again because the problem is solved for many of us. We leave it to others to look for sustainable treatment solutions for the waste we produce.

Scaling up the situation shows that new products (e.g., convenience food) are launched on the market continuously. These novelties influence consumer behaviour, volume and composition of household solid waste. Tourism, international events, and anticipated population growth also affect waste generation. Primarily, a waste management system exists within cities to clean up our houses and towns, leaving empty waste bins to be filled again. Moreover, the management is often supported or supplemented by people sorting street waste. Is this paradigm sustainable? What role are recycling and treatment technologies in this system?

What is the similarity between both perspectives? A paradigm exists intermittently. Moving waste from one place to another creates numerous issues because consumptive behaviours always end up as household solid waste (HSW) at home and the municipal level.

A global observation relates that urban societies in the Global South strongly desire to adopt similar or even luxurious lifestyles and personal ostentation to the Global North. The difficulties lie in how to urge a sense of urgency and change them, primarily when the reasons are related to natural processes (e.g., global warming and climate change). Comparable to the definition of inertia by Isaac Newton, many urban societies are looking for a lifestyle upgrade, which may create resistance to keeping progress in a straight line in the Global South. Many nations are busy setting new goals that address waste hierarchies, recycling procedures, and different treatment

technologies, while others are still filling their landfill sites or even open dumps. The challenge is that we are in a limited global sphere. A worldwide orientation and respective limits need to be rescued. A wide angle of thinking requires extensive efforts to generate a force of action to influence conscientious social change in lifestyle and behaviour.

Meanwhile, the amount of household solid waste is increasing dramatically. Reusing household solid waste is still not a usual procedure at home. How to treat it sustainably? The engagement with citizens from impoverished communities (i.e., waste pickers) is an opaque and critical issue. It is primordial to recognize the discrepancies resulting from social inequalities where household solid waste currently creates opportunities for waste pickers to meet the standard and socio-economic living conditions. While decision-makers look for the benefits of technologies to achieve fast solutions, we must strive to understand physical processes, new global initiatives, and the interaction with all actors involved to create long-term and fair strategies. The situation requires new system thinking and new methods of knowledge production to assist agents involved locally (e.g., waste producers, decision-makers and NGOs), especially concerning sustainability issues in emerging economies.

1.1 The aim of the thesis

Waste management is a technical field in the respective scientific community. It depends on awareness regarding the nature of waste generation to enable the elaboration of management actions for collection, transportation, treatment, and disposal (Arena et al. 2014; Shulman 2011). The mismanagement of such actions is a technical problem for cities of the Global South. It influences urban salubrity and quality of life, but it becomes a moving force that creates paths for waste pickers to obtain income sources simultaneously (Gutberlet 2018; Gutberlet et al. 2017; Rutkowski and Rutkowski 2017; Velis 2017).

Socio-integrated system is a commitment embraced by several scholars to suggest actions to improve collection, transportation and treatment procedures for household solid waste management, at the same time, the living conditions of waste pickers. The overall issue looks for integrating (and formalising) waste pickers as part of conventional household solid waste management systems (dos Muchangos, Leticia Sarmento et al. 2017; Giovannini and Huybrechts 2017; Gutberlet et al. 2017; Rateau and Tovar 2019; Rodić and Wilson 2017; Rutkowski and Rutkowski 2015; Uddin and

Gutberlet 2018). Rutkowski and Rutkowski (2015) called socio-integrated recycling the transformative model of combining the informal sector in recycling services (e.g., door-to-door collection), whereby the conventional selective collection and landfilling of recyclable waste can be minimised in Brazil.

The transformative model for socio-integrated household solid waste management system directs attention back to the discourse of the sustainability scientist Ariane König:

"A starting point is to develop a critical and reflective mind-set towards what we can and cannot know, how we know, and why we want to know in an age of accelerating and interconnected change. Furthermore, we need to practice to understand different facets of complex situations through very different perspectives rather than just defending a viewpoint through a particular (organizational) lens associated with a particular set of interests." (König 2018,4)

This thesis aims to enable agents and academics to understand the nuances that require household solid waste management in a way to deal with waste pickers as part of a societal transition in emerging economies. Within this aim, the objective is to make a case study a learning platform for collecting, presenting, and analysing data in a robust matter. The case study must have the purpose of a socio-integrated system. However, it has further identified problems in developing household solid waste management because of social obstacles regarding the integration of waste pickers.

The principles of this scientific work field facilitate bringing technical and sanitation constraints of household solid waste management with social-cultural and governmental facets together. The involvement of the non-scientific community (e.g., waste pickers and decision-makers) allows for gaining knowledge regarding their actions and existing social relationships. As such, interactive communication based on transdisciplinary research opens opportunities to discuss local technologies for improving household solid waste management and global initiatives (e.g., circular economy and sustainable development). Likewise, the methodological target of the research efforts is to gain sufficient information to merge other scientific methods and concepts of natural and social science to leverage a co-learning process for sustainability science (König 2018). The emerging sustainability science cares about the influences of transformative social learning processes to understand the non-

intended consequences of the Anthropogenic Age (König 2018; Kudo and Mino 2020).

This thesis provides a platform to discuss diverse perspectives (positive and negative criticism) for plausible and robust reflections involving household solid waste management and waste pickers.

1.2 Learning with a model-case study to create research questions

The geographical scope of this thesis concentrates on Belo Horizonte's city, Brazil. The constant social movements and actions, including household solid waste management, instigate the need to build critical and reflective mindsets, as in the study case.

Belo Horizonte launched its Municipal Solid Waste Plan in 2017, after three years of the target defined in the National Policy on Solid Waste (HORIZONTE, 2017). 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 waste picker cooperatives in comparison to other Brazilian cities. Belo Horizonte had the first political initiative to recognize waste pickers as household solid waste management agents in the 1990s (Campos 2014; Jacobi and Teixeira 1997). The political initiative demonstrated the working value of waste pickers, who were often confused as part of the marginalized groups of that time. It 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 labour in dumpsites and participative dialogue between governments and waste pickers, funded by the United Nations Children's Funds and the Brazilian government in 1997 and 2000, respectively (Campos 2014).

The situation in Belo Horizonte strongly influences the perspective for socio-integrated household solid waste management in other Brazilian cities and Latin American countries (IBGE 2018). Waste pickers cooperatives from Belo Horizonte began organizing themselves in groups, forming national networks, and inspiring international alliances. They seek to demonstrate their abilities, claim rights and expand recognition at the national and international political level (Alfaia et al. 2017;

Fernández 2010; Valenzuela-Levi 2019). The international efforts contributed to Peru and Columbia. Both countries enacted similar policies to the Brazilian one in 2014 and 2015 because the informal sector powerfully acts in Lima and Bogota (Rateau and Tovar 2019).

1.3 Research questions

In transdisciplinary research, scientific and non-scientific communities often raise several questions when the research focus concentrates on the integration of waste pickers in household solid waste management, such as:

I. How many waste pickers could a city afford economically to improve the current conditions of household solid waste management?
II. Which technology is appropriate from an economic and environmentally friendly standpoint?
III. Which recycling products are the sound-of interest for waste pickers and industries simultaneously?

These are all important questions pointed out during the development of this study. However, they are not directly addressed in this thesis. For instance, a question I is a clash between economists and social scientists working in the field of cost accounting for capacity building of a socio-integrated household solid waste management system. Question II is a dilemma in the scientific field of engineers, economists, and social scientists committed to new infrastructure, costs and social acceptance. Questions I and II are the process of weighting that could limit transboundary thinking because it involves emphasizing some criteria more than others. Question III introduces a complex issue involving material sciences to disclose all specific chemical substances that can be recycled in a household solid waste bin and transfer the know-how to waste pickers committed to sorting waste products properly.

The case of Belo Horizonte is carried out in the learning process to understand local actions in a complex global problem of increasing waste generation and properly management system. Throughout this perspective, two main research questions have been formulated:

I. What are the options to improve household solid waste management in Belo Horizonte?
II. Is Belo Horizonte’s transformative model the best path example to improve household solid waste management in the Global South?

This thesis considers the term “option” to be a set of possibilities (strategies) to indicate the direction household solid waste management can have through the integration of waste pickers. The two primary research questions are interconnected and comprise many other secondary ones exclusively associated with historical and present municipal solid waste management practices in Belo Horizonte. For instance, who comprises agent-network acting in household solid waste management? In what instances did waste pickers become essential for political actions? Both research questions create the background approach to provide a societal contribution to this study.

These questions mentioned above have the primordial scope to discuss diverse perspectives that can assist in building the answer to the third research question of this thesis:

III. Why do we want to integrate waste pickers in household solid waste management in an age of accelerating and interconnected technological change?

1.4 Thesis outline

This thesis is divided into three parts. The first part is devoted to the theoretical framework and methodological gaps. The second part is reserved for the main body of the thesis, which contains results to answer the research questions, discussions, conclusions, and recommendations. All additional scientific papers are annexed in the third part. They were developed during the research process and serve as background knowledge to build the methodological approach presented in the first part. They provide critical and reflective mindset results presented in the second part of this thesis.

Part I

Theoretical framework and methodological gaps

2. Methodology framework

This study employs the approach of transdisciplinary research in sustainability science. In its simplistic terms, it applies multiple methods driven by different disciplines with the participation of non-academics. Such an approach may entail examining the system under investigation (S.2.1) through documentary sources held in local archives, consultation of academic material, national legislations, semi-structural interviews and quantitative methods (e.g., material flow analysis). The tripartite transdisciplinary framework (TTF) was developed for this thesis. The major objective is to contribute to the community in sustainability science (S. 2.2). The TTF's structural approach is part of merged concepts taken from social sciences and transdisciplinary research in sustainability science, such as the ideal-typical transdisciplinary research process, value-sensitive design, and historical analogies (S.2.3). The TTF is a scientific instrument that follows its application according to the methodological knowledge obtained through four publications produced along with the thesis (2.3.1). Publications I and II disclosed household solid waste management problems that have merged into the social development of Belo Horizonte (Fuss et al., 2014; Fuss, et al., 2020a). Publication III provided the assessment of a technology to improve the status quo of Belo Horizonte's household solid waste management (Fuss et al., 2020b). Publication IV built an envisioned household solid waste management based on the principles of the Integrative Concept of Sustainability (Kopfmüller et al., 2001), which contrasts the conventional approach of sustainability that typically characterizes a sustainable future along the three dimensions of economy, environment and society (Fuss et al., 2018). The generic insights of TTF is a methodical and theoretical innovation that can trigger a learning process for communities in transdisciplinary research (S.2.3.2) and sustainability science (S. 2.3.3).

2.1 Outline of the system under investigation

Belo Horizonte, the capital of Minas Gerais' state, is placed in southeast Brazil. 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 characterised by high social inequalities (IBGE 2018). This socioeconomic situation and precarious household solid waste management are

reflected by the high relevance of informal collecting and sorting of household solid waste (Varella, 2011). No specialized treatment occurs in Belo Horizonte, as shown in Figure 1. The conventional system relies on landfilling after household solid waste is reloaded into larger vehicles at the transfer station (SLU, 2014). Consequently, the long-term collection of mixed waste motivated social interventions in household solid waste management activities accompanied by constant popular movements (Rutkowski, 2008; Varella, 2011). The recycling network system started with CataUnidos in 2004, collaborating waste picker cooperatives to promote joint action for marketing and technical support to reduce the influences of the informal sector (Tirado-Soto and Zamberlan, 2013; Varella, 2011). The formal and informal waste sector runs in parallel in Belo Horizonte (see Figure 1). The informal sector helps small and middle-sized middlemen businesses by creating the opportunity to generate fast income by selling recyclable waste with the lowest market prices (Varella, 2011).

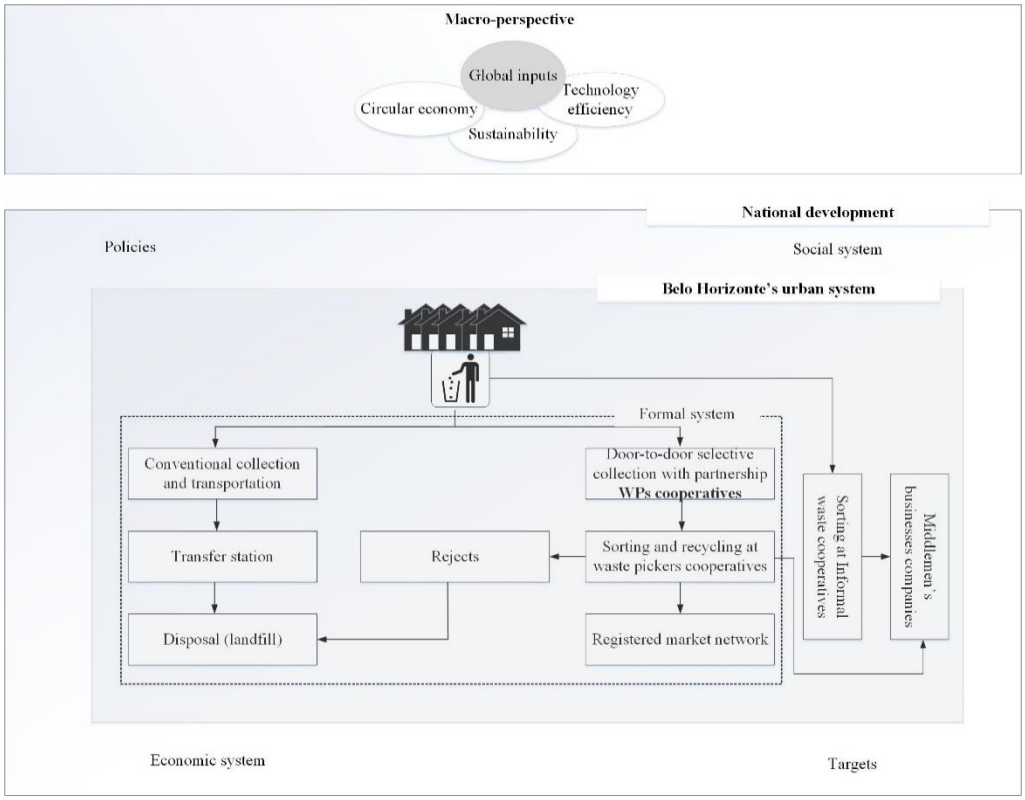

Figure 1. Overview of Belo Horizonte's household solid waste management

The fight against recognising the waste-pickers' role became the central axis of development policies in the late 1990s in Belo Horizonte, as introduced in this thesis. The local consensus influenced actions and attitudes that contributed to the enactment of the National Policy on Solid Waste in 2010 (Brazil, 2010; Campos, 2014). Figure 1 shows that household solid waste management is part of Belo

Horizonte's urban system with strong national influence because the city is the fourth largest economic axis of Brazil and one of the essential business cities in Latin America (IBGE, 2018). New perspectives from industries bring hope for waste picker cooperatives to create best-practices for a socio-integrated system under macro-perspectives discussed globally, such as circular economies and sustainability (Ometto et al., 2018). Although the socio-integrated system is part of the National Policy (BRAZIL, 2010), industries and Belo Horizonte's city council remain locked in a stalemate to invest in household solid waste management.

Belo Horizonte brings political and socio-economic challenges as critical steps on the transformative model for socio-integrated household solid waste management system. Dayball (2018) suggested that connecting political and socio-economic issues in sustainability requires technical understanding and social analysis. Hence, a novel methodological framework is needed to achieve the objective of this thesis.

2.2 The methodological state of the art

Transdisciplinary research had grown with the focus on "real" problems within the health and social sciences in the 1990s (Tejada et al., 2019). The merging of transdisciplinary research as a methodology for sustainability science was done in 2004 due to approaches and concepts opening the space to some similarities between them (Tejada et al., 2019). Sustainability sciences and transdisciplinary research call for a problem-based focus on world societal challenges (e.g., wellbeing, climate actions, and resources efficiency such as household solid waste) to bring action-oriented results for transformative paths (Brandt et al., 2013; Klein, 2014; Tejada et al., 2019).

An increasing number of studies contributed to determine three basic analytical processes to conduct transdisciplinary projects in sustainability science (Brandt et al., 2013; Tejada et al., 2019): (i) "structure of the problem" where the problem and agents[1] are identified; (ii) "problem analysis", the creation of knowledge and co-solutions and (iii) "integration and application", the application and communication of the results. A common understanding exists between scholars and practitioners to merge sustainability science, of which transdisciplinary research is the critical methodological component (Brandt et al., 2013; Klein, 2014; Lang et al., 2012; Tejada

[1] Agents are individual groups (actors) that execute directly or influence an action in the system under investigation. The definition of agents comes from the method approach of material-flow analysis and structural agent analysis (Binder 2007) applied in the Publication II.

et al., 2019; Woltersdorf et al., 2018). Nevertheless, many efforts remain according to the challenges identified as follows:

I. It is missing a coherent framing. Tejada et al. (2019) listed an extensive range of frameworks developed for undertaking transdisciplinary research in sustainability sciences that differ from practice-oriented design principles to back-casting guidelines and evaluation of the knowledge production.
II. The major challenge of transdisciplinary research is the extensive and broad range of methods. A clear set of methods does not exist, nor do measures on how to integrate them (Brandt, et al. 2013; Lang, et al. 2012; Tejada et al. 2019; Woltersdorf et al., 2018).
III. The major challenge of sustainability science is what “must be framed” as a sustainability challenge and the level of emergence for a “holistic treatment in the process of developing action plans” (Kudo and Mino 2020; Woltersdorf et al., 2018).
IV. The clarity in transdisciplinary research in sustainability sciences requires that the proposed framework and knowledge obtained are presented in a given study (Brandt et al., 2013; Woltersdorf et al., 2018).

2.3 Overview of constructing a tripartite transdisciplinary framework

The tripartite transdisciplinary framework (TTF) was developed to have a coherent framing to merge all lessons learned from the Belo Horizonte case study (see Part III) and make them helpful to introduce to local societal practice and scientific discourse. Simultaneously, TTF synthesizes and structures the research processes conducted in this thesis that match the purposes started through the ideal-typical transdisciplinary framework (Lang et al., 2012). The ideal-typical transdisciplinary framework is part of the consecutive research on practice-oriented processes for transdisciplinarity. This framework merged and adapted similarities of other models presented in the literature (Lang et al., 2012), like the ideal-typical conceptual model (Jahn 2008). The ideal-typical transdisciplinary framework adapted terminologies of sustainability sciences in the conceptual model (Jahn 2008). It underlined the need for academic and non-academic agents to collaborate with the study under analysis. According to Lang et al. (2012), the process of conducting transdisciplinary research in sustainability science consists of three phases that inspired the outline of the TTF (see Figure 1).

Phase “A” consists of "framing the problem" where the challenges, local actions, and agents are identified systematically. TTF explicitly overcomes the methodological gap found in the ideal-typical transdisciplinary framework between Phase “A” and Phase B "co-producing solution-oriented and transferable knowledge". In TTF, the outcomes of Phase “A” guide the research process to define normative aim(s) to allow the definition of co-solutions in Phase B. Otherwise, the solution would be just a change of the current situation, whether for better or worse, cannot be qualified. In this thesis, co-solutions are options to improve the conditions of the problem identified that are part of the societal practice.

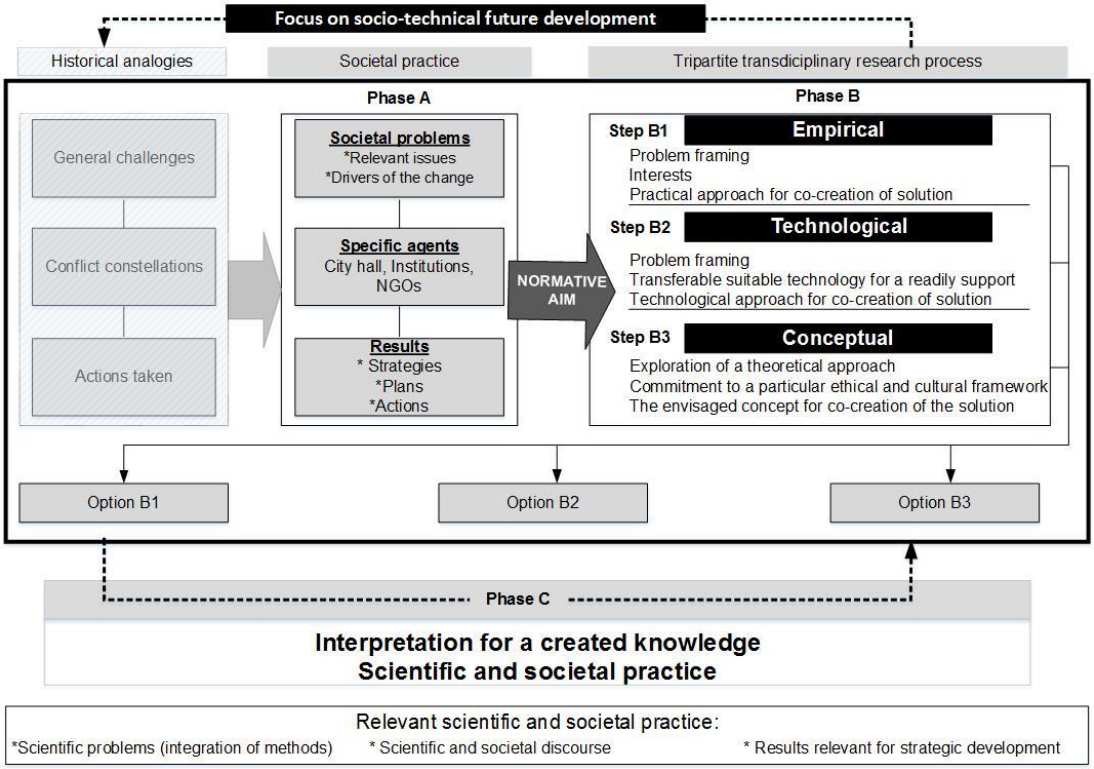

Figure 2. Tripartite Transdisciplinary Framework (TTF)
(adapted from Bergmann et al. 2005; Lang et al. 2012; Friedman and Hendry 2019; Parsons and Nalau 2016)

The determination of co-solutions is often driven by technology to improve the material flows in the research area of waste management (Arena et al., 2014). In order to expand the scope in this research area, TTF integrated the generic principles of the tripartite method of value-sensitive design (Friedman and Hendry 2019). The tripartite method of value-sensitive design provides an interactive outline to the research process in Phase B. Value-sensitive design brings the thinking that:

“*Technology is the outcome of human beings envisioning alternatives to the status quo and acting upon the environment. […]*

Including social values[2] offer creative opportunities for technical innovation as well as for improving the human conditions" (Friedman and Hendry 2019, p. 1) ".

Hence, the tripartite method of value-sensitive design divide Phase B into three steps and helps to develop three respective options at least (see Figure 2). The options differ according empirical, technological and conceptual focus.

Step B1 seeks the empirical context to describe material flows and agents involved in the system. Material flows are physical or chemical flows that can become troublesome for the current societal practices because of the management and the interaction with the environment, for example (Graedel 2019). This step focuses on a detailed quantitative description of each flow relevant for the system under investigation (Graedel 2019). The interaction of agents brings the focus on the individual social values and priorities of competing values that draw up the investigation on a range of qualitative methods used in social sciences. The interaction of different individuals with similar perspectives is seen as a first alternative solution, (i.e. option B1), which satisfies minimal decision criteria.

Step B2 concentrates on the technical investigation to maximise the efficient usage of the material flows under investigation. The technical investigation considers the principles of value-sensitive design that technologies are more suitable for certain activities than the human force (Friedman and Hendry 2019). The outcome of step B2 creates a systematic view considering the infrastructure features and policies to boost the technological development based on opportunities and constraints (i.e., option B2).

The conceptual investigation (Step B3) addresses central issues informed from theoretical explorations; i.e., it seeks to operationalise and integrate concepts based on theories or thoughts into the empirical or technical investigation (Friedman and Hendry 2019). In the context of TTF, the conceptual investigation explores the principles of sustainability theory to promote the strong involvement of stakeholders, experts, and decision-makers. Such exchange of information is used to develop a work conceptualisation to clarify fundamental issues for sustainability, such as (Dobson, 1996): (i) What is to sustain? (ii) Why should it be sustained? (iii) Who is

[2] Social values corresponds to the stability for a smooth society through a set of of guidelines, which provide orientation for personal development properly within a social system (Hyland 1999, 150-170).

concerned? The outcome of Step B3 is a careful working conceptualisation (i.e., option B3), which is based on the envisaged view of a sustainable system.

Before the interpretation of solutions (Phase C) is carried out, the current inattention to the histories, vulnerability and resilience provides a partial understanding of the status quo and represents a significant risk for failure. The interaction of the past, present and future paths draw up attention on social histories and cultural analyses used in historical analogies (Parsons and Nalau 2016). The TTF proposes feedback on historical analogies to disclose how past challenges were solved and resonated on current actions involving the problems identified in Phase A. Thus, the feedback becomes part of the process to understand value tensions identified along the development of both Phase A and Phase B. Value tensions are conflicts related to social values involved in the system under investigation and the respective trade-offs in which designing for one value can diminish the other one (Friedman and Hendry 2019, p. 53-58).

The purpose of Phase C follows the principles of the ideal-typical transdisciplinary framework (Lang et al., 2012) because it focuses on the integration of the entire knowledge obtained during the transdisciplinary research. This knowledge generates an intensive lessons-learned framework that can support the development of local societal practices, as well as the generalisation and incorporation of results into a scientific context. Especially in sustainability science, the centralised idea mainly driven by technical perspectives has to be questioned by pieces of evidence of the analysed social values that were integrated into TTF.

2.3.1 Application of the tripartite transdisciplinary framework

In practice, the application of the TTF starts with the process of collecting Belo Horizonte's challenges regarding the integration of waste pickers in household solid waste management that originated the research questions of this thesis. The identification of household solid waste flows and involvement of agents are mandatory to structure the purpose of Phase A. This means that life cycle thinking and the application of the national primary matrix provided the first method background to know the case of Belo Horizonte in-depth. Data was collected through fieldwork, literature review, and semi-structured interviews with local agents (Fuss et al., 2014). Life cycle thinking quantified the physical exchanges related to inputs (i.e., household solid waste flows) and outputs (e.g., emissions to air, water and soil) in the environment in each life cycle stage, including collection, transport, treatment and

disposal. The application of the national primary matrix that comprises 42 indicators categorised the level of Belo Horizonte's household solid waste management development according to political, technological, economic, environmental, cultural and social dimensions based on the framework of the Brazilian Policy for Solid Waste (Polaz and Teixeira, 2012). A platform with 34 agents from Belo Horizonte was developed. The purpose was to obtain feedback from local experts and agents in all phases of the study. Both methods provided a holistic treatment to determine the normative aims in Phase A.

Steps B1, B2 and B3 correspond to the empirical investigation (see Fuss et al., 2020a), technological assessment of mechanical biological treatment (see Fuss et al., 2020b) and conceptual analysis based on sustainability (see Fuss et al., 2018), respectively. The empirical analysis (Step B1) was based on a mixed quantitative and qualitative analysis following the approaches of participant observation (Kawulich 2005), material flow analysis and structural agent analysis (Binder, 2007a, b). The empirical investigation focused on the sociotechnical context to integrate waste pickers as the individual option to improve household solid waste management, for example, towards the macro-concept of the circular economy. The methodological focus concentrated on the relation of physical flows with structural regulations, such as legislations and market regulations, and social-cultural performance of the socio-integrated system with waste pickers.

Technology implementation is often considered the best-practice with which to execute a service related to one or more types of treatment of household solid waste, such as recycling, biological treatment, and pyrolysis (Arena et al. 2014; Shulman 2011). Mechanical biological treatment is the example taken in Step B2. The objective was to analyze the impacts to implement such a system in the environment and society in Belo Horizonte. Through a combination of scenario-based life cycle assessments and social impact analysis based on semi-structured interviews, the method framework for presenting the technological option in Belo Horizonte was created.

Sustainability is an overused term, and this leads to the impression that sustainability is well-known. Many agents in Belo Horizonte consider the principles for sustainability, as defined by Bruntland Commission (WCED, 1987), too abstract. They are not readily applicable to the establishment of a sustainable household solid waste management system. Even though all Brazilian cities are strongly being influenced by

concepts developed in the Global North in the search for strategic policies and long-term action plans for household solid waste management, many decision-makers have not paid much attention to an overall sustainability approach so far. Against this backdrop, the conceptual investigation seeks to establish an option based on the envisaged household solid waste management system for Belo Horizonte according to a mutual understanding of the principles of sustainability. The municipal solid waste diagram is the outcome of the sustainability option because it is the comprehensive framework for assessing the current state of a household solid waste management system against a future sustainable one (Fuss et al., 2018). The normative foundation of the municipal solid waste diagram is the Integrative Concept of Sustainability (Kopfmüller et al., 2001), which contrasts with the conventional approach of sustainability which typically characterizes a sustainable future along the three dimensions of economy, environment and society. Integrative Concept of Sustainability points out crucial documents for sustainable development (e.g., Brundtland report and Agenda 21), and it does not neglect the potential of the capability approach (Kopfmüller et al., 2001). According to Burger and Christen (2011), the capability approach is an advantage strategy beyond the pure environmental sustainability because it gives insights into the improvement of the quality of life, reinforces the capacity of humans to lead an active life, claims universal validity and assists further development.

Historical analogy is primordial because the majority of national and international researchers know Belo Horizonte's practices and difficulties in enforcing recycling plans partially (Alfaia et al. 2017; Campos 2014; Conke 2018; Jabbour et al. 2014; Rateau and Tovar 2019; Valenzuela-Levi 2019; Yoshida et al. 2007). Nevertheless, behind all nations or even cities[3] inhabited by waste pickers, a cultural and social dimension exists, which creates a vague understanding of the mutual challenge. It is important to understand political facts and interpret cultural and social skills, and a feedback-loop to historical analogies (see, Parsons and Nalau 2016) helps with identifying the current inattention to the history, vulnerability, and resilience of Belo Horizonte's agents. Thus, the integration of reports and written accounts build the historical analogies (see Parsons and Nalau 2016), and provide the feedback in Phases A and B.

[3] An example are Brazilian cities. Brazil and all its cities are shaped as a multicultural and multiethnic society (Araujo, P. "BRASIL CULTURA | O site da cultura brasileira. Archived from the original on February 5, 2020, in Portuguese).

The feedback process supports the interpretation (Phase C) in answering the research questions (see section 1.3) and transmitting credible and robust information. For this, three ideational elements of culture (i.e., knowledge, beliefs and information) suggested by Conke (2017) are taken into consideration to prevent unintentional interdisciplinary conflicts in Phase C. Because a debate still exists between anthropologists and behavioural scientists to justify the impact of actions on cultural defence (Conke 2017).

2.3.2 The methodological contribution to the challenge in transdisciplinary

The major challenges in transdisciplinary research are the missing of a comprehensible and clear framing, as well as, the re-organization of an extensive and broad range of methods systematically (see challenges in section 2.2). TTF is a result of the methodological solution found at the end of the transdisciplinary research to structure core lessons learned for the dissemination of results locally and scientifically. The community of transdisciplinary research in sustainability science expects such methodological development because it first belongs to the re-integration and application process of the co-created knowledge phase presented in the ideal-typical transdisciplinary framework (Lang et al. 2012). TTF is the scientific contribution that seeks to complement the steps of transdisciplinary process of the ideal-typical transdisciplinary framework (Lang et al., 2012) by integrating new principles to minimize the challenge of incoherence to perform such studies (challenge I and II). It brings the purpose of examining the problems with precise thinking, finding robust solutions based on (1) the best practices developed locally, (2) usual technological paths often taken as solution of the problem identified and (3) a theoretical orientation path for an envisaged future based on sustainability principles. The perspective seeks empirical, technological and conceptual solutions to help schematize methods for the assessment systematically. Hence, the discussion of the results provided through TTF follows the principle that takes place with agents directly connected to society, not for society (Tejada et al., 2019). TTF suggests that understanding local needs precisely can contribute to a better synchronisation in the time of local adaption for system changes and policies.

However, according to the principles of “learning-by-doing” by Reese (2011), the exclusive focus on Belo Horizonte’s case opened the opportunity to ponder new theoretical ideas to perform and evaluate the transdisciplinary research done. Very predictable questions stimulated the experiences of “learning-by-doing” arose during

the process of this transdisciplinary research to proof upon practice (Reese, 2011), such as the following:

I. Is there evidence suggesting that the outcomes of Belo Horizonte's case are desirable, feasible, and more effective than the best cases that cities in the Global North have done?
II. Is there a best way to proceed methodologically? Which research questions should the case study of Belo Horizonte attempt to answer?

Question I address some of the procedures that scholars use when they try to apply solutions from cities in the Global North to guide the development of cities in the Global South (see Brunner and Fellner, 2016; Souza et al., 2016; Azevedo et al., 2020). The best cases of cities in the Global North are often seen as examples to be mirrored. Because of that, the opinion of local scholars and agents are often influenced with a risk of failure when the problem is not analyzed systematically. Step "B2" worked with scenario-based life cycle assessments to identify what conflicts might arise if such options were to be chosen (Fuss et al., 2020b).

Question II brings the methodological challenge faced in transdisciplinary research. The introduction and application of the TTF in the same study helps to bring more clarity of transdisciplinary research in sustainability sciences done (challenge IV). The idea that urged the purpose of TTF started through the building-block process. At first, it was essential to learn the case of Belo Horizonte, to identify and frame the real problems. The number of research questions that arose before and at the beginning of the study created a social and scientific dilemma regarding which would be the most appropriate for this thesis (see section 1.3). Thus, the building-block process presented reflections on the lessons learned once each phase was completed. The research questions were reviewed during each phase to ensure that they were relevant to both societal and scientific practices because the study deals with a societally relevant research problem. For a scientific rigour, it was important to seek for a research question that addresses the generalizability of the lessons learned at the end of the research process in the phase "C" (see research question III).

2.3.3 The methodological contribution to the sustainability science

The major challenge in sustainability science is what "must be framed" as a sustainability challenge (challenge III, section 2.2). Waste pickers and mismanagement of household solid waste are two significant issues that drew interest to be studied in this thesis. It is suspicious to affirm that both are problem-based within

the frame of a sustainability challenge without a holistic analysis, resilience and transboundary thinking in the process of developing plans and acting strategies (Kudo and Mino 2020).

Framing sustainability challenges puts the focus on the interface of the results from Step B1 (empirical analysis), Step B2 (technological analysis) and Step B3 (conceptual analysis) of the TTF. The empirical analysis points out the existing social values and individual beliefs from a bottom-up perspective. This analysis creates a constructive perspective based on possible actions directly connected to the community involved. The technological analysis is considered part of the solution for household solid waste treatment. The conceptual analysis integrates the broad standpoint of issues that were still not perceptible locally. The description of how to apply step B3 (section 2.3.1) includes the work conceptualisation to answer the core questions for a sustainability study, for example, “sustain what” and “for whom”, which are part of the normative dimension of framing sustainability (Dobson, 1996; Kudo and Mino 2020).

Once both issues, waste pickers and mismanagement of household solid waste, are studied, phase “C” focuses on the discussion of the options identified (see section 2.3). In this phase, the framing process to discuss sustainability challenges requires the combination of the backcasting approach to provide a clear image of an ideal and sustainable system (Kudo and Mino 2020). The goals and rules of the Integrative Concept of Sustainability (Kopfmüller et al., 2001) reflect on the integration of a problem-based learning process to certify the empirical evidence (top-down) with a normative approach to the deductive definition of the sustainability model (bottom-up). Hence, the holistic analysis, resilience and transboundary thinking are merged in the concluding discussion in phase “C”.

Part II

Results & discussion, conclusions and recommendations

3. The holistic results of Belo Horizonte's case

The holistic analysis of Belo Horizonte obeys each phase and sub steps of the TTF (Figure 1) as follows.

3.1 Phase A: Framing the agents, problems and actions in Belo Horizonte

Three drivers of household solid waste management interconnect a large number of agents in Belo Horizonte (Figure 3). Belo Horizonte citizens are the first drivers. They are waste producers and seek a quality of life free of insalubrious produced by improper household solid waste management. Waste pickers are the second drivers. They seek the monetary value of waste products to guarantee a socio-economic domain with support of academia, financial institutions on social programs, non-governmental organisations (NGOs) and other influential communities (e.g. students and faithful of the church). Technology is the third driver. It determines the complementary technical solution of household solid waste management aimed by academia, decision-makers and investors. Urban and economic development is the major priority for city authorities, multinational industries (e.g., steel and food industries) and international (scientific) cooperation in Belo Horizonte.

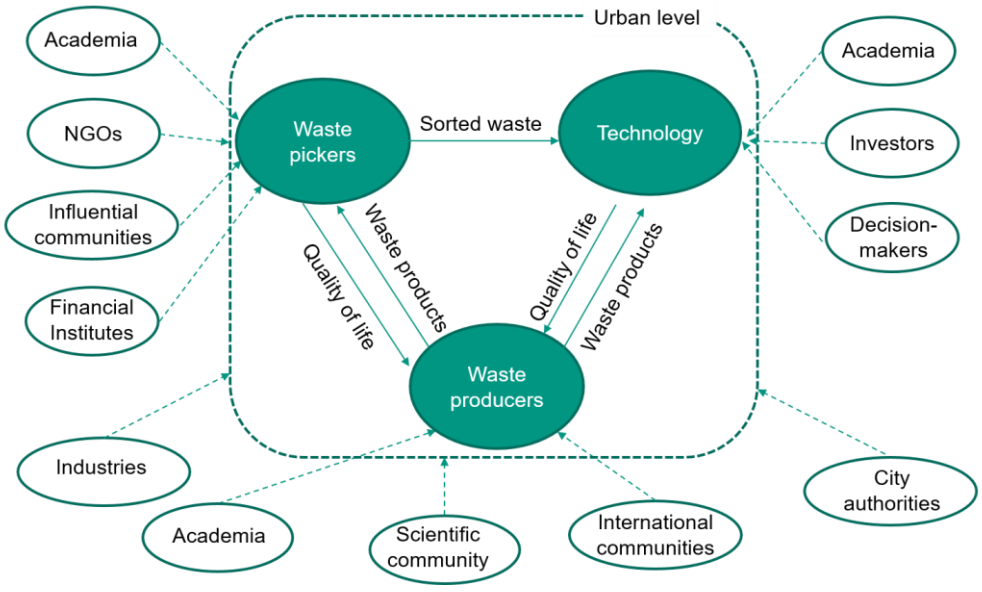

Figure 3. Specific agents connected to the trilemma of household solid waste management in Belo Horizonte

Waste generation is the current result of satisfying basic needs of householders who are chasing the trends of consumerism fed by local and multinational products offered in several supermarkets and hypermarkets in Belo Horizonte. Predicting the waste

generation of Belo Horizonte is a challenge (Figure 4). Additionally, to householder waste generation, waste peak production often occurs due to tourism and large-scale national and international events in Belo Horizonte. Over the years, the organic fraction does not dominate Belo Horizonte's waste composition anymore and shows less than 50% of the total waste generated from 2012 onwards. Figure 4 presents a significant increase in recyclable waste and other waste (e.g., batteries, textiles, personal care products).

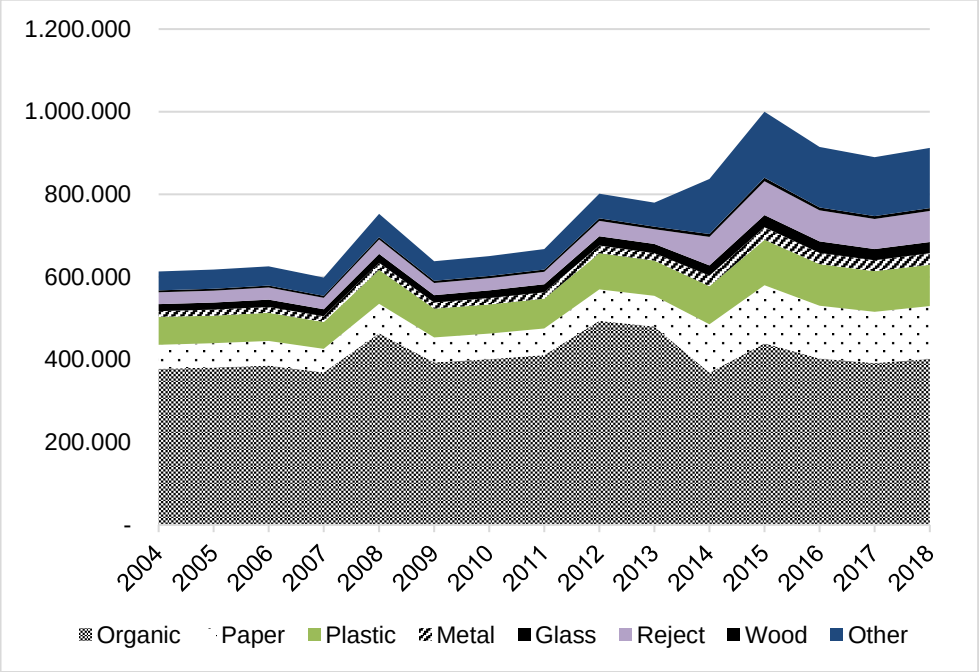

Figure 4. Waste generation in Belo Horizonte
(Graphic adapted from SLU reports 2004-2018)

3.1.1 Technical and geographical challenges

Reliable, trustful, and cost-effective household solid waste management turns to an issue that concerns the sanitation and environmental decision-makers because it must be offered for the entire population of about 2.5 Mio in Belo Horizonte (IBGE 2018). Belo Horizonte presents a growth rate of 0.6% per year since 2001 because of parallel socio-economic growth and cultural preferences for its metropolitan area (IBGE, 2018).

The conventional collection of unsegregated household solid waste achieved 96% of the total population from 2012 onwards (SLU 2018). The selective collection service occurs in a few neighborhoods of the city, and an outsourcing company executes it. The geographical condition, valleys and hills, is a problem to reach the entire

coverage area. Accumulation of garbage and inappropriate disposal are the ensuing results. Waste collection vehicles are not suitable to provide such services, especially in the hills where slums are formed. The collection service covers about 70% of the total population and happens once a week in the slum areas compared to a daily collection in the business center and other neighborhoods (SLU 2018). Belo Horizonte has about 226 slums spread in nine urban districts, in a total area of 331 km^2 (SLU 2018). Slum formation is the visible indication of socio-economic inequalities in Belo Horizonte (SLU 2018).

About 98% of household solid waste that arrived at the landfill in the neighbor city Sabara, coming from Belo Horizonte city, is mostly unsegregated and mixed with the biodegradable (organic) matter (SLU 2018). Formal waste picker cooperatives are responsible for the 2% of household solid waste not disposed of in the Sabará landfill since 2009 (SLU 2018). Belo Horizonte has limited space, and the transboundary movement of waste is the solution found.

3.1.2 Social practices and constraints

The development of household solid waste management varies significantly between the social, political, technological, economic, environmental, and cultural categories in Belo Horizonte. The social category reached the most extensive index of development (77%), compared to 35% in the environmental category (Fuss, et al., 2014). The significant social practice is the organisation and legalisation of waste pickers and turns to the point that involves influential religious communities (e.g., Street Pastoral Care), NGOs, and academia. These agents seek a fair acceptance of waste pickers as part of managing household solid waste because waste pickers' living and working conditions are the consequences of the unequal socioeconomic opportunities found in the city.

Eight legalised waste picker cooperatives, with about 312 members total, are part of two recycling network systems. Recycling network systems are merging waste picker cooperatives to promote joint action for marketing and technical support to reduce the influences of the informal sector. The first recycling network system is induced by an NGO (CataUnidos), and the second is self-organised by waste pickers (RedeSol). Specific characteristics differentiate the two groups' daily work performances and subsequent roles in household solid waste management (see Table 1).

Table 1. Characteristics of the daily performance of the two types of waste pickers of Belo Horizonte in a legal cooperative system

	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

Both recycling network systems regulate Belo Horizonte's cooperatives, while the cooperative council regulates waste pickers according to the specific rules (da Silva, 2018):

I. no child labor under 16 years old;
II. WPs must be registered at a cooperative;
III. legalized WP cooperative or in process of legalization with a fixed address;
IV. ban of trade with middlemen;
V. promoting physical security (equipment) and payment the Brazilian Social Security Institute for Retirement (INSS);
VI. be approved after the application for a membership at an assembly.

ASMARE is the oldest waste picker cooperative of Belo Horizonte and the head of CataUnidos. This cooperative is formed by 70% of women and 30% of men most 30 to 59 years old with an incomplete primary educational background (ASMARE, 2015). Many women had private issues (e.g., chauvinism) that limited them from entering the market during an early stage of their lives. It should be noted that the number of women in the Brazilian workforce grew from the year 2000, reaching 40% of the economically active population from 25% in the 1980s (Andrade, 2004; IBGE, 2018). Regardless, most of the women describe the same motivation to sort waste locally. They say that they want to "give a prosperous future to their children far away from

the marginality within a better educational perspective". The continuous subsidiary assistance has helped ASMARE to remain in Belo Horizonte's waste sorting system. This waste pickers cooperative started when a local councillor from the extreme left party established the first working shed in 1993 (Jacobi and Teixeira, 1997).

According to Table 1, ASMARE has expansionist objectives insofar as it can rescue its members from poverty (ASMARE, 2015). Equitable participation without prescribing authority and dictated rules is a considerable guideline that helps each member to identify strong family bonds as an essential path to achiving mutual benefits. All of the members consider themselves part of a big family, with the right to come and go in freedom. The assistance of NGOs and the Street Pastoral Care helps ASMARE to realise the motto "*together, we can do better*". The expansionist objective assisted ASMARE to create CataUnidos together with other waste picker cooperatives from the metropolitan area (Table 1). More than 100 waste pickers from ASMARE and 350 waste pickers from the metropolitan area compose CataUnidos. Researchers from the local university provide technical assistance such as by establishing the first plastic pellet production. CataUnidos is a social entrepreneurship that transforms plastic waste into secondary material for steel industries as a path towards open-loop recycling (Fuss et.al., 2020a).

The scope of professionalism and economic development through efficient waste-sorting is what formed RedeSol (RedeSol, 2013). About 200 waste pickers are taking part in five independent cooperatives and these are located in specific neighborhoods of Belo Belo Horizonte. Coopesol, waste picker cooperative the head of the RedeSol, was the first pilot waste picker cooperative to perform direct selective collection in a pre-defined neighbourhood without intervention from Belo Horizonte City Hall (Costa, 2019). Because of that, a remunerate agreement is present between Belo Horizonte's city hall and all five waste picker cooperatives in RedeSol. The work division of each service provider is a specific characteristic that differs sharply between RedeSol and CataUnidos (see Table 1). The council of each waste picker cooperative from RedeSol observes the competence, friendship, and empathy of individual service providers to define their strategic working place.

Although a partnership between waste picker cooperatives and Belo Horizonte's city hall exists, social conflicts happen when new decisions are discussed in the city council. Social obstacles mainly appear because of decision-makers' interest in treatment technologies. Waste pickers believe the duty to formalise waste-picker

cooperatives by working with influential communities is exposed to risk by the pushed-forward neoliberal economy. Brazil has created a vulnerable and competitive situation since the 1990s (Parreira 2010; Varella 2011).

Belo Horizonte's plan for 2035 follows the division of productivity according to the national production and infrastructure conditions (HORIZONTE 2017). Table 2 describes the level of efficiency expected for each waste picker cooperative in Belo Horizonte.

Table 2. Development pattern for waste picker cooperatives

Level	Description	Expected future productivity	
		Cooperative	**Waste picker**
Low	Small sheds received less than 300 t recyclable in 2014. None mechanical support. Sorting between 0.5 to 1.1 t/month	770 t/year	10 t /year
Middle	Few mechanical supports (e.g., belt) with less than 1,000 t/year received in 2014, but higher than 301 t/year.	2,310 t/year	17.4 t/year
High	Large sheds received more than 1,001t recyclables in 2014. Large number of mechanical support (e.g., hydraulic press, and trommel)	4,620 t/year	21.6 t/ year

Source: adapted from Belo Horizonte 2017; IPEA 2017.

The conditions of waste picker cooperatives have varied between low and middle technology in Belo Horizonte since 2014. Thus, the monthly workforce efficiency ranges from 0.5 t to 12 t waste sorted per waste picker, respectively (Belo Horizonte, 2017, da Silva, 2018). The large discrepancy reflects the daily performance and the strategies of each recycling network system (see Table 1). Waste-picker cooperatives must invest in mechanical devices (e.g., trommels and magnet separators) and capacity building to follow the recycling market's economy and Belo Horizonte's municipal solid waste management plan. Nevertheless, they are still struggling to keep the income for their members, among other issues.

3.1.3 Normative aims

Two normative aims conduct the current and future development of Belo Horizonte household solid waste management, the government and non-government aims (Figure 5). *The* formal targets in Belo Horizonte's household solid waste management plan are governmental aims. They were defined to address the national requirements

of the Brazilian National Policy and, at the same time, to contribute to the improvement of statistics indexes compared to other Brazilian cities. According to section 1.2, they should be achieved by 2035.

Figure 5. Normative aims for Belo Horizonte household solid waste management

The non-government aims are defined according to an interview with influential community agents (i.e., NGOs, local scholars and religious communities), waste picker cooperatives, funding organizations for social development and neighbourhood representatives. They are responsible to form the major niche in Belo Horizonte. This means that many actions for the social-integrated system are individually promoted initiatives and do not have the involvement of the government. Most of these targets represent their wishes for systemic change, which are part of the locally promoted Garbage and Citizenship Forum. Nowadays, the Garbage and Citizenship Forum is a platform to disscuss the niches related to protect the environment through the end of dumps, the recovery of degraded areas, the encouragement of selective collection and current actions of Belo Horizonte's authorities.

Through the fieldwork and interviews, local agents described the specific actions they took based on government aims (e.g., improvement of working sheds and organization of teamwork). For the agents mentioned above, the most challenging government aim is to reach 11% of the recycling index - 10% more than 2014, the

base-year of Belo Horizonte's municipal solid waste management plan (Belo Horizonte 2017). Also, waste picker cooperatives need to look for ways to reach the maximum mass flow input and mechanical development at working sheds (e.g., the use of belt conveyors) to continue as part of the integrated household solid waste management system.

Personal contact is the main compromise of waste picker cooperatives to provide the service of door-to-door selective collection, and at the same time, to disseminate awareness to assist with societal behaviour change. NGOs stress this action as a precise purpose for the massive communication campaigns argued by Belo Horizonte's government. Per NGOs, householders can quickly learn to identify that mixed waste is a problem and that sorted waste is a socio-economic resource for waste pickers.

A reduction in the use of landfills is not addressed in Belo Horizonte's municipal solid waste management plan (see section 3.1), but is a local agent aim often discussed in the Garbage and Citizenship Forum. Composting, mechanical biological treatment and recycling are accepted treatment paths for Belo Horizonte's household solid waste management. The implementation of any other treatment technologies is a challenge locally. With the support of the Garbage and Citizenship Forum, the legislation 21557/2014 was enacted to forbid the implementation of incineration technologies in all the cities of the Minas Gerais state, which has Belo Horizonte as capital (Minas Gerais 2014).

An example of many local agents' dissatisfaction with government aims is the massive investment in delivery points to increase the coverage of the service to 100% of the population. Decision-makers intend to stress the responsibility of entire waste providers to collaborate with the system (Belo Horizonte 2017). Innovative delivery points (i.e., wheelie bins with underground capacity) and treatment systems available worldwide are of interest at the national and local decision-makers level (Belo Horizonte 2017; IPEA 2017). Innovative delivery points, however, are costly and are seen as being not as effective as the door-to-door collection promoted by waste-picker cooperatives in other Brazilian cities (IPEA 2017).

3.2 Phase B: tripartite transdisciplinary research processes

Individual (B1), technological (B2), and sustainability (B3) are three options for the development of Belo Horizonte based on the analysis carried out in the scientific

publications of this thesis (see Part III). Options B1 and B2 are elements of value scenarios[4] based on judgments in favor of waste picker cooperatives or technological implementation.

The individual option (B1) focuses on the micro-level participation of legal waste pickers. The need to lead an active socio-economic life makes them the central working component in the household solid waste management system in the individual option. This option is comparable to the systemic effects of the current situation. Legal waste pickers are essential co-drivers of the waste management system for your self-interest, while other agents do not consider this system a priority public service. Technology implementation (B2) is the frame of the situation from a technical point of view for household solid waste management. The technological option concentrates on the technical benefits of mechanical biological treatment as a practical solution for household solid waste management. An envisioning household solid waste management is the focus of option B3. The core of option B3 is the sustainability principle, and it does not refer to waste pickers, nor to technology, as the co-drivers of the system. The sustainability option put forward crucial needs (criteria) to confront the two prior options at the same acting platform.

The options mentioned above are the results of each sub step of the tripartite transdisciplinary research process (Figure 1), as follows.

3.2.1 Step B1: individual option (Publication II)

The individual option offers a household solid waste management system based single on the approaches for the socio-integrated system. The individual option adheres to social practices worked in Belo Horizonte and realized through the CataUnidos and RedeSol (section 3.1.2). Regulations, individual behaviors based on the social values, and the socio-technical achievements establish the purpose of this option.

Enactment of regulations was the first step achieved to secure the sorting service provided by waste pickers in Belo Horizonte. Table 3 summarizes the most important national and local regulations for waste picker cooperatives. Each regulation has already generated specific results in Belo Horizonte and sustain the current situation.

[4] "*Value scenarios are humanistic and societal considerations of context and or technology. Elements of value scenarios are intended to emphasize implications for direct and indirect stakeholders, key values and systemic effects*" (Friedman and Hendry 2019, 71).

The decree 13 378, established 12 years ago, is an example. It regulates the standard conditions for waste picker cooperatives to perform selective collection in addition to public efforts in the area of Belo Horizonte (HORIZONTE 2008). This legislation is an amendment to the second Organic Law of Belo Horizonte that recognized waste pickers as part of the household solid waste management in 1992 (HORIZONTE 2008).

Table 3. Normative Resolution for waste pickers and cooperatives

Law	Level	Objective	Result
Decree 13 378/2008[1]	Local	Regulate the actions and activities for waste picker cooperatives	Legal waste picker cooperatives became part of the selective collection and sorting services
Decree 397/2002[2]	National	Integration of sorting service in the Ministry of Employment	Professional recognition of waste pickers
Law 5 940/2006[3]	National	Destination of recyclable to legal cooperatives	Increase the number of legal cooperatives
Law 11 445/2007[4]	National	Enact the legal procedure to contract legal cooperatives	Contract with Coopesol (RedeSol) started in 2018.
Law 12 305/2010[5]	National	Enactment of National Policy for Solid Waste	Determine the inclusion of waste picker cooperatives nationally
Decree 7 405/2010[6]	National	Designate the National Program "*Pro-Catador*" and the Interministerial Ordinance for Inclusion of waste pickers	Strengthening of the CataUnidos and RedeSol with equipment and capacity building.
Law 5 764/2012[6]	National	Regulate the organization and operation of cooperatives	New rules for cooperatives

[1] HORIZONTE 2008. Decree 13,378, amendment of 2º Law nº 6.290, 23 December 1992

[2] MTE 2002. Brazilian Classification of Occupations (CBO): waste pickers. 397.

[3] BRAZIL 2006. Municipal solid waste management priorities for socio-entrepreneurship of waste picker cooperatives: 5940/06

[4] BRAZIL 2007. National sanitation guidelines and the federal sanitation policy: §11445.

[4] BRAZIL 2010a. National Policy on Solid Waste Law 12,305/2010: §12305

[5] BRAZIL 2010b. Interministerial Ordinance for Inclusion of waste pickers. §7405.

[6] BRAZIL 2012. National Policy on Cooperativism for the society, amendment of §5764/1971.

The premise of the individual option is the continuation of the phenomenon based on strengthening human relationships. NGOs, leaders of legal cooperatives, university students and Street Pastoral Care promote a type of social influence between other waste pickers to promote social structure and solidity with attention to the regulations mentioned above. Because of the relationships between them, social values are visible during day-to-day work activities and group meetings. Figure 4 describes five social values that create ideological standards to transform the marginalized view of waste pickers in governmental actions.

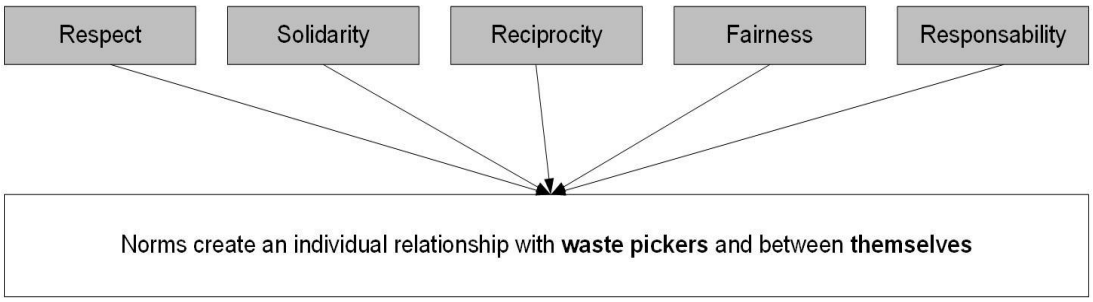

Figure 6. Social values in Belo Horizonte household solid waste management

The proactive orientation of Street Pastoral Care and NGOs built up the value based on respect towards the individual (waste pickers) and fairness in Belo Horizonte (Parreira, 2010; Oliveira and Lima, 2012; Varella, 2011). Respect and fairness values created belief in the generated motto of waste pickers that "*together, we can do better*" for ASMARE waste picker cooperative (see Section 3.1.2). Respect and fairness are the most persuasive values between waste pickers and those influential communities. Also, the value "respect" generates hopes for waste pickers, and even autonomies, to continue the purpose of freedom to change from CataUnidos to the RedeSol system or vice-versa. Respect and fairness encourage tolerance to maintain both recycling network systems stable because they have divergent strategies (see Table 1). Divergent structures and strategies are reasons that made similar engagement towards networks failed in other Brazilian cities (Tirado-Soto and Zamberlan, 2013). In Belo Horizonte, the collective commitment of both groups supports the general argument in defense of social inclusion during city council debates.

A form of recognized solidarity appears in the approach of Minister Paul Singer, who embraced the socio-economic challenges and the structure of the waste picker cooperative as best practices in a parallel solidarity economy system in the capitalist system (Singer 2002, 2011). The purpose of his speech was to encourage solidarity as an organization of agents (e.g., decision-makers, waste providers, and waste

pickers) to obtain mutual benefits. Civil responsibility includes providing sanitation and a decent quality of life, and waste pickers are responsible for acquiring knowledge and communicating best practices, whereby sorting waste is their work function and monetary reward. Another form of recognized solidarity is the sympathy, expressed by residents, with the door-to-door selective collection provided by waste pickers. These waste providers show their solidarity by sorting waste properly when they are confronted with the local socio-economic inequalities and the living and work conditions tolerated by waste pickers.

The recycling network systems represent two forms of reciprocity due to their distinct characteristics (see Table 1). The sharing ethos of CataUnidos provides the elementary and cultural structure of binary reciprocity. The binary reciprocity concerns the continuous structure for equal sharing agreements to create a close relationship between (waste pickers) members and those influential communities (Sabourin 2011). The historical compromise of the Street Pastoral Care, NGOs, and direct contact with waste pickers create friendship, mutual recognition, and fidelity. These feelings of satisfaction and expressions of gratitude generate stability for the current waste pickers because they find their working niche to be better than their previous living conditions. The bravery of RedeSol is to show the expertise and a secure system to decision-makers. The “bilateral” ternary reciprocity between RedeSol and city authorities is similar to the relationship between father and children that Sabourin (2011) described. The value transferred from RedeSol to city authorities is to show its responsibility to the system. RedeSol seeks for the responsibility value by conquering and demonstrating the success in the selective collection of pre-determined areas correctly. They preserve the necessary precautions and possession to join cooperatives with less than thirty waste pickers. The efficient work division and the prestige of the member who has sorted the most household solid waste is a form to get to the heart of the work and competence issue.

The social commitment needs to provide technical results that are remarkable for local decision makers. The reorganization of the socio-cooperatives in the CataUnidos and RedeSol reflected how the input flows of recyclable waste have been changed within the following recycling processes (Fuss et al., 2020a). Table 4 describes which waste products are sorted in the cooperatives according to the market of recyclables in Belo Horizonte and metropolitan area.

Table 4. Belo Horizonte recyclable waste vs. output of waste picker cooperatives (t/a)

Waste product	Generation[1]		WP cooperatives[2]		Recycling path
	2004	2014	2004	2014	
PET[3]	14,016	15,865	-	548	Closed-loop recycling[4]
HDPE[3]	11,346	12,843	402	410	Open-loop recycling[5]
LDPE[3]	25,362	28,708			
PP[3]	5,340	6,043	18	20	Open-loop recycling
PVC[3]	9,344	10,576	-	-	
PS[3]	101	87	-	-	
EVA	11	14	-	-	
Others	4,959	11,483	-	-	
Total plastic	**70,481**	**85,624**	**420**	**979**	
Office paper	9,40	12,774	128	206	Open-loop recycling
Magazine and news	3,135	4,258	42	68	Open-loop recycling
Cardboard	34,483	46,840	-	161	Closed-loop recycling
Tetrapak	3,135	4,258	-	-	
Others	8,306	22,520	-	-	
Total paper	**58,463**	**90,652**	**171**	**437**	
Aluminum can	1,567	2,129	-	1,235	Closed-loop recycling[3]
Non-ferrous metal	7,837	7,789	274	410	Open-loop recycling
Ferrous metal	4,644	7,789	672	468	Open-loop recycling
Total metal	**14,048**	**17,748**	**946**	**2,113**	
Total Glass	**23,511**	**31,158**	-	-	
Other recyclables[6]	**28,219**	**34,466**	-	-	

Source: Fuss et al., 2020a

[1] Uncertainties of data input varies from 15% to 31%. The most uncertain data is the category metals (ferrous and non-ferrous).

[2] Uncertainties of data input varies from 22% to 45%. The most uncertain data is the category 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

The participation of waste picker cooperatives in the selective collection provided several changes in 2004 (before the recycling network systems) and 2014 (after the recycling network system). Although the total waste sorted by waste picker cooperatives is not representative of the total recyclables generated in Belo Horizonte, the awareness and communication skills of CataUnidos or RedeSol members are noteworthy. Legal waste pickers help to minimize 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, for example. Such attitudes reflected that 48% of the total material sorted by waste picker cooperatives could be assigned to the closed-loop recycling system in 2014. The largest share corresponds to aluminum cans (30%), followed by PET bottles (14%) and cardboard (4%) (Fuss et al., 2020a). Such compromise reflected the trust and made decision-makers to hire all cooperatives from RedeSol and CataUnidos to

perform the selective collection service of 36 from 427 neighborhoods in Belo Horizonte since 2018.

3.2.2 Step B2: technological option (Publication III)

The technological option suggests a household solid waste management system based mainly on mechanical biological treatment plants. Engineers, economists, investors, and decision-makers of Belo Horizonte have highly warranted consideration for mechanical biological treatment plants because of the envisaged view (e.g., efficiency, profitability and adaptability) seen in the Global North. The credit for electricity increases the ambition purpose of engineers to recover the large amount of biodegradable waste produced in Belo Horizonte (see Figure 4).

Table 6 presents the future-oriented results according to the individual option and technological option for Belo Horizonte household solid waste management. Both options considered the achievement of the government and non-government aims. They focus on the treatment of recyclables and biodegradable waste. Details about the technology and parameters are available in Fuss et al. (2020b).

Table 5. Development of Belo Horizonte's household solid waste management following individual and technological options by 2035

General data				
	Unit	**2014**	**2035**	
Population[1]	hab.	2,491,109	2,801,326	
Total waste generation[2]	t/yr	837,580	982,388	
Organic waste generation	t/yr	368,535	432,250	
Recyclable fraction[3]	t/yr	259,650	304,540	
Avoided waste generation[4]	t/yr	-	109,154	
Physical products (output)				
		2014	Individual	Technological
Sorting at cooperatives	t/yr	3,299	18,018	-
Composting	t/yr	957	2,458	
Sorting at mechanical plants	t/yr	-		204,616
Fertilizer	t urea/yr	-		622.3
Electricity	MWh/yr	-		42,990
Physical refuse (output)				
Waste landfilled without treatment	t/yr	828,158	959,083	245,597
Leachate (landfill)	m^3/yr	90,894	106,615	26,652
Social development				
Job creation[5]	Number	-	1,112	167

Environmental impacts			
Global warming power	242,095.6	284,588.5	79,735.1
Marine ecotoxicity	10,46	12,26	4,03
Marine eutrophication	21,31	24,99	0,62

Source: Fuss et al., 2020b

[1] Forecast with an annual increase of 0.6%, since 2001 (IBGE, 2018).

[2] Forecast with an annual increase of 2.2% since 2001 (SLU,2014).

[3] Paper, plastic, glass and metal

[4] Results of awareness campaigns for waste prevention.

[5] Individual: Number estimated according to expected future productivity for waste pickers (see Table 2). Technological: Number estimated according to Sunset Park Materials Recovery (Fuss, et.al. 2020b)

The implementation of mechanical biological treatment draws special attention to the achievement of the government aim for the recycling index. The individual option has similar results than in 2014, 1.8% of total waste generated can be recycled.

The technological option brings into discussion the non-government aim regarding the minimization of waste landfilled. Mechanical biological treatment has the potential to reduce waste landfilled by 70% (see table 6). The remaining fraction corresponds to the disposal of rejects from waste cooperatives, the mechanical biological treatment plant and other collected waste (e.g., textile, ceramic and health care). Although that new inputs are needed (e.g., electricity, heat and polymers), mechanical biological treatment could supply an extra 5,946 households, counting the forecast annual consumption of 2,292 kWh/household in Belo Horizonte (Scari, 2011).

The individual option mainly focuses on the non-governmental aim to increase the number of waste pickers in the system. The individual option shows that waste picker cooperatives can increase their sorting process by six while the number of waste pickers needs almost four times more, compared to the year 2014. On the other hand, job creation and reducing emissions harmful to the environment, together with the credits obtained by mechanical biological treatment, are two indicators highly considered by local decision-makers as fundamental. They can assist in applying for national programs[5] to implement renewable energies and safeguard the environment. Mechanical biological treatment system can create about 167 job positions. Additionally, the deployment of the mechanical biological treatment ensues

[5] The PROINFA, ANEEL and Climate Funds are example of programs offered at national level. Programme of Incentives for Alternative (PROINFA) is an electricity sources system that promotes subsidies and incentives, which draw on an Energy Development Account. Brazilian Electricity Regulatory Agency (ANEEL) autarchy of the government of Brazil that reduces the taxe

environmental benefits. Global warming power, marine euthrophication and marine ecotoxicity are examples of reducing impacts harmful to the environment. These environmental impacts are associated with landfill gas emissions (Fuss et al. 2020b).

3.2.3 Step B3: sustainability option (Publication III)

The sustainability option is the envisioned view for household solid waste management view, as follows:

I. Social-economic benefits such as the creation of income and jobs which help to lower the poverty in the municipality;
I. Enhancement of the recovery of materials and reduction of the use of landfills in a society where a separate collection is still precarious or unknown in many districts;
II. Lowering costs for the municipality as the inclusion is seen less cost intensive compared to automated conventional sorting systems;
III. Dissemination of awareness by personal contact to assist societal behaviour change.
IV. Any improvement of the household solid waste management system concerns all citizens and visitors.
V. Replacements of sub-systems (e.g. collection and treatment) of the current management might be allowed as long as it is without prejudice or it does not threaten or exclude the joint work of all agents including waste picker cooperatives.

In total, 34 agents contributed to have the above-mentioned conceptual view for household solid waste management according to a reflection regarding the status-quo compared to the desired future according to the Integrative Concept of Sustainability (Fuss et al., 2018). The sustainability view of agents did not differ so much from the normative aims presented in section 3.1.3.

The sustainable view for household solid waste management corresponds to nine criteria relevant for further development. These criteria provide the link to the sustainability goals of the Integrative Sustainability Concept (see Kopfmüller et al., 2001), and 18 indicators are actions that carry out the assessment. Table 7 is an excerpt of the municipal solid waste diagram that was joint constructed to improve the acceptance of sustainability by the agents, including decision-makers. The entire diagram is the main scope presented in Fuss, et al. (2018).

Table 6. Excerpt from Municipal solid waste diagram

Criteria	Sustainability rules	Indicators	Target* 0 2 5
Securing human existence			
Collaboration embedment among households and municipality for an urban cleanness and quality of life	Protection of human health	1a. Share of households receiving basic waste collection services weekly	
Practices for reverse logistics to improve cobenefits of recovering secondary resources	Autonomous subsistence based on income from own work	1d. Quantity of recyclable material recovered per worker compared to previous working month (%)	
Maintaining society's productive potential			
Standard certification for recycled products	Use of renewable resources	2a. Number of inspection actions related to recycling processes	
	Sustainable use of the environment as a sink for waste and emission	2b. Shares of utilities consumed during the recycling processes (electricity, gas, water, etc.) compared annually	
Safety waste treatment and disposal	Avoidance of technical risks with potentially catastrophic impacts	2e. Decrease of environmental impacts of MSW treatment on air pollution and ecosystem (%)	
Preserving society's options for development and action			
Monitoring alternatives for testing the dissemination of knowledge	Conservation of the cultural function of nature	3e. % of permitted waste activities that have annual compliance monitoring reports	

Source: Fuss et al., 2018
*The actual state of each indicator is compared to a target value: 0 – target value is achieved by less than 35%, 2 – target value is achieved by less than 65%, 5 – target value is achieved by more than 65%.

The goal of the Integrative Concept of Sustainability, “securing human existence”, presumes that a sustainable household solid waste system has to be designed in a way to promote individual life condition and its welfare. The goal, “maintaining society's productive potential”, aims at preserving (human and natural) resources. Both goals are related to personal behavioral change. The last goal, “preserving society's options for development and action”, insinuates the necessity for protecting and safeguarding the future of society. The first set is an example shown in the excerpt of the municipal solid waste diagram (Table 7) that highlights the importance of an embedded collaboration, for example. The present generation has to receive equitable shares of public household solid waste services by collaborating with all those responsible for the management and the distribution of duties to conserve the environment and protect the human health against insalubrities caused by the mismanagement of solid waste. There is no need for a daily household solid waste collection according to the status quo. Agents agreed that population must learn how to sort waste for a weekly and biweekly collection (depending of the composition of the solid waste). An action towards the criteria for the goal “securing human existence” is expressed through the indicator “Share of households receiving basic waste collection services weekly”.

The sustainability option brings flexibility as it continuously adapts individual and technological options tousling the content-related indicators of the Municipal Solid Waste diagram (see Table 7). The technical development patterns, designed with the individual option in mind, are positive accomplishments and can promote larger quantities of recyclable materials recovered per each waste picker. More waste that is recyclable supports autonomous subsistence based on income from one’s own work for a more significant number of waste pickers, which is the sustainability rule of indicator 1d. The implementation of mechanical biological treatment (Table 7) has particularities that need to consider a sustainable system. The clearest example is the demand for electricity. Mechanical biological treatment demands about 12,800 MWh/year. Any negative balance ensures that the treatment process becomes one more sector, dependent on the national electricity system. This situation can become the forerunner of non-sustainable use of the environment as a sink for waste and emissions.

The set of goals, rules, criteria and indicators show advantages of this option, grounded in a sustainability concept for a city. Belo Horizonte does not have a sustainability plan. The objective of the Belo Horizonte’s household solid waste

management plan has a weak connection to most of the rules and indicators of the Municipal Solid Waste Diagram (Fuss, et al., 2018). For a merged purpose, there is an inescapable need for narrower targets and greater effectiveness in the fight against the underdevelopment of household solid waste management and the involvement of waste pickers.

3.3 The feedback on historical analogies

Knowledge, beliefs and information divide the feedback on historical analogies. Most agents have an overall knowledge that limits themselves to understand their problems under the jurisdictions or competences in the field they are acting in Belo Horizonte's household solid waste management. Each department of the city hall (e.g., sanitation and environment) dedicate to the narrow view to improve the technical problems associated to waste management and minimization of climate emissions.

On the other side, influential communities (NGOs, the Church, and academia) always stress the beliefs for social integration to waste pickers. The community is small compared to the demographic profile of Belo Horizonte's city. However, they are loud because the recognition of waste pickers became merit for Belo Horizonte at all and it makes individual options tangible for the current conditions.

The past is a sad episode for those who took part in the process of recognizing waste pickers in Belo Horizonte when such memories are asked to the oldest waste pickers at ASMARE cooperative. They remember episodes of political persecution because they were marginalized. Information is dispersed in different reports as part of the history of Belo Horizonte. None study got to the heart of the issue with a reflection on the status quo. Historians describe the process of how happened the enactment of the legislation that recognizes waste pickers in the 1990s (see Jacobi and Teixeira, 1997). The beliefs of the current generation of waste pickers are based on the disseminated information about the bravery or compassion to other pickers through the cooperatives and influential communities (scholars, NGOs, and Pastoral Care). Nowadays, the towering achievement is the recycling network systems and the specific rules that were taken in the empirical analysis (see section 3.2.1). The broad understanding is possible when the historical legacies of the Belo Horizonte urban system are previously analyzed.

3.3.1 Gathering information on historical legacies of Belo Horizonte urban system

Belo Horizonte belongs to a type of generative cities because it generates economic progress and cultural changes by assuming the fourth national economic axis in a long-term (IBGE, 2018). Belo Horizonte is one of the few planned cities of Brazil that strategically became the capital of Minas Gerais in 1897 (Britanica, 2019). Before that time, Belo Horizonte was a catholic hamlet with sizeable gold mining resources in its surrounding areas (Araújo 2017). The society is a cultural mix of Italian, Portuguese, Spanish, Germans, Sirians, Dutch, French, Austrians, Belgians, and Brazilians, who were mostly part of the human resources that moved to transform the infrastructure from the hamlet to Belo Horizonte's city (Araújo, 2017). Under an historical view of Barreto (1995, p. 31), the governmental wishes for modernization and industrialization made that Belo Horizonte has grown like a human being crossing the childhood to adult life in 20 years. The non-specialized job offers, especially for the construction and building sector and gold mining sector, attracted many brazilian citizens to move to Belo Horizonte (Barreto, 1995).

The transfer of capital from Ouro Preto to Belo Horizonte had a political culture interest (Barreto, 1995). The primary purposes were keeping the national supremacy based on the oligarchs of coffee (Sao Paulo) and milk production (Minas Gerais) and, secondly, exploring gold mining in the nearby areas (Barreto 1995; Souza, 2012). Both purposes helped the political alliance between the State and Church that supported the Coup in 1930 (Barreto, 1995; Souza, 2012).

The bravery and wishes of national supremacy are a political culture of the State of Minas Gerais (e.g., oligarchs and Coup in 1930), and both are explicitly reflected how Belo Horizonte started to be structured. Downtown and government buildings were inspired in Paris and Washington (Barreto, 1995). The surrounding areas were planned for workforce class exclusively (*Avenida dos Funcionários*) and the agricultural colonies (e.g., *Prates* and *Horto*), who found hope in a new system to build their life, because the system needed to run hierarchically and correctly (Barreto,1995). A historical milestone of early identification of socio-inequality and precarious health situation were the reasons of a joint project of engineers and Church with the governament acceptance to create the Compassion Hospital *(Santa Casa da Misericórdia*) in 1898 (Araújo, 2017). Unlike in many other states and cities in Brazil, the structural organization of the Catholic Church always played an influential role. The archdiocese often committed to the urban development of the State and Belo

Horizonte in favor of bringing them to national supremacy. The Street Care Pastoral dedicated to organizing faithful and padres to rescue ill and marginalized citizens, as well as citizens under the poverty condition by strengthening their religion and given them a life perspective better than their previous living conditions. The self-transcendent values of the doctrine of sovereignty, respect, solidarity, and reciprocity shaped the histories and practices in the city, as mentioned earlier.

Belo Horizonte's urban system was always an economically active population since its creation. The city was often under construction with many architectural art buildings and shifted the mooring berth of gold mining to, later on, iron and steel mining industries, packaging, and food, biotechnology, business, and tourism jewelry as the main branches (Barreto, 1995; PRODEMGE, 2019). Popular and luxury fronts strongly characterize the neighborhoods of Belo Horizonte today (PRODEMGE, 2019).

3.3.2 Resilience: the transformational social changes

The recognition of waste pickers in Belo Horizonte's legislation was an action that could have been done by any other Brazilian municipality due to the formal constitution of an organic law (BRAZIL, 1988). The joint-forces of citizens under the conditions of unemployment and extreme poverty is a consequence of long-term historical legacies of non-satisfaction regarding the organization of the society into Belo Horizonte's urban system. Such values created the causal approach that opened the gate of the recognition of waste pickers.

Political displeasure and socio-economic instability were the effects that created efforts for popular mobilizations in Belo Horizonte. Historical pieces of evidence revealed that the union of Street Pastoral Care and unemployed citizens claimed for new rights and consequently helped politically many families that were living in open-dumping sites in the 1990s. The transitional process was part of an intensive mobilization often induced by the Street Pastoral Care and sympathizer (Jacobi and Teixeira, 1997). In that period, hyperinflation and turbulence effects of the liberalization and alignment of the New Republic of the Brazilian economy in the international market denoted the socio-economic situation of Belo Horizonte (Corseuil and Kume, 2003). The negative effect of such economic transition was apparent with the job reduction of non-qualified employees in industries in the city (Ramos and Reis, 1997). Many unemployed citizens met their needs, by also picking waste, through a similar aggressiveness description of popular uprising that also provoked the

destruction of bins and dispersion of garbage in the streets. The history of Belo Horizonte's waste pickers is highly characterized by political persecution due to an aggregation of these negative aspects (Jacobi and Teixeira, 1997). The history confirmed the feelings reported by the oldest generation of waste pickers at ASMARE (see Section 3.3). The confrontational situation was exacerbated during the transition of power from the right-wing party to the center-left party. A new political team was emerging in Brazil and one of the heads were democratically elected in Belo Horizonte by combining the principles of social liberalism and economic liberalism in a democratic society (PSDB, 2016). The result of the continuous mobilization of society was the enactment of a new decree in the organic law of Belo Horizonte that recognized waste pickers as official agents of household solid waste management in 1992 (Belo Horizonte, 2008).

The New Real economic plan, the solution found to stabilize the Brazilian economy that started in 1994, brought back hope because the job market opened again in a time that the extreme left party assumed the government of Belo Horizonte (Ramos and Reis, 1997; PSDB, 2016). A local councilor from the extreme left, who assisted the creation of ASMARE, won the election for mayor of Belo Horizonte (Pereira and Teixeira 2011). ASMARE performed the selective collection in none determined neighborhoods of Belo Horizonte as the first national initiative between 1993 to 1996 (Pereira and Teixeira 2011).

The historical analogies justify how the two groups are organized and characterized today (see section 3.2.1). They have distinct characterization as a reflection of the form of civilization of the Belo Horizonte how was structured. They are described as follows:

I. The cultural competence waste picker is a citizen who had the cultural life and practices of sorting waste as a condition to improve quality of life. The oldest generation belonging to this competence was already sorting waste and living in the surrounding areas of the open-dumping site in Belo Horizonte in the 1990s. They are mostly among the citizens who lived in the intersections of Belo Horizonte histories on governance structures and remained in informal life mostly. They accepted their lifestyle as part of their social values and existing practices of urban development. They are the citizens that form CataUnidos today.

II. The economic competence waste picker is a citizen who has been seeking economic development as a path for the improvement of quality of life. The primary joint-force motivation of these waste pickers was based on the popular uprising brought about by the crises of the 1990s because the driving forces were part of the fraction of unemployed citizens and those who suffered political persecution or felt prejudiced by the political system. Most of those citizens are part of RedeSol today, although they started together through ASMARE. RedeSol was created later by mirroring the weakness of the organizations under cultural competence with different rules (see section 3.2.1).

4. Phase C: Holistic discussion, resilience and transboundary thinking

The outputs of the holistic analysis assisted to identify goals and purposes, social values, procedures and technological potential to create the background knowledge behind each identified option (see section 3.2). Individual, technological and sustainability options distinguished in this thesis require enormous effort between all agents that are involved in the participative platform of the city as well as the involvement of indirect ones at the national level.

The current social engagement, the technological potential to recovery material and energy or the visionary sustainable household solid waste management was not sufficient for reaching a conclusion for Belo Horizonte. It was just a piece of the holistic analysis. The historical analogies broaden the understanding of essential facts that were not heeded in the process of merging waste pickers and household solid waste management into a single system. The historical analogies created the ability to analyse the resilience. Such procedures justify the social influences and practices that allowed Belo Horizonte to become the nationally and internationally recognised socio-integrated model city that it is today. Both analyses create a context for discussing the research questions of this thesis and provide a transboundary thinking, as follows.

4.1 What are the options to improve household solid waste management in Belo Horizonte?

Individual, technological and sustainability options can affect household solid waste management of Belo Horizonte in different patterns. It is suspicious to affirm which option is the best one. Each option depends on the mutual interest to conduct, at the

same time to confront, the regulatory structures that drive agents' actions (Fuss et al., 2020a).

The choice for one of the options identified in this thesis would be an isolated decision. This thesis leaves open the options for further considerations following the principles of the TTF. A new debate (confrontation of opinions) is proposed for future assessment over the following arguments discussed below.

The individual option brings household solid waste management to disclose the social challenges in the urban system of Belo Horizonte. Waste pickers are part of the percentage of poor and extreme poor of 0.79% and 3.80% in 2010, respectively (IBGE, 2018). As such, an average between 2,412 (based on national statistics[6]) to 114,822 citizens (based on poor and extreme poor social indexes) crosses the activities of waste picking. Part of those citizens is similar to the characteristics of the "riff-raff" class named by Souza (2018). They are citizens that need assistance because their life conditions are accompanied by social disturbances (e.g., drug use, alcoholism, and homelessness). Albeit the characteristics, they can stand the scope for the evolution of the individual option.

The historical and empirical analysis summed-up the experiences that led to local academia and NGOs to commit exclusively to the social development of citizens excluded from the labor market and economic society. The engagement to help those citizens and later the compromise with household solid waste management showed the human needs for an active life. The legal action of sorting household solid waste turned into a business occupation that promotes the inclusion of citizens from impoverished communities. Social inclusion and the legalization of waste pickers are a continuous process, and both actions will last for an extended time because the comprehension of decision makers is required to develop strategies to deal with social problems faced by the local society.

Legal waste pickers are confident about their importance in a system change in Belo Horizonte. They are the most motivated to become real mediators of a self-management strategy for a local circular economy (Fuss et al., 2020a). The challenge is that waste picker cooperatives must develop self-sufficient social recycling entrepreneurship. The differences between the scope of each recycling network system (CataUnidos and RedeSol) need to be understood, instead of bringing them

[6] Dagnino and Johansen (2017) provide a prescription that 1 in every 1,000 Brazilians is a waste picker and each 10 waste-pickers 7 remains in the informality.

to the same development scale. Both recycling network systems are eager to stand in the way of progress towards self-sufficient enterpreneurship, but under their roots of development (see Table 1). CataUnidos follows the creation of new products to promote open-loop recycling. The attitude of the members of CataUnidos shows the openness of learning and adapting the social values (Figure 6) from early experience according to their human limitations. Many of CataUnidos members have the hand-crafting and technical practice to reuse the resources available, regardless of the economic value. The members of RedeSol have different perspective. RedeSol follow the principles of operating a semi-mechanized sorting system because the members are fully oriented in the running economic system.

The market interest for recyclables is increasing quickly.There are now more middlemen controlling (mostly) informal waste pickers and small to middle-size recycling industries directly and indirectly at bargain price for recyclable waste. The expansion of the informal market makes that the non-gorverment aim “reduction of informal recycling systems” will be not achieved so fast. Also, prices for bales of plastics, papers, newspapers, for example, differ from each recycling companies, middlemen and cities. They are not connected to the production process (CEMPRE 2018). Such aspect is the major issue for the individual option because the income of waste picker cooperatives is narrowed on the best market price for recyclables. Self-sufficient recycling companies demand investment on their infrastructure to become the service partners of Belo Horizonte’s city hall (Fuss et al., 2020a).

The involvement of industries is fundamental to extend the producer responsibility for recyclable waste. However, it is not a simple case. There is a pattern 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[7] in 2008. 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, 2008). 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). Consequently, there

[7] ANVISA is the Brazilian Health Regulatory Agency (in Portuguese, *Agência Nacional de Vigilância Sanitária*).

are no local or national policies for waste management that obligate packaging industries to participate in reverse logistics. Closed-loop recycling from household solid waste is low attractive 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), who found in the recycling process an alternative method for minimizing energy demand and the dependence on the primary sector by investing in closed-loop recycling countrywide. The industrial attitude reflects on competitiveness for aluminum cans, but also on effectiveness of sorting at waste cooperatives. More than 30% of the aluminum cans are destined to recycling from legal waste picker cooperatives in Belo Horizonte, compared to 14% of PET and 4% of cardboard (Fuss et a., 2020a).

However, household solid waste management is not limited to recyclable materials and this aspect should be a reflection for all agents in favor of the individual option. Biodegradable waste and other wastes also need treatment, which the individual option does not provide.

The technology option is a pathway in a wholly competitive environment. The agents of Belo Horizonte need to be flexible for the implementation of a technological option. Otherwise, the implementation of mechanical biological treatment can continuously find obstacles by thumbing through the legislation and rules for the integration of waste pickers. For example, social obstacles, weak targets and missing legislation to recover biodegradable waste and recyclable waste can make mechanical biological treatment energetically inefficient (Fuss, et al., 2020b).

Local engineers and decision-makers see mechanical biological treatment as a profitable technology because of the sophisticated sorting system and production of electricity through the treatment of biodegradable waste. The initiatives are rational and appealing. Consequently, the win-win perspective exposes formal waste picker cooperatives in a comparative portfolio of subcontracting companies that provide services; despite that fact, stick to the idea of cooperativism. Intermediate waste picker cooperatives have opportunities to achieve advanced statuses because they have already received prior financial (subsidy) support (see Table 2). However, a challenge confronts less developed waste picker cooperatives because they face the risk of being considered inappropriate (e.g., small sheds and lack of machinery) and can be excluded from the system because there is no more subsidiary liability. Shifting

technology from Global North to Belo Horizonte already demonstrated the short-term money investment in household solid waste management. Belo Horizonte is one of the cities that closed its landfill because of the Kyoto Program “Clean Development Mechanism.” No more waste is allowed to be landfilled in an area of 65 ha in Belo Horizonte. In the meantime, an international company owned the right to obtain emissions credits by giving a new structure to collect and flare landfill biogas (captured methane) to transform it into energy for more than 20,000 households (HORIZONTE, 2018). The period of biogas collection has finished, and the area is abandoned, while local people did not realize that the generation of mixed-waste is the problem and not the final disposal.

The technological option could still create a path (i.e., jobs) if there are both an understanding and a commitment to contribute to the individual option in the case of Belo Horizonte. Nevertheless, two reasons already demonstrated that sorting waste is not seen as a job position among the working class in Belo Horizonte. The first is that household solid waste still has a garbage view. Secondly, the institutional structure of Belo Horizonte’s population is improving significantly (net rates for children aged 6 to 14 years is 97.6% (IBGE, 2018)), and this has the potential to be a threat of the workforce absence since sorting waste, for example, could be seen as a low-paying job.

The integration of the cooperative system requires a timeframe for each person (who is acting as a waste picker) to adapt to the conventional employment and market position without losing their know-how system engagement. The transitional period and withdrawal of waste pickers are the risks of rendering unfeasible investment on the integration commitment and instigating subsequent social obstacles. The technological option depends on how public and private-partnerships would invest in social capital (Adler and Kwon, 2002). Investment in social capital can bring the eagerness to work through grouping low-qualified citizens under extremely socio-economic and psychological conditions for capital markets into cooperatives.

The technological option does not guarantee that household solid waste management will be robust and feasible in Belo Horizonte. Mechanical biological treatment provides just a better destination for recyclables and biodegradable wastes. The challenges to promote recycling prevail because it is dependent of other agents and legislations, as previously described for the individual option.

The sustainability option is the most complex in Belo Horizonte's case because it reveals the tensions and perceives the realities identified through empirical and technical research. For instance, it is noted that decision-makers lie in a comfort zone (Bardwick 1995, pp. 8-10). For more than 20 years, decision makers paid attention to the nuances of national legislation for waste management in Belo Horizonte. They know there are precarious service conditions for waste picker cooperatives. They are still cheap option to promote the sanitation system, disseminate best practices, and make the city compliant with the National Policy on Solid Waste (BRAZIL, 2010). It is no wonder about the social living conditions those informal and formal waste pickers face because decision-makers and the majority of the population have adapted their behaviour to the economic growth system.

This option shows the relationship that household solid waste management has with the urban development of Belo Horizonte through the Integrative Concept of Sustainability (Kopfmüller, 2001). The sustainability option seeks transparency in the interrelationship among the conflicts of interest and shared values behind the transformative model. As previously mentioned (section 2.2), the transformative model encompasses the sociotechnical background of reducing waste generation, improving the mismanagement of household solid waste, and the integration of waste pickers. The sustainability option consists of meeting all those multiple objectives and requires a broad reflection and understanding of agents.

Positive insights of stakeholders and decision-makers affirmed that their knowledge about sustainability was improved due to the construction of the household solid waste management framework (section 3.2.3). An engagement towards the indicators set can help to better harness the experience in Belo Horizonte for the future of other Brazilian cities since the city is one of the Brazil's economic-axes and has strong historical influences in governmental decisions (Fuss et al., 2018). This fact, however, does not imply any certainty that household solid waste management will achieve the limits of the sustainability option in Belo Horizonte, according to the solid waste management framework designed (Fuss, et al., 2018). However, implementing the sustainability option is a challenge of initiating a productive dialogue for conscious actions towards the indicators set, as the first step for a transformative system. For a prolonged period, the indicators set need to be updated to keep running the willingness to behave in favor of capacity building, awareness programs, and environment-friendly attitudes between agents with very different interests.

4.2 Is Belo Horizonte's transformative model the best path example to improve household solid waste management in the Global South?

Belo Horizonte's transformative model is summarized through three main characterizes identified in this study:

I. Grouping citizens induced by influential communities regardless their past and future wishes because these citizens found household solid waste as a valuable resource to meet socio-economic needs;
II. Strengthen social values to keep the union of the groups to defend themselves from the political and market-economy issues;
III. Create network of services as a path to acquire political support and self-sufficiency.
IV. Create sorting routines to work with specific recyclable materials.

Belo Horizonte's transformative model designed the practice of progress, not its perfection, although agents (e.g., influential communities and waste-picker cooperatives) have been seeking this path for about three decades. Belo Horizonte's transformative model urged a bottom-up purpose that contributed to top-down management, such as formulating the first insights for the National Policy on Solid Waste by providing national awareness to other cities affected by socio-technical problems in urban and sanitation systems. The historical analysis reported that the action adopted in Belo Horizonte was a political strategy to slow social movements through the enactment of a policy in 1992 (Section 3.3). The political strategy is part of the Belo Horizonte's resilience to solve local conflicts with an aspiring view to broaden it to the national level, ie. at the meso level. The political strategy's response was ambitious to promote the inclusion of citizens from impoverished communities, which represented a significant number of inhabitants in Belo Horizonte (see section 4.1).

The progress of the transformative model in Belo Horizonte arose in response to the beliefs and peoples' interactions with one another to influence the engagement with waste-sorting and recycling. The individual option foresees the social value implications as the unique tool to introduce themselves against the political and market system presented in Belo Horizonte and make the transformative system visible despite the fact it was not technically representative enough for the future (Table 6). Nowadays, tensions exist due to the structure of the two networks of waste-

picker cooperatives (Table 1), such as socio-cultural expansionism and social-economic concentration. An advantage of Belo Horizonte's transformative model was observed in that both networks can agree on the course of action and conditions to improve their systems without agreeing on the reason for sharing the same worldview.

Political and social issues identified in Belo Horizonte could be similar, but these issues can also differ in the cities of the Global South. The disadvantage of Belo Horizonte's path is the political confrontation, and it does not bring flexible solutions. The perfection of the transformative model is still in a testing phase to create trustworthiness between agents with different interests. The social values worked out in Belo Horizonte are also observed in the majority of cultures seen in the anthropology study of Curry et al., (2019). Respect, fairness, and reciprocity are social values to induce cooperative behaviour that assists a group in dividing disputed resources and reciprocating costs and benefits in human social life (Curry et al., 2019). The path II and IV of Belo Horizonte's transformative model positively reinforces the learning process to work with those social values for a joint-force, as well as, to lead the competitiveness for specific recyclable waste products (see Table 4).

In the Global South, proper management of household solid waste calls for the integration of human sources, regardless of whether it is a profitable business or not. To be clear, a feasible and efficient household solid waste management system means meaningful progress in the outcomes of material and energy flows, impacts, consequences, governance and risks in an active society predominated by waste picking (Fuss et al., 2020a; Fuss et al., 2020). Household solid waste management must differ from the paths done for the mechanized household solid waste management system in the Global North because urbanization and social development did not grow together with the sanitary services. Brazil, for example, experienced a high urbanization speed in parallel with positive economic growth based on the export of primary commodities and manufactured goods (Brito 2006; Jenkins 2012; Medeiros et al., 2018; Nations 2018). At the same time, Brazilian governance did not focus on the local population to move forward on their path to self-sufficiency through education and well-being (Jenkins 2012). Household solid waste management became part of an adjacent public service area that did not follow the changes that occurred due to urbanization, which tripled in the last 65 years, and the transition from agrarian to industrialized societies, which started 56 years ago in Brazil (Brito 2006, Nations 2018). In contrast, household solid waste management followed

mostly urbanization and industrialization processes according to histories of space, place and resilience that required about 80 years and 250 years, respectively, in many countries in the Global North (Nations 2018).

4.3 Why do we want to integrate waste pickers in household solid waste management?

The answer to this question requires the merger of the transboundary thinking based on the holistic analysis of Belo Horizonte's case, as a critical element for visualizing the sustainability framing for societal transformation (Kudo and Mino, 2020). To make the discussion clear, first, the sense of urgency was created based that the mismanagement of Belo Horizonte''s household solid waste is part of the global waste problem. Second, the interface of Step B1 (see empirical analysis - Fuss et al., 2020a), Step B2 (see technological analysis - Fuss et al., 2020b) and Step B3 (see conceptual analysis -Fuss et al., 2018) recapped the goals of sustainability for generalizing a societal contribution with household solid waste management, and to answer the above-mentioned question.

4.3.1 Belo Horizonte's case and the global waste problem

The sense of urgency depends on human perception to include the increased generation and mismanagement of household solid waste of Belo Horizonte as part of a complex global problem. World waste generation is estimated to increase by 70% in 2050, compared to the 2 billion tons of household solid waste generated in 2016 (Bank, 2019a). More than 40% of the projected world waste generation is expected to increase in the Global South, compared to 19% in countries that are currently acknowledged as waste generators, like the United States and European countries Bank, 2019b). The statistics demonstrate that poor management is linked to local socio-economic and political issues (Bank 2019a). Partially, the affirmation is applicable because Belo Horizonte's household solid waste management increases and is mostly not treated (section 2.1). It comprises about 20–50% of the municipal budgets for sanitation services and still relies on landfill sites. The technical development of the individual option confirmed that few changes can happen based on Belo Horizonte's household solid waste management plan for 2035 (see Table 6).

The mismanagement of Belo Horizonte's household solid waste is breaking geographical barriers. If local household solid waste management is not treated as part of the global problem (i.e., from local to global and vice-versa), the various actions

and research slots (e.g., the protection and sustainable use of oceans (WOR 2015)) are not significant enough for the global quality of life. The impacts of untreated waste can be tremendous, especially when water bodies are affected. Belo Horizonte has direct flow access to the river *Ribeirao Arrudas*, where the surrounding areas have illegal open-dumps. A supposed accumulation of waste and pollution of this river compromises the Sao Francisco basin that flows into the Atlantic Ocean. Sao Francisco is the largest national basin in Brazil (IBGE 2018). Water bodies play an explicit connectivity role for the development of cities and nations in the Global South and the Global North (WOR 2015; Spiegel-Feld and Wyman, 2020). Studies often show how several components of household solid waste reach water bodies and increase the global problem because of delayed actions at city level (WOR 2015; Spiegel-Feld and Wyman, 2020). The impact of plastic in the pollution of oceans is an example of extrapolating effects from marine life to human life since both are compromised due to the increase in microplastics in the food chain worldwide (Thiele and Hudson, 2018).

Global and long-term perspectives are alternatives that can instigate local system change like circular economy. But, there is the need to consider that household solid waste management is not an isolated system. It is also dependent on the globalised economic market system. Waste is generated because diversified products are continually being produced. More food packages and convenience foods are available on the market, providing the consumers with diversified choices to adapt to the modern lifestyle, fortified by many large industrial production rates worldwide (Karak et al. 2012). The industrial attitude and national and international legislations ensure that the global market is safe from improper recycling systems and force supply cities to export products based on primary materials, otherwise the exported product is not accepted. Such actions guarantee the running of both the economy of Belo Horizonte and the national economy since raw materials are still cheaper to implement than new processes to promote the circular economy (Fuss, et. al.2020a). Such actions make that industries do not assume any compromise for the products launched and consumed locally.

The current life trends for consumerism make them neglect the need to think about global problems and conscious consumption or even sort waste voluntarily. Game-changers are needed to improve the entire household solid waste management in many cities in emerging economy countries.

4.3.2 Waste pickers: the bottom-up game-changers

The above-mentioned global problems for household solid waste require people to reach a compromise and act in favour of improvements. Especially in emerging countries, few people are willing to change their daily routines because they left their respective comfort zones (see Bardwick 1995) to create new ones fortified by purchasing power development. However, waste pickers are assuming the responsibility voluntarily or involuntarily. A citizen becomes a waste picker because doing so addresses the root causes of social problems, which are embedded in the conditions of the urban running system (Fuss et al., 2020a). The act of waste picking is an intentional process for working through frustration with the governance or the wish to have a life perspective better than the previous living conditions. Waste pickers are able to share their beliefs and emotions; at the same time, they show appreciation for being active through the work of picking waste when it is recognized. Waste picking in Belo Horizonte is not a humiliating act, but dignified work that few people take care of in a capitalist system.

To integrate waste pickers in household solid waste management means to bring into consciousness the fact that development is still dependent on the collaboration of the human will and social values to rethink local needs systematically. The purpose attempts to deal with some causes of urban social problems, but many of them will continue to exist. Low educational structure, poverty, chauvinism and a sense of exclusion are some of the social problems that waste pickers from Belo Horizonte face, and this is similar to many other cities (Fuss, et al., 2020a) and can be similar to many other cities. However, integrating impoverished communities provides a helpful way of understanding them and evaluating their role inside the service to change the household solid waste management system and to recap the need for better social development.

Figure 7 shows the context of the five social values (see section 3.2.1) interconnected with the goals of the Integrative Concept of Sustainability (Kopfmüller, et al., 2001). The interconnection creates a sense of coherence regarding the integration of waste pickers in an age of accelerating and interconnected technological change.

All five social values are directly linked to each goal of the Integrative Concept of Sustainability. For instance, household solid waste management is seen as the opportunity to improve the overall quality of life, at the same time, by strengthening the ability of people to lead an active life. The relationship between respect and

fairness—with the working theme that built the social inclusion objective of "*together we can do better*" in Belo Horizonte—is seen as the most persuasive social value to group citizens compromised with household solid waste. Waste pickers require the minimum conditions of human dignity to make them active to secure their lives.

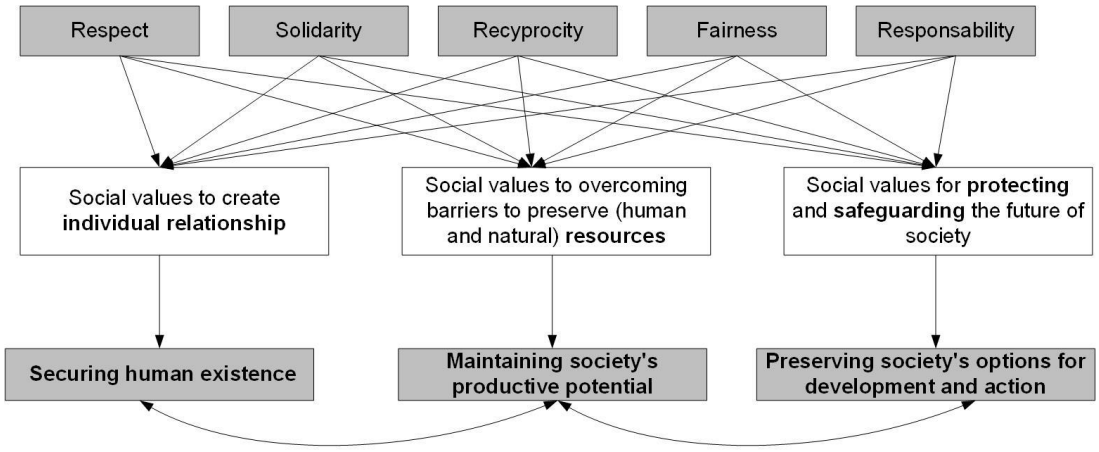

Figure 7. Social values interconneted with sustainability goals of the Integrative Concept of Sustainability

Respect and fairness encourage tolerance and keep conflicting systems stable (see Section 3.2.1). Cooperatives will often face different ambitious purposes. Two structural waste picker competences exist in Belo Horizonte: socio-cultural expansionism and social-economic concentration (section 4.2). The socio-cultural expansionism competence, for example, is seen as the group that can meet the problem of sorting waste within citizens under extreme poverty head-on, even though local investment projects for such waste cooperatives are needed with the support of influential communities. Distributive justice relates directly to maintaining the capability and freedom to change from one waste picker competence to another at a particular time.

The simple action to trust the operations of door-to-door collection services demonstrates that social obstacles against cooperatives can be removed. The importance is to rethink expectations and realize that future household solid waste management can be very different from what it is currently; i.e., the massive dominance of a human workforce instead of machinery, an elderly workforce, and female dominance due to loss of market opportunities. Hence, solidarity and reciprocity can lead the commitment to maintain the productiveness of society. Nonetheless, the figure of the waste picker needs to be recognized—and their limitations respected by any other agents. Belo Horizonte's case demonstrated that

solidarity and reciprocity are the social values that can create a possible division of functionalities at cooperatives and the altruistic family structure without being SB's kin with the coordination to gain a mutual advantage (Fuss et al., 2020a). Waste picking is an opportunity or choice that requires respect because it preserves a society's option for social development and action. Waste pickers are the agents that learn the importance of recycling and can collaborate to maintain society's potential to preserve resources (ecosystem and climate).

5. Final conclusions and future recommendations

The main line of this thesis began by observing the challenges of creating a socio-integrated system embraced by several scholars to suggest actions to improve household solid waste management and, at the same time, the living conditions of waste pickers. Belo Horizonte, Brazil, was the learning case chosen for this thesis because it is one of the international reference cities for a transformative model (Chapter 1). Corresponding to the challenges of Belo Horizonte and the analysis presented in the publications (I–IV), the methodological approach for a tripartite transdisciplinary framework (TTF) is introduced in practice (Chapter 2). TTF provided the structural approach for a holistic analysis, resilience, and transboundary thinking for a local and scientific contribution (Chapters 3 and 4). This chapter summarizes the case study's lessons through the TTF application (Section 5.1). Finally, this chapter closes with some opportunities for applying TTF from an individual perspective (Section 5.2).

5.1 Towards a socio-integrated household solid waste management through the application of TTF

Waste pickers will endure long, as long as socioeconomic challenges exist. The purpose of a socio-integrated household solid waste management system is highly complex due to the multitude of factors and perspectives to be considered. The case of Belo Horizonte helped to create knowledge on the characteristic patterns of change in both the technical fields of household solid waste management and society through waste pickers.

This case study has a double effect on value-sensitive design (Friedman & Hendry, 2019). At first, it is a practical example of the interrelatedness of managing household solid waste, which is an unintended consequence of human life and potentially has a chance to give back any human experience (double-effect). Thus, the empirical

analysis came with the approach to understand how the socio-integrated household solid waste system is currently functioning, i.e., perceptions, expectations, and social values of human relationships. It supported identifying barriers that create obstacles for the socio-integrated system, like the number of WPs registered in cooperatives, market price set-up by recycling companies, regulatory legislation for packing products and new small enterprises promoting open-loop recycling (section 3.2.1). The technical investigation demonstrated a single path for improvement of the current system that produced sharp relief of the problem (e.g., environmental benefits) and consequently generated trade-offs (e.g., cultural pressure), considered by Friedman and Hendry (2019, p.50-55) as value conflict (section 4.1). The conceptual analysis became the balance step where both individual and technological intersected. The tripartite frame provided spaces to integrate, among other methods, the analytical analysis, agent analysis, observations, collections of relevant documents, and interviews for targeting factual findings in this thesis.

This study concluded that waste pickers cooperatives and influential communities designed the practice of progress for a transformative model, not its perfection, in Belo Horizonte (section 4.2). The inclusion of historical analogies guided the transformational scope that any change that involves society as a driving force does not start from scratch. Among past and present actions, mutual learning provides clear evidence about the created gaps and resilience.

The interconnection of goals of the Integrative Concept of Sustainability presents that regardless of waste, pickers are often neglected in a capitalist system; there is the need to secure the overall human existence individually. Due to the mismanagement of solid waste, waste pickers, part of impoverished communities in cities, take the known (or unknown) responsibility of maintaining the society's productive potential to sort recycling materials from other household waste components for the future preservation of resources (ecosystem and climate).

5.2 Future application of the tripartite transdisciplinary framework

Transdisciplinary research in sustainability science demands considering the diversity of interests and experiences of agents in academia and non-academic areas regarding a specific problem or solution. The tripartite transdisciplinary framework was developed as a guideline to translate the plurality of options, not only the logic of exclusion and inclusion but also the unexpected, unwanted and innovative ones. The

TTF's challenge is learning and thinking in a network, not just exclusively and linearly, which implies the adoption or acceptance of new ways of thinking. Applying the TTF requires individual and social awareness to identify how each agent contributes to the problem.

From a methodological point of view, the discussion above discloses the necessity to broaden the scope of the transdisciplinary research processes to capture the different views of niches (e.g., niches built that influence society politically) and different views of technologies through a holistic sustainability assessment. The extension of Belo Horizonte's case study to other Brazilian cities is another suggestion for future research. An innovative suggestion is to analyze further the affinity between the socio-cultural expansionism cooperative from Belo Horizonte with waste picker cooperatives from the Amazon state and indifference to other states. Along with the development of this thesis, it was observed that few cooperatives follow the socio-cultural expansionism in Brazil and most of the existing ones are from Amazonas. Many cities in the Amazon state have flaring waste and open-dumping in riverside communities. Manaus's capital city faces the mismanagement of the household solid waste problem with increased tourism. It is a visible problem that plastics and other waste materials are seen in the Amazon River. There is a need for an in-depth investigation on a cultural level because indigenous roots still prevail in some Amazonas cities. New research questions could be further studied. For example: could a cultural waste picker competence become the single system to operate the transformative model of cities in the Amazonas state? What are the cultural similarities between Belo Horizonte's and Amazonas's waste picker's cooperatives, and what is their impact on urban development?

The application of the TTF can tackle fundamental societal challenges in other countries, which mirrored their legislation in Belo Horizonte's transformative model. Peruvian and Colombian cities, for example, enacted similar legislation recognizing waste pickers as part of HSWM mentioned in Chapter 1.

TTF's approach also allows opportunities for other fields of work. Therefore, it is suggested that real-world problems remain the same, focusing on the unintended consequences of human life and urban development. New approaches like water-energy, waste nexus, or even competition for resources are examples of other application areas. The increasing demand for resources (e.g., water, energy and metals) would require further investigation to create additional methodological insights

on limits and risks for the conceptual framework of the tripartite transdisciplinary framework.

References

ABIPET, 2018. Brazilian PET Industry. http://www.abipet.org.br/index.html?method=mostrarInstitucional&id=72.

Adler, P.S., Kwon, S.-W., 2002. Social Capital: Prospects for a New Concept. Academy of Management Review 27(1), 17–40.

Alfaia, R., Costa, A.; Campos, J.. 2017. 'Municipal solid waste in Brazil: A review', Waste management & research: the journal of the International Solid Wastes and Public Cleansing Association, ISWA, 35: 1195–209.

Andrade, A.S.C., 2004. Women in the Brazilian job market, PhD Thesis ed., Campinas.

ANVISA, 2016. Law number 9782/99 and RDC nº 91 de 11/05/2001 - Control of packaging products: 9782/99. p. 9782/9799.

Araújo, A., 2017. Belo Horizonte 120 years. http://especiais.g1.globo.com/minas-gerais/viva-bh/2017/linha-do-tempo-historia-de-belo-horizonte/. (Accessed 05/07/2020)

Arena, U., Barlaz, M., He, P.J., 2014. Editorial Board/Aims and Scope. Waste Management 34(3), IFC.

ASMARE, 2015. Socio-inclusion of waste pickers.

Azevedo, B.D., Scavarda, L.F., Caiado, R.G.G., Fuss, M., 2020. Urban Household Solid Waste Management in Developing Countries: Lessons from a Cross-Case Analysis Between Brazil and Germany Waste Management, in review.

Bank, W., 2019a. Solid Waste Management. https://www.worldbank.org/en/topic/urbandevelopment/brief/solid-waste-management. (Accessed 31.07.2019).

Bank, W., 2019b. What a waste 2.0 - A Global Snapshot of Solid Waste Management to 2050: Trends in Solid Waste Management. http://datatopics.worldbank.org/what-a-waste/trends_in_solid_waste_management.html. (Accessed 08.10.2019).

Bardwick, J.M., 1995. Danger in the Comfort Zone, Danger in the Comfort Zone: From Boardroom to Mailroom-How to Break the Entitlement Habit Thats Killing American Business. . AMACOM, New York.

Barreto, A., 1995. Belo Horizonte - Historic and descriptive memories. Fundacao Joao Pinheiro, Centro de Estudo Históricos e Culturais, Belo Horizonte

Bergmann, M., Brohmann B., Hoffmann E., MC. Loibl, Rehaag R., E. Schramm, and J-P Voß. 2005. "Quality criteria of transdiciplinary research. A guide for the formative evaluation of research projects." In. Frankfurt am Main, Germany.

Binder, C.R., 2007a. From material flow analysis to material flow management Part I: Social sciences modeling approaches coupled to MFA. Journal of Cleaner Production 15(17), 1596–1604.

Binder, C.R., 2007b. From material flow analysis to material flow management Part II: the role of structural agent analysis. Journal of Cleaner Production 15(17), 1605–1617.

Brandt, P., Ernst, A., Gralla, F., Luederitz, C., Lang, D.J., Newig, J., Reinert, F., Abson, D.J., von Wehrden, H., 2013. A review of transdisciplinary research in sustainability science. Ecological Economics 92, 1-15.

BRACELPA, 2015. Brazilian Association for Celullose and Paper - Sustainability report. http://www.sinpesc.com.br/images/publicacoes/02sustentabilidade.pdf. (Accessed 30.07.2019.

BRASKEN, 2018. Price of plastic resins increases by 30%. http://www.neoplastic.com.br/pt/noticias/noticias-do-site/braskem-sobe-preco-de-resinas-apos-alta-de-30. (Accessed 13.08.2019.

BRAZIL, 1988. Structural organization of state and municipalities in Brazil - the Federal constitution laws, in: Brazil, F.o. (Ed.). Brasilia

BRAZIL, 2010. National Policy on Solid Waste Law 12,305/2010. BRAZIL.

Britannica, E., 2019. Belo Horizonte, Cidades de Minas Chicago.

Brito, F., 2006. O deslocamento da população brasileira para as metrópoles. Estudos Avançados 20(57), 221–236.

Brunner, P.H., Fellner, J., 2016. Setting priorities for waste management strategies in developing countries. Waste Management & Research 25(3), 234-240

Burger, P., Christen, M., 2011. Towards a capability approach of sustainability. Journal of Cleaner Production 19(8), 787-795.

Campos, H.K.T., 2014. Recycling in Brazil: Challenges and prospects. Resources, Conservation and Recycling 85, 130–138.

CEMPRE, 2018. Market price of recyclables. CEMPRE, Sao Paulo.

Conke, L.S., 2018. Barriers to waste recycling development: Evidence from Brazil. Resources, Conservation and Recycling 134, 129–135.

Corseuil, C.H., Kume, H., 2003. A Abertura Comercial Brasileira nos Anos 1990: impactos sobre emprego e salário. Instituto de Pesquisa Economica Aplicada (IPEA), Brasilia. (in portuguese)

Costa, D., 2019. Market creates jobs that pay maximum 2 minimum salaries. https://oglobo.globo.com/economia/mercado-so-gera-emprego-que-paga-ate-dois-salarios-minimos-mostra-ipea-23955311. (Accessed 21.10.2019).

Curry, O.S., Mullins, D.A., Whitehouse, H., 2019. Is It Good to Cooperate? Testing the Theory of Morality-as-Cooperation in 60 Societies. Current Anthropology 60(1), 47-69.

da Silva, L.R. 2018. "Interview: Changes after the re-organization of waste pickers cooperatives into union organizations." In, edited by L. R. da Silva. Phone.

Dayball, F.D.R., 2018. Food systems and human ecology, in: König, A. (Ed.) Sustainability Science - Key Issues. Routledge, New York, pp. 183-210.

Dobson, A., 1996. Environment sustainabilities: An analysis and a typology. Environmental Politics 5(3), 401-428.

dos Muchangos, L.S., Tokai, A., Hanashima, A., 2017. Stakeholder analysis and social network analysis to evaluate the stakeholders of a MSWM system – A pilot study of Maputo City. Environmental Development 24, 124–135.

Fernández, L. 2010. 'Towards a Global Network: Waste Pickers without Borders', Accessed 27.11.2019. https://globalrec.org/history/.

Friedman, B., Hendry, D., 2019. Value sensitive design: Shaping technology with moral imagination. The MIT Press, Cambridge, Massachusetts.

Fuss, M.; W.-R. Poganietz, and R. T. V. Barros. 2014. 'Towards to sustainable waste management: opportunities and challenges of Belo Horizonte city, Brazil', Proceedings of the 5th International Conference on Engineering for Waste and Biomass Valorization: 1298-313.

Fuss, M., Vasconcelos Barros, R.T., Poganietz, W.-R., 2018. Designing a framework for municipal solid waste management towards sustainability in emerging-economy countries - An application to a case study in Belo Horizonte (Brazil). Journal of Cleaner Production(178), 655–664.

Fuss, M., Vasconcelos, R.B.T., Poganietz, W.-R., 2020a. The role of a socio-integrated recycling system for implementing a circular economy - the case of Belo Horizonte, Brazil. Waste Management under review process.

Fuss, M., Vergara-Araya, M., Barros, R.T.V., Poganietz, W.-R., 2020b. Implementing mechanical biological treatment in an emerging waste management system predominated by waste pickers: A Brazilian case study. Resources, Conservation and Recycling 162, 105031.

Giovannini, M., Huybrechts, B., 2017. How inclusive is inclusive recycling ? Recyclers' perspectives on a cross-sector partnership in Santiago de Chile. Local Environment 22(12), 1497–1509.

Graedel, T.E., 2019. Material Flow Analysis from Origin to Evolution. Environmental science & technology.

Gutberlet, J., 2018. Waste in the City: Challenges and Opportunities for Urban Agglomerations, in: Ergen, M. (Ed.) Urban Agglomeration. InTech.

Gutberlet, J., Carenzo, S., Kain, J.-H., Mantovani Martiniano de Azevedo, A., 2017. Waste Picker Organizations and Their Contribution to the Circular Economy: Two Case Studies from a Global South Perspective. Resources 6(4), 52.

HORIZONTE, B., 2008. Decree 13 378, amendment of 2º Law nº 6.290, 23 December 1992, 13 378. Belo Horizonte.

HORIZONTE, B., 2017. Belo Horizonte Municipal Solid Waste Plan. 325.

IBGE, 2018. Belo Horizonte's population and indexes. Instituto Brasileiro de Geografia e Estatística, Brasilia.

Jabbour, A.B.L.d.S., Jabbour, C.J.C., Sarkis, J., Govindan, K., 2014. Brazil's new national policy on solid waste: challenges and opportunities. Clean Technologies and Environmental Policy 16(1), 7–9.

Jacobi, P., Teixeira, M.A.C., 1997. Social capital: ASMARE - Waste Pickers Cooperative of paper, cardboard and recyclable resources of Belo Horizonte. Cadernos Gestao Pública e Cidadania.

Jahn, T., 2008. Transdisciplinarity in the Practice of Research, in: (Hg.), M.B.E.S. (Ed.) Transdisziplinäre Forschung. Integrative Forschungsprozesse verstehen und bewerten. Campus Verlag, Frankfurt/New York, pp. 21-37.

Jenkins, R., 2012. China and Brazil: Economic Impacts of a Growing Relationship, 1 ed., pp. 21–47

Karak, T., Bhagat, R.M., Bhattacharyya, P., 2012. Municipal Solid Waste Generation, Composition, and Management: The World Scenario. Critical Reviews in Environmental Science and Technology 42(15), 1509–1630.

Kawulich, B.B., 2005. Participant Observation as a Data Collection Method. Forum: Qualitative social research 6(II).

Klein, J.T., 2014. Discourses of transdisciplinarity: Looking Back to the Future. Futures 63, 68-74.

Kopfmüller, J., Volker, B., Jörissen, J., Paetau, M., Banse, G., Coenen, R., Grunwald, A., 2001. Nachhaltige Entwicklung integrativ betrachtet: Konstitutive Elemente Regeln Indikatoren. Ed. Sigma, Berlin.

König, A. 2018. 'Sustainability science as a transformative social learning process.' in Ariane König and Jerome R. Ravetz (eds.), Sustainability Science (Routledge, Taylor & Francis Group: London; New York, NY).

Kudo, S., Mino, T., 2020. Framing in Sustainability Science, in: Mino, T., Kudo, S. (Eds.), Framing in Sustainability Science. Springer Singapore, Singapore, pp. 3-15.

Lang, D.J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., Thomas, C.J., 2012. Transdisciplinary research in sustainability science: practice, principles, and challenges. Sustainability Science 7(S1), 25–43.

Medeiros, S.E., de Cassia Oliveira Feodrippe, R., Martucci Benvenuto, L., 2018. Defense Economy and National Development.

Nations, U., 2018. The speed of urbanization around the world. Department of Economic and Social Affairs.

Oliveira, F.G., Lima, F.P.A., 2012. Efficiency and solidarity at waste pickers cooperatives, 22 ed., pp. 1–25.

Ometto, A., Amaral, W.A., Iritani, D., Costa, J., 2018. Economia Circular: Oportunidades e desafios para a indústria brasileira, Brasilia.

Parreira, G.F., 2010. Solidarity selective collection: aggregating value for integrated recycling chain, Belo Horizonte.

Parsons, M., Nalau, J., 2016. Historical analogies as tools in understanding transformation. Global Environmental Change 38, 82–96.

Pereira, M.C.G., Teixeira, M.A.C., 2011. The inclusion of collectors in selective recyclable waste programs: from the local to the national agenda. FGV EBAPE. (in portuguese)

Petri, R., 2018. Increase of price for cellulose. https://www.dci.com.br/industria/preco-da-celulose-cresce-em-ritmo-mais-lento-e-pressiona-menos-o-papel-1.675493. (Accessed 30.07.2019).

Polaz, C.N.M., Teixeira, B.A.d.N., 2012. Indicadores de sustentabilidade para a gestão municipal de resíduos sólidos urbanos: um estudo para São Carlos (SP). Engenharia Sanitaria e Ambiental 14(3), 411–420.

PRODEMGE, 2019. Belo Horizonte - the capital of Minas Gerais. https://www.mg.gov.br/conteudo/conheca-minas/turismo/capital. (Accessed 07/05/2019).

PSDB. 2016. 'History of the Brazilian Social Democracy Party', Partido Social Democrata Brasileiro, Accessed 08/05/2019. https://www.psdb.org.br/conheca/historia/

Ramos, L., Reis, J.G.A., 1997. Jobs in Brazil in the 90s. IPEA, Rio de Janeiro. (in portuguese)

Rateau, M., Tovar, L., 2019. Formalization of wastepickers in Bogota and Lima: Recognize, regulate, and then integrate? EchoGéo(47).

RedeSol, 2013. RedeSol Transformando lixo em cidadania. https://www.redesolmg.org.br/p/quem-somos.html. (Accessed 05/06/2020).

Reese, H.W., 2011. The learning-by-doing principle. Behavioral Development Bulletin 17(1), 1-19

Rodić, L., Wilson, D., 2017. Resolving Governance Issues to Achieve Priority Sustainable Development Goals Related to Solid Waste Management in Developing Countries. Sustainability 9(3), 404.

Rutkowski, J., Rutkowski, E., 2017. Recycling in Brasil: Paper and Plastic Supply Chain. Resources 6(3), 43.

Rutkowski, J.E., 2008. Sustainability of solidary enterprise: an approach on production engineering. Federal University of Rio de Janeiro.

Rutkowski, J.E., Rutkowski, E.W., 2015. Expanding worldwide urban solid waste recycling: The Brazilian social technology in waste pickers inclusion. Waste management & research : the journal of the International Solid Wastes and Public Cleansing Association, ISWA 33(12), 1084–1093.

Sabourin, E., 2011. Theory of reciprocity, 27 ed., pp. 24–51.

Scari, M.E., 2011. An analysis of the electricity consumption structure of the residential sector in Belo Horizonte 2030, Belo Horizonte.

Shulman, V.L., 2011. Trends in Waste Management, Waste. Elsevier, pp. 3–10.

Singer, P., 2002. Introduction of the solidarity economy. Fundacao Perseu Abramo, Sao Paulo.

Singer, P., 2011. Community development and solidarity economy. http://paulsinger.com.br/secao/ineditos/. (Accessed 22.07.2019).

SLU, 2014. Annual monitoring reports of entire waste management of Belo Horizonte 2014.

SLU, 2018. Annual monitoring reports of entire waste management of Belo Horizonte from 2015 - 2018.

Souza, J., 2018. The Brazilian "riff-raff" society: Employment that brings human dignity, 3 ed. Contracorrente, Sao Paulo.

Souza, M., Fuss, M., Varella, C., Lima, F., 2016. Lixo Zero: por uma rota tecnológica alinhada às diretrizes da Política Nacional de Resíduos Sólidos. IPEA, Brasilia (in portuguese).

Souza, R., 2012. Revolution of 1930: Main facts of the Brazilian Revelotion in 1930. https://brasilescola.uol.com.br/historiab/revolucao-30.htm. (Accessed 04/08/2020).

Spiegel-Feld, D., Wyman, K.M., 2020. Cities as International Environmental Actors: The Case of Marine Plastics. Ariz. L. Rev. 62(487).

Tejada, G., Cracco, M., Bouleau, C.R., Bolay, J.-C., Hostettler, S., 2019. Testing Analytical Frameworks in Transdisciplinary Research for Sustainable Development. Sustainability 11(16), 4343.

Thiele, C., Hudson, M.D., 2018. You're eating microplastics in ways you don't even realise. The conversation, London.

Tirado-Soto, M.M., Zamberlan, F.L., 2013. Networks of recyclable material waste-picker's cooperatives: an alternative for the solid waste management in the city of Rio de Janeiro. Waste management (New York, N.Y.) 33(4), 1004–1012.

Uddin, S.M.N., Gutberlet, J., 2018. Livelihoods and health status of informal recyclers in Mongolia. Resources, Conservation and Recycling 134, 1–9.

Valenzuela-Levi, N., 2019. Factors influencing municipal recycling in the Global South: The case of Chile. Resources, Conservation and Recycling 150, 104441.

Varella, C.V.S., 2011. Turn-out the garbage bin: possibilities and limits of recycling as an alternative for waste treatment, Belo Horizonte.

Velis, C., 2017. Waste pickers in Global South: Informal recycling sector in a circular economy era. Waste management & research : the journal of the International Solid Wastes and Public Cleansing Association, ISWA 35(4), 329–331.

WCED, 1987. Our common future. World Commission on Environment and Development, Oxford.

Woltersdorf, L., Petra L., Petra D. 2018. 'How to set up a transdisciplinary research project in Central Asia: description and evaluation', Sustainability Science, 14: 697-711.

WOR, 2015. Sustainable Use of Our Oceans – Making Ideas Work: Chapter 3 - Politics and the oceans, Chapter 3 - Politics and the oceans.

Yoshida, H., Shimamura, K., Aizawa, H., 2007. 3R strategies for the establishment of an international sound material-cycle society. Journal of Material Cycles and Waste Management 9(2), 101–11

Part III

Scientific publications

Publication I

Towards to sustainable waste management: opportunities and challenges of Belo Horizonte city, Brazil

* This article is published in the proceedings of the 5th International Conference on Engineering for Waste and Biomass Valorization. France, 2014; 1298-1313. ISBN: 979-10-91526-03-6. Authors: Maryegli Fuss, Raphael Tobias Vasconcelos Barros and Witold-Roger Poganietz

Abstract

Municipal solid waste management has become one of society's most discussed issues. In Brazil, this discussion has been intensified with the enactment of the National Policy for Waste Management in 2010. The common practice of collecting and disposing of waste in landfills without any previous treatment is not the most viable and environmentally friendly alternative. Many Brazilian municipalities search for integrated management performed by participative appraisals, strategic planning, public-private partnership, and sharing mechanisms for measures and delegated acts. In this context, Belo Horizonte, the capital city of the state of Minas Gerais, is pointed out as a reference city in Brazil.

The present paper analyses the current waste management of Belo Horizonte and provides an overview of its level of development towards sustainable waste management.

Indicators are a helpful tool for analyzing and monitoring waste management progress. The application of the primary matrix comprises 42 indicators. All indicators were carried out through a meta-analysis review of research publications in the Brazilian literature about sustainable indicators for solid waste management. According to the matrix, Belo Horizonte is on the medium level of development, which 77% of its development being placed on social inclusion. In this way, the first approach has demonstrated that Belo Horizonte has failed to cover political, technological, economic, environmental, cultural and social inclusion dimensions in a balanced way.

Keywords: Sustainability, Indicators, Brazilian legal framework; household solid waste management, Belo Horizonte

1 Introduction

Waste is *"a symbol of inefficiency of any modern society and a representation of misallocated resources",* according to UN-Habitat (2010c). Integrating municipal solid waste management brought the approach to minimize the preference for landfill sites and, primarily, to strengthen municipal solid waste valorization favoring sustainable development (UN-Habitat, 2010). Most research and development activities on sustainable municipal solid waste management have been carried out in developed countries, especially in European countries, through advanced and effective integrated solid waste management systems (Boer and Jager, 2007). Nevertheless,

waste streams continue to rise in emerging and fastest growing economy countries in oversized proportions.

For IPCC (2010d) and Mavropoulos (2014), in fastest growing economy countries such as Brazil, population growth and its consumption pattern (mainly controlled by the boost of Gross Domestic Product per capita (Mavropoulos, 2014)) are the main driving forces for increasing of waste volume. In the last decade, the growth rate of the Brazilian Gross Domestic Product and the population was 36% and 12.6%, respectively (IBGE, 2013). During this period, the national waste volume generated per day rose by 35.7% (ABRELPE, 2012). Consequently, due to a lack of appropriate policies, the majority of thousands of tons of waste were only collected and directly disposed of in non-regulated landfill sites. Therefore, in 2010, the Brazilian Policy for Solid Waste was institutionalized through law 12,305/2010 (Brazil, 2010).

With the enactment of the National Policy for Solid Waste (Brazil, 2010), all municipalities need to redesign their current waste management system and overcome the array of problems, including low collection coverage and irregular selective collection services, non-regulated landfills (dumpsites) and burning without air and water pollution control and handling of informal waste picking and scavenging activities.

Many Brazilian municipalities are searching for integrated management composed of participative appraisals, strategic planning, public-private partnership, sharing mechanism for measures and delegated acts instead of just shifting to new technologies of waste management systems (Polaz and Teixeira, 2012). In this context, Belo Horizonte is a reference city to other municipalities in Brazil. Although best efforts were made to integrate stakeholders, sustainable waste management is a conceptual approach Belo Horizonte claims to put into practice. This paper deals with a challenge faced by researchers and decision-makers: how to move towards more sustainable waste management in a balanced manner.

Assessing the current solid waste management is essential not only to understand the magnitude of the problems faced by the municipality but also to analyze associated changes that must be made. Ultimately, it is critical to identify sound indicators for monitoring the life cycle performance of municipal waste management. Recently, mainly in Europe, studies have applied lifecycle-based waste management indicators for monitoring the quality assured by many municipalities for environmental impact reduction (Greene and D., 2014; Lazarevic et al., 2012; Manfredi and M.,

2013). Most of those studies confirm that life cycle thinking in waste management policy may be better for identifying problematic areas of environmental impacts and assisting the construction of solutions. Despite the discussions, using a set of lifecycle-based indicators for waste management from international experiences is challenging for Brazilian study cases (Polaz and Teixeira, 2009). It is an enormous risk to leave out critical information. Polaz and Teixeira (Santiago and Dias, 2012), through a meta-analysis review of the last ten years' research publications about sustainable indicators for urban solid waste management, grouped into a primary matrix of 42 indicators available in the Brazilian literature. The approach of the primary matrix is to offer a tool based on a set of indicators and descriptors for monitoring the status of the development of Brazilian municipalities towards sustainable development.

This paper's background is assessing the current municipal solid waste management of Belo Horizonte city. The paper focuses on a detailed case description of the actions taken in Belo Horizonte regarding the implementation of the National Policy for Solid Waste (BRAZIL, 2010). The following objective is to identify the challenges and opportunities towards more sustainable solid waste management in this city through a combination of the primary matrix developed by (Santiago and Dias, 2012) and life cycle thinking and assessment (Greene and D., 2014; Lazarevic et al., 2012; Manfredi and M., 2013). The primary matrix eases the communication with stakeholders in Belo Horizonte and supports the learning processes about the criteria for sustainable municipal solid waste management under the Brazilian Legislation. The life cycle thinking assessment assists in exploring the question: Is Belo Horizonte reflecting its objectives according to international environmental approaches? The objectives are to identify possible improvements to goods and services by lowering environmental impacts across all life cycle stages (Lazarevic et al., 2012; Manfredi and M., 2013).

This paper is structured as follows: section 2.2 introduces the methods applied in this study and the primary matrix proposed by (Santiago and Dias, 2012). Subsequently, Belo Horizonte city and its waste management system are described in Section 2.3. Section 2.4 results of the Belo Horizonte waste management assessment are presented and discussed. Final remarks are concluded in Section 2.5.

2 Method

Belo Horizonte records, provided by the city council, are the resources to obtain primary data from 2012.

Personal interviews with stakeholders (e.g. academia, NGOs, waste picker's association and governance) have been carried out for the primary matrix application.

2.1 Primary matrix and indicators

The primary matrix comprises 42 indicators, as shown in Table 1. The relevant information about sustainable municipal solid waste development is summarized and weighted based on the framework of the National Policy for Solid Waste (2010a; Santiago and Dias, 2012):

- Political dimension: includes the identification of institutional cooperation and integration of international and national guidelines for sustainable municipal solid waste management.
- Technological dimension: implies the promotion of environmentally friendly technologies for waste management, which has to be chosen according to the local social-economic, cultural and environmental conditions.
- Economic/financial dimension: denotes the description of institutional abilities to manage, appropriately, the administration of the financial resources available for operational and maintenance of municipal solid waste management.
- Environmental/ecological dimension: identifies the values of biodiversity conservation, preservation of self-purifying ecosystem capacity, reduction of waste generation, recycling, reuse, recovery and environmentally friendly disposal.
- Cultural dimension: considers the population awareness and environmental education about the problem of waste management are the basis of all further development.
- Social inclusion dimension: focuses on integrating social actors in the waste management chain

Table 1 – Primary matrix for municipal solid waste management analysis[1]

Political dimension			
Key-question	Indicator	Descriptor	Score
Is the Municipality fulfilling the requirement of the National Policy for Sanitation?	(1a) Intersectoriality	More than 3 bureaus	5
		2 bureaus	3
		Only 1 bureau	1
	(1b) Universality	75 to 100%	5
		30 to 75%	3
		< 30%	1
	(1c) Integration of basic sanitation services	Water/wastewater/ solid waste/ drainage	5
		Two or three basic services	3
		Only water supply	1
		Developed	5

Is the municipality fulfilling the requirement of the National Policy for Solid Waste?	(1d) Municipal Plan for Integrated Solid Waste Management	In process of development No plan developed	3 0
	(1e) There is audit for urban clean service	In the whole municipality Only in downtown No audit	5 2 0
Subtotal			**25**
	Technological dimension		
Key-question	Indicator	Descriptor	Score
Is the technology according to local conditions?	(2a) Use of local labor force	For all the sectors of waste management For collecting and administration Only for collecting	5 3 1
	(2b) Maintenance of machinery and equipment locally	All type of machinery and equipment Only transport machinery External maintenance	5 2 1
	(2c) Technology with low power consumption; easy maintenance; use of local labor force	Cover all requirements Lower power consumption No technology available	5 3 0
	(2d) Specific waste compactor trucks appropriate for waste management collection and transportation	Yes, only for waste management usage Yes, but also for other municipal other functionalities No waste compact trucks available	5 3 0
Subtotal			**20**
	Economic/financial dimension		
Key-question	Indicator	Descriptor	Score
Is the municipality already charging the population for waste management services?	(3a) Payment of solid waste management fee	There is already a specific tax for solid waste management Surcharge on Urban Land and Building Tax for waste management purposes There is no tax for waste management	5 2 0
Is waste management self-funded in the municipality?	(3b) Percentage of self-funded costs for collecting, treatment and disposal of municipal solid waste	90 to 100% 40% to 90% < 40%	5 3 1
	(3c) Percentage of municipal budget for solid waste management	until 5% 5% to 10% More than 10%	1 3 5
	(3d) Allocation of financial resources from selective collection	For improvement of selective collection For socio-cultural and assistance activities Other	5 3 1
Subtotal			**20**
	Environmental dimension		
Key-question	Indicator	Descriptor	Score
Does the city have low environmental problems?	(4a) Efficiency of the selective collection	91 to 100% 31 to 90% Less than 30%	5 2 1
	(4b) Population satisfaction about selective collection (frequency of collection)	> 70% 30 to 70% < 30%	5 3 1
	(4c) Availability of public waste bins	In all public spaces Only in downtown None available	5 2 0
	(4d) There is selective collection	Yes In process of development None	5 3 0
	(4e) Coverage of selective in the municipality	In the whole municipality Only in the urbanized area Only in some neighborhoods	5 4 0
	(4f) There is local voluntary delivery	Offered for more than 50% of residents Offered for less than 50% of residents None available	5 3 0
	(4g) Recycling index	More than 10% 5.1 to 10%	5 3

		Less than 5%	1
	(4h)Organic waste recovery index	More than 30%	5
		5.1 to 30%	3
		Less than 5%	1
	(4i) Household solid waste generation per capita ($kg.hab^{-1}.year$)	< 307	5
		307 to 376	3
		> 376	1
	(4j) Sanitary landfill authorized	Yes	5
		In process	2
		No, open dumping existence	0
	(4l) Sanitary landfill for inert waste (e.g. construction waste)	Yes, with recycling systems	5
		Yes, only for disposal	2
		None	0
	(4m) Number of illegal disposal area / km extension	None	5
		0.1 to 0.4	3
		> 0.4	1
	(4n) Recovery of degraded area	Total coverage	5
		Partial coverage	3
		None	0
Subtotal			**65**
		Cultural dimension	
Key-question	Indicator	Descriptor	Score
Is the Municipality fulfilling the requirement of the National Policy of Environmental Education? What is the contribution of environmental education with municipal solid waste management? Is the population aware about selective collection?	(5a) Budget allocated for Environmental Education Program (% from urban cleaning budget)	≥ 3%	5
		1 to 2.9%	2
		< 1 %	1
	(5b) Integration of Environmental Education and municipal solid waste management	All the process (since planning to implementation)	5
		Only implementation	3
		None	0
	(5c) Continuous training of employees of waste management sector	Always	5
		Sometimes	3
		None	0
	(5d) Solid waste management audits	Once per year	5
		In a sporadic way	3
		None	0
	(5e) Informative material about waste management	Written through residents participation	5
		Written only by technical team	3
		None	0
	(5f) Community engagement through workshops	Once per year	5
		In a sporadic way	3
		None	0
	(5g) Partnership (University, private sector, others)	Two or more	5
		Less than two	2
		None	0
	(5h) Municipal Advisory Councils (Environmental, Sanitation, Healthcare)	Sanitation Council	5
		Other	3
		None	0
	(5i) Awareness manner	Through participative appraisals	5
		Through Informative meetings	3
		None	0
	(5j) Reject index (%) of the selective collection	≤ 7%	5
		7.1 to 20%	3
		> 21%	1
Subtotal			**50**
		Social inclusion dimension	
Key-question	Indicator	Descriptor	Score
Are waste pickers integrated in the waste management?	(6a) Organized waste pickers (associations)	All waste pickers are organized	5
		Part of waste pickers	3
		Scavenging in landfills or dumping sites	0
	(6b) Average of waste pickers income per capita (monthly)	> 1 minimum wage	5
		1 minimum wage	3
		< 1 minimum wage	1
	(6c) Environmental education promoted for waste pickers	> 90%	5
		50% to 90%	4
		< 50%	1
	(6d) Salubrity s of waste pickers sheds (individual protection equipment,	All the requirements are fulfilled	5
		Only individual protection equipment, closed sheds with bathrooms	3
			0

	closed sheds with recyclable storage, bathrooms, lunchroom)	None	
	(6e) Craftsmen who reuse waste as a source of income	Organized in associations with fix income	5
		Organized in associations without fix income	3
		None	0
	(6f) Waste agents have access to support as defined by National Policy for Waste	There is municipal program for waste pickers support with partnership agreement	5
		There is municipal program for waste pickers support without partnership agreement	3
		None	0
Subtotal			**30**
TOTAL			**210**

[1]Source: (Santiago and Dias, 2012)

For each indicator of the primary matrix, a set of descriptors is ranked against each other, with each indicator given equal importance. Considering the results of the Delphi Method presented by Polaz and Teixeira (2012), the level of development (LD) of municipal solid waste management, after applying the primary matrix, is assessed according to Eq. 1.

$$LD = \frac{\sum of\ the\ municipal\ score}{\sum\ of\ maximum\ score\ in\ each\ dimension} * 10 \qquad \text{Eq. (1)}$$

Where the denominator is equal to 21, then LD is classified as:

0 = no development
1.0 ≤ LD ≤ 4.0 = low development
5.0 ≤ LD ≤ 8.0 = medium development
9 ≥ LD ≤ 10 = high development

2.2 Life cycle thinking and assessment

In this study, life cycle thinking assessment represents the quantification of the physical exchanges, inputs (materials) and outputs (emissions to air, water and soil) with the environment in each life cycle stage (e.g. collection, transport, treatment, processing of recovered materials to products) of municipal solid waste management. Global warming potential (emissions to air), terrestrial acidification (emissions to soil) and human toxicity (emissions to air and water of certain substances, which can have impacts on human health) are the assessment of the environmental impact (EA) investigated.

The key aspects for the analysis taken in this paper are (1) waste type, and composition; (2) collecting and transportation distances; (3) the overall amount of pollutant emissions; (4) credits counted for each waste type which is not landfilled anymore; (5) the boundaries of the system.

The environmental assessment (EA) is expressed according to Eq. (2):

$$EA = \left(\sum_n \sum_i CT_{i,n} \ * EF_{i,n} + \ \sum_i \sum_j V\,A_{i,j} \ * \ EF_{i,j}\right) - \sum_i \sum_j DR_{i,j} \qquad \text{Eq.2}$$

with

CT_i = amount of collected material "i" transported by truck type "n" in metric tons-kilometers

EF_i = emission factor of the material "i", transported by truck type "n" in tons per metric tons-kilometers

$VA_{i,j}$ = amount of material "i" treated by technology "j", in metric tons

$EF_{i,j}$ = emission factor of the material "i" treated by technology "j", in tons per metric tons-kilometers

$DR_{i,j}$ = recycling credits of the material "i" treated by technology "j", in tons per metric tons-kilometers

3 Municipal solid waste management in Belo Horizonte

3.1 Background information

Belo Horizonte is the capital of the state of Minas Gerais, situated in Southeast Brazil, with a total land area of approximately 331km^2 (Fig. 1). Belo Horizonte has a tropical climate characterized by dry winter and rainy summer. Temperatures range from 10 °C to 34 °C, and relative humidity ranges from 64% to 79%

As a planned city[8], Belo Horizonte has a positive economic development that makes it one of the richest cities in Brazil. The city, as the entire Minas Gerais state, has natural resources in areas such as agriculture and mineral. Until the 1960s, Belo Horizonte was known as the hub of the Brazilian mining & processing (mainly gold, manganese and gemstones) and iron & steel industries. However, the service sector (particularly in biotechnology, computer sciences, business and tourism jewelry) is playing a central role in the city's economy nowadays. Unlike many other Brazilian cities, Belo Horizonte is limited in terms of space for any further expansion, which demands large areas or even when logistic activity is crucial. Consequently, Belo

[8] Belo Horizonte was planned and constructed in the 1890s to replace the old capital of Minas Gerais state, Ouro Preto, after the Proclamation of the Republic (Brazil).

Horizonte is one of the Brazilian cities with lower population growth at an average rate of 0.6% per year since 2001(IBGE, 2013).

Figure 1 – Brazil and Belo Horizonte Political Map. Source: Freemap

Nowadays, the Belo Horizonte Metropolitan Region, composed of 33 cities and 16 adjacent municipalities, is the preferable place for housing and a host of large and new industries. The metropolitan region avoids a possible over-population problem and the decline of industry development in Belo Horizonte city. Because of this close interaction between Belo Horizonte and its metropolitan region, Table 2 shows that the economic performance of Belo Horizonte city rose 69% in the last years; as well the income per capita increased by 36% (IBGE, 2013).

Table 2 – Population and economy development of Belo Horizonte, 2001 – 2012[1]

	Population	Gross Domestic Product	Average income per capita [R$/hab./month]
2001	2 238 526	R$ 17 047 615 000.00	R$ 814.22
2002	2 284 468	R$ 18 622 989 000.00	R$ 862.79
2003	2 305 812	R$ 23 297 813 000.00	R$ 789.53
2004	2 327 049	R$ 27 323 046 000.00	R$ 810.85
2005	2 375 329	R$ 28 951 081 000.00	R$ 900.93
2006	2 399 920	R$ 32 473 102 000.00	R$ 1 009.67
2007	2 424 292	R$ 38 285 100 000.00	R$ 999.07
2008	2 434 642	R$ 42 255 583 000.00	R$ 1 055.61
2009	2 452 617	R$ 44 595 205 000.00	R$ 1 090.09
2010	2 375 151	R$ 51 661 760 000.00	R$ 1 197.00
PBH 2011	2 385 639	R$ 54 996 326 000.00	R$ 1 231.48
PBH 2012	2 385 639	R$ 54 996 327 231.48	R$ 1 265.97

[1]Source: (2013a; 2013b)

Belo Horizonte is one of the Brazilian cities with stark contrast. Most of the nine districts of the city (Barreiro, Centro-Sul, Leste, Nordeste, Noroeste, Norte, Oeste, Pampulha and Venda Nova districts) share the same neighbourhood with slums and luxury houses. The average income per capita in a suburban area is less than R$ 595.00 per month (Barreiro) – the equivalent of less than 0.72 US$ per day – while the average income per capita is higher than R$ 3 016.28 per month downtown (Centro-Sul) (IBGE, 2013).

3.2 Municipal solid waste management and characteristics

According to the Brazilian legal framework, municipalities are responsible for delegating the service related to the management of solid waste in their territories, including collecting, processing and disposal. In the case of Belo Horizonte, these services are commissioned to the Superintendence of Urban Cleaning or SLU. Superintendence of Urban Cleaning or SLU. SLU is a self-administered municipal entity that was created according to the Decree-Law 2,220/1973 (SLU, 2013). SLU's main objective is, among other services, the cleaning of public spaces (e.g. sweeping of public parks and streets), the collecting of household waste (residential and commercial), the collecting and disposal of construction and demolition waste, as well as the collecting and proper disposal of waste produced by the city healthcare facilities (SLU, 2013). Fig. 2 (a) shows the historical progression of Belo Horizonte solid waste collection between 2001 and 2012; Fig 2 (b) shows the distribution of the 1,732 thousand tons of waste generated annually in the city of Belo Horizonte in 2012.

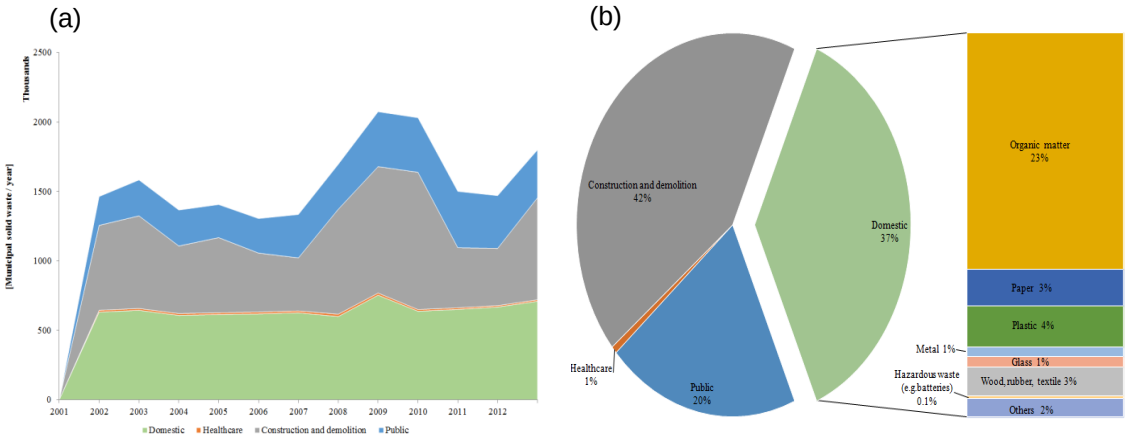

Figure 2– *(a) Average amount of Belo Horizonte solid waste collection between 2001 and 2012 (b) Distribution of annually generated waste in the city of Belo Horizonte in 2012 Source: adapted from records of SLU (2013)*

According to SLU (2013a), more than 75% of the total operational costs are related to urban cleaning and household solid waste. Specifically, 50.1% of the expenditure is for household waste collection. About 31.2% of the expenditure is for waste transfer and disposal. The collection in slums accounts for 10.3%, while 7.2% of the expenditure is related to operational, maintenance and security of machinery and office stuff. SLU provide about 1.1% subsides for waste pickers associations (e.g. operational and maintenance of recycling sheds). In 2012, SLU registered an average coverage of household waste collection of 96% or about 710 thousand tons (Fig.2.3.2.1 (a)).

With the pioneering initiative in 1993, the Fundamental Municipal Law on urban cleaning n.11 secures that waste pickers are agents of selective collection (1996). Until then, in Brazil, waste pickers were treated as criminals and thieves on the streets and dumping sites, living and working places of thousands of families (Campos, 2014b). The legislation, which has been the base ground for Belo Horizonte's city until nowadays, establishes that recyclable materials (paper, plastic, glass and metals) collected through selective collection have to be allocated to the waste pickers association (BELO HORIZONTE, 2008).

The selective collection in Belo Horizonte is performed in an inclusive and solidarity form through door-to-door collecting or local voluntary delivery (LEVs). According to SLU (2013d), 30 of 450 neighbourhoods of Belo Horizonte have access to one or both forms of selective collection at the present moment.

In total, there are eight waste picker associations spread out across the entire Belo Horizonte territory (Table 3). All those associations are receiving subsidies from Belo Horizonte or any other external governance in the form of cost support or even the use of public facilities (e.g. SLU sheds). Many of the waste pickers, who are partners and members of an association, are no longer picking up recyclable materials on landfills or streets. The recyclable materials are delivered by SLU to each waste picker's association for sorting and commercialization, respecting the SLU logistic map and the location area of the waste picker's association. Waste pickers' association controls the number of recyclable materials they receive, according to the volume capacity of their sheds and the number of waste pickers registered.

The total number of waste pickers in Belo Horizonte still needs to be discovered. Many waste pickers do not want to work in associations and prefer the scavenging life, i.e., preference for antagonist attitudes to civil society. For instance, ASMARE (Belo

Horizonte and Brazil's first waste picker association) assumes more than 280 waste pickers have already commercialized recyclable materials at their sheds. However, only 65 waste pickers are officially registered and working daily as solidarity partners and association members.

Table 3– Subsidies and membership agreement between waste picker cooperatives and Belo Horizonte city's hall[1]

Cooperatives	PBH[2]/SLU subsidies [No/Yes]	External subsidies [No/Yes]	Use of SLU sheds	Use of rented sheds	Average of recyclables SLU [t/month][3]	Network Membership
ASMARE	Y (1992)/N	N	Y	N	94	Cataunidos
Associrecicle	N/N	N	N	N	18.5	Redesol
Astemarp	N/N	Y	N	N	0	-
Coomarp	N/Y (2004)	Y	Y	Y	156	Redesol
Coopemar	N/Y (2009)	N	Y	Y	90	-
Coopersol-L	N/N	Y (2009)	Y	N	36	Redesol
Coopersoli	N/Y (2003)	Y	Y	N	105	Redesol
Coopersol-VN	N/N	Y (2002)	Y	N	26	Redesol

[1] Adapted from (BELO HORIZONTE, 2012). [2]PBH: Belo Horizonte Governance; [3]Average capacities from 2012

With the creation of the National Movement of Collectors of Recyclable Materials (MNCR) in 2001, waste picker associations are motivated to organize themselves into networks. In networks, waste picker's associations can apply for sustainable financing and National subsidy programs (e.g. Cataforte Program). These subsidy programs aim the infrastructure improvements and operating capital for the professional education of waste picker's network (Rutkowski, 2008). In Belo Horizonte, most waste picker's associations are members of two different consortiums: Cataunidos (the first consortium of Brazil with Asmare association as a leadership) and Redesol (organized by five associations from Belo Horizonte and six associations from Belo Horizonte Metropolitan Area).

Although Belo Horizonte is highlighted for its selective collection model system, approximately 98% of the waste collected is still disposed of in sanitary landfills. Since 2007, household waste is not disposed of in the Belo Horizonte landfill anymore. After 32 years of operation and because of a Clean Development Mechanism project, Belo Horizonte sanitary landfill has been closed. The thousands of tons of landfill gas accumulated during the entire period is collected gradually, treated and transmitted through a light pressure line to the modular internal combustion engine for electricity generation.

However, the household waste collected in many neighbourhoods daily is transported and disposed of at the Macaúba landfill in Sabará (around 47 km from Belo Horizonte centre). Because of the long distances between the collection and disposal sites, in 2009, the transhipment station started its operation in the Noroeste district (Figure 2.3.1.1) (SLU, 2013). In the transhipment station, after SLU collects the household waste, household waste is transferred from trucks with a volume capacity of 15 m^3 (mostly compactors and garbage tippers) to lorry trucks of 50 m^3 capacity.

4 Results and discussion

4.1 Status of Belo Horizonte municipal solid waste management

In a general context, according to the results of the primary matrix, Belo Horizonte has a medium status of development of its current municipal solid waste management *(LD=6)*. Taking the approach of the National Policy for Solid Waste, the city still needs to cover political, economic, environmental, cultural and social inclusion dimensions in a balanced way. Figure 3 shows the results classified according to the status of development of each dimension, from the best performance to the worse one. Observing each dimension's development status separately, it varies between 77% (outcome from social inclusion dimension) and 35% (outcome from economic/financial dimension) from its total development.

Looking at the social inclusion dimension in Fig. 3, there is no low score (0 or 1) indicator. For Belo Horizonte NGOs, researchers and governance, the social integration of waste pickers is fundamental. Nowadays, the outcomes of this integration are (1) job creation and poverty alleviation and (2) reduction of recyclable materials volume in landfill. For instance, each waste picker sorts an average of 4 tons of solid waste monthly. Their income is based on the total amount paid for the material sorted weekly or monthly, depending on each waste association agreement. The wages can vary from R$ 730.00 (current value of minimum wage in Brazil in 2012) to R$ 1 520.00 (best cases).

Regarding the economic dimension in Fig. 3, most indicators presented the lowest score, except those related to waste pickers. The results showed the need to find alternatives to support waste management's economic and financial expenditures. However, social acceptance is still doubtful for any other waste treatment technology that would provide economic returns.

From results obtained from the primary matrix method, it is recognized that selective collection and recycling are the main priorities for developing sustainable municipal solid waste management in Belo Horizonte. Challenges and opportunities are described as following:

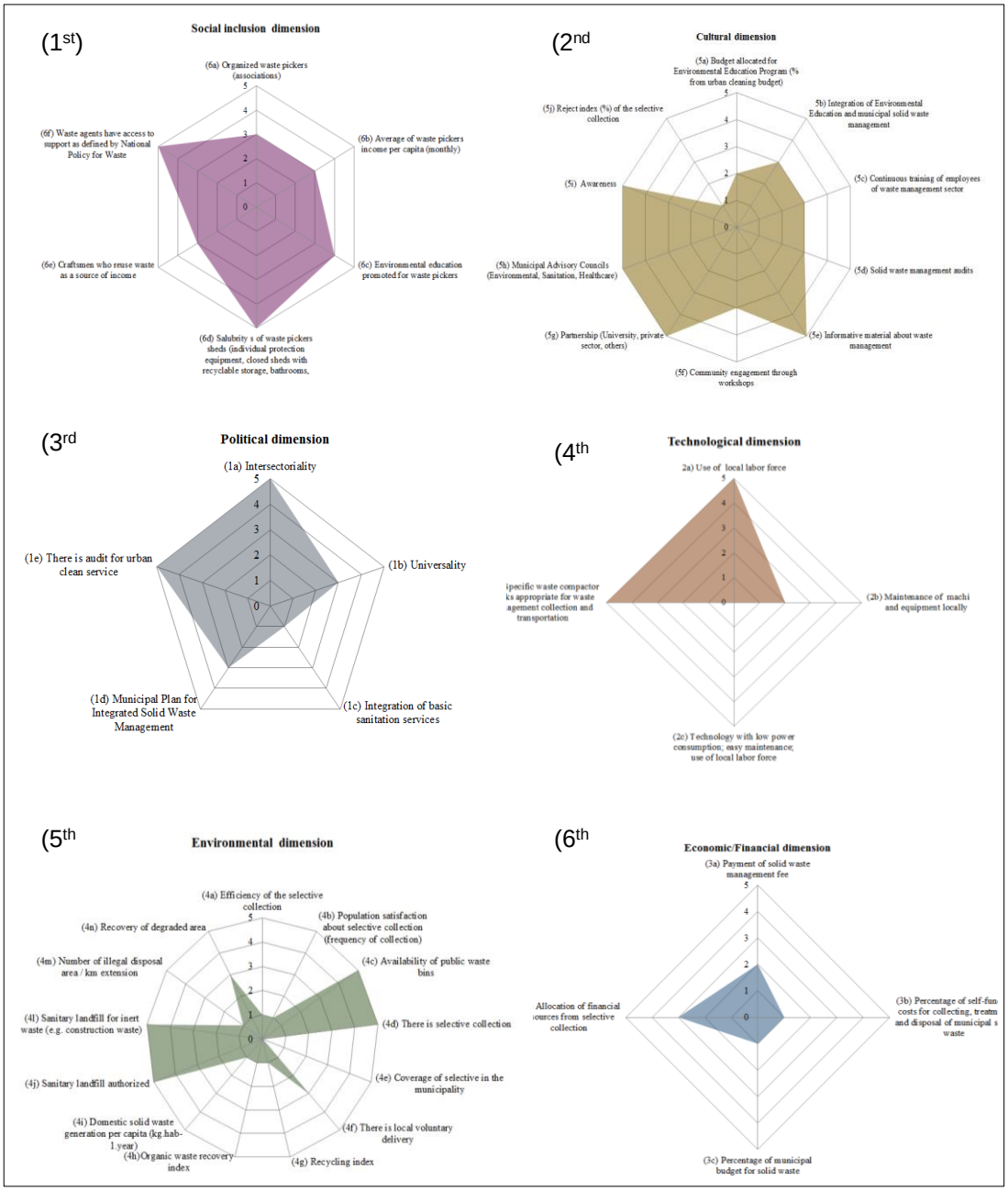

Figure 3- Development ranking of Belo Horizonte municipal solid waste management

- Social inclusion dimension: Extending the coverage of selective collection in Belo Horizonte to other neighbourhoods will bring the opportunity for job creation, as well as for catching pickers who prefers the scavenging activities into waste picker's association. However, the acceptance of new members is

not easy. Some associations organize their wages based on an equal share of the number of members and the total amount of recyclable sorted, i.e. there is a risk that more members have as lower wages become.

- Cultural dimension: For NGOs, selective solidarity collection is the opportunity to increase effectiveness and reduce the percentage of rejects. Through personal contact, waste pickers become responsible for teaching citizens about what is or is not recyclable materials and making them more aware once the waste is the income for many waste pickers' families.
- Political dimension: The challenge is the total commitment to municipal and state governance before any further opportunity takes place in Belo Horizonte for an integrated system. Belo Horizonte has yet to have specific priorities for solid waste management and treats all sanitation services (water, wastewater, and solid waste) equally, but with low priorities in comparison with other sectors.
- Technological and environmental dimension: The current challenge faced for the commercialization of recyclables is ensuring that the recycled materials match the quality demands of the industry. Nowadays, a few industries buy the pressed bales of the waste picker's association. The material is usually sold to industry conveyors for low prices.
- Economic/financial dimension: decision-makers highlight public and private partnerships as an opportunity to develop the strategic implementation of technologies for energy recovery. The main challenge is public acceptance.

4.2 Life cycle thinking and assessment

The life cycle assessment is based on the material flow model of the current Belo Horizonte municipal solid waste. The household waste stream sets the system boundaries of the model. It starts with the collection and ends with the end-of-life phase of recycling. Credits are given for avoiding recyclable materials in the landfill site and for the destination biowaste to composting (Fig. 2.4.2.1). The model shows a maximum of 709,056 t/year. The average coverage of the household waste collection is 96% which means 0.848 kg/habitant/day collected in 2012. The governance expects this tendency to rise because of changes in each resident's lifestyle and economic growth (Table 2.2.1.1).

In addition, the model considers two steps of sorting: (1) gross sorting where 30% (index counted by waste picker's associations (ASMARE, ASSOCIRECICLE,

COPEMAR, & COPERSOLI, 2014)) of the total recyclable materials collected is rejected and (2) sorting for commercialization according to industry conveyors requirement.

The environmental assessment has been modelled in the software Umberto NxT with the support of the Ecoinvent V.3 database and ReCiPe life cycle impact assessment. Fig. 4 allows the analysis of the global warming potential impact (a), human toxicity (b) and terrestrial acidification (c) of each waste stream with a breakdown of the different steps of the current Belo Horizonte municipal solid waste management.

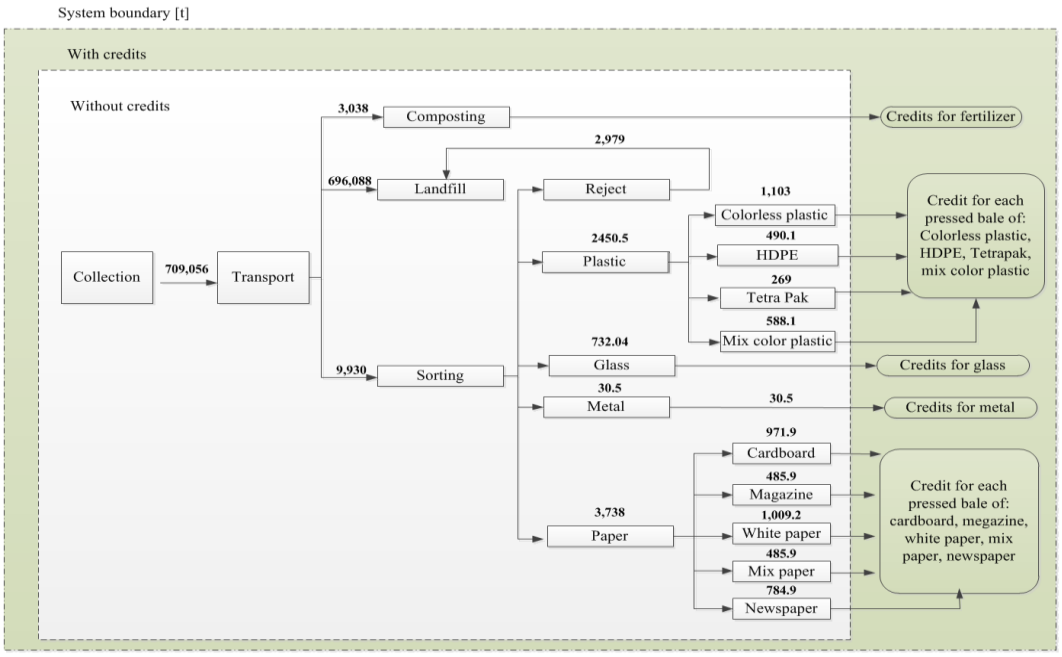

Figure 4 - System boundary for the waste stream "household" in Belo Horizonte 2012

The global warming potential (Fig. 5 (a)) is dominated by dinitrogen monoxide, methane and carbon dioxide emissions that occur because of the disposal of a large volume of unsorted recyclable and organic waste in landfill mainly. The global warming potential credits obtained because of avoidance of disposal of recyclable materials (plastic, glass, metal and paper) in landfill could be more noteworthy at the current instance. However, among them, paper waste has the most significant contribution since it is the primary commercialized recyclable material in Belo Horizonte (Fig. 4).

Taking into account the waste management steps (collecting and transportation, treatment and disposal), terrestrial acidification has the most distinguished results.

Terrestrial acidification has the most outstanding results. The impacts caused by the large amount of unsorted solid waste, which is the daily pick-up by garbage trucks and the distance to the transshipment and disposal site are higher than disposal impacts. The stop-and-go routes of garbage trucks demand a large amount of diesel fuel, influencing the two most common nutrients of acidification impact: nitrogen (N) and sulphur (S).

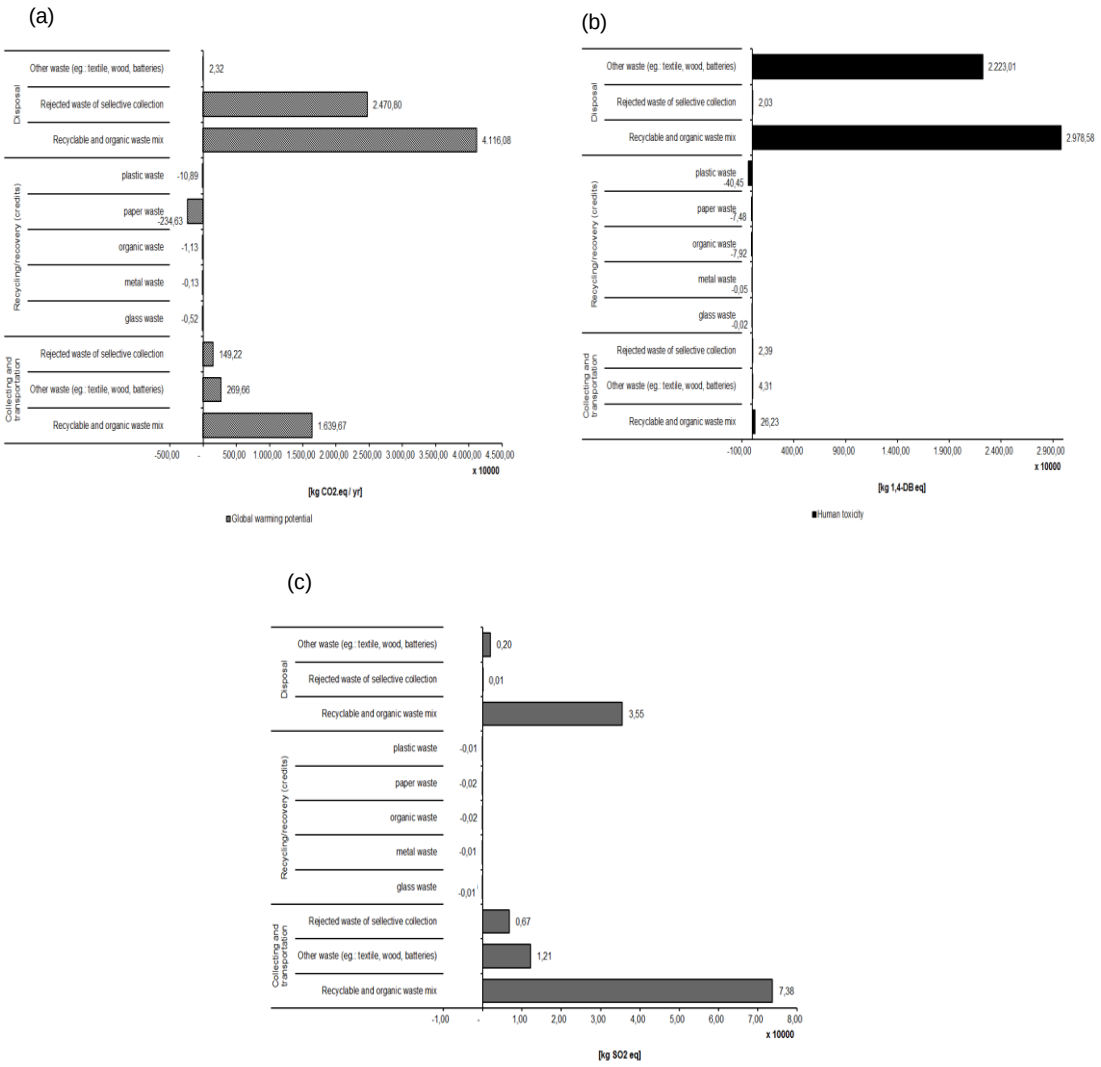

Figure 5 - Contribution to global warming potential (a), human toxicity (b) and terrestrial acidification (c) according to waste streams and breakdown to the different steps of waste management

The environmental sound of any municipal solid waste management can be doubtful when the system boundaries are faced. This study defines the system boundary as the entire Belo Horizonte waste management, independent of the political and geographical map. According to previous descriptions, Sabará city legally absorbs a

large amount of waste for final disposal. Consequently, this neighbouring city owns the environmental impacts related to the disposal phase as global warming potential and human toxicity. For instance, observing human toxicity impact, the large volume of Belo Horizonte biowaste disposed of in Sabará's landfill is handling the negative environmental impact of harmful effects on the water of pathogens and organic contaminants.

5 Conclusions

This study analyses the current progress and the effectiveness of measures implemented in Belo Horizonte municipal solid waste management. At the moment, solid waste management actions in this city have taken selective collection and recycling as the main priority. Nonetheless, through the full results of this study (primary matrix coupled with life cycle thinking assessment), it is essential to note that recycling is an important part of sustainable policies, and selective collection is its driving force. Recycling is not plentiful for achieving the entire sustainability goal (recyclable materials represent less than 50% of the municipal solid waste composition of Belo Horizonte city). The approach to cover political, technological, economic, environmental, cultural and social inclusion dimensions in a balanced way will fail continuously. Actions like increasing the diversion of biodegradable waste from landfills, promoting responsible and equitable consumption patterns and increasing material recovery would lead to additional reductions of environmental impacts and, at the same time, support the balance between the other sustainable dimensions for further development.

References

[1] UN-Habitat, " Solid Waste Management in the World's Cities. Water and Sanitation in the World's Cities Report 2010," Earthscan, Washington, 2010.

[2] J. Boer and E. Jager, "LCA-IWM: A decision support tool for sustainability assessment of waste management systems," Waste management, vol. 27, pp. 1032-1045, 2007.

[3] IPCC, "Waste Management," Intergovernmental Panel on Climate Change, Geneva, 2010.

[4] A. Mavropoulos, "Waste management 2030+," Waste Management World Monthly, 1 March 2014.

[5] ABRELPE, "Overview of Solid Waste in Brazil 2012," Associacao Brasileira de Empresas de Limpeza Pública e Resíduos Especiais, Sao Paulo, 2012.

[6] Brazil, "Law n. 12,305/2010 National Policy for Solid Waste," Presidência da República. Casa Civil., Brasília, 2010.

[7] C. Polaz and B. Teixeira, "Indicators of sustainability for municipal solid waste management: case study of the city of Sao Carlos," Engenharia Sanitária Ambiental, pp. 411-420, 2012.

[8] S. Manfredi and G. M., "Life cycle indicators for monitoring the environmental performance of European waste management," Resources, Conservation and Recycling, pp. 8-16, 11 September 2013.

[9] K. Greene and T. D., "Quantitative assessments of municipal waste management systems: Using different indicators to compare the rank programs in New York," Waste Management, pp. 825-836, 23 January 2014.

[10] D. Lazarevic, N. Buclet and N. Brandt, "The application of life cycle thinking in the context of European waste policy," Journal of Cleaner Production, pp. 199-207, 17 January 2012.

[11] L. Santiago and S. Dias, "Primary Matrix of sustainability indicators for the urban solid waste management in Brazil," Engenharia Sanitária Ambiental, vol. 17, no. 2, pp. 203-2012, 2012.

[12] IBGE, "National Report of Population in Brazil 2013," Instituto Brasileiro de Geografia e Estatística, Brasília, 2013.

[13] IBGE, "Gross Domestic Product report," IBGE, Brasilia, 2013.

[14] SLU, "Annual Report of Municipal Solid Waste - 2001 to 2012," Prefeitura Municipal de Belo Horizonte, Belo Horizonte, 2013.

[15] BELO HORIZONTE, "Lei Orgânica do Município de Belo Horizonte," Prefeitura Municipal , Belo Horizonte, 1996.

[16] BELO HORIZONTE, "Municipal solid waste management in Belo Horizonte - Overview," PBH, Belo Horizonte, 2012.

[17] J. Rutkowski, Sustainability of solidary enterprise: An approach on production engineering, Rio de Janeiro: COPPE/UFRJ, 2008.

[18] ASMARE, ASSOCIRECICLE, COOPEMAR and COOPERSOLI, Interviewees, Recycling and waste picker's association in Belo Horizonte. [Interview]. 23 April 2014.

Publication II

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

* This article is published in the International Journal Waste management, 2021. 121, 215–225. DOI:10.1016/j.wasman.2020.12.006 Authors: Maryegli Fuss, Raphael Tobias Vasconcelos Barros and Witold-Roger Poganietz

Abstract

Waste pickers (WPs) are considered a strong suggestion to become the 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 recognise 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 operationalising 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 are classified as barriers for a successful extending of a socio-integrated recycling system identified in the SAA analysis. This study suggested 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.

Keywords: Emerging economies; Recyclable solid waste; Material flow analyis; Agent-structure analysis; Waste pickers.

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 system 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 when it happens, 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 for HSW sorting and treatment systems (Gutberlet, 2018; Hartmann, 2018; Welivita et al., 2015). The novelty is to create a frame to embed waste pickers (WPs) as mediators for 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 "underveloped treatment systems” (Velis, 2017). Many citizens in those countries are under the conditions of poverty and unstructured life that find for the mismanagement of HSW, i.e., open-dumpings and landfilling of mixed waste, 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 recognise WPs as service providers frequently discriminate against them (Azevedo et al., 2019; Chen et al., 2018; 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, “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 socio-integrated recycling system, but economic prosperity is still the primary aim of the CE and might imply trade-offs 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, 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 analysed on a local scale. The situation of WPs can differ among countries or cities because of, for example, legal issues, social behaviour, 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 organisational 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 analyse the socio-integration development of individual groups that execute directly 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 it is fundamental for operationalising 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 discussion and conclusions are summarized in sections 5 and 6.

2. A literature review about the situation of Belo Horizonte

Belo Horizonte, the capital of Minas Gerais' state, is placed 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 ranges 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 characterised by high social inequalities, with a Gini coefficient of 0.60 (IBGE, 2018). This socioeconomic 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 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 recognise 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 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 labour 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 Figure 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, collaborating WP cooperatives to 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 Figure 1, the formal and the informal waste sector still runs in parallel in Belo Horizonte. The informal sector helps small and middle-sized middlemen businesses by creating the opportunity to generate fast income by selling recyclable waste with the lowest market prices (Varella, 2011).

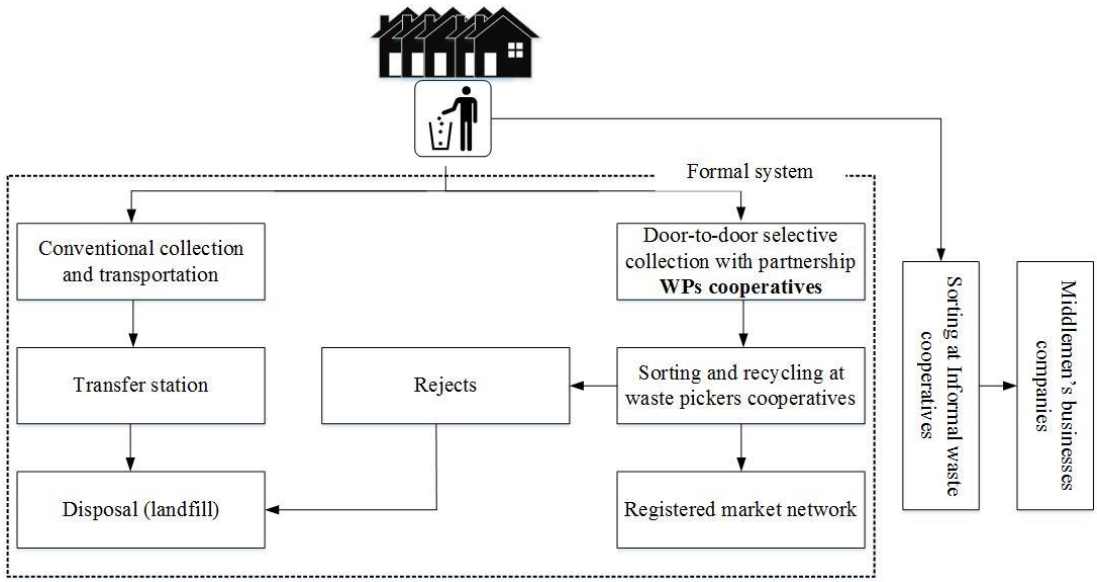

Figure 1. Belo Horizonte's HSW management in 2014
Processes are part of the description presented in Varella (2011) and SLU (2018)

The difference between the formal (registered) WP cooperatives and informal sector is the services that formal WP cooperatives are providing 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 a service provider for the city (Rutkowski, 2008; Rutkowski and Rutkowski, 2015; Varella, 2011).

A significant gap regarding the efficiency of the socio-integrated recycling system causes the Belo Horizonte HSW management to be seen stagnated by many decision-makers (HORIZONTE, 2017). New perspectives from industries bring hope for WP cooperatives to create best-practices for the socio-integrated system under 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 to invest 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 Figure 2.

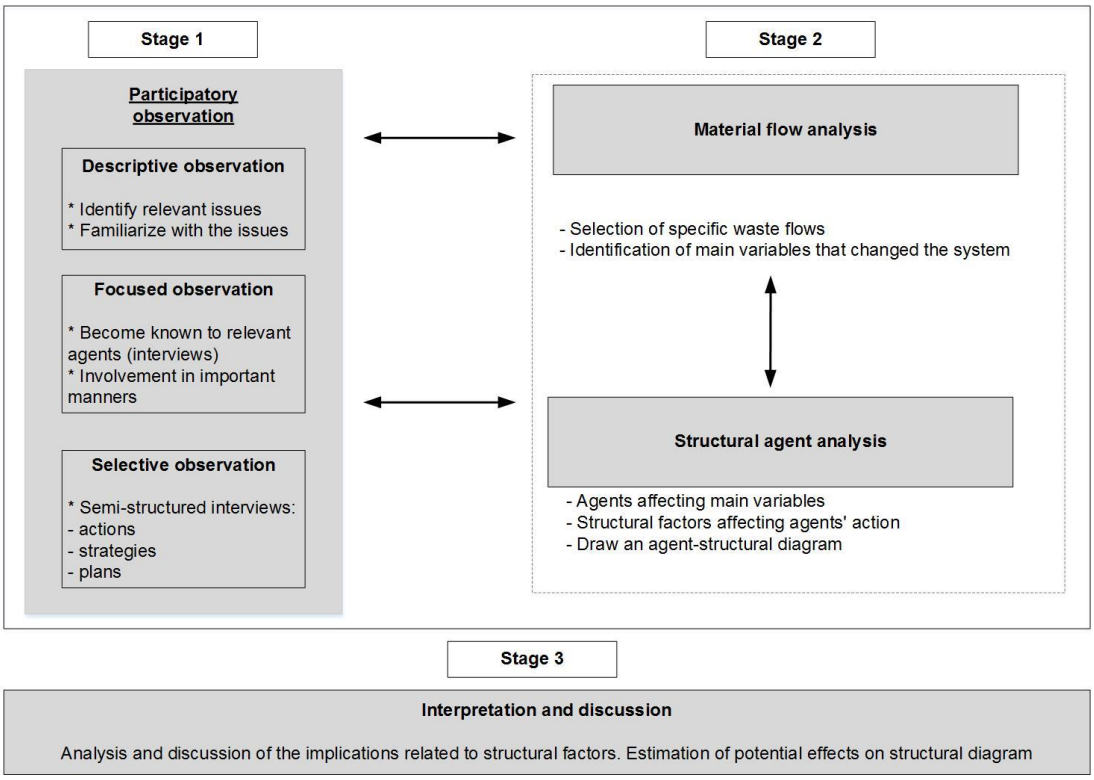

Figure 2 Research method stages based on a combination of participatory observation and MFA-SAA. Stages adapted from (Binder, 2007b; Kawulich, 2005)

The first stage aims 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 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 familiarise them with the activities and interactions that they have done formally and informally, as unplanned activities. Mainly, WPs were observed in how they were acting during day-to-day activities. Their historical background and beliefs were taken into account in interviews. The producer of household solid wastes was also investigated. Different parts of the city were visited to investigate mainly how the society acts regarding waste generation, integration of WPs, and satisfaction of the current HSW management situation. This study's first stage was documented through pictures and recorded videos to be used in the following research processes.

One of the researchers of this study (the one who conducted the participatory observation) became an integrant of the Waste and Citizenship Forum of Belo Horizonte. Such involvement provided the advantage of building a platform of communication with about 34 agents of Belo Horizonte. This platform was essential to develop structural agent analysis (SAA). Direct contact with local agents enabled us to obtain 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 analysed 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 the MFA-SAA to provide an up-to-date discussion of the findings (Stage 3).

3.2. Detailed characterization of the MFA-SAA

The MFA is well established within the field of waste management and the agent analysis within the field of sociology (Binder, 2007a; Graedel, 2019; Long, 2004; Moriguchi and Hashimoto, 2016). This paper is related to the combined issues determined in the 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 MFA-SAA application helped to investigate the relationship between agents and structural mechanisms by recognising 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 analysis because the results are derived from conflicts of actions from 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 to understand, in a practical matter, the systematic assessment of MFA analysis (Binder, 2007a, b; Brunner and Rechberger, 2004).

One challenge identified to analyse the city of Belo Horizonte is that no precise systems boundaries exist when the circularity approach of recyclable materials is taken into account. The scope of this study entailed that each agent corresponds 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 modelling approach focused on various packaging products available for consumption. This approach provided an in-depth analysis of the material flow sector, legislation and market regarding the product value chain.

At the city level, the MFA follows the Belo Horizonte's recyclable HSW management (see Figure 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). The closed-loop recycling pursues recyclables that can still substitute original resources for the traditional processing industry while the open-loop recycling recyclables go for 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 composed the SAA analysis (Binder, 2007a) in this study:

I. Classification of the relevant agents, i.e., the 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 cans 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.: the signification 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. Vizualization of the SAA outcomes through the agent-structure diagram. The diagram shows the structural factors driving agents' actions and their interactions.

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

3.3. Data management

The MFA-SAA application 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 terms matches the total consumption demand (availability), while the total consumption must be correspondent to the total post-consumption (accumulation and discard) (Brunner and Rechberger, 2004; Pedersen and Haan, 2006). 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 of Courtonne et al. (2015 p. 69): “consumption is almost proportional to the population growth”. For instance, the consumption of glass (U) at a local scale would be:

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

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

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

Table 1. Data source for MFA analysis

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

The SAA follows the qualitative approach based on semi-structured interviews and secondary data to determine the allocative resources, legitimation and cultural values. Table 2 describes the main data sources used for SAA analysis.

Table 2. Data source for SAA analysis

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; ublic authorities; third-party companies
The needs for socio-integrated sorting system	Round-table discussion (15 persons)	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

The output of participatory observation helped to fulfill the first and second steps of SAA analysis (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 analyse the prolonged individual relationships 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.

4. Results

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

4.1 Recyclable waste flows and the impact on 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 income (about 2.7% each year), higher demands for recyclable products and 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 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 5.2% growth in plastics.

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	-	548.15	Closed-loop recycling[4]
HDPE[3]	11,346	15,663	402.68	410.89	Open-loop recycling[5]
LDPE[3]	25,362	35,011			
PP[3]	5,340	7,371	18.30	20.16	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**	**420.98**	**979.20**	
Office paper	9,404	15,579	128.49	206.96	Open-loop recycling
Magazine and news	3,135	5,193	42.83	68.99	Open-loop recycling
Cardboard	34,483	57,123	-	161.72	Closed-loop recycling
Multi-material tetrapack	3,135	5,193	-	-	
Others	8,306	34,173	-	-	
Total paper	**58,463**	**117,261**	**171.32**	**437.66**	
Aluminum can	1,567	2,596	-	1,235.16	Closed-loop recycling[3]
Non-ferrous metal	7,837	12,982	274.63	410.07	Open-loop recycling
Ferrous metal	4,644	9,548	672.36	468.03	Open-loop recycling
Total metal	**14,048**	**25,127**	**946.99**	**2,113.26**	
Total Glass	**23,511**	**38,947**	-	-	
Other recyclables[6]	**28,219**	**68,933**	-	-	

[1] Uncertainties of data input varies from 15% to 31%. The most uncertain data is the category metals (ferrous and non-ferrous).

[2] Uncertainties of data input varies from 22% to 45%. The most uncertain data is the category 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

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 how the input flows have been changed in recycling processes. WP cooperatives are becoming more professionalised. Each member has assumed a labour division of collecting (selective collection), sorting (with or without the support of bells), operating the mechanical recycling (i.e., shredding or pressing) and assisting the office staff. Their participation in the selective collection has supported the minimisation 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 were considered the easiest recyclables to be identified and the cleanest compared to any other recyclable wastes. Therefore, the difference between both waste products is the strong market demand for aluminum cans, where its market price was around R$ 4.00/kg in contrast to that of cardboard at R$ 0.22/kg in 2014 (CEMPRE, 2014). PET bottles have become attractive for WP cooperatives in Belo Horizonte because of 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), but the recycling network systems still face 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, schreding 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 has been shifting the opportunities of the recycling networks to directly start the trade of sorted recyclables with small to mid-sized recycling companies, without the intervention of middlemen, as was commonly done 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 the coarse and fine sorting, and no significant changes in the quality of waste received by service companies happened 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 purposes of CataUnidos, started in 2014, is the mechanical transformation of colored PET, PEs and PP into pellets. It is estimated, based on the number of WPs in cooperatives and share of metals in total waste input for the recycling networks, 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 commercialised with textile and unsaturated and alkyd resin industries in the metropolitan region. A specific share of plastic bales designated for each industry is unknown.

4.2 The socio-integrated recycling system on the view of SAA

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

The overall responsibility of HSW management is on the city council, while formal WPs raised the jurisdiction issue to assume the selective collection responsibility instead of third-party companies. The agent-structure diagram (Figure 3) provides a visualisation of how Belo Horizonte’s agents (depicted in ovals) are interacting according to the structural elements (grey 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 norms, knowledge and rights. Industries simultaneously play a direct or indirect role by demanding high-quality sorting of recyclables while leading enterprises assist with setting technical norms.

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

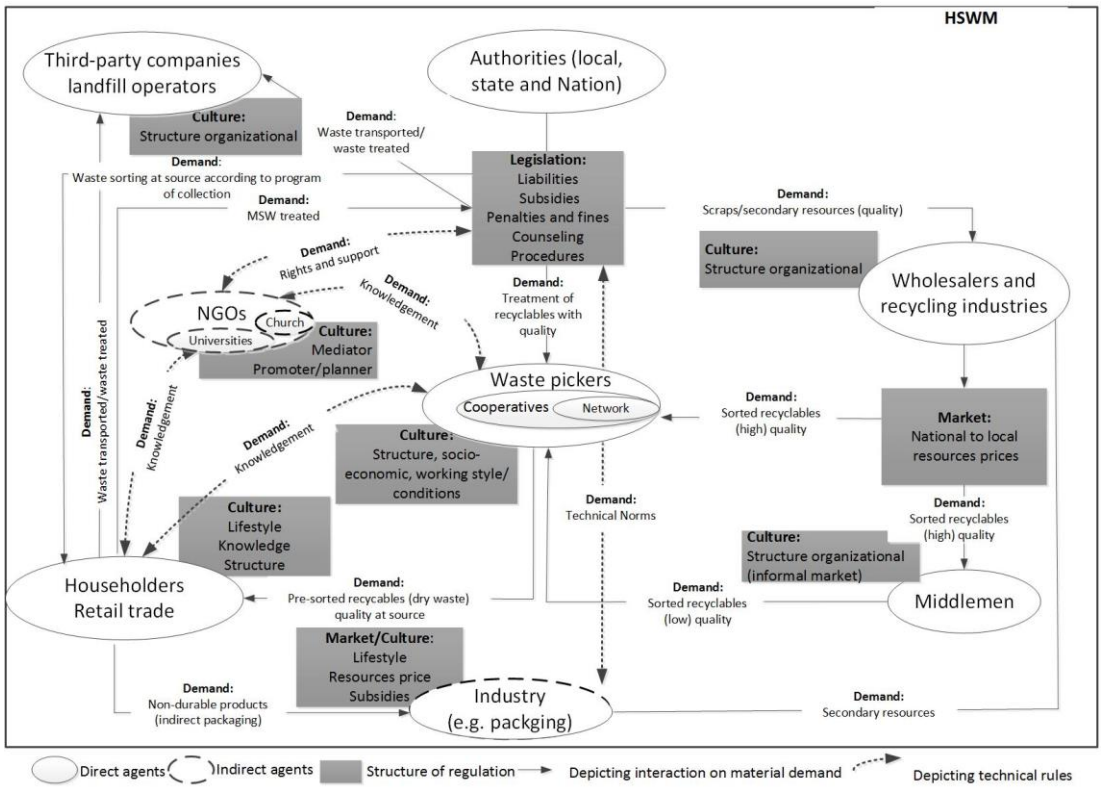

Figure 3. Agent structure diagram within the scope of socio-integrated recycling system
Adapted SAA diagram based on Binder (2007b)

The *culture & legislation mechanism* represent the merge of cultural values and legitimation. They consolidate 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*") had substantial participation 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 (Figure 3).

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

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

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 recognised 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 consummate a plastic pellets facility in 2014.

The integrated social system in Belo Horizonte differs from other Brazilian cities that failed to implement the socio-integrated model due to trust (Tirado-Soto and Zamberlan, 2013). The cultural behaviour 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 the Brazilian Social Security Institute for Retirement (INSS);
VII. be 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 leave the business of waste picking. Those 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 norms for industrial processes standardisation (NBR, 2006) regulates 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 standardised 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 found in the recycling process an alternative method for minimising energy demand and

dependence on the primary sector by investing in closed-loop recycling countrywide. Because of that, many WP cooperatives in Belo Horizonte became exclusively “aluminum cans pickers" creating a highly competitive system. On the other side, Brazil became the worldly leading country of recycled aluminum cans (ABRALATAS, 2018). An opposite action happened for glass beverage industries and there was a stifling of the returnable glass bottles to the producer. 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 to open new businesses, small enterprises are looking at 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) 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 1,071.78 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 better infrastructure to achieve an average of 1,800 kg/month based on the national standard for high efficiency (IPEA, 2017). 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 socioeconomic paths. 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 steel industries, one of the most energy-intensive and largest CO2 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 needs 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 an 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 developed new products from waste. Such a 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 the 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 2,412 (based on national statistics) to 33,766 citizens (based 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 need for socioeconomic embeddedness into CE approach gains importance worldwide (Laurenti et al., 2018). This study acknowledges that a CE approach can be too broad to boost socio-integrated systems for HSW management if it is taken at macro-scale. According to the case study of Belo Horizonte, the macro-perspective of CE concept obscures the real problem, procedures, challenges, and even targets. WPs are the most vulnerable in the HSW management system regarding any economic, legal, technical, and political changes.

The results of this study identified regulatory structures that encompass cultural values (grounded on collectivism, solidarity and reciprocity), market mechanisms and legislation constraints that integrate the WP system within the practice of CE. The number of WPs registered in cooperatives, market price set-up by recycling companies, regulatory legislation for packing products and new small enterprises

promoting open-loop recycling are some of the identified barriers that create obstacles for the socio-integrated system.

The case of Belo Horizonte showed the paradigm connected to the intersections of HSW management efficiency and development centered on well-being where the standpoint of human functioning, capabilities, and needs should be taken into account. Belo Horizonte's case built a new consensus and strategies with relevant agents (e.g., NGOs, religious community, academia, WPs) to evaluate options for improving the flows of recyclable materials. But, 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 suggested that 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 the need to develop an insalubrious working environment for those people that are engaged, with an aware or unaware behaviour, to collaborate with a practical approach of the CE. Also, effective communication and mutual understanding about 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.

References

ABIPET, 2018. Brazilian PET Industry. http://www.abipet.org.br. (Accessed 26.07.2019).

ABPO, 2014. Brazilian Association of Cardboard. http://www.abpo.org.br/. (Accessed 26.07.2019).

ABRALATAS, 2018. Brazilian Association of Aluminium cans producers. http://www.abralatas.org.br/. (Accessed 26.07.2019).

ABRE, 2015. Brazilian Association of Packaging: Physical production of Packagings. ABRE, Sao Paulo.

Alfaia, R.G.d.S.M., Costa, A.M., Campos, J.C., 2017. Municipal solid waste in Brazil: A review. Waste management & research : the journal of the International Solid Wastes and Public Cleansing Association, ISWA 35(12), 1195–1209.

Andrade, A.S.C., 2004. Women in the Brazilian job market, PhD Thesis ed., Campinas.

ANVISA, 1996. Permission or restriction of the use of recycled materials for food contact materials, RDC n. 27/1996, RDC n. 20/2007 ed.

ANVISA, 2016. Law number 9782/99 and RDC nº 91 de 11/05/2001 - Control of packaging products: 9782/99. p. 9782/9799.

ASMARE, 2015. Socio-inclusion of waste pickers.

Azevedo, B.D., Scavarda, L.F., Caiado, R.G.G., 2019. Urban solid waste management in developing countries from the sustainable supply chain management perspective: A case study of Brazil's largest slum. Journal of Cleaner Production 233, 1377–1386.

Binder, C.R., 2007a. From material flow analysis to material flow management Part I: Social sciences modeling approaches coupled to MFA. Journal of Cleaner Production 15(17), 1596–1604.

Binder, C.R., 2007b. From material flow analysis to material flow management Part II: the role of structural agent analysis. Journal of Cleaner Production 15(17), 1605–1617.

Bouças, C., 2017. Beverage industries try to to grow their product's consumption with returnable glass bottles. ABIVIDRO, Sao Paulo.

BRASKEN, 2018. Price of plastic resins increases by 30%. http://www.neoplastic.com.br/pt/noticias/noticias-do-site/braskem-sobe-preco-de-resinas-apos-alta-de-30. (Accessed 13.08.2019.

BRAZIL, 2006. Municipal solid waste management priorities for socio-entrepreneurship of WP cooperatives, 5940/06.

BRAZIL, 2010a. National Policy on Cooperativism for the society.

BRAZIL, 2010b. National Policy on Solid Waste Law 12,305/2010. BRAZIL.

Brunner, P.H., Rechberger, H., 2004. Practical handbook of material flow analysis. CRC/Lewis, Boca Raton, FL.

Bugge, M.M., Fevolden, A.M., Klitkou, A., 2019. Governance for system optimization and system change: The case of urban waste. Research Policy 48(4), 1076-1090.

Campos, H.K.T., 2014. Recycling in Brazil: Challenges and prospects. Resources, Conservation and Recycling 85, 130–138.

Carvalho, P.S.L., Mesquita, P.P.D., Araújo, E.D.G., 2015. Sustainability of Brazilian steel industries: energy efficiency, emissions and competitiveness, 41 ed., pp. 181–236.

Chen, F., Luo, Z., Yang, Y., Liu, G.-J., Ma, J., 2018. Enhancing municipal solid waste recycling through reorganizing waste pickers: A case study in Nanjing, China. Waste management & research : the journal of the International Solid Wastes and Public Cleansing Association, ISWA 36(9), 767–778.

Commission, E., 2019. Waste and Circular Economy. Brussels.

da Silva, L.R., 2018. Interview: Changes after the re-organization of waste pickers cooperatives into union organizations, in: da Silva, L.R. (Ed.). Phone.

Ferronato, N., Torretta, V., 2019. Waste Mismanagement in Developing Countries: A Review of Global Issues. International journal of environmental research and public health 16(6).

Foundation, E.M., 2019. Completing the Picture: How the Circular Economy Tackles Climate Change Ellen MacArthur Foundation pp. 20-24.

Ghosh, S.K., Agamuthu, P., 2018. Circular economy: The way forward. Waste management & research : the journal of the International Solid Wastes and Public Cleansing Association, ISWA 36(6), 481–482.

Graedel, T.E., 2019. Material Flow Analysis from Origin to Evolution. Environmental science & technology.

Guerrero, L.A., Maas, G., Hogland, W., 2013. Solid waste management challenges for cities in developing countries. Waste Management 33(1), 220–232.

Hartmann, C., 2018. Waste picker livelihoods and inclusive neoliberal municipal solid waste management policies: The case of the La Chureca garbage dump site in Managua, Nicaragua. Waste management (New York, N.Y.) 71, 565–577.

Haupt, M., Vadenbo, C., Hellweg, S., 2017. Do We Have the Right Performance Indicators for the Circular Economy?: Insight into the Swiss Waste Management System. Journal of Industrial Ecology 21(3), 615–627.

Hoff, K., Walsh, J., 2018. The Whys of Social Exclusion: Insights from Behavioral Economics. The World Bank Research Observer 33(1), 1–33.

HORIZONTE, B., 2017. Belo Horizonte Municipal Solid Waste Plan. 325.

IBGE, 2015. Packaging production. https://www.ibge.gov.br/estatisticas/economicas/industria/9324-indices-especiais-de-embalagens.html?=&t=resultados. (Accessed 22.10.2018.

IBGE, 2018. Belo Horizonte's population and indexes. Instituto Brasileiro de Geografia e Estatística, Brasilia.

IPEA, 2017. The integrated selective collection system in Brazil: Challenges and opportunities under the aspects of solidarity economy, Rio de Janeiro.

Jacobi, P., Teixeira, M.A.C., 1997. Social capital: ASMARE - Waste Pickers Cooperative of paper, cardboard and recyclable resources of Belo Horizonte. Cadernos Gestao Pública e Cidadania.

Kalmykova, Y., Sadagopan, M., Rosado, L., 2018. Circular economy – From review of theories and practices to development of implementation tools. Resources, Conservation and Recycling 135, 190–201.

Kawulich, B.B., 2005. Participant Observation as a Data Collection Method. Forum: Qualitative social research 6(II).

Kirchherr, J., Reike, D., Hekkert, M., 2017. Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation and Recycling 127, 221–232.

Kugel, S., 2007. A Town Where All the World Is a Bar. https://www.nytimes.com/2007/10/28/travel/28next.html. (Accessed 26.09.2019.

Laurenti, R., Singh, J., Frostell, B., Sinha, R., Binder, C., 2018. The Socio-Economic Embeddedness of the Circular Economy: An Integrative Framework. Sustainability 10(7), 2129.

Long, N., 2004. Theoretical and methodology issues, in: Long, N. (Ed.) Development sociology - Actors perspective. Taylor & Francis e-library, New York, pp. 7-73.

Madrian, B., 2014. Applying Insights from Behavioral Economics to Policy Design. Annual Review of Economics, Annual Reviews, Annual Reviews, pp. 663-688.

Marshall, R.E., Farahbakhsh, K., 2013. Systems approaches to integrated solid waste management in developing countries. Waste management (New York, N.Y.) 33(4), 988–1003.

MNCR, 2017. Model for the Statute for Waste Pickers Cooperatives to adapt the Law.

Moriguchi, Y., Hashimoto, S., 2016. Material Flow Analysis and Waste Management. 247-262.

NBR, 2006. Recyclable plastic containers and packing, 13230.

Pedersen, O.G., Haan, M., 2006. The System of Environmental and Economic Accounts-2003 and the Economic Relevance of Physical Flow Accounting. Journal of Industrial Ecology 10(1-2), 19–42.

Petri, R., 2018. Increase of price for cellulose. https://www.dci.com.br/industria/preco-da-celulose-cresce-em-ritmo-mais-lento-e-pressiona-menos-o-papel-1.675493. (Accessed 30.07.2019.

Rateau, M., Tovar, L., 2019. Formalization of wastepickers in Bogota and Lima: Recognize, regulate, and then integrate? EchoGéo(47).

Rutkowski, J.E., 2008. Sustainability of solidary enterprise: an approach on production engineering. Federal University of Rio de Janeiro.

SAE, 2014. Defining the new socio-classes of Brazil.

SLU, 2014. Annual monitoring reports of entire waste management of Belo Horizonte 2014.

SLU, 2018. Annual Report of Municipal Solid Waste - 2001 to 2018.

Suárez-Eiroa, B., Fernández, E., Méndez-Martínez, G., Soto-Oñate, D., 2019. Operational principles of circular economy for sustainable development: Linking theory and practice. Journal of Cleaner Production 214, 952–961.

Tirado-Soto, M.M., Zamberlan, F.L., 2013. Networks of recyclable material waste-picker's cooperatives: an alternative for the solid waste management in the city of Rio de Janeiro. Waste management (New York, N.Y.) 33(4), 1004–1012.

UN-HABITAT, 2014. Solid waste management in the world's cities: Water and sanitation in the world's cities 2010. Routledge, London; New York.

Varella, C.V.S., 2011. Turn-out the garbage bin: possibilities and limits of recycling as an alternative for waste treatment, Belo Horizonte.

Velis, C., 2017. Waste pickers in Global South: Informal recycling sector in a circular economy era. Waste management & research : the journal of the International Solid Wastes and Public Cleansing Association, ISWA 35(4), 329–331.

Publication III

Implementing Mechanical Biological Treatment in an emerging waste management system predominated by waste pickers: A Brazilian case study

* This article is published in the International Journal Resource, Conservation and Recycling 2020; 162:105031. DOI: 10.1016/j.resconrec.2020.105031. Authors: Maryegli Fuss, Mónica Vergara-Araya, Raphael Tobias Vasconcelos Barros and Witold-Roger Poganietz

Abstract

Mechanical Biological Treatment (MBT) could be a decisive game-changer for the development of household solid waste management (e.g., reduce waste in landfills). However, in a nascent household waste management (HSWM) system, which is characterized by divergent interest groups ranging from the national government, municipalities, waste pickers and householders as providers of waste, implementing MBTs could create positive but also adverse impacts, in particular on waste pickers (WPs). Formal WPs are in cities, like Belo Horizonte (Brazil), a constituent part of the HSWM. This study builds strategies as a form of normative scenarios to assist decision-making processes to deal with WPs and implement MBTs systems. The present study includes material and energy flows, life cycle environmental impacts and social indicators characterized by the number of active WPs and capacity building. The results show that an integrated commitment of the local society can reduce landfilling by 70% and global warming emissions to a quarter. An emphasis on greenhouse gas emissions, like Belo Horizonte's promise for long-term attitude, brings a broad commitment to developing HSWM since a functioning system based on focused strategies will consequently reflect a positive action on climate. Waste pickers can fulfill the estimated vacancies at MBT plants and promote their active life or not according to the capacity building. MBT has substantial room to grow. Therefore, this growth will only happen with new thoughts on the adaptability of MBT systems focused on sufficiency to secure fair conditions for local livelihoods and targets with systemic implications.

Keywords: Belo Horizonte; life cycle assessment; material and energy flow; normative scenario analysis; policy orientation

1. Introduction

Mechanical biological plants (MBTs) create a series of wins for household solid waste management (HSWM) and change the treatment processes by reducing amongst others the environmental impacts of waste treatment (Beylot et al., 2015; Fei et al., 2018; Trulli et al., 2018). Before landfilling, applying MBT provides a decisive advantage of mass reduction and saving landfill space (Trulli et al., 2018). Additionally, MBT and biogas purification are effective for quick waste separation (Fei et al., 2018). Nonetheless, expanding MBTs is a challenge in the Global South, although household solid waste (HSW) is increasing significantly due to economic growth (Bank, 2019).

In emerging- economy countries, socio-integrated household solid waste management is essential (Conke, 2018; Fuss et al., 2018; Ma et al., 2017; Serrona et al., 2014; Sinthumule and Mkumbuzi, 2019; Yıldız-Geyhan et al., 2019). Waste pickers are part of the household solid waste management system and their integration and legalisation are critical in many Latin American countries (Alfaia et al., 2017; Campos, 2014; Fernández, 2010; Rateau and Tovar, 2019; Valenzuela-Levi, 2019; Villalba et al., 2020). Integrating and formalising the informal sector are co-procedures of the public participatory approach because the mismanagement of household solid waste is a source of income and employment for many people (Fuss et al., 2018; Serrona et al., 2014; Sinthumule and Mkumbuzi, 2019).

The need for policy attention through transboundary thinking has emerged (Kudo and Mino, 2020). The increase in a waste generation will certainly push decision-makers to adopt new technological paths; it will also decrease the chances of waste pickers obtaining monetary resources. In principle, MBTs require mostly the same type of recyclable waste (e.g., paper, plastics and metals) and provide the same services (source-separation manually and mechanically) as waste pickers. Thus, existing MBT pilot plans could fail because of missing public participation and targeted communication to integrate waste pickers. The diverse interest groups, ranging from the national government, municipalities, and waste pickers to private households as providers of waste, could adversely affect the implementation of MBTs in a nascent HSWM system particular, the waste pickers. However, this study concentrates on building strategies as a form of normative scenarios to assist decision-making processes to deal with waste pickers and implement MBTs systems. Detailed normative scenarios are extremely crucial to investigating the effectiveness of alternative pathways that contribute significantly to policy design and social development for emerging household solid waste management systems.

This study focuses on broad systemic analysis based on material and energy flows, life cycle environmental impacts and social indicators characterized by the number of active waste pickers and capacity building. Three normative scenarios are created, aiming an open mind to improve and promote proactive communication. Critical and reflective mindsets are built up based on the quantitative findings of a case study analysis. Strategic alternatives for waste technology routes are often only seen from an economic or environmental perspective (Goulart Coelho and Lange, 2018; Lino and Ismail, 2013; Medina Jimenez et al., 2017). Social impacts usually follow standard guidelines for the social life cycle assessment of products and this procedure indicates

a chance that critical social implications are being underestimated (Benoît and Mazijn, 2009; Gautam, 2011; Ibañez-Forés et al., 2020; Lu et al., 2017). Also, scholars commonly consider the sustainability assessment of waste treatment technologies according to multicriteria methods that are strongly dependent on the weighting criteria and judgments of decision-makers (Antonopoulos et al., 2014). Potential benefits and systemic effects need to be understood first because they are at risk of being hidden or minimized when compared to the environment, social-urban development with economic criteria. Economic criteria are frequently preferable for decision-makers and investors who often focus on cost-benefit and financial issues. Therefore, a system failure can potentially happen because of missing in obtaining a systemic view.

The structure of this study is as follows. The methodological approach, including the description of a case study, socio-technical scenarios for implementing MBTs plant, is described systematically. The subsequent section presents the modeling results and discusses the interrelated challenges and opportunities. Conclusions are summarized in the final section.

2. Case study description and methods

Scholars have repeatedly explained the need to understand specific aspects of waste pickers because of social movements that are trying to integrate them (Davis and Garb, 2015; Gall et al., 2020; Gutberlet et al., 2017; Ibáñez-Forés et al., 2018; Valenzuela-Levi, 2019; Villalba et al., 2020). These studies indicate how important it is to build up insight through a case study analysis of various countries in which waste pickers predominate. Therefore, those studies are limited to future orientation. This paper brings this novelty grounded on three methodological steps. Step 1 considers the basic process of knowing the case under investigation. Step 2 integrates the day-a-day activities into the scope of the study to create reliable normative scenarios. Step 3 captures the complementary data collection to supply the socio-technical analysis grounded on material flows, lifecycle assessment, and social indicators. The overall methodological objective is to contribute to a narrowed understanding of how to build socio-technical scenarios for a realistic and effective future orientation to implement mechanical biological treatment in countries with emerging economies.

2.1. Step 1: knowing the case of Belo Horizonte, Brazil

This study concentrates on the southeastern Brazilian city of Belo Horizonte. Belo Horizonte was the first city in the world that recognized waste pickers as part of the conventional household solid waste management system in 1993 (Campos, 2014). Belo Horizonte's political initiative opened opportunities in line with Eco 92 for social and governmental programs such as the Garbage and Citizenship and the National Forum on Garbage and Citizenship (Campos, 2014).

Belo Horizonte has a population of 2.5 million inhabitants (IBGE, 2018). The composition of household solid waste (HSW) is depicted in Figure 1, according to local annual monitoring reports (SLU, 2018). Waste peak production often occurs in Belo Horizonte due to tourism and large-scale national and international events. Over the years, the organic fraction does not dominate Belo Horizonte's waste composition anymore. It shows less than 50% of the total waste generated. Belo Horizonte assumed the waste composition characteristics of large industrialized cities (Bank, 2019). Moreover, figure 1 presents that a significant increase in recyclable waste and other waste (e.g., batteries, textiles, personal care products) is happening.

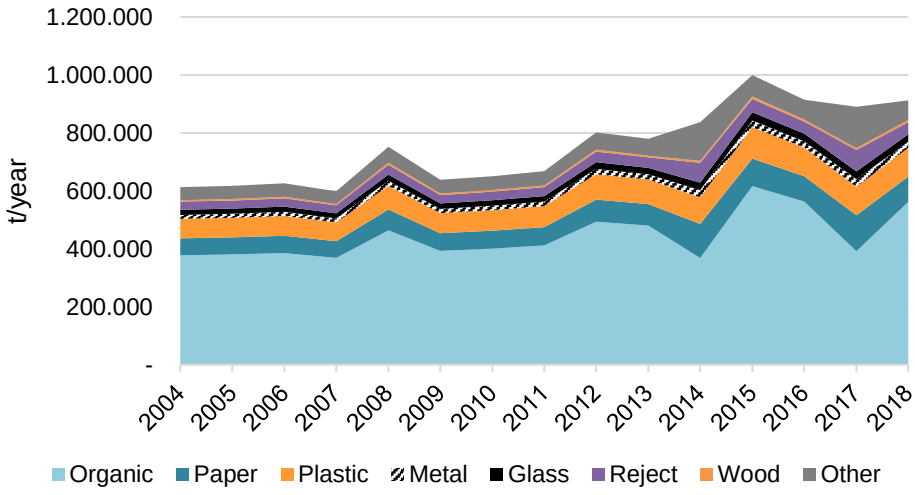

Figure 1. Gravimetric waste generation in Belo Horizonte

Source: Superintendence of Urban Cleaning (SLU, 2018)

A consultant company finalized the Belo Horizonte target plan in 2017 (HORIZONTE, 2017), after several public movements and manifestations. The document addresses the city's guidelines and strategies that were set through an aligned participatory platform with agents' representatives. They are individual groups that execute directly

or influence action in household solid waste management in Belo Horizonte. The integrated plan has a strong focus, so far, on social campaigns, environment education and technological development for the next 20 years. The reference data of Belo Horizonte's target plan is 2014 (HORIZONTE, 2017), the same assumption in the following steps of this study.

The joint-workforce of agents is a strong characteristic found in the city because they act on the management system with different views (Table 1). Such participatory approach became necessary for Belo Horizonte due to the local legislation (Horizonte, 1992, 2008), National Act (BRAZIL, 2010), and the Decree 5,940 (BRAZIL, 2006) that requires all Brazilian municipalities to include the destination of recyclables to waste picker cooperatives.

Table 1. Agents of Belo Horizonte's HSWM

Agents	Description
Superintendence of Urban Cleaning (SLU)	• Offers urban cleanning services with the commitment to build an environmental friendly city; • Conquer political credits between social media and population;
Subcontracting private companies	• Provide the collection system with the lowest cost; • Satisfy the collection needs of the society; • Provide the disposal facility (sanitary landfill) with the lowest cost;
Legalized waste pickers cooperatives	• Ensure the social inclusion of WP cooperatives in HSWM; • Provide the selective collection in exchange for basic operational costs (e.g., rent of sheds) • Commercialize sorted bales according to standards of recycling companies and industries to meet the needs of registered members;
Informal waste pickers	• Provide collection of recyclables in paralell to formal WP cooperatives;
Middlemen	• Intermediaries between (mostly) informal WPs and small to middle-size recycling industries for recyclable waste;
NGOs	• Provide technical and consulting conditions for social inclusion as the intermediate between industries, city hall, and WP cooperatives;
Funding organizations	• Provide funds and consulting for WPs cooperatives as private or governmental entities;
University	• Develop projects by providing technical support and assistance through campaigns for social inclusion;
Households (society)	• Generate household solid waste; • Impose or refuse to collaborate with the service conditions of the city hall.

Source: adapted by the authors from (Parreira, 2010, Varella, 2011)

The objective of each agent differs significantly, as recognized first by Varella (2011) and Parreira (2010). Eight legalised waste picker cooperatives, with about 312 registered members in total, are part of two union systems. An NGO and religious from Street Pastoral Care induce the first union system (CataUnidos), and the second one is self-organised by waste pickers (RedeSol). ASMARE has the largest number of members and formed CataUnidos together with other waste picker cooperatives from Belo Horizonte's metropolitan region. COOPERSOL concentrated a small

number of waste pickers and created RedeSol together with other cooperatives from Belo Horizonte. Both systems look for solidarity and a collectivism commitment to meet their socio-economic needs through sorting and commercializing recyclable solid waste as a group of waste picker cooperatives. Handcraft made with recyclables and bales of sorted beverage plastic bottles and cardboard are examples of outputs provided at formal waste picker cooperatives.

The socio-economic conditions of middlemen are better than formal waste pickers, and those make the procedure of dictating rules for informal waste pickers as a new business model (Varella, 2011). Informal waste pickers are unknown. Each person, who sort and commercialize waste with middlemen, can be an informal waste picker. Informal waste pickers usually have different ambitions than a cooperative system and prefer to be independent, unrecognizable, or ignored because of social disturbances (e.g., drugs and homelessness).

The Superintendence of Urban Cleaning (SLU) is the public entity responsible for the entire HSWM in Belo Horizonte. SLU is often looking for robust and cheap conditions. In 2014, SLU offered collection of recyclable waste in 36 of 417 neighborhoods and service 15% of the total population (HORIZONTE, 2017; SLU, 2014). As indicated in Table 2, around 9 kt of household waste were collected selectively in 2014 (SLU, 2014; SNIS, 2018). A subcontracting company and waste picker cooperatives, who go door-to-door disseminating best practices for sorting, performed the collection of recyclables, called locally as dry waste. All formal waste picker cooperatives are participating in the socio-integrated HSWM. Table 2 shows that 6.2 kt of dry waste (paper, plastic, glass, and metal) were destinated to waste picker cooperatives in 2014, while 2.8 kt of organic waste was composted (SNIS, 2018).

Table 2. Quantities of waste received by waste pickers' cooperatives in 2014

Waste Fraction	Cooperatives	Waste sorted in 2014 (t)
Recyclable waste	ASMARE	743
	Associrecicle	135
	COMARP I	502
	COMARP II	752
	Coopemar Oeste	1,396
	COOPERSOL	232
	COOPERSOL Leste	1,514
	COOPERSOLI	932
Organic waste	Composting center	2,786
TOTAL		**8,992**

Source: (SNIS, 2018)

In 2014, most of the collected household solid waste was compacted and reloaded in containers trucks to be transported to a private landfill located 36 km away from the transfer station in Sabará. About 98% of household solid waste that arrived at the

landfill in Sabara, coming from Belo Horizonte city, was mostly unsegregated and mixed with the biodegradable (organic) matter (SLU, 2014).

Belo Horizonte's 2035 target for sorting and recycling is 11% of the total household solid waste generated, representing 10% more than 2014 (HORIZONTE, 2017). The partnership between Belo Horizonte's city and waste cooperatives will stand based on the division of productivity and infrastructure conditions (Table 3) prescribed by the National Institute of Applied Economic Research to collaborate with the target for sorting and recycling (HORIZONTE, 2017; IPEA, 2017).

Table 3. Development pattern for waste picker cooperatives

	Description	Personal productivity of waste pickers (manual sorting)	Future perspective for cooperatives
Low	Small sheds received less than 300 t recyclable in 2014. None mechanical support. Sorting between 0.5 to 1.1 t/month	10 t /year	770 t/year
Middle	Few mechanical supports (e.g., belt) with less than 1,000 t/year received in 2014, but higher than 301 t/year. Sorting 1.1 to 1.8 t/ month	17.4 t/year	2,310 t/year
High	Large sheds received more than 1,001t recyclables in 2014. Large number of mechanical support (e.g., hydraulic press, and trommel). Sorting more than 1.8 t/month	21.6 t/ year	4,620 t/year

Source: (HORIZONTE, 2017; IPEA, 2017)

The conditions of waste picker cooperatives vary between low and middle sorting efficiency in Belo Horizonte since 2014. The conditions of waste picker cooperatives are not harmonized and the monthly personal productivity of waste pickers ranges from 0.5 t to 2 t waste sorted (Belo Horizonte, 2017, da Silva, 2018). The discrepancy reflects the daily performance of each waste picker cooperatives. COOPERSOL, for example, adopts the share of income according to weight sorted per month. Such a procedure creates the motivation to achieve the merit of who sorted the highest amount of waste per month. Best cases already reached 12 t in a month. ASMARE adopts the equitable share of income instead of promoting individual economic development.

While Belo Horizonte has a 2035 objective for selective collection and the promise to reduce greenhouse gas emissions, the integrated plan lacks clarity on the

identification of technology treatment to reduce the amount of waste taken to landfill sites.

2.2 Step 2: Participant observation to define normative scenarios

Two different purposes are presumed to shape the set of scenarios. In the first part, two normative scenarios seek the desired outcome of achieving the targets of Belo Horizonte's plan. The third scenario focuses on a wide-range purpose according to intuitive logic for implementing the MBTs plant. Critical attributes included in the first two scenarios are particular outputs of the participant observation method that were achieved through semi-structured interviews, observation of the HSWM system and analysis of Belo Horizonte's plan (Kawulich, 2005). Fieldwork was done in 2014, and since then, day-a-day routine activities process have been under-observation. The interviewed agents belonged to the environmental and engineering department as well as the public health and sanitation department of the administration of the municipality of Belo Horizonte, private recycling companies, community-based organisations, and leaders and members of waste pickers cooperatives, NGOs and funding agencies. Descriptions and opinions of 34 agents contributed to the participant observation process in Belo Horizonte. Figure 2 shows significant aspects identified in the participant observation that were considered in scenario construction and analysis.

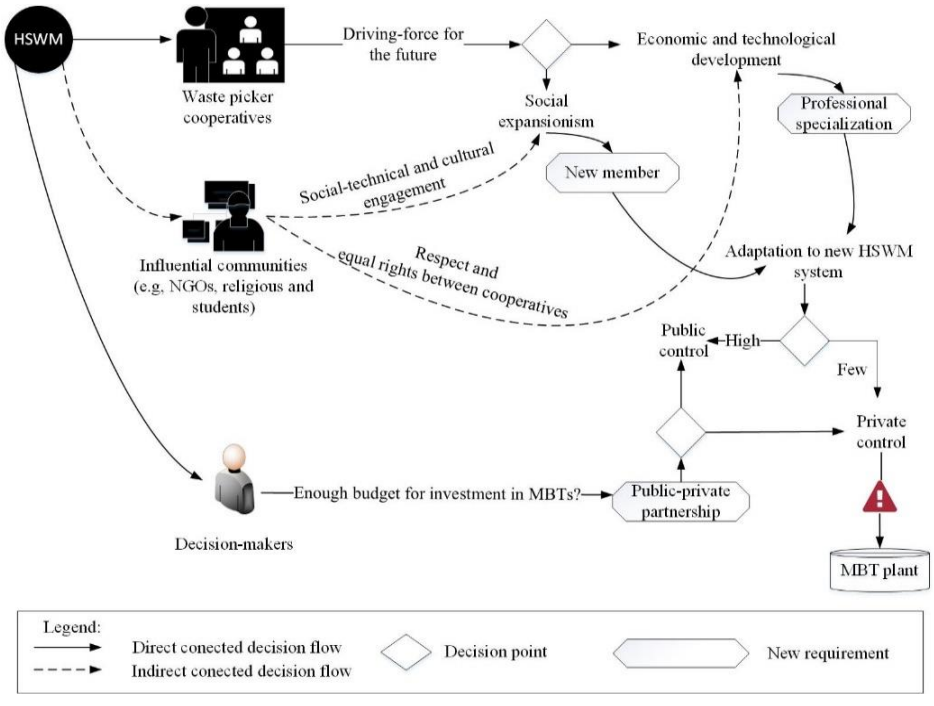

Figure 2. An overview of concluding remarks of participant observation critical for narrative scenarios

The two waste picker union systems have different purposes and reflect on the pathway they will use to conduct their working system in the future. The purpose of socio-expansionism seeks to rescue new members from poverty by strengthening their religion and giving them a life perspective better than their previous living conditions. The economic development purpose looks for the professional specialization of waste pickers in waste sorting. Indirectly, influential communities (NGOs, Street Pastoral Care, and university students) play a role in keeping both union systems running smoothly due to the commitment to waste pickers started in the 1990s. Influential communities assist in holding respect and equal rights, despite the fact that the two union systems have different purposes. The first scenario (S1) includes all those characteristics and makes it comparable to business-as-usual.
Waste picker cooperatives continue to be the single agents moving straightforward actions to reach new development procedures to show decision-makers their abilities in the HSWM. They seek to achieve development patterns (see Table 3). Waste picker cooperatives continue to collect dry waste or receive the material through the subcontracting company. Additionally, this scenario considers the results of massive communication campaigns over the predicted waste generation (represented by 10% rate reduction) and functional efficiency of selective collection of 90% through 2035, representing 30% more than 2014.

The second and third scenarios represent a situation in which the MBT plant is introduced as a treatment for the HSWM in Belo Horizonte. The second scenario (S2) represents the social obstacles when a new system is introduced. It describes a few acceptances and possible rejection of waste picker cooperatives, the warning symbol is shown in Figure 2. This scenario represents a political breakdown within the regime for a socio-integrated HSWM system as it is considering a public-private partnership (PPP). This scenario explores the hypothesis identified that the public authority could not bear the investment costs. Since then, the PPP creates a long-term administrative concession for hiring services. That means the MBT infrastructure's capital investment is from the private sector, without government financial compensation, and the reward (revenue) is obtained through the use of the public service and controlled by an on-balance sheet (Rossa, 2011). The S2 explores similar approaches aimed at other Brazilian cities (MNCR, 2019). Such political action creates a massive rejection of waste picker cooperatives to accept the changes and also to be integrated into the new system. Since the National Policy on Solid Waste (NPSW) and local legislation (Horizonte, 2008) prioritise the integration of waste cooperatives (BRAZIL, 2006,

2010), both systems operate in isolation. The MBT plant operates at a small scale to achieve the existing selective collection treatment target, and waste picker cooperatives meet the same conditions described in S1 to provide an extra recycling rate.

The core focus of MBT plants is to promote individual waste sorting for efficient and safe recycling as well as environment-friendly disposal (UBA, 2015). According to the statement, the third scenario (S3) stands on the hypothesis that no recyclable or organic waste shall be landfilled without pre-treatment as a compromise of public authorities with HSWM. This scenario considers the largest acceptance of the MBT plant between waste picker cooperatives due to a public administration (Figure 2). Advanced waste picker cooperatives become self-sustained while low and middle technology waste cooperatives priotise to adapt their professional conditions to the MBT plant. For local agents, the collaboration of the entire society to reduce (10%) and pre-sort waste into dry and wet categories is primordial and it is taken as an assumption to be analysed.

2.3: Step 3: Data collection for socio-technical analysis and life cycle assessment

The socio-technical analysis of the three pre-defined scenarios is formulated in adequated worksheets in Excel. Local reports elaborated by city authorities and waste picker cooperatives are used for developing the technical HSWM balance sheet. Belo Horizonte's waste composition indexes remain the same as the base year 2014. Population and waste generation follow the forecast increase of 0.6% (IBGE, 2018) and 2.2% since 2001 (SLU, 2018), respectively. Figure 3 depicts the overall framework for the data collection of this study, where foreground and background systems are adopted from Clift et al., (2000).

The foreground system shows the main waste management activities comparable to the base year 2014 (Scenario S1) and with the implementation of the MBT plant (Scenario S2 and S3). The difference between S2 and S3 follows the narratives described in section 2.2. The process and products (material or energy) are affected directly by the decisions based on the study. Fuel, energy, chemical and water are primary resources input for the transport and treatment processes. Data for each primary resources were estimated from local scientific research (e.g., the fuel consumption of garbage trucks (Xavier, 2010)), national emission characterizations (MMA, 2011) and complimentary company reports (e.g., synthetic polymers for

dewatering process (Hurst, 2013). After the treatment processes, materials and electricity are returned to the background system to enter new processes (e.g., recycling and grid connection) that are not included in this study. Also, emissions return to the environment. A detailed parameter description is available in the Supplementary material.

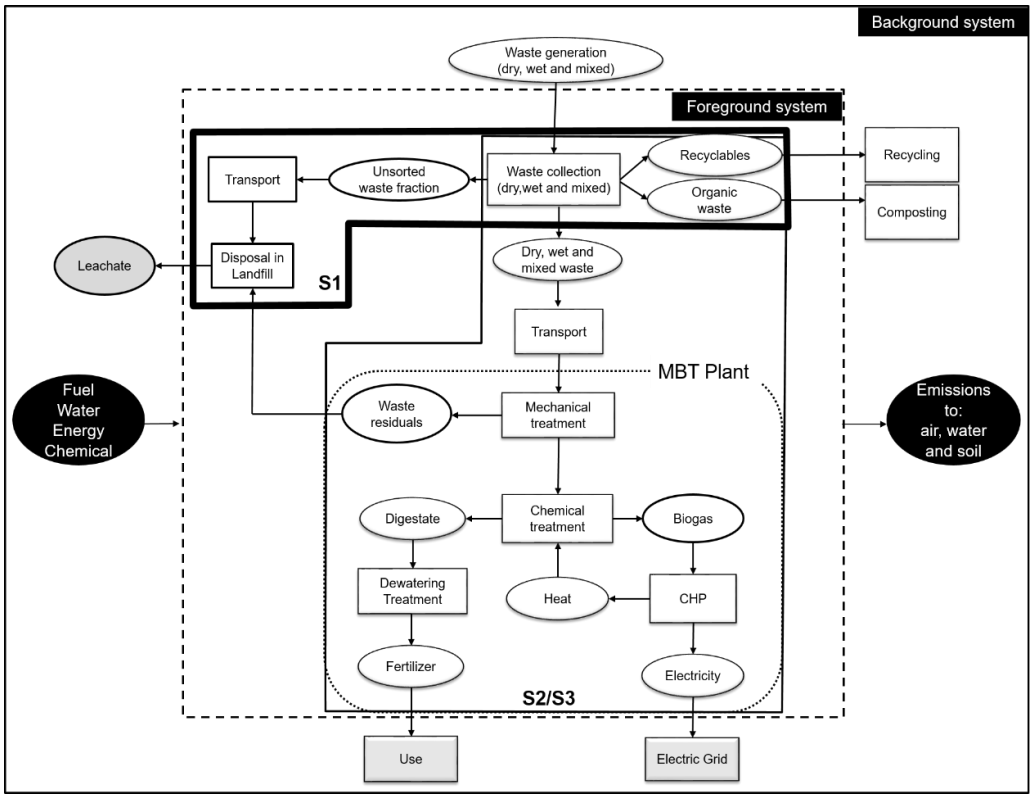

Figure 3. Overall scheme of Belo Horizonte waste management system, showing the materials and energy (oval) and processes (square) of each socio-technical scenarios

The selection of social indicators is a complex issue. Legalisation is fundamental for a society predominated by waste pickrs because it decreases the informal sector. Two criteria were taken into consideration: the number of vacancies and capacity building. A defined number of vacancies and capacity building are two indicators created to bring transparency to the real situation for socio-integrated HSWM (Gutberlet, 2015, 2018). S1 considers the development patterns of waste picker cooperatives exclusively (see Table 3). Table 4 describes three input values to estimate the number of vacancies for S2 and S3, in which the creation of vacancies at MBT plants is combined with capacity building. It should be observed that waste pickers can fulfil the estimated vacancies and promote their active life or not according to the scenarios' narratives.

Table 4. *Parameters for capacity building and creation of vacancies at MBTs plant*

Capacity building	Description	Vacancies	Parameter sorted waste	Reference
Low	The personal productivity for manual and mechanical sorting is comparable to the expertise of waste pickers at advanced waste picker cooperatives found in Brazil.	1	0.09 $t_{dw}.day^{-1}$	(IPEA, 2017)
Middle	Belo Horizonte's Plan considers the manual and mechanical treatment in Sao Bernardo do Campo an example for an integrated system.	1	6 $t_{dw}.day^{-1}$	(HORIZONTE, 2017)
High	Sunset Park Materials Recovery Facility located in New York is an example of socio-integrated approach for local engineers because of high sophisticated mechanical sorting system.	85	1000 t_{dw}/day^{1}	(SIMS, 2018)

Table 4 discloses three different workforce structures to discuss the future pattern. The first two parameters are secondary data that describe the average productivity efficiency per waste picker through a manual sorting system comparable to advanced waste picker cooperatives or a semi-automated sorting system in Brazil. The third parameter stands on a highly-sophisticated material recovery facility. The Sunset Park Facility is responsible for the treatment of 1,000 t of dry waste daily and supports the local community by offering 85 permanent jobs (SIMS, 2018).

It should be observed that the number of vacancies can differ from the number of jobs created. The system in waste picker cooperatives differs from that in an economic society in Brazil. These cooperatives are undertaken as part of a solidarity economy and are exempted from some obligatory national taxes until they reach their objectives (CATAFORTE, 2015). The total number of vacancies considers a group with subsequent working roles that are compatible with waste picker cooperatives and MBT plants, such as managers (or legal representatives of WP cooperatives),

administrative staff, supervisory board, executive marketing committee for recyclables, collectors and assistants.

The capacity building follows the logic that the skill level is indirectly associated with manual labour demanded in the sorting process. A subsequent analysis of secondary data based on policies for HSWM and socio-economic statistics (e.g., age and educational skilsols) supports the quantitative outputs to establish a reliable discussion on the real conditions found for waste pickers, the political institutions and urban system in Belo Horizonte.

A technical description of the MBT is fundamental for the life cycle assessment (LCA). The MBT plant was projected according to existing plants and companies reports and followed the conditions of HSWM and climate of Belo Horizonte (Baere, 2012; Deublein and Steinhauser, 2008; Vafabmiljo, 2015). The plant considers manual and mechanical processes with the trommel screen and milling by removing large and heavy disturbing materials and homogenizing to the standard size to less than 40 mm respectively (Nithikul et al., 2011; Visvanathan, 2010). The physic-chemical and biological treatment processes consist of hydrolysis, anaerobic digestion, and dewatering. The technical description of the digester follows the Dranco technology system (Baere, 2012; Visvanathan, 2010), which has, among other advantages, the high rate of input flow suitable for the case of Belo Horizonte. These data are inputs for the life cycle inventory and are complemented by the Ecoinvent database with manual data adjustment at the Software “openLCA” (GreenDelta, 2018). Life cycle impact assessment follows the midpoint impact categories of the method ReCiPe (RECIPE, 2016). All midpoint impact categories are normalized to identify the most relevant impacts that are directly associated with the foreground system of Belo Horizonte HSWM. Results related to the background system of Belo Horizonte HSWM do not apply to this study because they are interconnected to primary resources (Figure 3). The functional unit of 1 ton of generated household solid waste drives the results of the environmental impact assessment.

3. Results and discussion

The technical results are based on the material and energy flow analysis for each normative scenario. Table 5 describes the most important input and output flows.

Table 5. *Technical characterization of each defined scenario based on material and energy flow analysis*

General information					
	Unit	**2014**		**2035**	
Population[1]	hab.	2,491,109		2,801,326	
HSW waste generation (input)[2]					
Organic fraction	t/yr	368,535		432,251	
Recyclable fraction[3]	t/yr	259,650		304,540	
Others	t/yr	175,892		206,302	
Non-collected waste[4]	t/yr	33,503		39,295	
Total waste generation	**t/yr**	**837,580**		**982,388**	
Avoided waste generation[5]	**t/yr**	**-**		**109,154**	
Additional input					
		2014	**S1**	**S2**	**S3**
Fuel (transport)	$toil_{eq}$/yr	1,812	2,743	2,630	1,972
Net electricity (MBT plant)	MWh/yr	-	-	12,797	23,462
Net heat (MBT plant)	GJ/yr	-	-	28,193	247,450
Acrylonitrile polymer	t/yr	-	-	52.5	358
Products (output)					
		2014	**S1**	**S2**	**S3**
Composting (composting center)	t urea/yr	8.1	9.7	-	-
Manual sorting (cooperatives)	t/yr	3,529	18,018	18,018	9.1
Manual sorting (MBT plant)	t/yr	-	-	30,149	197,248
Metal scrap (magnet separation)	t/yr	-	-	1,081	7,368
Fertilizer (MBT plant)	t urea/yr	-	-	91.3	622.3
Electricity (CHP)	MWh/yr	-	-	6,305	42,990
Refuse (output)					
		2014	**S1**	**S2**	**S3**
Reject at cooperatives (selective collection)	t/yr	3,338	2,002	2,002	924
Reject (composting)	t/yr	328	394	-	-
Reject (manual sorting)	t/yr			3,350	21,916
Reject (trommel)	t/yr	-	-	10,569	26,303
Waste landfilled	t/yr	828,158	959,083	854,305	245,597
Leachate (landfill)[6]	m^3/yr	90,894	106,615	92,722	26,652
Wastewater (MBT plant)	m^3/yr	-	-	27,156	185,092

[1] Forecast with an annual increase of 0.6%, since 2001 (IBGE, 2018).
[2] Forecast with an annual increase of 2.2% since 2001 (SLU,2014).
[3] Paper, plastic, glass and metal
[4] Collection rate of 96% (SLU, 2018).
[5] Results of awareness campaigns for waste prevention.
[6] Considering local precipitation (1,602.6 mm/year) and (4 months) rainy periods (IBGE,2018).
[7] Estimation of members in cooperatives according to local records and interview.
[8] Before slash: estimation of members at cooperatives. After slash: estimation of job opportunites at the MBT system.

The estimation results for 2035 reveal that waste generation grows significantly and the total amount of waste landfilled remains high at 961,479 t (S1) and 870,224 t (S2), even with the commitment to promote awareness campaigns for waste prevention.

The recycling rate (recyclables destined to waste picker cooperatives and biodegradable waste for the composting center divided by the total household solid waste generated) increases by 2.2% in S1, compared with the rate of 1.7% in 2014. The targeted approach focused on selective collection in S2 redoubles the recycling rate by 5.5%. Therefore, a target focused exclusively on selective collection does not guarantee an efficient functionality of the MBT plant from a mass and energy perspective. The MBT plant is not self-sufficient energetically, i.e., the production of the electricity is not enough to keep the plant running, and 53% of the demanded power is an external input from the national grid (Table 5). The advantage of the MBT plant in S2 would be restricted to bio-fertilizer production, compared with the production of composting in S1. The bio-fertilizer produced can replace chemical fertilizer for 168 ha/year, considering an average amount of 0.4% w/v of Nitrogen (N) and an inorganic N-fertilizer use of 250 kg N per hectare (Pastorelli et al., 2013).

The third scenario (S3) has the potential to reduce waste landfilled by 70%. The remaining fraction corresponds to the disposal of rejects from advanced waste cooperatives, the MBT plant and other collected waste (e.g., textile, ceramic and health care). The results of the S3 create opportunities to have a treatment plant self-sustained energetically and a hub of electricity production from HSW. The amount of electricity generated through the MBT plant could supply extra 5,946 households, counting the annual forecast consumption of 2,292 kWh/household in Belo Horizonte (Scari, 2011). The produced bio-fertilizer would replace 1,145 ha/yr fertilized area at the same conditions taken for S2. An especially notable increase is the amount of wastewater that resulted from exhaust steam and centrifuge (Table 5). On a national scale, state facilities are responsible for the leachate treatment produced in landfill sites, according to Brazilian legislation 430/2011 (CONAMA, 2011). The same procedures could be assumed for the MBT plant. It should be considered that a problem could be shifted to another sanitation system since local functioning facilities treat 76% of household wastewater in Belo Horizonte nowadays (Oliveira et al., 2019).

The implementation of mechanical biological treatment can enhance social development compared to the situation in 2014. Table 6 shows the results according to the number of vacancies.

Evidently, many more legalised waste pickers are necessary to fulfill the increasing demand for sorting dry waste and to reach the development patterns for middle and high levels of cooperatives in S1 and S2. Both union systems, aiming towards popular

expansionism and technological development, face a challenge moving forward. They need to acquire new members (a constraint for the technically orientated union system) and raise the motivation and abilities to improve their cooperatives from low to middle level (a constraint for popular expansionism) and from the middle to high level (a constraint for both unions).

Table 6. *Social development for each socio-technical scenario of Belo Horizonte's HSWM*

Scenarios	Waste picker cooperatives[1]			MBT plant[2]		
	Low	Middle	High	Low	Middle	High
2014	177	135	-	-	-	-
S1	154	531	427	-	-	-
S2	154	531	427	4,613	70	35
S3	-	-	427	21,810	328	167

[1] Waste pickers cooperatives are defined in low, middle and high sorting efficiency (see Table 3).

[2] MBT plants follows the capacity building (see Table 4)

The operation of an MBT plant with the productivity efficiency of an advanced waste picker cooperative demands more than a hundred times the vacancies than of a high-mechanised system in S2 and S3. A high-mechanised system does not yet exist in Brazil. The implementation of such a system challenges Belo Horizonte to invest in capacity building. The middle capacity building, based on a Brazilian experience, shows the weakness of the existing system because it requires almost double the number of vacancies to fulfill the same amount of sorted waste daily. S3 would require almost the same number of waste pickers that are active since 2014 but under the condition of middle capacity building.

3.1 Impacts on the environment

The results of the environmental assessment represent the total impacts of the base year and each scenario. They encompass implications from the household solid waste collection (transportation), MBT operations (electricity generation and bio-fertilizer production) in addition to the landfill disposal. Five impact categories caught the most attention because they are related to the foreground of the overall scheme for Belo Horizonte HSWM (Figure 3). Table 7 shows the five impact categories that are sound of interest for Belo Horizonte's local decision-makers. Belo Horizonte HSWM integrated plan (HORIZONTE, 2017) and Climate Sectoral Inventory plan (FEAM, 2018b) have the objective focused on the minimization of local contribution to greenhouse gas emissions. Additionally, Belo Horizonte is considered one of the

"tree-lined capital's state of Brazil (IBGE, 2018). Anthropogenic HSW activities should not cause damage to terrestrial species either to marine life. Table 7 shows the results for each scenario.

Table 7. Environmental impacts of Belo Horizonte transformation paths

	Unit	2014	S1	S2	S3
Global warming power	tCO_{2eq}	242,095.6	284,588.5	247,745.6	79,735.1
Photochemical oxidant formation	tNMVOC	1.021,85	1.199,79	1.026,26	204,55
Marine ecotoxicity	$t1\text{-}4\text{-}DB_{eq}$	10,46	12,26	10,76	4,03
Marine eutrophication	$t\ N_{eq}$	21,31	24,99	20,83	0,62
Terrestrial acidification	tSO_{2eq}	72,72	86,50	116,24	301,66

Considering global warming power (GWP) and photochemical oxidant formation, the deployment of the MBT plant as the major HSW treatment (S3) ensues environmental benefits. The main contributor to those two environmental impacts in the base year as well as in S1 and S2 is almost entirely associated with landfill gas emissions. This study assumed that Belo Horizonte has the responsibility of the emission where 100% of the landfill gas is emitted to the atmosphere as it happens in Sabará. It should be noted that the environmental impacts of the landfill processes are often neglected in discussion with decision-makers because it is outside of the territorial jurisdiction of Belo Horizonte.

Three sources of GWP emissions mainly contribute to the designed MBT plant in S3: the biogas storage and combustion (31% of the impact), anaerobic digestion (associated with leakages 11%) and the remaining HSW fraction disposed of in the landfill (43% of the impact). Beyond the emissions associated with landfill gas emissions, the decrease of photochemical oxidant formation in S3 is related to saving transportation to landfill in Sabará as collection and transport contribute to almost 5% to this impact in S1 and S2. The emissions linked to HSW transportation are associated mainly with nitrogen oxide (NOx) presented in the Brazilian diesel. The emission factor assumed is relatively high at 3.99 g/km (FEAM, 2018a) in contrast to the European level of 0.17 g/km (VDA, 2019). Both environmental impacts categories represent the aiming towards policies focused on HSWM treatment. The same changes happened with impacts associated with damage to aquatic life. Marine ecotoxicity and marine eutrophication reduced their impact due to the avoidance of leachate infiltration that may happen in landfill sites.

The environmental balance is still a challenge forward where the deployment of the MBT plant increased the terrestrial acidification in S3. Biogas storage and combustion

for electricity generation in the CHP system contribute to over 85% of the impact. The emissions of ammonia and NOx during the combustion are the main contributors to terrestrial acidification.

The largest contribution to almost all other environmental categories of the ReCiPe method is the background system (Figure 3). They are not sound of interest for further discussion because it depends on the development of the energy sector and the chemical sector. An example is a particulate matter and metal depletion. Although Brazil has one of the world's cleanest electricity grid, the need for electricity increases three times the impact on particulate matter and ten times by metal depletion. A further investigation of Brazillian electricity is required. All the results of the LCA analysis are available in the Supplementary material.

In response to Belo Horizonte's 2035 integrated plan, the results presented the material, energy, socio-technical characterization with the environmental impacts of the potential scenarios by integrating the designed MBT plant. Since the scope is highly dependent on the HSWM system (including HSW composition) and institutional factors of Belo Horizonte, it may not be meaningful to compare the results with other cities and countries. The exception lies in the environmental assessment linked to the MBT plant, which can be compared with those reported by Beylot et al. (2015). Beylot et al. (2015) focused solely on the environmental performance of 57 French plants in operation, who identified the drawbacks of the technology itself due to the non-abatement of ammonia and NOx emitted from biogas combustion that directly influenced the terrestrial acidification impact. Accordingly, Beylot et al. (2015) recommended that engineers and project developers should focus on filter systems to reduce non-intended pollutants. Otherwise, acidification results provide a warning to identify prevention methods if the city follows the target focused on tree-lined capitals.

3.2 Interrelated challenges

Household solid waste management is not an isolated system. It belongs to multi-scalar modernized mixtures in a different political and material context (Guibrunet et al., 2017). This interconnection creates several challenges for implementing MBT systems at various levels. These challenges generate additional dilemmas for Belo Horizonte that are discussed below.

3.2.1 National policy vs. the involvement of planners

The National Policy on Solid Waste (BRAZIL, 2010b) does not lay down any clear restrictions or targets, thus allowing Belo Horizonte's decision-makers to overlook HSWM and avoid making comprehensive plans. As shown in this study, the target of the Belo Horizonte's integrated plan is not ambitious enough to make dramatic changes (the results associated with S1 and S2). There is no monitoring or commitment to enforcement at either a national or a state level that could push Belo Horizonte to improve the plan. The situation is further aggravated because the Belo Horizonte superintendent (who is responsible for HSWM) has been constantly being replaced, which results in changes to previous decisions and shifts in the focus of procedures and infrastructures, all of which discourage office (i.e., environmental) managers from improving the situation. Although the participatory approach exists (Belo Horizonte, 2017), it is not uncommon to find that procedures to improve Belo Horizonte's HSWM have failed because they are implemented without the prior involvement of or consultation with stakeholders (e.g., representative of neighborhoods and formal WP cooperatives).

Compared to disposal activities in landfill that are suitable for all type of waste and least demanding of management at the city level, MBT systems need policy instruments to reinforce the application of waste hierarchy presented in the NPSW (BRAZIL, 2010b), compliance adjustment agreement (BRAZIL, 1990) and technology guidelines. An emphasis on greenhouse gas emissions, like Belo Horizonte's promise for long-term attitude, brings a broad commitment to developing HSWM since a functioning system based on focused strategies will consequently reflect a positive action on climate suggested by the results for S3.

Currently, regulations are designed aiming the energy recovery from landfill site since many Brazilian facilities (which include the Belo Horizonte's landfill closed in 2009) obtain credit benefits from Clean Development Mechanism projects (CME, 2019). At the same time, such regulation reinforces complacency impeding other paths for HSWM. They may help reduce the opposition of energy providers to adapt the electricity produced in the grid system. The use of bio-fertilizer (as the second valuable product from the MBT) also needs to be regulated. End-users do not trust on the quality of biofertilizers and give preference for chemicals. This barrier is currently faced by the local composting center that uses the product produced only in the parks and public areas of Belo Horizonte (BELO Horizonte, 2017). The common

priority is to bring awareness through policies and further strategies (e.g., green label and bonus for bio-fertilizer usage), instead of looking for “end-of-pipe” technologies that form a single part of an environmentally sound solution (e.g., GWP).

Although this study does not consider investment costs, it should be noted that many manufacturers of MBT plants require additional charges due to patent rights (e.g., Dranco technology), which necessitate even more commitment, engagement, and knowledge of local planners when decisions for such a technological path are made. This study does not ignore the possibility of failure patterns since the engagement of decision-makers is low; the interests are diffused and accommodated to each political mandate. A straight-forward compromise for HSWM is necessary and the situation calls, particularly, the application of the compliance adjustment agreement (BRAZIL, 1990). Such local regulation brings the evolvement of sanctions by creating a compromise of the entire city in establishing effective solutions harshly to minimize the adverse effects of HSWM on the environment. Because the results presented for S2 reveals how well-accepted international technology could be inefficient if policy and focused-targets are not taken into account.

3.2.2 Culture aspects vs. political and market pressure

The deployment of a MBT plant brings socio-economic, cultural, and political challenges forward. The number of vacancies estimated in S2 and S3 demonstrates a positive socio-economic and political impact, but a complex problem is launched. In the scope of S2 and S3, MBT plant could provide opportunities for the working class, who are struggling with the turbulent unemployment rates that have been varying between 5.7% and 19.3% in the last ten years in Belo Horizonte (IBGE, 2018). Nonetheless, the educational structure of Belo Horizonte’s population is improving significantly (net rates for children aged 6 to 14 years is 97.6% (IBGE, 2018)), and this has the potential to be a threat of the workforce absence since household solid waste sorting, for example, could be seen as a low-paying job.

The results of S3 bring to the forefront the debate that efficient management should accompany self-sufficient household solid waste treatment or be within citizens’ means in securing livelihoods.

Efficient management would require strong PPP to minimize public resource management by investing in capacity building (e.g., job-training and learning centers) and very sophisticated processes to overcome the potential threat of workforce

absence while creating an attractive and profitable household solid waste business in Belo Horizonte. The constraints of profit-oriented businesses of S3 are related to the timeframe that each person (who is acting as a waste picker) needs to adapt to the conventional employment and market position without losing the know-how engagement of the cooperative system. For example, the social expansionism of the largest waste picker cooperative of Belo Horizonte described rotational functions (instead of a fixed working division) and the shared interest to define a fair income among members. Hence, the transitional period and withdrawal of waste pickers are the risks of rendering unfeasible investment on the integration commitment and instigating subsequent social obstacles. Formal waste picker cooperatives currently reached a specific number (between 20 and 100 members). Some cooperatives reported their income is higher than the minimum salary (Costa, 2019) with the additional coverage of social insurance expenses (e.g., 2.3% of the income covers the social pension security system (INSS, 2017).

Belo Horizonte is part of an emerging economic system that has faced rapid economic growth (the fourth highest in Brazil) and reflected a decrease in the poverty rate from 10.6% (in 2000) to 3.8% (in 2010) distinguished in the last statistics (BRASIL, 2015). Although the share seems low, if the rate is not decreasing further, about one hundred thousand citizens could still live in such conditions in 2035. In the Brazilian capitalism system, economic privation is a driver to join forces of citizens creating meaningful social and collaborative actions (Singer, 2002, 2011). Thereby, solidarity, empathy, reciprocity, and strong religious belief are common characteristics found between formal waste picker cooperatives in Belo Horizonte.

The number of vacancies could be reached in S3 at a low level of capacity b following the conditions of waste pickers at the cooperative system. However, it would depend on how PPP would invest in social capital (Adler and Kwon, 2002), bringing an eagerness to work for grouping poor people in cooperatives. Other Brazilian cities try to invest in social capital by creating a market relation, in which the sorting service is exchanged by payments for environmental services, as part of a process to improve the transition from informality to the formality of WPs (Conke, 2018). These cities act as managers that set new rules, such as registration of workers, safety procedures, disposal of toxic waste and paying taxes (Conke, 2018). The initiatives are rational and appealing. Consequently, the business case and the win-win perspective expose formal waste picker cooperatives in a comparative portfolio of subcontracting companies that provide services; despite that fact, stick to the idea of cooperativism.

Intermediate waste picker cooperatives have opportunities to achieve advanced statuses because they have already received prior financial (subsidy) support. However, a challenge confronts less developed waste picker cooperatives because they face the risk of being considered inappropriate (e.g., small sheds and lack of machinery) and can be excluded from the system because there is no more subsidiary liability. Waste picker cooperatives have been organizing themselves into unions in Belo Horizonte and metropolitan regions since 2014, to overcome their fragmentation, and thus to risk to become negligible in economic and political respect. According to Fuss et al. (2019) legalised waste picker cooperatives still provide their services in a system that lacks a market mechanism for recyclables and a legislation that impedes secondary materials' entrance into the production system. That means, any attempts to commercialize for waste services requires capacity building and government intervention in that respect. All these issues impose additional barriers and decrease the hope that waste picker cooperatives will grow and achieve self-sufficiency, with the risk they return to the informality or stay in these conflicting condition.

A market relation based on the exchange of services rather than money would recognize the significant benefits that a socio-integrated HSWM would create during this transition time in Belo Horizonte. The public-private partnership could offer capacity building, fixing prices for a market of recyclables (to avoid middlemen and illegal market), and coordinating application processes for technological (e.g., the transformation of sheds into MBT stations) and administrative assistance of WP cooperatives. On the other hand, WP cooperatives could offer sorting and recycling services with an addition of a market for hand-crafted products. Granting that a barrier of implicit discrimination exists in WP cooperatives (Fuss et al., 2019), the participatory approach, which includes the intervention of NGOs and church communities, would continue to facilitating the psychosocial recovery of citizens that also act on waste picking (e.g., alcoholic and ex-drug addicts) by establishing teamwork interactions between them as a core priority for sorting waste. At the same time, it creates new opportunities for the formality of waste pickers and obstacles for the informal market. The involvement of decision-makers is primary to a systemic understanding of local conditions in Belo Horizonte. Moreover, within the scope of a participatory approach, a development agreement (Schwartz, 2000) would additionally bring the core approach of the regulations for socio-integrated HSWM in exchange for public benefits, in which the main conditions between the supply and demand of such services are settled.

5. Conclusion

MBT systems help in mitigating measures to solve primary problems of HSWM (e.g., odor and inadequate accumulation). MBT systems have so far developed following intrinsically intertwined political efforts and requirements on waste handling (e.g., ban on disposal of untreated waste in Germany and Europe (AbfAblV, 2001; Commission, 2003), reconstruction measures in Italy and the standardization of treatment plants in Austria (Nelles et al., 2012). According to this study, implementing an MBT plant leads prima facie to better techno-efficient treatment while reducing the environmental burden due to a large amount of biodegradable waste in Belo Horizonte. Still, it could also lead to an implosion of the current system and contribute to more poor people on the streets of Belo Horizonte by 2035, characterized by socio-cultural dependence on the recyclable waste that presented a historical increase (Section 2.1).

Belo Horizonte had the first political initiative to recognize waste pickers part of conventional HSWM. The legislation did not bring considerable advantages after almost thirty years. HSWM is stagnated while a few numbers of people are bending over backward to become crucial mediators for a system change. New ideas are presented to balance the efficiency and sufficiency of implementing an MBT system and to secure fair conditions for local livelihoods in Belo Horizonte. For example, the application of the compliance adjustment agreement and a market relation based on the exchange of services rather than for money. Those ideas are recommendable to other cities in emerging economy countries. The overall challenge is to improve mutual understanding across the outcomes of material and energy flows, impacts, consequences, governance and risks of implementing MBT systems in an active society predominated by waste picking. The discussion is appropriate in specific political consideration because, in many contexts, the advantages of such technology have been seen from an ideological message taken from other cities and countries. There is a human value behind the functionality of HSWM to pursue a process of empowerment and compromise with a process of social and technical transformation (van Zeeland, 2013). It is now crucial to find a balance between economic soundness, environmental efficiency and social aspirations (monetary and emotional wealth), considering the frame, the society is acting in such cities.

References

AbfAblV, 2001. Ordinance on the environmentally compatible storage of waste from human settlements of 2001, 305 ed.

Adler, P.S., Kwon, S.-W., 2002. Social Capital: Prospects for a New Concept. Academy of Management Review 27(1), 17–40.

Alfaia, R.G.d.S.M., Costa, A.M., Campos, J.C., 2017. Municipal solid waste in Brazil: A review. Waste management & research : the journal of the International Solid Wastes and Public Cleansing Association, ISWA 35(12), 1195–1209.

Antonopoulos, A., Perkoulidis, G., Logothetis, D., Karkanias, C., 2014. Ranking municipal solid waste treatment alternatives considering sustainability criteria using the analytical hierarchical process tool. Resources, Conservation and Recycling 86, 149-159.

Baere, L., 2012. The Dranco technology: a unique digestion technology for solid waste. https://www.ows.be/household_waste/dranco/. (Accessed 28.08.2019.

Bank, W., 2019. What a waste 2.0 - A Global Snapshot of Solid Waste Management to 2050: Trends in Solid Waste Management. http://datatopics.worldbank.org/what-a-waste/trends_in_solid_waste_management.html. (Accessed 08.10.2019.

Benoît, C., Mazijn, B., 2009. Guidelines for social life cycle assessment of products. United Nations Environment Programme, Paris, France.

Beylot, A., Vaxelaire, S., Zdanevitch, I., Auvinet, N., Villeneuve, J., 2015. Life Cycle Assessment of mechanical biological pre-treatment of Municipal Solid Waste: a case study. Waste management (New York, N.Y.) 39, 287–294.

BRASIL, 2015. Belo Horizonte's socio-economic profile. http://www.atlasbrasil.org.br/2013/pt/perfil_m/belo-horizonte_mg. (Accessed 11.09.2019.

BRAZIL, 1990. Compliance Adjustment Agreement. L. 8078; 1990

BRAZIL, 2006. Municipal solid waste management priorities for socio-entrepreneurship of WP cooperatives, 5940/06.

BRAZIL, 2010. National Policy on Solid Waste Law 12,305/2010. BRAZIL.

Campos, H.K.T., 2014. Recycling in Brazil: Challenges and prospects. Resources, Conservation and Recycling 85, 130–138.

CATAFORTE, 2015. Manual for Taxes and fees for waste pickers cooperatives. Sao Paulo, pp. 18-30.

Clift, R., Doig, A., Finnveden, G., 2000. The Application of Life Cycle Assessment to Integrated Solid Waste Management: Part 1—Methodology. Process Safety and Environmental Protection 78(4), 279-287.

CME, 2019. Energy from waste. https://www.camara.leg.br/noticias/425644-projeto-cria-incentivo-a-geracao-de-energia-a-partir-de-residuos/. (Accessed 18.09.2019.

Commission, E., 2003. Landfill Directive.

CONAMA, 2011. Parameters and conditions of sewage for State wastewater treatment plants.

Conke, L.S., 2018. Barriers to waste recycling development: Evidence from Brazil. Resources, Conservation and Recycling 134, 129–135.

Costa, D., 2019. Market creates jobs that pay maximum 2 minimum salaries. https://oglobo.globo.com/economia/mercado-so-gera-emprego-que-paga-ate-dois-salarios-minimos-mostra-ipea-23955311. (Accessed 21.10.2019.

Davis, J.-M., Garb, Y., 2015. A model for partnering with the informal e-waste industry: Rationale, principles and a case study. Resources, Conservation and Recycling 105, 73-83.

Deublein, D., Steinhauser, A., 2008. Substrates and biogas. In: “Biogas from waste and renewable sources. An introduction”. WILEY-VCH Verlag GmbH & Co. KGaA., Weinheim, Germany, pp. 62-69.

FEAM, 2018a. Parameters for fleet emissions at municipal level. FEAM, Belo Horizonte.

FEAM, 2018b. Sectoral emissions in the regions of Belo Horizonte, Contagem and Betim. Petrobras, Belo Horizonte.

Fei, F., Wen, Z., Huang, S., Clercq, D.d., 2018. Mechanical biological treatment of municipal solid waste: Energy efficiency, environmental impact and economic feasibility analysis. Journal of Cleaner Production 178, 731–739.

Fernández, L., 2010. Towards a Global Network: Waste Pickers without Borders. https://globalrec.org/history/. (Accessed 27.11.2019.

Fuss, M., Vasconcelos Barros, R.T., Poganietz, W.-R., 2018. Designing a framework for municipal solid waste management towards sustainability in emerging-economy countries - An application to a case study in Belo Horizonte (Brazil). Journal of Cleaner Production(178), 655–664.

Fuss, M., Vasconcelos, R.B.T., Poganietz, W.-R., 2019. The role of socio-integrated recycling system in case of circular economy implementation – the case of Belo Horizonte (Brazil).

Gall, M., Wiener, M., Chagas de Oliveira, C., Lang, R.W., Hansen, E.G., 2020. Building a circular plastics economy with informal waste pickers: Recyclate quality, business model, and societal impacts. Resources, Conservation and Recycling 156, 104685.

Gautam, P., 2011. Social life cycle assessment of solid waste management in Kathmandu City Nepal, Proceedings of the Life Cycle Management Conference 2011 ed., Berlin.

Goulart Coelho, L.M., Lange, L.C., 2018. Applying life cycle assessment to support environmentally sustainable waste management strategies in Brazil. Resources, Conservation and Recycling 128, 438–450.

GreenDelta, 2018. The life cycle of thinking. http://www.openlca.org/. (Accessed 01.03.2018.

Guibrunet, L., Calvet, M.S., Broto, V.C., 2017. Flows, system boundaries and the politics of urban metabolism: Waste management in Mexico City and Santiago de Chile. Geoforum 85, 353-367.

Gutberlet, J., 2015. More inclusive and cleaner cities with waste management co-production: Insights from participatory epistemologies and methods. Habitat International 46, 234–243.

Gutberlet, J., 2018. Waste in the City: Challenges and Opportunities for Urban Agglomerations, in: Ergen, M. (Ed.) Urban Agglomeration. InTech.

Gutberlet, J., Carenzo, S., Kain, J.-H., Mantovani Martiniano de Azevedo, A., 2017. Waste Picker Organizations and Their Contribution to the Circular Economy: Two Case Studies from a Global South Perspective. Resources 6(4), 52.

Horizonte, B., 1992. Organic Law and the inclusion of waste pickers cooperatives. 2º Law nº 6.290, 23 December 1992, in: council, B.H.c. (Ed.) 6,290. Belo Horizonte.

Horizonte, B., 2008. Decree 13 378, amendment of 2º Law nº 6.290, 23 December 1992, 13 378. Belo Horizonte.

HORIZONTE, B., 2017. Belo Horizonte Municipal Solid Waste Plan. 325.

Hurst, S., 2013. Dewatering Equipment selection: Squeezing the most out of your decision. Andritz Separation.

Ibañez-Forés, V., Bovea, M.D., Coutinho-Nóbrega, C., 2020. Proposal of Social Indicators to Assess the Social Performance of Waste Management Systems in Developing Countries: A Brazilian Case Study, in: Traverso, M., Petti, L., Zamagni, A. (Eds.), Perspectives on Social LCA. Springer International Publishing, Cham, pp. 95–103.

Ibáñez-Forés, V., Coutinho-Nóbrega, C., Bovea, M.D., Mello-Silva, C.d., Lessa-Feitosa-Virgolino, J., 2018. Influence of implementing selective collection on municipal waste management systems in developing countries: A Brazilian case study. Resources, Conservation and Recycling 134, 100–111.

IBGE, 2018. Belo Horizonte's population and indexes. Instituto Brasileiro de Geografia e Estatística, Brasilia.

INSS, 2017. Contribution to social pension security system. https://www.inss.gov.br/servicos-do-inss/calculo-da-guia-da-previdencia-social-gps/tabela-de-contribuicao-mensal/. (Accessed 07.10.2019.

IPEA, 2017. The integrated selective collection system in Brazil: Challenges and opportunities under the aspects of solidarity economy, Rio de Janeiro.

Kawulich, B.B., 2005. Participant Observation as a Data Collection Method. Forum: Qualitative social research 6(II).

Kudo, S., Mino, T., 2020. Framing in Sustainability Science, in: Mino, T., Kudo, S. (Eds.), Framing in Sustainability Science. Springer Singapore, Singapore, pp. 3-15.

Lino, F.A.M., Ismail, K.A.R., 2013. Alternative treatments for the municipal solid waste and domestic sewage in Campinas, Brazil. Resources, Conservation and Recycling 81, 24–30.

Lu, Y.-T., Lee, Y.-M., Hong, C.-Y., 2017. Inventory Analysis and Social Life Cycle Assessment of Greenhouse Gas Emissions from Waste-to-Energy Incineration in Taiwan. Sustainability 9(11), 1959.

Ma, J., Hipel, K.W., Hanson, M.L., 2017. Public participation in municipal solid waste source-separated collection in Guilin, China: status and influencing factors. Journal of Environmental Planning and Management 60(12), 2174–2191.

Medina Jimenez, A.C., Nordi, G.H., Palacios Bereche, M.C., Bereche, R.P., Gallego, A.G., Nebra, S.A., 2017. Evaluation of two different alternatives of energy recovery from municipal solid waste in Brazil. Waste management & research : the journal of the International Solid Wastes and Public Cleansing Association, ISWA 35(11), 1137–1148.

MMA, 2011. First National inventory for air pollution for passengers and road transportation. MMA, Brasilia.

MNCR, 2019. Viamão wants to deliver public cleaning to a single company for 20 years. http://www.movimentodoscatadores.org.br/site/noticias/blog-do-sul/viamao-quer-entregar-limpeza-publica-por-20-anos-a-uma-unica-empresa. (Accessed 17.10.2019.

Nelles, M., Morscheck, G., Grünes, J., 2012. MBT in Germany and Europe - Development, Status and Outlook, Proceedings ed., Göttingen.

Nithikul, J., Karthikeyan, O.P., Visvanathan, C., 2011. Reject management from a Mechanical Biological Treatment plant in Bangkok, Thailand. Resources, Conservation and Recycling 55(4), 417–422.

Oliveira, G., Scazufca, P., Pires, R.C., 2019. Sanitation index of Brazilian cities, Sao Paulo.

Parreira, G.F., 2010. Solidarity selective collection: aggregating value for integrated recycling chain, Belo Horizonte.

Pastorelli, R., Lagomarsino, N., Vignozzi, G., Valboa, R., Papini, A., Fabiani, S., Simoncini, S., Mocali, R., 2013. Anaerobic digestate from biogas production as a resource for improving soil fertility: effects on crop yield and soil properties.

Rateau, M., Tovar, L., 2019. Formalization of wastepickers in Bogota and Lima: Recognize, regulate, and then integrate? EchoGéo(47).

RECIPE, 2016. A life cycle impact assessment method which comprises harmonised category indicators.

Rossa, F.A.F., 2011. Public-private partnership in Brasil. http://fernandorossa.blogspot.com/2011/11/concessao-de-servico-publico-concessao.html. (Accessed 04.10.2019.

Scari, M.E., 2011. An analysis of the electricity consumption structure of the residential sector in Belo Horizonte 2030, Belo Horizonte.

Schwartz, B.K., 2000. Development Agreements: Contracting for Vested Rights. p. 719.

Serrona, K.R.B., Yu, J., Aguinaldo, E., Florece, L.M., 2014. Developing a monitoring and evaluation framework to integrate and formalize the informal waste and recycling sector: the case of the Philippine National Framework Plan. Waste management & research : the journal of the International Solid Wastes and Public Cleansing Association, ISWA 32(9), 882–895.

SIMS, 2018. Sunset Park Materials Recovery Facility. https://www.simsmunicipal.com/locations/sunset-park-mrf/. (Accessed 29.08.2019.

Singer, P., 2002. Introduction of the solidarity economy. Fundacao Perseu Abramo, Sao Paulo.

Singer, P., 2011. Community development and solidarity economy. http://paulsinger.com.br/secao/ineditos/. (Accessed 22.07.2019.

Sinthumule, N., Mkumbuzi, S., 2019. Participation in Community-Based Solid Waste Management in Nkulumane Suburb, Bulawayo, Zimbabwe. Resources 8(1), 30.

SLU, 2014. Annual monitoring reports of entire waste management of Belo Horizonte 2014.

SLU, 2018. Annual Report of Municipal Solid Waste - 2001 to 2018.

SNIS, 2018. Indicators of solid waste management. http://app4.mdr.gov.br/serieHistorica/#. (Accessed April, 08 2020).

Trulli, E., Ferronato, N., Torretta, V., Piscitelli, M., Masi, S., Mancini, I., 2018. Sustainable mechanical biological treatment of solid waste in urbanized areas with low recycling rates. Waste management (New York, N.Y.) 71, 556–564.

UBA, 2015. Mechanical Biological Treatment. https://www.umweltbundesamt.de/en/topics/waste-resources/waste-disposal/mechanical-biological-treatment. (Accessed 13.04.2020 2020).

Vafabmiljo, 2015. Biogas and impurities removal in Västeras. Vafabmiljo.

Valenzuela-Levi, N., 2019. Factors influencing municipal recycling in the Global South: The case of Chile. Resources, Conservation and Recycling 150, 104441.

van Zeeland, A., 2013. Challenges for Sustainability of SSE. The Interaction between Popular Economy, Social Movements and Public Policies-Case Study of the Global Alliance of Waste Pickers. pp. 6–8.

Varella, C.V.S., 2011. Turn-out the garbage bin: possibilities and limits of recycling as an alternative for waste treatment, Belo Horizonte.

VDA, 2019. Diesel technology: Quo Vadis, Diesel? https://www.vda.de/de/themen/umwelt-und-klima/diesel/grenzwerte.html. (Accessed 09.09.2019.

Villalba, L., Donalisio, R.S., Cisneros Basualdo, N.E., Noriega, R.B., 2020. Household solid waste characterization in Tandil (Argentina): Socioeconomic, institutional, temporal and cultural aspects influencing waste quantity and composition. Resources, Conservation and Recycling 152, 104530.

Visvanathan, C., 2010. Bioenergy Production from Organic Fraction of Municipal Solid Waste (OFMSW) through Dry Anaerobic Digestion, in: Khanal, S.K., Surampalli, R.Y., Zhang, T.C., Lamsal, B.P., Tyagi, R.D., Kao, C.M. (Eds.), Bioenergy and Biofuel from Biowastes and Biomass. American Society of Civil Engineers, Reston, VA, pp. 71–87.

Xavier, R.S., 2010. Modeling and minimizing the fuel consumption for the municipal solid waste collection, Belo Horizonte.

Yıldız-Geyhan, E., Yılan, G., Altun-Çiftçioğlu, G.A., Kadırgan, M.A.N., 2019. Environmental and social life cycle sustainability assessment of different packaging waste collection systems. Resources, Conservation and Recycling 143, 119–132.

Chapter 5

Designing a framework for municipal solid waste management towards sustainability in emerging economy countries - An application to a case study in Belo Horizonte (Brazil)

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Abstract:

A sustainable municipal solid waste management (MSWM) system is recognized by Agenda 21 as an opportunity for cities for creating decent jobs, raising incentives for responsible consumption, and protecting the natural environment. However, according to our experience for many stakeholders and decision-makers in Belo Horizonte, Brazil, the principles for sustainability defined by the Bruntland Commission are far too abstract. They are not readily applicable to establish a sustainable MSWM system. Even though Brazilian cities are strongly being influenced by concepts developed in high-income countries to search for strategic policies and long-term action plans for MSWM, many decisions-makers have not paid much attention to an overall sustainability approach so far. Against this backdrop, the present paper introduces the municipal solid waste diagram (MSWD) as a comprehensive framework for assessing the current state of a MSWM system against a future sustainable one. The normative foundation of MSWD is the Integrative Concept of Sustainability (ICoS), which contrasts the conventional approach of sustainability, which typically characterizes a sustainable future along the three dimensions of economy, environment and society. ICoS points out crucial documents for sustainable development (e.g., Brundtland report and Agenda 21), and it does not neglect the potential of the capability approach. By this, the dynamic interrelationship between the abovementioned dimensions is taken into account. Another characteristic of the MSWD is the strong involvement of stakeholders, experts, and decision-makers during the construction and application of that instrument. Their central task was to certify the relevance, compatibility, flexibility of the chosen nine assessment criteria and the related 18 indicators on the ground of the ICoS.

Any other study is known which looks for the dynamics of MSWM. The proposed approach helps to identify the constitute elements of MSWM clearly and to match to goals of sustainability without distinguishing and prioritizing any dimensionality. This approach clarifies the scientific background for sustainable development in the process of decision making regarding MSWM, which is not done by conventional sustainability assessment methodologies. By the participation of the most relevant stakeholders of Belo Horizonte, the municipal solid waste diagram is verified.

Belo Horizonte has currently obtained a level of development of about one third towards the goals of sustainability. The city had the best performance on securing

human existence, in which the individual protection takes currently a high priority. The presented MSWD and thus the findings are specific to Belo Horizonte, but not the proposed approach.

Keywords: Municipal solid waste management; Assessment criteria; Integrative Sustainability Concept; Indicators; Belo Horizonte.

1. Introduction

In recent years, studies stress different solutions for a public service provision of municipal solid waste management despite that similar problems are often faced by many cities (see,(Bel et al., 2010; Plata-Diaz et al., 2014)). Because of divergent economic and political conditions (see,(Plata-Diaz et al., 2014; Wassenaar et al., 2013)), many countries are searching for different pathways to restructuring their solid waste (MSW) services at the municipal level aiming achievement of certain targets, such as sustainable targets. For instance, in the transition towards sustainable solutions for MSWM in Europe(2016b), privatization and inter-municipal cooperation appear to be more relevant for Spain's cities than for Netherlands' cities due to strong Spanish government intervention into local public service provision and lower opportunities of Spanish municipal authorities to exploit scale economies(Bel et al., 2010).

As a consequence of the fast economic development of Brazil in the last decade – it now belongs to the 10 largest economies worldwide – national and international organizations, e.g. the Organization for Economic Co-operation and Development (OECD), demanded from Brazilian municipalities to run for more sustainable municipal solid waste management (MSWM) systems. Sustainable MSWM, which is characterized by balancing societal, economic, environmental, and institutional aspects, is recognized as part of sustainable development goals by Agenda 21 (1992; 2010b) and later adopted by Brazilian laws (see(2000; 2007; 2016a; Brazil, 2010)). It is seen as an opportunity for Brazilian's cities for creating decent jobs, raising incentives for responsible consumption, standardize the public services and protecting the natural environment under the level of emerging countries, as the goal envisioned in National Policy on Solid Waste(2016a; Brazil, 2010).

International efforts for zero waste (Song et al., 2015; Zaman, 2014) and zero carbon waste (Premalatha et al., 2013) or waste-to-energy (Bosmans et al., 2013; Kadir et al., 2013) and smart waste systems (Fujii et al., 2014; Wahab et al., 2014) are

commonly framed as pathways for achieving more sustainable MSWM systems. In Brazil, the perception of reducing waste generation (zero waste) and lowering carbon emissions (zero carbon waste) or having a new technological system (waste-to-energy or smart waste systems) are troublesome for municipalities. The tight public budgets lead to a focus of policies on low costs and non-sustainable solutions rather than on sustainable one. Moreover, the divergent political, business and economic interests often conduct to short-term solutions determined by the duration of the legislative periods. As a consequence, a small part of the solid waste is recycled or in the case of organic wastes composted (e.g.(2014)). Initiatives to overcome the drawbacks of the current MSWM are limited in their financial and personal resources. For example in Belo Horizonte mainly NGOs and university researchers are struggling to spread technical knowledge regarding a proper waste collection and treatment system, organizational capacities of waste pickers cooperatives, clear sanitation rules, or even providing campaigns for separation of waste at source.

Comparing the current situation in Brazilian municipalities with the demands set by Agenda 21 and Brazilian laws the necessity is obvious to find successful strategies to a more sustainable MSWM system(2010b; 2016a; Wilson, 2007). The importance to move towards more sustainable systems is stressed amongst others by Gray(Gray, 2010); but the principles are rarely discussed or analyzed explicitly. For instance, aiming to assist decision-makers concerning sustainable MSWM, a plenty of studies are available. Those studies had evaluated strategies or compared the environmental impacts of different technologies for specific process steps of MSWM systems (such as collection(Feo et al., 2013; Mantovani et al., 2016; Rogge and Jaeger, 2013; Saeed et al., 2009), transport(Das and Bhattacharyya, 2015; Menikpura et al., 2013; Mora et al., 2014; Sanneh et al., 2011; Son and Louati, 2016), and treatment(Al-Khatib et al., 2015; Bosmans et al., 2013; Surendra et al., 2014)) or over the entire process chain from collection to disposal(2010b; 2013c; Marshall and Farahbakhsh, 2013; Ripa et al., 2017; Wilson et al., 2013).

The relevance of the informal sector is widely debated regarding the social aspects of MSWM. Some studies analyze the lack of or integration measures for the informal sector as part of the MSWM (Campos, 2014a; Oguntoyinbo, 2012; Rutkowski and Rutkowski, 2015; Scheinberg, 2012); others studies explore the working conditions of waste pickers(Ferri et al., 2015; Marello et al., 2014; Prakash and Manhart, 2010; Sasaki et al., 2014; Vilijoen et al., 2016). All these studies focus on specific

dimensions of sustainability, i.e. either the economic, environmental or the societal one.

A broader approach is presented amongst others by Vinyes et al.(Vinyes, 2012), Martinez-Sanches et al.(Martinez-Sanchez, 2016), Menikupura et al(Menikpura et al., 2013). and Schluchter et al.(Schluchter and Rybaczewska- Błażejowska, 2012). Vinyes et al. (Vinyes, 2012)and Martinez-Sanches et al.(Martinez-Sanchez, 2016) curb their studies to methods of prevention and collection systems recommendable for Mediterranean countries and Denmark. Comparable to other contributions, Vinyes et al. (Vinyes, 2012)and Martinez-Sanches et al.(Martinez-Sanchez, 2016) narrow the assessment only to climate change and welfare, uncovering other environmental or social impacts (such as human health impacts or job opportunities) and whether trade-offs choices exists or not. Menikupura et al.(Menikpura et al., 2012) and Schluchter et al.(Schluchter and Rybaczewska- Błażejowska, 2012) propose a comprehensive set of indicators for MSWM considering the classical three dimensions of sustainability, but without taking into account the potential interconnection between the dimensions.

In this article, an integrated approach for supporting the identification of sustainable MSWM systems will be presented and discussed. The “integrative” claim relates to three levels: the first recognizes the complex interrelationship between the three dimensions by using the Integrative Concept of Sustainability (ICoS) of the German Helmholtz Research Association(Kopfmüller et al., 2001). The ICoS bases on three constitutive elements rather than on the classical dimensions of sustainability(Kopfmüller et al., 2001). The constitutive elements shape a dynamic understanding of sustainability for different societal systems and cultures characterized by reflections to govern societal transformation processes(Grunwald, 2012). The second one sees an integration of a problem-based learning process to certify the empirical evidence (top-down) with a normative approach to the deductive definition of the sustainability model (bottom-up) augmented in the ICoS. This integration effort is summarized in an innovative municipal solid waste diagram (MSWD). This article shows the usefulness of the concept for assessing the current MSWM systems compared to a desired, i.e. sustainable, one, using Belo Horizonte as an example. Such an instrument will help to identify necessary paths to achieve a sustainable MSWM.

The third level of integration relates to the necessity to involve all relevant stakeholders and decision-makers in the process of building an adequate strategy to achieve a sustainable MSWM. This need is advocated by academics (see(Marshall and Farahbakhsh, 2013; Wilson, 2007)) and stakeholders to manage the tensions and synergies between environmental, social-cultural and economic concerns. In case of Brazil this would mean, to involve for example the informal sector. The integration of experts, stakeholders, and decision-makers promotes the exchange of knowledge regarding sustainability concepts and local demands and challenges.

The reminder of this paper is organized as follows. In section 2, sustainability is analyzed in depth under the lens of the integrative sustainability concept ICoS. In section 3, the situation of MSWM in Belo Horizonte is described. The overall research method is detailed in section 4. The assessment criteria and indicators for a sustainable MSWM are defined; then the method of linking MSWM assessment criteria, indicators and goals for sustainable development is explored. Based on that, the MSWD is constructed. The discussion of the approach takes place in section 5 Finally, section 6 offers some conclusions.

2. Conceptualizing the goals of sustainability regarding a sustainable MSWM system

The normative backbone of the MSWD is the Integrative Concept of Sustainability. ICoS was originally developed by researchers' institutions for Germany. The contextualizing strategy of this concept makes it suitable for application to other structural and country levels. For instance, the ICoS was applied to the assessment of German energy production and technologies(Grunwald, 2012; Rösch et al., 2009), housing and construction(Jörissen et al., 2005), food and agricultural sector(Meyer, 2006), but also for evaluating challenging areas of activity like municipal waste water treatment in Chile(Hartmuth et al., 2008; Kopfmüller, 2011). But no study developed a comparable approach to the one presented in this paper.

There are three main reasons for coupling a MSWM system with the goals and rules of the ICoS. First, besides the hundreds of definitions of sustainability, ICoS does not neglect the potential of capability approach. According to Burger and Christen(Burger and Christen, 2011), the capability approach is an advantage strategy beyond the pure environmental sustainability because it gives insights to the improvement of the quality of life, reinforces the capacity of humans to lead an active life, claims universal validity and assists further development.

Second, ICoS is based on three constitutive elements rather than on the classical dimensions of sustainability identified out of Brundtland Commission's definition(WCED, 1987), results of the World Summit at Rio de Janeiro 1992 and ongoing scientific results and debates(Grunwald, 2016; Kopfmüller et al., 2001). The three constitutive elements shape a dynamic understanding of sustainability for different societal systems and cultures characterized by reflections to govern societal transformation processes(Grunwald, 2012, 2016). The first and second constitutive element is the viewpoint of the Brundtland Commission (WCED, 1987) which is also taken in the normative principle of justice of Dobson (Dobson, 1996) by referring to the "postulate [of] intra-intergenerational justice" and "global orientation". For the intragenerational justice postulate, it is assumed for this study that the present generation has to receive equitable shares of public municipal solid waste services by collaborating with all those responsible for the management and the distribution of duties to conserve the environment as well as to compensate it for the harm caused by degradation. The second constitutive element of ICoS applies to intergenerational justice Municipal solid waste services should presume sustaining the potential of the natural environment to regenerate itself, and according to Dobson(Dobson, 1996), preserve stocks of natural capital for an unknown future by increasing the usage of secondary resources presented by recyclable materials. This statement reinforces the milestone of Agenda 21(1992), by which a non-functioning MSWM also contributes to the global environmental deterioration, enforcing a global perspective to a seemingly local challenge. The third constitutive element of ICoS, the anthropocentric point of departure as a characteristic taken from Brundtland Report and Rio-Declaration to assure satisfaction of human needs(Grunwald, 2016), highlights the responsibility of human beings to use existing resources to generate income to satisfy the human demands with the commitment for a cautious use of the environment. The search for sources of income generation to meet basic human needs is one of the most discussed and challenging factor in Belo Horizonte, for example.

Three goals have been defined for ICoS (see(Grunwald, 2012, 2016; Kopfmüller et al., 2001)) and adapted for MSWM to overarching development measures, and strategies towards the constitutive elements above mentioned. The first goal of the ICoS, "securing human existence", presumes that a sustainable (MWSM) system has to be designed in a way to promote individual life condition and its welfare. The second one, "maintaining society's productive potential", aims at preserving (human and natural) resources. Both goals are related to personal behavioral change. The third

goal, “preserving society’s options for development and action”, insinuates the necessity for protecting and safeguarding the future of society. Each of the three goals is explicitly described by five rules, which are shown in Table 1. Table 1 also presents the adaption of the goals and rules of the ICoS to the MSWM.

Table 1 Integrative Concept of Sustainability adapted to MSWM

Pre-conditional rules	Description
Securing human existence	
Protection of human health	Human health must be protected from anthropogenic environmental burdening of hazards and unacceptable risks caused by MSWM.
Satisfaction of basic needs	Every member of society (active or passive in MSWM) must be protected against risks to life (sickness and disabilities).
Autonomous subsistence based on income from own work	All members of society must have conditions to afford undertaken activities (e.g. food and health care). In MSWM this rule is directly connected to the workers involved.
Just distribution of opportunities to use natural resources	Distribution of natural and environmental resources must be shared fairly, i.e., all members of society must have a fair participation of resources usage. In MSWM, there are any natural resources involved. But, it assumes that MSW is a resource that generates opportunities for many low income citizens. They should have opportunity to make use of them.
Reduction of extreme income or wealth inequality	Social inequalities must be reduced by promoting incentives for waste pickers cooperatives.
Maintaining society’s productive potential	
Sustainable use of renewable resources	The rate of renewable resources usage must not exceed the capability of ecosystem to regenerate. In MSWM, recyclable and organic materials are renewable resources that needs a properly treatment for a sustainable use.
Sustainable use of non-renewable resources	The rate of non-renewable resources must be maintained or reduced. In MSWM, recovery of municipal solid waste by incineration can be unsustainable by the energy ratio (energy output is lower than input), for example.
Sustainable use of the environment as a sink for waste and emissions	Emissions of toxic substance must not exceed the absorption capacity of the environment and ecosystem.
Avoidance of technical risks with potentially catastrophic impacts	Any technical risks for catastrophic impacts must be avoided. Disposal, for example, of untreated MSWM has high technical risks for surrounding area and for the environment in general.
Sustainable development of man-made, human, and knowledge capital	The improvement the economy’s performance must maintain or create man-made, human, or knowledge capital.
Preserving society’s options for development and action	
Equal access for all to information, education and occupation	All members of society must have equal access ongoing procedures for education, information center, public functions and social or political positions.

Participation in social decision-making processes	All members of society must have the chance to participate in decision-making processes.
Conservation of cultural heritage and cultural diversity	Cultural diversity as well as cultural heritage must be protected.
Conservation of the cultural function of nature	Natural landscape or beauty and unique places must be protected.
Conservation of social resources	Tolerance, solidarity and perception of common welfare must be secured.

Source: Adapted from (Kopfmüller et al., 2001)

According to ICoS structure, the construction of the MSWD is facilitated (third reason for coupling). The analytical groundwork for combining the description of the problem (called in the concept as bottom-up approach) with substantial pre-conditional rules to achieve sustainability (rules for defining a top-down strategy) is combined by indicators.

3. Study domain

With recent recognition (2010b; Campos, 2014a; Rutkowski and Rutkowski, 2015; Scheinberg, 2012), the city of Belo Horizonte in the South-eastern of Brazil is a successful international model of social integration of waste pickers' cooperatives in MSWM. Thereby, it became attractive to further explore the local system conditions in this study.

Belo Horizonte is a large-sized city with slightly more than 2.5 million inhabitants divided into 9 district-areas. It comprises regions characterized by residential areas (including many slums), industries and intense commerce activities. Unlike many other Brazilian cities, Belo Horizonte is limited regarding space for any further expansion, which demands large areas or when logistic activity is crucial. Consequently, Belo Horizonte has shown a low average population growth rate of about 0.6% per year, since 2001 (2015). The most preferable place for housing and host of large and new industries is in the metropolitan region, with its growing infrastructure areas that buffer a possible over-population and decline of industries development in Belo Horizonte.

Belo Horizonte can be characterized by a strong socioeconomic contrast. The average *per capita* household income in suburban areas and slums is less than 0.72 US$ per day, while in the business area it is higher than 31.45 US$ per day(2015). With low *per capita* household income, many citizens look for waste picking. Waste pickers are mainly citizens between 30 and 60 years with low educational level. For

many of these citizens to be a waste picker is the possibility to generate income for their family and to reintegrate into society. Seven waste pickers' cooperatives are officially organized by voluntary memberships in Belo Horizonte.

Waste pickers' cooperatives are mainly in charge for the primary recycling of plastic, metal, paper and glass materials from households and commercial establishments in Belo Horizonte. In accordance to the Municipal Solid Waste Policy (1990) and the National Policy on Solid Waste (Brazil, 2010), these cooperatives are registered as voluntary service providers and integrated into the formal collection system. They receive direct financial assistance from Belo Horizonte administration and national government agencies such as infrastructures (e.g. rent, construction and improvements of sheds) and equipment (e.g. handcart and individual protection equipment). Some cooperatives provide door-to-door selective collection services. But most of the recyclable materials are delivered by the municipal transport agency to each waste picker's cooperative for sorting and commercialization. In cooperatives, the recyclable materials are sorted by colour and composition (e.g., in polypropylene, ethylene terephthalate, high-density polyethylene). Each waste picker sorts an average of 4 tons of recycled materials per month. The monthly profits are either allocated per member or according to the individual amount each picker has sorted. As a member of a cooperative, waste pickers are obligated to contribute to cooperative expenses. Members are subject to the social insurance system, like the statutory pension fund. However, it should be noted, that the acceptance rate of recyclable materials sorted and compacted in bales by waste pickers' cooperatives by industries is still rather low.

The total number of waste pickers in Belo Horizonte is unknown. Many waste pickers are still reluctant to become a member of a cooperative and prefer the "living on the street". They are commonly found in border regions of Belo Horizonte. For instance, ASMARE (the first waste picker cooperative of Belo Horizonte and Brazil) assumes more than 280 waste pickers provide daily basis work, but only 65 waste pickers are officially registered as a voluntary member of the cooperative. Members of a cooperative have a working slot position at the shed. The sorting of waste is done manually without any support of belts or similar equipment. Consequently, the number of waste pickers' cooperatives and members is low and infrastructures are not adequate for the total amount of Belo Horizonte municipal solid waste (MSW) generated.

Belo Horizonte generates about 2,275.84 tons of MSW per day (2014). MSW is composed of 61% of organic waste, 26% of recyclable materials (plastics, papers, glasses, and metals), 8% of other materials (wood, rubbers and textiles) and 5% of rejects (batteries, personal hygiene waste, and others) (2014). The Belo Horizonte Superintendence of Urban Cleaning, or SLU, provides the traditional MSWM with a coverage area of 96% (2014). More than 75% of the total operational costs related to sanitation services and urban cleaning are with MSWM. An average of 50.1% of this budget is spent on daily household collection 2014). The MSW collection in slums, wide roads and steep streets are made with a larger number of workers and different transport methods such as on foot, motorcycles and small trucks. All these collection services cost the SLU an extra 10.3%. SLU does not offer any pre-treatment for Belo Horizonte MSW. About 31.2% of the budget for MSWM is spent with the transfer of MSW from the transhipment station to the disposal site and 7.2% are operational, maintenance and security of machinery and office stuff (2014). The remaining of the budget is designated to private companies (11.5%) such as the disposal private company which is the owner of the landfill site(2014).

Nearly all MSW is shipped to landfills without sorting. Only in the business area of Belo Horizonte a selective collection system is offered, which accounts for a recycling rate lower than 2%. No measures are implemented to reduce the volume of waste to be shipped untreated to landfills. For example, less than 0.5% of organic waste is composted(2014).

4. The municipal solid waste diagram (MSWD)

4.1 Overview over constructing a MSWD

The overall aim of a municipal solid waste diagram (MSWD) is to show visually the current state of a MSWM system in comparison to a desired future, i.e. sustainable, one. The building of a MSWD involves four major steps:

1. Selection of assessment criteria, to evaluate a MSWM (s.4.2);
2. Selection of indicators, to operationalize the assessment (s.4.3);
3. Building the MSWD framework, by screening and evaluating the assessment and criteria and indicators using the principles of the ICoS as a reference (s.4.4);

4. Operationalizing of the MSWD framework, by comparing the actual state of each indicator with a desired status (s.4.5). The results can be visualized in a radar diagram.

4.2 Selection of assessment criteria

To identify and select assessment criteria, 50 peer-reviewed scientific papers on MSWM were analyzed, including existing framework and practical research papers. Twelve assessment criteria were identified. Thereof, eight criteria were selected for further analysis because of their above average quotation in literature (see complete literature review in Appendix A – download is available in Supplementary information, SI).

A semi-structured interview was developed with the aim of obtaining the feedback of local experts and stakeholders, especially whether assessment criteria are missing. The experts and stakeholders were asked to follow the following guidelines: transparency (easily understandable), practicability (foresee the implementation), applicability (applicable to MSWM) and comprehensiveness (implications on sustainability objectives)(Akadiri et al., 2013; Gibson, 2006). The local experts were mainly persons with a scientific or educational background. The interviewed stakeholders belong to the environmental and engineering department as well as the public health and sanitation department of the administration of the municipality of Belo Horizonte, private recycling companies, community-based organization, waste pickers cooperatives, NGOs and funding agencies.

In total, 34 participants (23 experts and 9 stakeholders) contributed to identify the relevant assessment criteria.

All experts and stakeholders stated that all criteria from the literature were relevant, practical and transparent. Therefore, most of the participants commented different aspects to make the assessment criteria applicable to Belo Horizonte. For instance, in literature, the impact of urban cleanness on the quality of life is directly connected to a well-organized daily collection system(Prakash and Manhart, 2010; Sanneh et al., 2011). Belo Horizonte faces several problems with its traffic system, such as narrow and highly congested streets. A weekly collection system to reduce congestion could be an option which, however, would require an embedded collaboration among stakeholders and inhabitants, as pointed out by local researchers. According to such type of comments, each criterion and its scope were rephrased. An additional criterion based on participants' suggestion was added: monitoring alternatives for testing the

dissemination of knowledge. Most of the participants highlighted that awareness program and campaigns for behavior changes towards sustainable MSWM are not enough. There is the need to identify monitoring alternatives to certify the dissemination of knowledge. The complete list of participants' comments for each criterion of MSWD is available in Appendix B (see SI), as well as, the comparison between each assessment criterion before and after the semi-structured interview.

4.3 Selection of indicators

Indicators are instruments to assist decision-makers in planning, implementing and assessing frameworks from local to global strategies (Kopfmüller, 2011). For the MSWD, indicators are the tangible way to delegate actions and also to measure the level of achievement regarding the specific goal and rules of the ICoS. An extensive literature review led to a set of 240 indicators (the list is available in Appendix C, see SI). A pre-screening of indicators reduced the number to approximately 190 by removing recurrent indicators. The particular content of each indicator and their relation to the MSWM criteria were considered in the next screening process. In total, 70 indicators fulfilled the four requirements defined for this study: relevant for implementing a MSWM system, compatible with the goals of the ICoS, flexible regarding changed policies or governance, informative and practical on a suitable communication with stakeholders. For instance, because of correlation between consequence of inappropriate management, diseases and protection of human health the indicator, the number of disease cases per year related to poor management practices and inadequate management of MSW, matched those four requirements and was selected it. Indicators with end-of-pipe viewpoint were directly excluded (e.g. number of bins, lifespan of landfills, number of illegal dumping).

4.4 Building the MSWD framework

Thus, the identified assessment criteria (section 4.2) and the related indicators (section 5.4.3) had to be set in line with the ICoS. The assignment process of criteria and indicators make use of the meta-analytical scheme for sustainability conceptions of Dobson (Dobson, 1996) as well as of Burger and Christen(Burger and Christen, 2011). The general idea of the meta-analytical scheme is to reflect the status of a current (MSWM) system compared to a desired future one, by clarifying in a nutshell (i) What is to sustain?; (ii) Why should it be sustained?; (iii) Who is concerned?; and (iv) In what respect is a replacement of the current system allowed?. Based on the answers to the four questions, given by local experts and stakeholders, the final

assessment criteria and the related indicators were defined. In case of Belo Horizonte, the interviewee highlighted the necessity to include empowered waste picker cooperatives into an improved municipal value chain system. The main reason are (1) social-economic benefits such as the creation of income and jobs which help to lower the poverty in the municipality; (2) enhancement of the recovery of materials and reduction of the use of landfills in a society where a separate collection is still precarious or unknown in many districts; (3) lowering costs for the municipality as the inclusion is seen less cost intensive compared to automated conventional sorting systems; and (4) dissemination of awareness by a direct contact to assist societal behaviour change. Any improvement of the MSWM system concerns all citizens and visitors. Replacements of sub-systems (e.g. collection and treatment) of the current management might be allowed as long as it is without prejudice or it does not threatens or excludes the joint work of all stakeholders including waste picker cooperatives.

As a result of the meta-analytical scheme, the identified nine assessment criteria (section 4.1) were assigned to the 15 sustainability rules of the ICoS: see first two columns of the MSWD represented by the Table 2.

Table 2. Scheme to calculate the Municipal Solid Waste Diagram (MSWD)

MSWM criteria	Sustainability rules	Indicators	Target*		
			0	2	5
Securing human existence					
Collaboration embedment among households and municipality for an urban cleanness and quality of life	Protection of human health	1a. Share of households receiving basic waste collection services weekly 1b. Total waste collected compared to the total of waste generated (%)			
Practices for reverse logistics to improve co-benefits of recovering secondary resources	Satisfaction of basic needs	1c. Report of well-being (Number of complaint and conflicts solved compared to previous year)			
	Autonomous subsistence based on income from own work	1d. Quantity of recyclable material recovered per worker compared to previous working month (%)			
	Just distribution of opportunities to use natural resources	1e. Annual revenue from sales of recyclable products, plus annual saving due to reduced disposal cost compared to annual total costs			
	Reduction of extreme income or wealth inequality	1f. Income of the waste pickers in cooperative in relation to the minimal wages (%)			
Maintaining society's productive potential					
Standard certification for recycled products	Sustainable use of renewable resources	2a. Number of inspection actions related to recycling processes according to industry legislation compared to previous year			
	Sustainable use of the environment as a sink for waste and emissions	2b. Shares of utilities consumed during the recycling processes (electricity, gas, water, etc.) compared annually			
Strategic alternatives for waste transportation paths	Sustainable use of non-renewable resources	2c. Share of of population served per type of vehicles with non-fossil fuel			
Safety waste treatment and disposal	Avoidance of technical risks with potentially catastrophic impacts	2d. Amount of waste properly treated per treatment method (%) 2e. Decrease of environmental impacts of MSW treatment on air pollution and ecosystem (%)			
Intellectual capital for service provision	Sustainable development of man-made, human and knowledge capital	2f. Work qualification. Number of training programs and education for service providers and waste pickers with participation of decision makers per year (ratio compared to previous year)			
Preserving society's options for development and action					
Promotion of information management	Equal access for all to information, education and occupation	3a –Share of of schools implementing waste awareness programs 3b- Share of citizens with access to annual running local awareness campaigns			
Promoting action and reaction of a close cooperation and responsibility of all actors	Participation in social decision-making processes	3c - Documentation and records of all MSWM activities kept in archives to make follow up actions possible			
	Conservation of social resources	3d -Associativism (e.g. number of waste pickers in cooperatives compared to previous year)			
Monitoring alternatives for testing the dissemination of knowledge	Conservation of the cultural function of nature	3e - % of permitted waste activities that have annual compliance monitoring reports			
	Conservation of cultural heritage and cultural diversity	3f - Number of organized public communication activities (e.g., mass-media campaign, exhibitions, community cleanup contests, community meetings, recycling bazaars) compared annually			

Comparable to the final selection of the assessment criteria the identified 70 indicators (s. 5.4.2) has to be set in line to the ICoS. This exercise was combined with the identification of the most relevant indicator for the MSWD (see Figure 1, step 2).

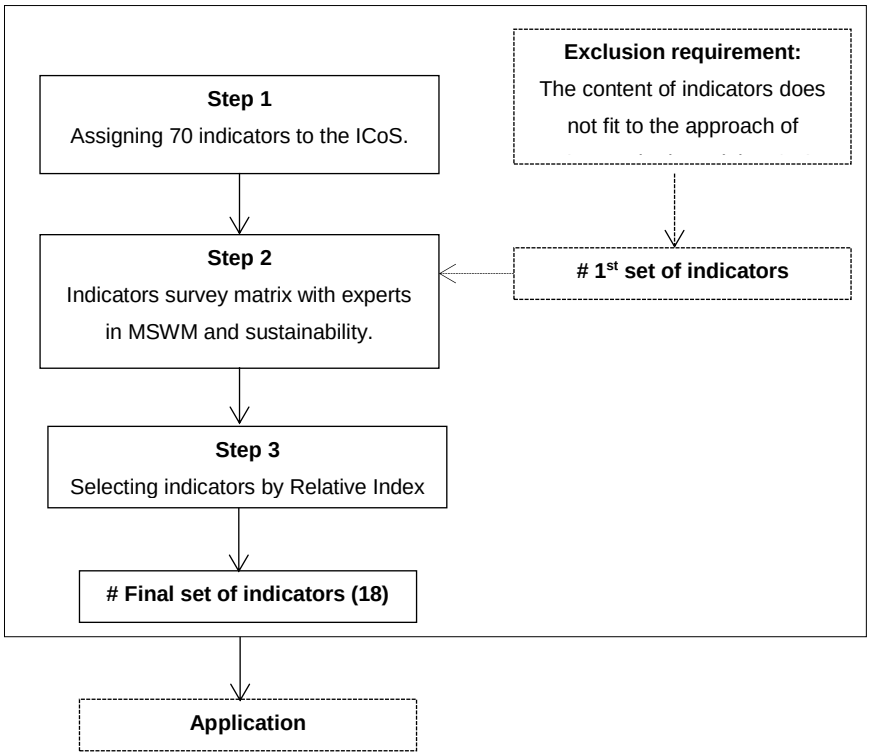


Figure 1. Outline of the steps to define indicators for the MSWD

For assigning and evaluating the indicators, 85 waste and sustainability experts were contacted. The experts represented academia, industry and waste funding organizations from around the world (e.g. Germany, Belgium, Spain, Turkey, and Nigeria). The experts were firstly instructed regarding the goal of this work, ICoS, and the assessment criteria. Secondly, they were invited to rate the indicators with 1 to 5, with 1 valuing a very low relevance of the indicator in the respective assessment criterion and 5 for very high relevance. The response ratio of this questionnaire was 33%.

For the final selection of indicators, the relative index (RI) was taken into account (Adnan and Morledge, 2003; Akadiri et al., 2013) (see Figure. 4.4.1, step 3). The relative index weights each indicator according to handling the assessments of the experts as a sample. The relative index is applied by Delphi method studies (Adnan and Morledge, 2003) to aggregate the scores rated on ordinal scales and identify the most important indicators from a sample based on experts' opinions. The relative index was considered an appropriate tool to prioritize indicators measured on Likert-type scales(Akadiri et al., 2013). The formula of RI is:

$$RI = \sum_{i=1}^{i=5} \frac{w_i f_i}{N} \qquad \text{Eq.(1)}$$

w_i is the weighing factor obtained from dividing the rating score by the highest score (5: very high relevance), f_i is the frequency of responses and N is the total number of responses(Akadiri et al., 2013). RI scale is [0;1].

The most critical and important indicators were chosen for MSWD, i.e., the indicators that showed an RI of 0.8 and more. Table 3 provides an example of the results obtained by RI analysis (complete analysis is available in Appendix D, see SI).

Table 3. Excerpt of the relative index (RI) analysis

Sustainability rule	Indicator	% VHR	% MR	% VLR	RI
Protection of human health	Share of households receiving basic waste collection services weekly	0.89	0.07	0.00	0.89
	Total waste collected compared to the total of waste generated (%)	0.89	0.04	0.07	0.89
	Number of deaths per year caused by diseases related to poor MSW management	0.00	0.14	0.50	0.09

VHR = very high relevance (score 5); MR = medium relevance (score 3); very low relevance (score 1). The results of the scores high relevance (4) and low relevance (2) are available in Appendix D. RI = relative index.

According to Table 3, to the rule “Protection of human health” three indicators were listed as the most relevant. But, according to the results of RI, just two indicators fulfilled the benchmark of 0.8 and were selected for the MSWD. The third one scored only 0.09 and was excluded.

All results of the indicators’ selection process are summarized in Table 3 (third column), showing the framework of the MSWD.

4.5 Operationalizing of the MSWD framework

To operationalize the framework the actual state of each indicator is compared to a desired state and evaluated by using a distant-to-target approach. At first, in cooperation with stakeholders and decision-makers for each indicator a desired target was defined, taking into account the MSWM criteria under the goals and rules of the ICoS. Then the current state of each indicator was scrutinized and evaluated. Stakeholders and decision-makers were asked to rate the current state of an indicator because not for all indicators a number is available. If the current value of an indicator is seen as below of 35% of the target state the indicator value is set to 0; if the current state achieves a range of 35% to 65% of the target state the indicator value is set to 2. In case an indicator reaches more than 65% of the target state the indicator value is set to 5. The results of the evaluation are recorded in the last three columns of Table 4.4.1 and then can be transferred into a radar diagram (Figure 6.1).

The number of alternatives as well as the valuing of the indicators should be coordinated with the involved stakeholders and decision-makers. The selected system to evaluate and value

the indicators influences considerably the findings and thus, the possible strategies to achieve a sustainable MSWM system.

To calculate the entire level of development according to the ICoS ($MSWD_{LoD}$) the individual results have to be aggregated:

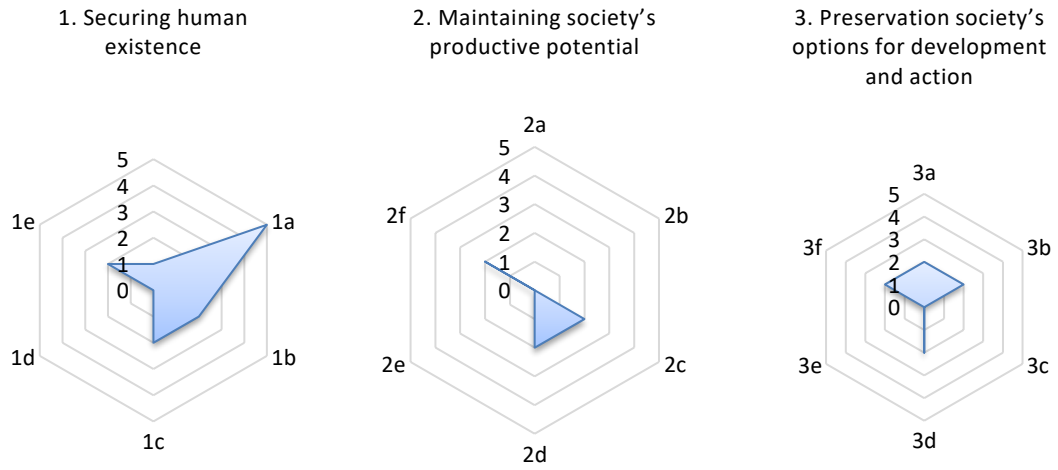
$$MSWD_{LoD} = \frac{\sum of\ the\ indicator\ values}{\sum of\ maximum\ score} * 100 \qquad \text{Eq.(2)}$$

It should be noted that eq. (2) implicitly assumes that all indicators are equivalent, but not the rules. Some rules are characterized by two indicators, i.e. indicators 1a, b, 2d, e, and 3a, b, are assigned in each case to one rule (Table 4.4.1). The assignment is an outcome of the discussion with the stakeholders and experts. Since each goal is characterized by six indicators, there is no bias towards a specific goal. Eq. (2) could also be used to calculate the $MSWD_{LoD}$ for each goal. In that case, only those indicators are taken into account, which are assigned to the respective goal.

5. Application and discussion of the MSWD

The results of the evaluation process of each indicator are visualized in Figure 2. To improve the clarity of the findings the indicators are grouped according to the respective goals. As mentioned above, the best performance of an indicator is rated with 5, the lowest with zero.

According to the stakeholders and decision-makers only indicator (1a: Share of households receiving basic waste collection services weekly) realizes the highest figure. Contrasting that four indicators are valued with zero (1d: Quantity of recyclable material recovered per worker compared to previous working month (%), 2a: Number of inspection actions related to recycling processes according to industry legislation compared to previous year, 3c: Documentation and records of all MSWM activities kept in archives to make follow up actions possible, and 3d: Associativism (e.g. number of waste pickers in cooperatives compared to previous year)).



Note: the indicators are listed in the Table 3.

Figure 2 - Radar Diagram representing the Belo Horizonte level of development

Comparing the goals, i.e. each diagram in Figure 2, it demonstrates that "securing human existence" exhibits the best development: the value of $MSWD_{LoD}$ in respect to that goal is about 37%. The goals "preservation society's options for development and action" reaches a $MSWD_{LoD}$ of 27%, while the $MSWD_{LoD}$ of "maintaining society's productive potential" is just 20%. Summing the derived figures, according to the participant responses, Belo Horizonte has currently obtained a level of development of 30% towards sustainability.

The findings were discussed with experts and stakeholders – a process which is recommended for building a widely accepted strategy for transforming a MSWM to a more sustainable one. Decisions could be more traceable. In general, the MSWD has a positive acceptance among the participants of the discussions. They confirmed that MSWD helped them to create a better vision and gave better idea about sustainability issues which has the chance to help them to work more effectively and collaboratively. The discussions demonstrated a positive understanding about how complex goals and rules of sustainability could be connected to measures that are already taken. According to a decision-maker, being able to explore the importance of collecting MSW to preserve human health can favor communication with citizens who observe this service only as a municipal obligation. Future discussions will allow stakeholders to frame the issues highlighted in the MSWD under sustainability lens. For instance, the industry representatives accentuate the importance to have a standard procedure to measure the quality of recycled materials at the source.

But, the participants highlighted one drawback of the MSWD. The main advantage of the MSWD is the transparency and continuous monitoring of MSWM. Under this perspective,

interviewed decision-makers argued that there is a need for incentives from the national level, e.g., laws or directives, to continue to use such an instrument.

The findings of this research were also discussed with sustainability experts such as the ICoS developers(Grunwald, 2016; Kopfmüller et al., 2001). The experts acknowledged the flexibility to verify how the goals and rules of the ICoS can be worked out with stakeholders and decision-makers.

The fact that the MSWD was based on challenges and characteristics of Belo Horizonte did not affect the double check. It helped to verify its reliability. However, the discussants pointed out some limitations of the MSWD framework. Depending on the chosen target value to achieving the highest indicator value, i.e. achieve at least 65% of a target could be ambitious, even though achievable. But, attaining a commitment of all stakeholders involved in MSWM to meet all MSWD targets requires great efforts, which are in particular difficult in emerging economy societies. Exceptional divergent interests between the involved stakeholders characterize emerging economy societies. However, the message to be left is that many indicators may not be more innovative, but re-evaluated and replaceable over time.

6. Conclusions

Developing frameworks attempting to apply sustainability concept is a challenge that requires a holistic perspective, handling of vast amounts of information of different nature and methodological rigour. MSWM is a well-known field that cuts across various disciplines and sectors, thus having broad implications on environment and society. Sustainability is a concept deeply discussed in the scientific community and less disseminated between stakeholders and decision-makers. MSWD is an innovative framework how to structure the communication about the complexities around sustainable development and MSWM. Hence, this study emerged the challenges imposed by MSWM with sustainability concept by adapting the goals and rules of the ICoS. This approach was succeeded in a form to analyze the potential to encourage cities' stakeholders to reduce their MSW, treat them properly, decrease the environmental impacts and arouse the commitment of all members involved in this system fairly.

The construction and application of the MSWD, although rather straightforward, is time-consuming, but by involving stakeholder and sustainability experts, the findings shall be rather robust. The setting shows the advantages of a sustainability concept for a city. The MSWD brings this practice of thinking about MSWM target towards sustainable development. For instance, respecting the environment, the set composed by the sustainability goal "maintaining society's productive potential" leads the technical aspects to improve MSWM while the set composed by the goals "securing human existence" and "preservation society's options for

development and action" work on the commitment between stakeholders. The role of citizens as an individual part of a society with responsibilities and commitments is strengthened by the goal of securing human existence.

Before this study, any stakeholder in Belo Horizonte never practiced the core principles of sustainability concept. Positive insights of stakeholders and decision-makers affirmed that their knowledge about sustainability was improved due to the construction of the MSWD. At the first glance, principles of sustainability as well as the ICoS were considered broad, scientific and not applicable to their day-a-day work challenges. MSWD has the potential to assist the development of public policies and provide advises to public managers in Belo Horizonte. For this use, the rules of MSWD should be institutionalized and supported by flexible organizational forms (such as cooperation and mixed public-private companies, see(Bel et al., 2010)). Round-tables, where stakeholders and decision makers are encouraged to apply the MSWD, are highly recommended to have joint-agreements and delegate who is liable to act on the rules and monitor the indicators accurately.

MSWD is recommendable to others emerging economy countries; but, pre-conditions need to be fulfilled. Firstly, the relevant stakeholders at municipal level shall recognize the current MSWM as a problem. Secondly, a structured platform of communication with representative of (formal and informal) stakeholders and decision should exist. Thirdly, to make use of the findings, scope and boundaries should be similar to the case of Belo Horizonte's city (e.g., from culture, climate, education and living standards). However, the conceptual approach of MSWD is, in principle, transferable and applicable globally in a sense that criteria and indicators can be updated by the method described in this study.

References

Adnan, H., morledge, R., 2003. Application of Dephi Method on critical sucess factors in joint venture projects in Malaysia construction industry. In: Egbu, C.O.,Tong, M.K.L. (Eds.), First Scottish Conference for POstgraduate Researchers of the Built and Natural Nevironment. Caledonian University, Glasgow, pp. 41-49.

Akadiri, P., Olomolaiye, P., Chinyio, E., March 2013. Multi-criteria evaluation model

for the selection of sustainable materials for building projects. Autom. ConStruct. 30, 113-125.

Al-Khatib, I.A., et al., February 2015. Public perception of hazardousness caused by

current trends of municipal solid waste management. Waste Manag. 36, 323-330.

Bel, G., et al., 05 April 2010. Similar problems, different solutions: comparing refuse collection in The Netherlands and Spain. Publ. Adm. 88 (2), 479-495.

Bosmans, A., et al., 2013. The crucial role of waste-to-energy technologies in enhancing landfill mining: a technology review. J. Clean. Prod. 55, 10-23.

Brazil, 2000. Nature and Conservation - Law 9.985/2000. Brazil: [s.n.] (in Portuguese).

Brazil, 2007. National Sanitation Law - 11.445/2007. Brasilia: Brazil (in Portuguese).

Brazil, 2010. National Policy on Solid Waste - Law 12305/2010 [S.l.]: [s.n.].

Burger, P., Christen, M., 2011. Towards a capability approach of sustainability. J. Clean. Prod. 19, 787-795.

Campos, H.K.T., April 2014. Recycling in Brazil: challenges and prospects. Resour. Conserv. Recycl. 12, 130-138.

Das, S., Bhattacharyya, B.K., September 2015. Optimization of municipal solid waste collection and transportation routes. Waste Manag. 43, 9-18.

Dobson, A., 1996. Environmental Sustainabilities: an analysis and a typology. Environ. Polit. 5, 401-428.

EEA, 2016. Municipal Waste Management across European Countries. European Environmental Agency, Brussels.

Environmental Ministery of Brazil, 2016. Integrated Municipal Solid Waste Plan. Brasilia. MMA.

Feo, G., Gisi, S., Williams, I., April 2013. Public perception of odour and environmental pollution attributed to MSW treatment and disposal facilities: a case study. Waste Manag. 33 (4), 974-987.

Ferri, G.L., Chaves, G.L.D., Ribeiro, G.M., June 2015. Reverse Logistics network for municipal solid waste management: the inclusion of waste pickers as a Brazilian legal requirement. Waste Manag. 40, 173-191.

Fujii, M., et al., 2014. Regional and temporal simulation of a smart recycling system for municipal organic solid wastes. J. Clean. Prod. 78, 208-215.

Gibson, R.B., 2006. Sustainability assessment: basic components of a practical approach. Impact Assess. Proj. Apprais. 24, 170-182.

Gray, R., January 2010. Is accounting for sustainability actually accounting for sustainability and how would we know? An exploration of narratives of organisations and the planet. Account. Org. Soc. I, 47-62.

Grunwald, A., 2016. Nachhaltigkeit verstehen - Arbeiten an der Bedeutung nachhaltiger Entwicklung, 2nd. ed. oekom, München (in German).

Grunwald, A., 2012. Sustainability assessment of technologies - an integrative approach. In: Ghenai, C. (Ed.), Sustainable Development - Energy, Engineering and Technologies - Manufacturing and Environment. INTECH - open science, Rijeka, Croatia, pp. 35-62.

Hartmuth, G., Huber, K., Rink, D., 2008. Operationalization and contextualization of sustainability at the local level. Sustain. Dev. 261-270.

Horizonte, Belo, 1990. Belo Horizonte Organic Law - Lei Org^anica do Município de Belo Horizonte. Belo Horizonte. in Portuguese.

IBGE, 2015. Demographic Census 2010-2015. Instituto Brasileiro de Geografia e Estatística, Brasilia.

Jeorissen, J., Coenen, R., Stelzer, V., 2005. Sustainable Housing and Construction.

Sigma, Berlin in German language. Original Title: Zukunftfähiges Wohnen und Bauen.

Kadir, S.A.S.A., et al., August 2013. Incineration, of municipal solid waste in Malysia: salient issues, policies and waste-to-energy initiatives. Renew. Sustain. Energy Rev. 24, 181-186.

Kopfmüller, J., et al., 2001. Sustainable Development Considered Integrative - Constitutive Elements, Rules, and Indicators. Sigma, Berlin. ISBN 3-89404-571-X. (in German).

Kopfmüller, J., 2011. The integrative sustainability concept of the Helmholtz association - the "risk habitat megacity" project as a case of application. In: Banse, G., Nelson, G.P.O. (Eds.), Sustainable Dvelopment - the Cultural Perspective. Sigma, Berlin, pp. 138-149.

Mantovani, V.A., et al., 2016. Evaluation and quantification of households wastes sent for recycling through a selective waste collection system. J. Solid Waste Technol. Manag. 42 (2), 116-127.

Marello, M., Helwege, A., September 2014. Solid Waste Management and Social Inclusion of Waste Pickers: Opportunities and Challenges. GEGI Working Paper, Boston, pp. 1-23.

Marshall, R.E., Farahbakhsh, K., January 2013. Systems approaches to integrated solid waste management in developing countries. Waste Manag. 33, 988-1003.

Martinez-Sanchez, V., Tonini, D., Moller, F., Astrup, T.F., March 2016. Life-cycle costing of food waste management in Denmark: importance of indirect effects. Environ. Sci. Technol. 50 (8), 4513e4523. ISSN 10.1021/acs.est.5b03536.

Menikpura, S.N.M., Gheewala, S.H., Bonnet, S., July 2012. Framework for life cycle sustainaiblity assessment of municipal solid waste management systems with an application to a case study in Thailand. Waste Manag. Res. 30 (7), 708-719.

Menikpura, S.N.M., Sang-Arun, J., Bengtsson, M., November 2013. Integrated solid waste management: an approach for enhancing climate co-benefits through resource recovery. J. Clean. Prod. 58 (1), 34-42.

Meyer, R., 2006. Integrative sustainability concept: operationalisation for the food and agriculture sector. In: ETHICS, P. O. T. 6. C. O. T. E. S. F. A. A. F. Ethics and the Politics of Food. EuSAFE, Oslo, pp. 214e219, 2006. Cap. 5.

Mora, C., et al., January 2014. Environmental and economic assessment for the optimal configuration of a sustainable solid waste collection system: a kerbside case study. J. Prod. Plan. Control Manag. Oper. 25 (9), 737-761.

Oguntoyinbo, O., April 2012. Informal waste management system in Nigeria and barriers to an inclusive modern waste management system: a review. Publ. Health 04, 441-447.

Plata-Diaz, A., et al., November 2014. Alternative management structures for municipal waste collection services: the influence of economic and political factors. Waste Manag. 34 (11), 1967-1976.

Prakash, S., Manhart, A., 2010. Socio-economic assessment and feasibility study on

sustainable e-waste management in Ghana. €Oko-Institut e.V., Freiburg, pp. 20-44.

Premalatha, M., et al., 2013. The promise and the performance of the world's first two zero carbon eco-cities. Renew. Sustain. Energy Rev. 25, 660-669.

Ripa, M., et al., January 2017. The relevance of site-specific data in Life Cycle Assessment (LCA). The case of the municipal solid waste management in the metropolitan city of Naples (Italy). J. Clean. Prod. 142 (1), 445-460.

Rogge, N., Jaeger, S., August 2013. Measuring and explaining the cost efficiency of municipal solid waste collection and processing services. Omega 41 (4), 653-664.

Rösch, C., et al., April 2009. Energy production from grassland - assessing the sustainability of different process chains under German conditions. Biomass Bioenergy 33 (4), 689e700.

Rutkowski, J., Rutkowski, E., December 2015. Expanding wordwide urban waste recycling:The Brazilian social technology in waste pickers inclusion. Waste Manag. Res. 15, 1084-1093.

Saeed, M.O., Hassan, M.N., Mujeebu, M.A., July 2009. Assessment of municipal solid waste generation and recyclable materials potential in Kuala Lumpur, Malaysia. Waste Manag. 29 (7), 2209-2213.

Sanneh, E.S., et al., December 2011. Introduction of a recycling system for sustainable municipal solid waste management: a case study on the greater Banjul area of the Gambia. Environ. Dev. Sustain. 13 (6), 1065-1080.

Sasaki, S., et al., August 2014. Household income, living and working conditions of dumpsite waste pickers in Bantar Gebang: toward integrated waste management in Indonesia. Resour. Conserv. Recycl. 89, 11-21.

Scheinberg, A., 2012. Informal Sector Integration and High Performance Recycling: Evidence from 20 Cities. WIEGO - Women in Informal Employement. Globalizing and Organizing, Cambridge, p. 36 (978-92-95095-15-1).

Schluchter, W., Rybaczewska- Bła_zejowska, M., 2012. Life cycle sustainability assessment of municipal waste management systems. Management 16 (2), 361-372.

SLU, 2014. Annual Report of Municipal Solid Waste - 2001 to 2014. Superitendencia de Limpeza Urbana - SLU, Belo Horizonte in portuguese.

Son, L.H., Louati, A., June 2016. Modeling municipal solid waste collection: a generalized vehicle routing model with multiple transfer stations, gather sites and inhomogeneous vehicles in time windows. Waste Manag. 52, 34-49.

Song, Q., Li, J., Zeng, X., 2015. Minimizing the increasing solid waste through zero waste strategy. J. Clean. Prod. 104, 199-210.

Surendra, K.C., et al., March 2014. Biogas as a sustainable energy source for developing countries: opportunities and challenges. Renew. Sustain. Energy Rev. 31, 846-859.

UN-HABITAT, 2010. Solid Waste Management in the World's Cities - Water and Sanitation in the World's Cities 2010. London (978-92-1-132218-7).

UNCED, 1992. Environmentallly sound management of solid wastes and sewage related issues. In: UNCED Agenda 21: Earth Summit. New York: United Nations Conference on Environment and Development. Cap. 21, p. 21.1.

UNEP, 2013. Guidelines for National Waste Management Strategies: Moving from Challenges to Opportunities. Nairobi, Kenya.

Vilijoen, J.M.M., Blaauw, P.F., Schenck, C.J., April 2016. "Sometimes You Don't Make Enough to Buy Food" - an Analysis of South African Street Waste Pickers' Income. ERSA, pp. 1-30.

Vinyes, E., O.-S.J., U.C., R.J., G.C.M., 2012. Application of LCSA to used cooking oil waste management. Int. J. Life Cycle Assess. 18, 445-455.

Wahab, M.H.A., et al., 2014. A conceptual approach of smart waste management with integrated web based system. In: IT Convergence and Security (ICITCS) International Conference. [S.l.]. IEEE, pp. 1-4.

Wassenaar, M., Groot, T., Gradus, R., May 2013. Municipalities' contracting out decisions: an empirical study on motives. Local Govern. Stud. 07, 414-434.

WCED, 1987. Our Common Future. World Commission on Environment and Development, Oxford.

Wilson, D.C., 2007. Development drives for waste management. Waste Manag. 25, 198-207.

Wilson, D., Velis, C., Rodic, L., May 2013. Integrated sustainable waste management in developing countries. Water Resour. Manag. 166, 52-68. WR2.

Zaman, A.U., 2014. Identification of key assessment indicators of the zero waste management systems. Ecol. Indicat. 36, 682-693.