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Urban household solid waste management in developing countries: a sustainable supply chain management perspective

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Thesis presented to the Programa de Pós-Graduação em Engenharia de Produção of the Departamento de Engenharia Industrial, PUC-Rio in partial fulfillment of the requirements for the degree of Doutor em Engenharia de Produção

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Abstract

Azevedo, Bruno Duarte; Carmo, Luiz Felipe R. R. Scavarda do (Advisor), Caiado, Rodrigo Goyannes Gusmão (Co-Advisor). **Urban household solid waste management in developing countries: a Sustainable Supply Chain Management perspective.** Rio de Janeiro, 2022. 91 p. D.Sc. Thesis – Departamento de Engenharia Industrial, Pontifícia Universidade Católica do Rio de Janeiro.

Urban household solid waste management (UHSWM) is a central problem in cities worldwide. The amount of waste produced daily in urban areas challenges society to improve its waste management (WM) practices. While developed countries like Germany have achieved respectable results with different UHSWM initiatives, developing countries still struggle to be effective with their policies. Given the constant growth of slums, the lack of economic resources, the social inequality, and the lack of participation of the main stakeholders of the process, countries like Brazil still have not found the right path towards a sustainable WM system, which is an essential part of the sustainable supply chain management (SSCM). Although the literature offers a large and growing number of publications in SSCM and UHSWM, there is a lack of studies linking the two themes, especially considering the practical reality of a developing country. The present thesis aims to fulfill this gap by analyzing UHSWM integrating the principles of the SSCM from the perspective of industry, public sector, and the local community, towards presenting alternatives for its improvement in Brazil. To achieve this goal, a multimethod approach with four main research steps was adopted: firstly, a Systematic Literature Review (SLR) in SSCM; secondly a longitudinal case study at the Rocinha slum located in the city Rio de Janeiro (Brazil); thirdly a within and cross-case analysis on UHSWM between two cities from Brazil (Macaé) and Germany (Münster); and finally, a survey with residents of the metropolitan area of Macaé to understand their acceptance of German practices. The violence present in Brazilian slums, as well as the need to live in another country were the biggest challenges linked to the case studies cited. The main research findings indicate that to tackle environmental problems related to UHSWM in developing countries, it is necessary to solve basic social issues related to education, security, and infrastructure, with the integration and support of government, local community, and industry. The comparison with the German UHSWM system indicates that the

Brazilian industry is still far from fulfilling the social and environmental pillars of SSCM and should be held economically responsible for the life cycle of its products, facing the principle of extended producer responsibility (EPR). This additional investment can enable improvement in work conditions, in technologies, and on regular public campaigns to increase education in important sustainable matters, leading to the formalization of the recycling chain. The pillars of the German system (i.e., clear laws, regular public campaigns, and fee methodology) appear as a viable solution to improve UHSWM in developing countries, however the research findings indicate that Brazilians are still not willing to pay (WTP) for all the costs involved in this process, especially those related to the collection and treatment of recyclables. This scenario reinforces the need for large educational campaigns, especially in schools, strengthening a holistic and multi-perspective view to increase the comprehension of the problem. To facilitate this agenda, a guideline with feasible alternatives to support policy makers in developing countries to deal with the challenges associated to UHSWM, and to meet the related Sustainable Development Goals (SDGs), is also presented. This research contributes to academics and practitioners providing empirical evidence to enrich the ongoing debate on the topic, as it not only presents real-life case situations in different realities, but also highlights issues that should be considered and managed in a real context to develop and implement appropriate techniques to deal with UHSWM in developing countries.

Keywords

Sustainability; Green supply chain; Triple bottom line; Developing countries; Sustainable supply chain management; Waste management; Slums.

Resumo

Azevedo, Bruno Duarte; Carmo, Luiz Felipe R. R. Scavarda do (Orientador), Caiado, Rodrigo Goyannes Gusmão (Co-orientador). **Gestão de resíduos sólidos urbanos em países em desenvolvimento: uma perspectiva da gestão sustentável da cadeia de suprimentos.** Rio de Janeiro, 2022. 91 p. Tese de Doutorado– Departamento de Engenharia Industrial, Pontifícia Universidade Católica do Rio de Janeiro.

A gestão de resíduos sólidos urbanos domésticos (GRSU) é um problema central nas cidades do mundo inteiro. A quantidade de resíduos produzidos diariamente nessas áreas desafia a sociedade a melhorar suas práticas de gerenciamento de resíduos. Embora países desenvolvidos como a Alemanha tenham alcançado resultados respeitáveis com diferentes iniciativas de GRSU, países em desenvolvimento ainda lutam para ser eficazes com suas políticas. Dado o constante crescimento das favelas, a falta de recursos econômicos, a desigualdade social e a falta de participação dos principais atores do processo, países como o Brasil ainda não encontraram o caminho certo para um sistema sustentável de gestão de resíduos, que é uma parte essencial da gestão sustentável da cadeia de suprimento (SSCM). Embora a literatura ofereça um grande e crescente número de publicações em SSCM e GRSU, há uma falta de estudos ligando os dois temas, especialmente considerando a realidade prática de um país em desenvolvimento. A presente tese visa preencher esta lacuna estudando formas de melhorar a GRSU nos países em desenvolvimento incorporando os conceitos da SSCM a partir da perspectiva da indústria, do setor público e da comunidade local, no sentido de apresentar alternativas para sua melhoria no Brasil. Para isso, foi adotada uma abordagem multimétodo com quatro etapas principais de pesquisa: primeiro, uma Revisão Sistemática da Literatura em SSCM; em segundo, um estudo de caso longitudinal na favela da Rocinha localizada na cidade do Rio de Janeiro (Brasil); em terceiro, uma análise interna e cruzada do GRSU entre duas cidades do Brasil (Macaé) e da Alemanha (Münster); e, finalmente, uma pesquisa com residentes da região metropolitana de Macaé para compreender sua aceitação quanto a adoção das práticas alemãs. A violência presente em favelas brasileiras, assim como a necessidade de moradia em outro país foram os maiores desafios ligados aos estudos de caso citados. Os principais resultados da pesquisa indicam que para enfrentar os problemas ambientais

relacionados ao GRSU nos países em desenvolvimento, é necessário resolver questões sociais básicas relacionadas à educação, segurança e infraestrutura, com a integração e apoio do governo, da comunidade local e da indústria. A comparação com o sistema alemão indica que a indústria brasileira ainda está longe de cumprir os pilares social e ambiental do SSCM e deve ser considerada economicamente responsável pelo ciclo de vida de seus produtos, enfrentando o princípio da responsabilidade ampliada do produtor (EPR). Este investimento adicional pode permitir a melhoria das condições de trabalho, investimento em tecnologias e em campanhas públicas regulares para aumentar a educação em assuntos importantes na área de sustentabilidade, levando à formalização da cadeia de reciclagem. Os pilares do sistema alemão (i.e., leis claras, campanhas públicas regulares e a metodologia de taxas) aparecem como uma solução viável para a GRSU nos países em desenvolvimento, porém os resultados da pesquisa indicam que a população ainda não está disposta a pagar (WTP) por todos os custos envolvidos no processo, especialmente aqueles relacionados à coleta/tratamento de recicláveis. Este cenário reforça a necessidade de grandes campanhas educacionais, sobretudo em escolas, que fortaleçam uma visão holística e multi-perspectiva capaz de ampliar a compreensão do problema. Para facilitar esta agenda, também são apresentadas diretrizes para apoiar os formuladores de políticas públicas nos países em desenvolvimento a lidarem com os desafios associados ao GRSU, e para cumprir as Metas de Desenvolvimento Sustentável (MDS) relacionadas. Finalmente, esta pesquisa contribui para que acadêmicos e profissionais forneçam evidências empíricas para enriquecer o debate contínuo sobre o tema, dado que esta não apenas apresenta situações de casos reais em diferentes realidades, mas também destaca questões que devem ser consideradas e gerenciadas na prática, no desenvolvimento e na implementação de técnicas apropriadas para lidar com o GRSU nos países em desenvolvimento.

Palavras-chave

Sustentabilidade; Cadeia de suprimento verde; Triplo Botton-Line; Países em desenvolvimento; Gerenciamento sustentável da cadeia de suprimento; Gerenciamento de resíduos, Favelas.

Summary

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Glossary

CE - Circular Economy

CSTR - Continuous Stirred-tank Reactor

DSD - Duales System Deutschland

EPR – Extended Producer Responsability

GNI – Gross National Income

GrSCM – Green Supply Chain Management

ICT – Information and Communication Technologies

IRS - Informal recycling sector

ISWM – Integrated Solid Waste Management

LCA - Life cycle analysis

MBI - Market-based instrument

NGOs – Non-Government Organizations

OM – Operations Management

PAYT - Pay-As-You-Throw

PFD – Process Flow Diagrams

PNRS - National Solid Waste Policy

RQ – Research Question

SCM – Supply Chain Management

SLR – Sistematic Literature Review

SSCM - Sustainable Supply Chain Management

TBL - Triple Bottom Line

TLR – Terciary Literature Review

UHSWM – Urban Household Solid Waste Management

WM – Waste Management

WTP – Willingness to Pay

1 Introduction

This introduction chapter presents first the research problem of this thesis, together with the motivation to comprehend its phenomena and its relevance and gaps. Then, it provides the research questions and goals, as well as its main contributions.

1.1. Research problem, motivation, and gaps

The emergence of concerns such as environmental protection, climate change, resource conservation, and the development of logistics operations and manufacturing technology has led several countries to implement formal systems for solid waste collection, recycling, and treatment. These systems benefit from the possibility of reducing environmental pollution, increasing the economy through the creation of new jobs, and generating income through the commercialization of recyclable materials (Xu et al., 2017; Zhou et al., 2021). Nevertheless, urban household solid waste management (UHSWM) remains a global challenge (Coelho and Lange, 2018; Kanhai et al., 2021), with consequences that frighten the world, with plastic pollution in the oceans (Brandon et al., 2019), plastic rain (Wetherbee et al., 2019), sewage clogging and flooding, the spread of diseases, and the negative impact on economic development (Kaza et al., 2018). Solid waste is being generated at a rate that outstrips the ability of the natural environment to assimilate it and municipal authorities to manage it (Tan et al., 2015; Azevedo et al., 2021a). Over the next 30 years, population growth, fast urbanization, and economic development may increase worldwide waste by 70%, achieving 3.4 billion tons of waste generated annually (World Bank, 2019).

Given the urgency of the theme, the “2030 Agenda for Sustainable Development”, adopted by all United Nations Member States in 2015, has specific sustainable development goals (SDGs) which are related to better UHSWM, as follows: SDG 12 which states: *"Ensure sustainable consumption and production patterns";* SDG 11: *"Make cities and human settlements inclusive, safe, resilient, and sustainable"*; and SDG 8 which states: *"Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all"* (UN, 2015). The targets to be achieved by these goals comprise inclusive and

sustainable urbanization; the reduction of the environmental impacts of cities; the reduction on waste generation through prevention, reduction, recycling and reuse; encourage companies to adopt sustainable practices; promote public procurement practices that are sustainable; achieve the sustainable management and efficient use of natural resources; achieve the environmentally sound management of chemicals and all waste throughout its life cycle; and to ensure that people everywhere have the relevant information and awareness for sustainable development. This approach also reinforces the need for better education, which is promoted by SDG 4: *"Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all"* (UN, 2015).

The most significant growth in waste production is expected to happen in developing countries (or emerging economies), including a percentage rise in packaging waste (Kaza et al., 2018; Ayeleru et al., 2020). In these countries, the unplanned growth of many cities has resulted in infrastructural challenges that weakened the capacity of national and municipal governments to increase household waste management (WM) service levels at the rate they are demanded (Marshall and Farahbakhsh, 2013; Guerrero et al., 2013; Lohri et al., 2014; World Bank, 2019; Alzamora and Barros, 2020; Azevedo et al., 2021a). The continuous growth of slums is a clear example of the problem (Azevedo et al., 2019). With illegal occupation, high population density, and a lack of adequate infrastructure, slums appear as a major challenge to achieve proper UHSWM (Coffey and Coad, 2010; Elgizawy et al., 2016; Rashid et al., 2018; Azevedo et al., 2019). The number of slum dwellers reached more than one billion in 2018, which corresponds to 24% of the urban population (UN, 2021). Additionally, WM professionals in developing countries also must also deal with the lack of general infrastructure, lack of budget, corruption, informal workers, low educational level of the population, and community distrust of the government (Tadesse, 2008; Guerrero et al., 2013; Marshall and Farahbakhsh, 2013; Lohri et al., 2014; Azevedo et al., 2019; Massoud et al. 2021).

Once the public sector is unable to manage alone the increasing rate of solid waste generation (Tan et al., 2015), it is essential to increase industry participation within the topic (Azevedo et al., 2019; Azevedo et al., 2021a). In this sense,

gradually, increased laws are formulated to hold the manufacturer of the material responsible in case of any environmental damage caused by it, which is named as the Expanded Producer Responsibility (EPR) principle (Guarnieri et al., 2015; Ferreira et al., 2017). Moreover, the incessant search for some competitive advantage, since pressures from consumer groups and non-governmental organizations have led these organizations to seek certifications that qualify them as "environmentally friendly," appears as a driving force for a new posture of companies (Srivastava, 2007; Walker et al., 2008). Initially, the focus was only on issues related to the environment (Singh and Trivedi, 2016), with the emergence of concepts such as GrSCM - Green Supply Chain Management (Srivastava, 2007; Qinghua et al., 2008). However, given that sustainability is a broader concept, composed, at least, of three distinct dimensions: economic, environmental, and social (Elkington, 1998), the organizational management model is transforming itself to adjust companies to achieve economic objectives not only in an environmentally responsible manner but also socially (Buil et al., 2016; Dubey et al., 2017; Caiado et al., 2022). The Sustainable Supply Chain Management (SSCM) incorporates these three basic pillars, embracing GrSCM as part of its field, and states that industry has responsibility for its products and packaging, from a project to its final disposal (Ahi and Searcy, 2013).

In Brazil, the Federal Government launched the National Solid Waste Policy (PNRS) through the Law 12.305/2010 (MMA, 2020) in 2010. Aiming to improve the local situation, this law defined shared responsibility for the product life cycle between public power, industry, and final consumers (Rebehy et al., 2017); the mandatory implementation of reverse logistics, based on the EPR principle (Guarnieri et al., 2015); and the inclusion of waste-pickers in the formal recycling system (Fuss et al., 2020). However, after more than one decade, most of the targets have not been achieved (Cetrulo et al., 2018; ISLU, 2020; ABRELPE, 2020). Household waste collection is far from universalization, more than 40% of the waste isn't proper disposed of, and waste hierarchy is still not applied in the great majority of the cities (ISLU, 2020; ABRELPE, 2020). As regards recycling, the processes continue to be based on informality and on the precarious labor conditions for the waste-pickers (Campos 2014, Gutberlet, 2015; Azevedo et al., 2019; Azevedo et al., 2021a), who face daily occupational hazards, such as long working

hours; exposures to physical, chemical, mechanical, biological, ergonomic, and social agents; and frequent work accidents (Zolnikov et al., 2018). The numbers brought by ISLU (2020) and ABRELPE (2020) attests to the failure to turn the PNRS into good practical results in the Brazilian household solid waste recycling chain: according to them, the recycling rate in Brazil is lower than 4%.

1.2. Research Question, Goals and main contributions

The scenario above-described attests to the relevance and to the urgency of the theme. In this sense, the present thesis poses the following research question (RQ): **"How to improve UHSWM in developing countries such as Brazil by incorporating SSCM concepts"?** The research´s main goal is to analyze UHSWM integrating the principles of the SSCM from the perspective of industry, public sector, and the local community, towards presenting alternatives for its improvement in Brazil. The author understands that the conversion to sustainable UHSWM should be understood as a holistic and complex process that encompasses a sociotechnical transition involving a revolutionary shift at infrastructural, institutional, and social levels (Morone et al., 2020). These transitions are characterized as major shifts in society that can take decades to gradually develop, and which may include a variety of interacting elements, including industry, science, technology, markets, policy, culture, and civil society. As presented, the landscape is already putting pressure on the existing regime for UHSWM (e.g., resources overexploitation, water pollution, spread of diseases, etc.). Furthermore, niche initiatives are already under way. In this sense, a multi-level perspective approach is required, as it can provide a holistic comprehension of elements and actors involved in the process (Geels, 2012).

To fulfill the main objective of the thesis, the following specific goals (SGs), are posed:

- SG 1: Identify the major topics covered in the SSCM literature, revealing the main findings and gaps;
- SG 2: Develop a framework for UHSWM from the SSCM perspective in areas of slums;

- SG 3: Analyze UHSWM from the perspective of two different realities, one from Brazil, representing the case of developing countries, and one from Germany, representing a benchmark case, which can be of practical relevance to improve household recycling in urban areas of developing countries;
- SG 4: Analyze the feasibility of implementing a German UHSWM practice in a real-world scenario in Brazil.
- SG 5: Propose a set of guidelines with feasible alternatives in UHSWM to assist cities in developing countries to meet the SDGs.

Towards addressing the thesis´ RQ and goals, a multimethod approach is conducted (Creswell and Plano Clark, 2011), as the combination of qualitative and quantitative research provides a better understanding of a research problem. It also gives multiple angles argument, with different "pictures", and more evidence (Creswell et al., 2003). The research design is classified as sequential exploratory as the qualitative phase precedes the quantitative phase. The focus of this design is to explore a given phenomenon, in this case SWM. The priority is given to the qualitative aspect of the study; however, the findings of both phases are integrated during the interpretation phase. The research counts with four main research steps: first, a Systematic Literature Review (SLR) in SSCM; then a longitudinal case study in the Rocinha slum located in the city of Rio de Janeiro (Brazil); then a within and cross-case analysis on UHSWM between two cities, one from Brazil (Macaé) and another from Germany (Münster); and finally, a survey with residents of the metropolitan region of Macaé to understand their acceptance on German practices. Figure 1 synthesizes the match of this multimethod approach with the thesis specific goals. It is important to highlight that the violence present in Brazilian slums, and the need to live in another country were massive challenges to allow proper field work, a mandatory step in case studs. Furthermore, the exploratory survey was made during the pandemic, which demanded different tools and strategies to achieve the planned goals

The research steps are presented in Figure 2, which also bring the different publications in conferences, books and academic journals associated to this thesis.

The master dissertation of the author, Azevedo (2008), was used as an input for the longitudinal case study. As demonstrated, the triangulation of the main results brought by steps 1 to 4 were the central base for the author to build the guideline that answers the main RQ of the thesis.

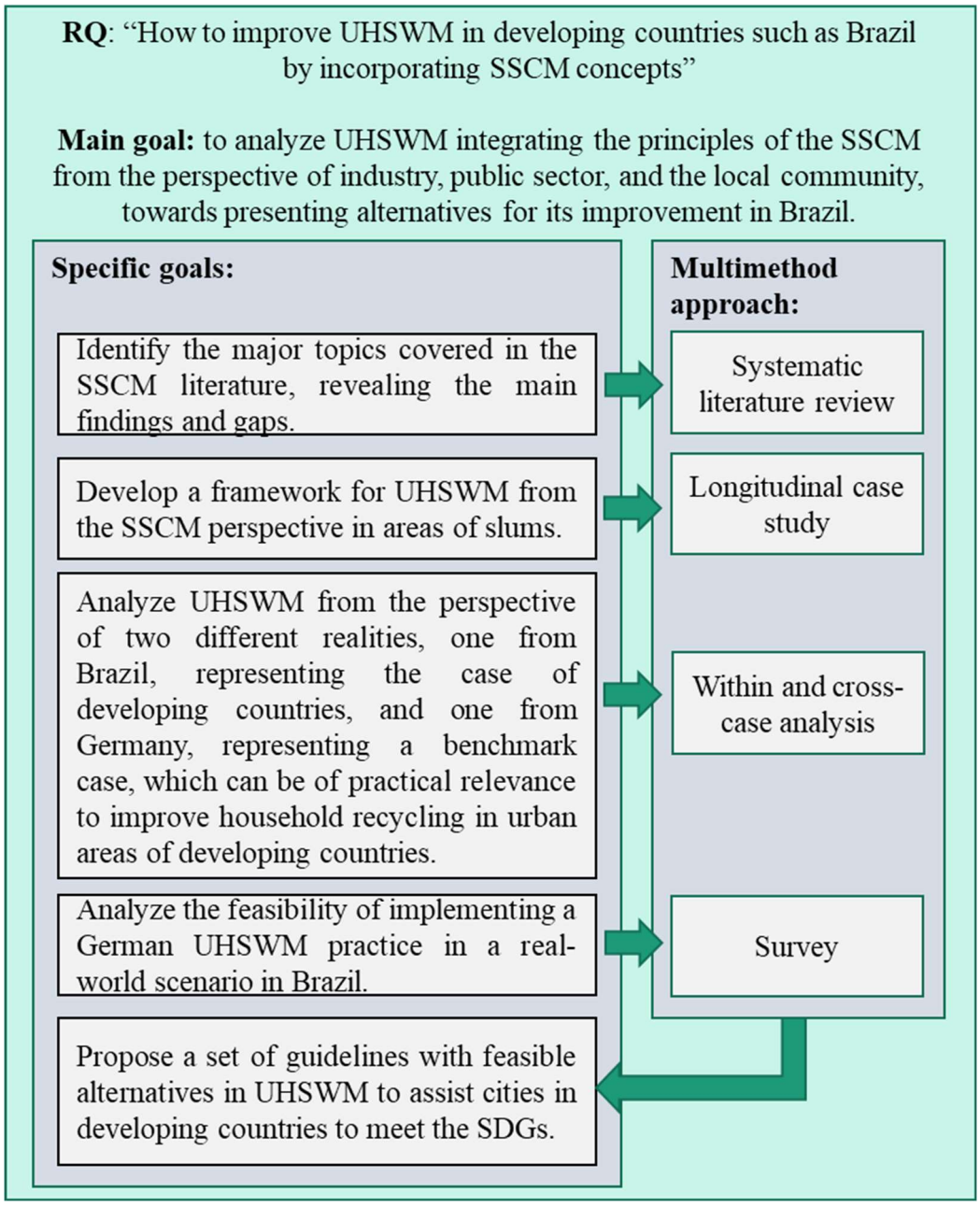

Fig. 1: Synthesis of Methods

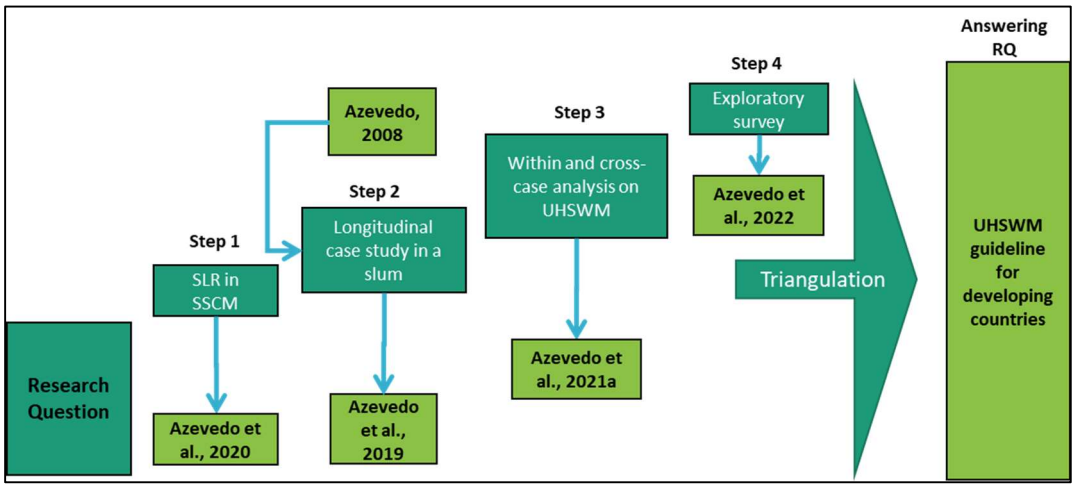

Fig. 2: Research steps and related publications

This thesis addresses the practical application of the SSCM concept within the context of UHSWM in developing countries, which presents itself as a fertile field for research. By strengthening the union between the socio-environmental area and Operations Management (OM), this thesis contributes to the literature in different manners:

- Providing knowledge about good waste practices, their responsibilities, and consequences of poor WM, as suggested in Mukama et al. (2016) and Yang et al. (2020);
- Improving the comprehension on the impact of UHSWM from the holistic perspective of sustainability, as suggested in Tan et al. (2015), Singh and Trivedi (2016), Kruger et al. (2018);
- Reinforcing the need for industries to take more responsibility over the end-of-life of their products (including their packaging), as suggested by Li et al. (2016) and Azevedo et al. (2019);
- Discussing interventions capable of changing the UHSWM Brazilian reality, improving the practical application and effectiveness of the PNRS in different regions of the country as suggested in Cetrulo et al. (2018) and Azevedo et al. (2021a);
- Presenting alternatives to the informal recycling sector - IRS, who still have their returns deeply dependent on the secondary resource price (Steuer et al., 2018; Yang et al., 2020; Azevedo et al. 2021a);

- Embracing the transdisciplinary aspects of UHSWM (Chammas et al., 2020), and the connections related to global supply chains and circular economy (Julianelli et al., 2020).
- Encompassing the revolutionary changes needed at the infrastructural, institutional, political, and social levels to green the waste sector, as cited by Morone et al. (2020).
- Complementing other studies on WTP for waste management in emerging economies, such as Ezebilo (2013), in Nigeria, Challcharoenwattana and Pharino (2016), in Thailand, Han et al. (2019), in China, and Massoud et al. (2021), in Lebanon, aiming generalization and addressing the specific case of Brazil.

This thesis is organized into six chapters, with this first being the introduction. Chapter two provides the literature background. Chapter three describes the multimethod approach adopted, while chapter four presents the research findings. Chapter five discusses the results and presents eight guidelines for UHSWM in developing countries. Finally, the last chapter offers the main conclusions and suggestions for future research. One may notice that different parts of the thesis were published along the years of this research, disseminating the preliminary findings in academic journals and book chapters. To avoid redundancy among these publications and this thesis, additional details can be obtained in Azevedo et al. (2019), Azevedo et al. (2020), Scavarda et al. (2020), and Azevedo et al. (2021a; 2021b), and Azevedo et al. (2022).

2 Literature background

This chapter presents the theoretical foundation of the research. It first discusses the evolution from GrSCM to SSCM. Then it presents the concepts of Solid Waste Management (SWM) and UHSWM, bridging them with sustainable matters. Finally, it highlights the missing link between SSCM and UHSWM in developing countries, placing the current research within the literature.

2.1. From Green Supply Chain Management (GrSCM) to Sustainable Supply Chain Management (SSCM)

GrSCM is the application of environmental management principles to the entire cycle of client orders, including design, procurement, manufacturing, assembly, packaging, logistics and distribution (Ahi and Searcy, 2013). For Srivastava (2007), it consists of integrating environmental thinking into supply chain management, including product design, material selection and supply, manufacturing processes, delivery of the final product to consumers, and management of the product at the end of its useful life. The scope of implementing practices in GrSCM ranges from "green purchasing" to integrated supply chain life cycle management, moving from supplier to manufacturer, consumer and closing the cycle with reverse logistics (Qinghua et al., 2008).

As the life of a product, logistically, does not end with the delivery to the customer, behind the concept of reverse logistics must be the product life cycle analysis (LCA), which is a method to assess the environmental impacts related to a particular product or process, from the acquisition of raw materials to their final disposal (Coelho and Lange, 2018). However, for this to occur, companies must consider the logistical management, along with the end-of-life management, not as a form of organized disposal of the product, but as a "closed circuit", that is, as a strategy of economic recovery and environmental value (Dias, 2006). Such practices may involve source reduction activities, such as: (1) recycling, reuse, purification of inputs, design of less dense packaging; (2) collecting environmental data from suppliers, products or processes; (3) efforts to eliminate waste, such as biodegradation and nontoxic incineration. Examples of "green" supply chain management practices may include reducing packaging and waste, working with

suppliers on their environmental performance, developing eco-friendly products and reducing carbon emissions associated with freight (Walker et al., 2008).

Since the approach brought by GrSCM does not incorporate the "social" pillar cited by Elkington (1998) on his Triple Bottom Line (TBL) view for sustainability, the organizational management model is transforming itself to adjust organizations to the achievement of economic goals not only environmentally, but also socially responsible (Buil et al., 2016). In this sense, the SSCM aims to improve the three dimensions of sustainable development: economic, environmental and social, and has a broader definition, combining sustainability with efficient supply chain management, and integrating the concept of Green Supply Chain Management as a part of its field (Seuring and Muller, 2008; Ahi and Searcy, 2013). SSCM incorporates environmental performance, social performance, and economic contribution - or what has been referred to as an intersection of three sustainable development spheres (Ansari and Kant, 2017), and has become a major issue in academia (Miemczyk, 2012; Seuring, 2013; Touboulic and Walker, 2015; Dubey et al., 2017). Seuring and Muller (2008) highlights that social and environmental aspects has to be extended beyond the boards of the industry. As an example, the authors cited cases of clothing distributors blamed for problems occurring during production along their supply chains, often with suppliers associated with sub-human working conditions and environmental contamination. More recently, some scholars have been adopting a five-dimensional approach, including technical, and institutional aspects, beyond the TBL pillars, especially for energy production systems sustainability aspects (Ebrahimi and Rahmani, 2019), as the TBL aspects alone do not address holistically a country's energy system (Iddrisu and Bhattacharyya, 2015). Although this is an interesting approach, this thesis follows the TBL approach and suggests the inclusion of the five-dimensional approach for future research.

Nevertheless, there has been much confusion about sustainability, with many researchers and managers using the term for subjects that were exclusively related to the environment and economics (Carter and Easton, 2011, Azevedo et al., 2020). Given its more quantifiable characteristics, the prevalence of environmental and economic approaches to SSCM seems to correlate with the emphasis on

performance. There is certainly a gap around the social and human dimension of sustainability (Touboulic and Walker, 2015; Dubey et al., 2017, Köksal et al., 2017). Köksal et al. (2017) shows a continuous lack of research on the social dimension of the triple bottom line at SSCM in their article on social and sustainable SCM in the textile and apparel industry. According to their findings, the internal orientation of a company is the main supporting factor in SSCM practices. When supply chain focal companies are not sustainability oriented and provide final value to their products aiming only at profit maximization, sustainable risk management practices do not result in anything, being locked in a vicious circle (Köksal et al., 2017). Since traditional perspectives were strongly influenced by the neoclassical economy, the competitive paradigm seems to dominate the SSCM landscape (Touboulic and Walker, 2015). In this sense, sustainability issues may require a change in mentality and business models. This could allow the transition to new concepts of consumption and the purpose of a company, as well as develop alternatives to the dominant growth discourse. This new mentality corroborates Marshall and Farahbakhsh (2013) who defended the need for a more holistic view, with methodologies capable of integrating socio-cultural, environmental, economic, and technical spheres in SWM. True sustainability occurs at the intersection of environmental, social, and economic performance, but it is of the utmost importance that all actors involved (e.g., government, local community, and industry) find a joint vision of sustainability (Azevedo et al., 2019).

2.2. Urban Household Solid Waste Management (UHSWM)

The Directive 2008/98/European Community (EC), define waste as any substance or object which the holder discards or intends or is required to discard (UNEP, 2013). Waste management refers to the treatment of solid wastes, liquid wastes, or atmospheric emissions prior to their release to the environment (Scur and Barbosa, 2017). In general, municipal solid waste is composed of electronic waste (e-waste), construction and demolition waste, medical care waste, agricultural and industrial, and waste produced by offices, shops, schools, and households (UNEP, 2013). The latter includes food waste, paper, wood, textiles, rubber, plastics, metal, and glass and is named in this research as urban household solid waste.

The GrSCM framework offered in Srivastava (2007) present solid waste management as part of the green operations. According to it, the main steps for proper SWM are source reduction, pollution prevention, and final disposal. The term pollution prevention focuses on preventing pollution at source, both in products and in manufacturing processes, instead of having to remove it after manufacturing them. Processes such as recycling plants, composting and incineration are waste treatments or treatment processes and cannot be referred to as final disposal. The final waste disposal process, in general, consists of landfills and industrial landfills (Rubio et al., 2019). However, due to the constant population growth in urban centers, which reduces the options of areas for the construction of landfills, together with the increase in environmental restrictions, it is necessary to rationalize the use of landfills to increase their useful life. A tool frequently used to describe the order of preferred actions for reducing and managing waste according to its environmental impacts is the waste hierarchy. The most desired option is characterized by prevention, followed by reuse, recycling, and recovery (as well as energy recovery) and, lastly, safe disposal (Morone et al., 2020). Therefore, a new and different perspective on the organizational and operational systems of production and consumption is changing this linear economy approach: the Circular Economy (CE). CE is focused on restoring the value of used resources, providing economic, environmental, and social benefits to organizations that replace the traditional perspective of 'take, make, use and dispose' (Jabbour et al., 2018). In the same direction, Dubey et al. (2017) present green product design; green procurement; green packaging; reverse logic; social dimensions; public awareness and organizational culture and corporate strategy as facilitators of SSCM, making the connection with solid waste management and its practices, such as reuse, reduction, and recycling.

UHSWM has become one of the central problems in urban planning in developing countries (Guerrero et al., 2013; Rebehy et al., 2017; Coelho and Lange, 2018) as it is being generated at a rate that outstrips the ability of the natural environment to assimilate it and municipal authorities to manage it (Tan et al., 2015; Azevedo et al., 2019). Given the durability of the materials produced, mainly plastic, the pollution caused by improper UHSWM is becoming not only a local problem but also a global one. In a study that analyzed 239 cleanups and brand

audits spanning 42 countries and 6 continents, thousands of brands whose packaging relies on the single-use plastics that pollute oceans and waterways globally were identified (Greenpeace, 2018).

In many developed countries, UHSWM programs are formal and have the effective participation of the population, of the government, and of the industry, which is responsible for the entire life cycle of its products, including the payment of the costs related to collection, treatment, and final disposal (Da Cruz et al., 2013; Rebehy et al., 2017; Azevedo et al., 2021a). As an example, Germany is known as one of the world references in relation to legislation focused on responsibility, recycling, treatment and waste disposal schemes (Da Cruz et al., 2013; Ferreira et al., 2017). The success of the German strategies has led other EU countries to implement EPR policies for packaging waste, which has increased their recycling rates throughout the years (Rubio et al., 2019). All packaging manufacturers and distributors of packaging operating in Germany are entirely liable for their waste and must comply with and finance integrally a system that ensures their recycling and recovery operations (Ferreira et al., 2017). Therefore, the German packaging industry founded the Duales System Deutschland (DSD), a logistical system that picks up household packaging in parallel to the existing municipal waste-collection systems. This system has a fee applied to each product that varies according to the weight and the type of material used in the package. This methodology encourages and rewards companies that work green design strategies in their product development, which is aligned with the SSCM paradigm and the concept of circular economy. Germany has been improving its results, achieving in 2017 a recycling rate of 67%t of typical household waste (BMU, 2018). The current challenge is the need to improve technologies, processes, and legislation towards a truly circular system, where a discarded product can be transformed into a new one, with the same characteristics (BMU, 2018).

Compared to those in developed countries, residents in developing countries, especially the urban poor, are more severely impacted by unsustainably managed waste (World Bank, 2019; Massoud et al., 2021). According to Coffey and Coad (2010), the collection process is the most important aspect in low- and middle-income countries. For instance, in cities of Ethiopia, waste separation is poor and

there is widespread illegal dumping, with dire consequences for the environment (Tadesse, 2009). Waste-pickers play an active role to collect, sort and commercialize recyclable waste in several developing countries like Argentina (Villalba et al., 2020), Brazil (Gutberlet et al., 2017), Chile (Rojas et al., 2018), India (Sharma et al., 2018), Turkey (Yıldız-Geyhan et al., 2019), Malaysia (Moh and Manaf, 2017) and China (Steuer et al., 2018). Furthermore, the indiscriminate growth of the slums makes SWM an uncontrollable problem (Elgizawy et al., 2016; Azevedo et al., 2019). According to Habitat-UN (2013), one in every six human beings is a slum dweller. Present in most big cities of developing countries, slums are characterized by the absence of government plans and services, illegal occupations, and the lack of proper sanitation systems (Friesen et al., 2018). They are also usually associated with high population density and a lack of adequate housing. Azevedo et al. (2019) revealed different UHSWM limitations in slums, such as: absence of traffic control agencies; local commerce's chaotic system of loading and unloading; impossibility of night operations due to the violence; institutionalization of a parallel power with force of law, which prevents the inclusion of external agents of change; steep gradient on the hills; high density of houses; lack of streets; disbelief in the state; and low educational level of the population.

Scholars have been analyzing and reporting different initiatives to face WM challenges in the developing countries. Grounded on the assessment of 66 municipalities, Olay-Romero et al. (2020) found an incipient implementation of solid WM, emphasizing the need to increase the collection coverage and to improve the conditions of the disposal sites in most of the municipalities in Mexico. Also in Mexico, Cervantes et al. (2020) used a new set of indicators to evaluate some aspects of the governance of municipal SWM and found a strong correlation between the development and implementation of legislation and policies on waste management systems and its correct operation. They also found a substantial presence of the informal sector in WM and concluded that the absence of official fees for the service hinders the recovery of expenses directly. In Malaysia despite the government's efforts, waste management remains one of the critical environmental issues (Tan et al., 2015). In this sense, the Malaysian federal government implemented a Strategic Plan 2014–2020 focusing on subjects like

mindset, behavior and culture, aiming to achieve a recycling rate of 22% by 2020 (Moh and Manaf, 2017). In Chile, the government set a target to recycle 25% of municipal inorganic waste by 2020 (Rojas et al., 2018). However, results from these initiatives are still not satisfactory. By 2018 a little more than half of local governments had implemented recycling, and the separate collection rate is much lower than in any OECD country with available data (Valenzuela-Levi, 2019). In Pakistan, although UHSWM became a relevant issue, most of the municipal waste collected is still disposed of in open dumps without any pretreatment or environmental protection actions (Ali et al., 2019). Lebanon suffers with the negative repercussions associated with improper SWM for decades, with governmental authorities struggling to manage locally generated waste in a sustainable manner. The core barriers that hinder the adoption of sustainable WM practices include the lack of appropriate facilities and adequate infrastructure, weak public knowledge on sorting, recycling, and composting, as well as the lack of guiding policies (Massoud et al. 2021). Other studies focused on the willingness to pay - WTP of its inhabitants for improving WM services: Ezebilo (2013) analyzed the WTP for improved residential waste management in Nigeria; Challcharoenwattana and Pharino (2016) evaluated the WTP of dwellers to finance a recycling program in Thailand; and Han et al. (2019) studied the WTP and to participate in domestic waste management in rural areas of China.

In Brazil, more than one decade after launching the PNRS, most of its targets have not been achieved (Cetrulo et al., 2018). According to Conke (2018), the main barriers to the development of waste recycling strategies are the lack of knowledge about aspects of programs; an unequal distribution of the costs and benefits; the lack of infrastructure and a deficit of professional administration. The reality is that government, industry, and consumers have not yet found an adequate solution to the social and environmental issues related to UHSWM (Rebehy et al., 2017; Azevedo et al., 2021a).

2.3. Sustainable Supply Chain Management (SSCM) and Urban Household Solid Waste Management (UHSWM) – a missing link in developing countries

Despite literature that offers numerous SSCM models for more than a decade (Carter and Rogers, 2008; Seuring and Muller, 2008; Ahi and Searcy, 2013; Touboulic and Walker, 2015; Gao et al., 2017; Ansari and Kant, 2017; Dubey et al., 2017; Rajeev et al., 2017; Abbasi, 2017; Bastas and Liyanage, 2018), there is an absence of models specifically aimed at solid waste management, mainly for the reality of developing countries. This absence in the literature is accompanied by a lack of participation of the industry in UHSWM (Azevedo et al., 2019, Azevedo et al., 2021a) which contributes to a high percentage of participation of the IRS in UHSWM in developing countries (Gutberlet, 2015). As presented in the last section, waste-pickers play an active role in the UHSWM of developing countries. This reality is not sustainable over the TBL perspective (Elkington, 1998) and the delivered results are not satisfactory. For instance, in Brazil most of the waste-pickers earn less than a minimum wage and "the low income of the recyclers poses a major livelihood obstacle and basically keeps this population in poverty" Gutberlet (2015, p 27).

The existence of slums, the lack of adequate infrastructure and the low level of education of the population require a new approach to industries selling products in developing countries and aiming to create a sustainable supply chain (Azevedo et al., 2019, Azevedo et al., 2021a). In this sense, it is urgent to consider the transdisciplinary aspects of UHSWM (Chammas et al., 2020). Yet, there is an absence of investigation regarding the social dimension of TBL, specially the ethical (Dubey et al., 2017) and human (Touboulic and Walker, 2015) aspects of sustainability, and a need for more empirical research and qualitative methods in SSCM (Carter and Easton, 2011), particularly in developing countries (Köksal et al., 2017). It is necessary to understand the impact of USWM from the holistic perspective of sustainability (Kruger et al., 2018), providing sufficient knowledge about good waste practices, their responsibilities, and consequences of poor waste management (Mukama et al., 2016). The understanding of specific realities particular to developing countries and their irregular occupations, such as slums

should also be explored (Marshall and Farahbakhsh, 2013), where the successful SWM approaches conducted in developed countries may have limited applicability (Fuss et al., 2018). There is a need for industries to take responsibility for the end-of-life of their products (including their packaging), as suggested by Li et al. (2016) and Azevedo et al. (2021a). Finally, it is urgent to build sustainable waste management strategies (Tan et al., 2015), involving all relevant stakeholders, from government officials, industry and formal private sector services providers to local communities and rag pickers (Marshall and Farahbakhsh, 2013).

3 Research methods

This chapter describes the multimethod approach adopted in this thesis, which was designed according to Figure 1 (introduced in Chapter 1). Mixed methods is the procedure of collecting, analyzing, and combining quantitative and qualitative techniques in the same research design. The central assumption justifying this approach is that the interaction between different methods provides better analytical possibilities (Creswell and Plano Clark, 2011). And that it will help and support the author to better understand the transition to sustainable UHSWM, which can be seen as a holistic and complex process that encompasses a socio-technical transition (Morone et al., 2020), and requires a multi-level perspective approach (Geels, 2012). The research is designed as exploratory sequential and attended to the Creswell checklist, which will be presented in the following sections. In the Systematic Literature Review (SLR) conducted for the review in SSCM, and in the case study approach conducted at the Rocinha slum (Brazil) (respectively Section 3.1 and Section 3.2.), the approach was mainly qualitative. The within and cross-case analysis conducted on UHSWM of two relevant cities from Brazil and Germany (Section 3.3), combined both quantitative and qualitative approaches, ensuring a comprehensive understanding of the problem (Ali et al., 2019). Finally, the exploratory survey aiming to understand the feasibility of applying the German model in Brazil (Section 3.4) has a quantitative approach, but it was formulated with insights brought by the initial qualitative phase.

3.1. Systematic Literature Review in Sustainable Supply Chain Management (SSCM)

The SLR was classified as exploratory and descriptive, with data collection from secondary sources and qualitative approach through a thematic synthesis analysis to map the main areas of research and methodological procedures. The literature on SSCM is considered mature, which can be reflected on the high number of existing literature reviews on the subject. This fact makes the subject ready for a tertiary study (TLR) (Thomé et al., 2016). Based on the main steps of SLRs (Garza-Reyes, 2015; Thomé et al., 2016), the TLR was composed of five steps: (1) mapping RQs; (2) setting search strings and databases; (3) determining inclusion / exclusion

criteria; (4) selecting and evaluating studies which includes: initial filtering by titles and keywords, secondary filtering by abstracts, applying backward snowballing and full-text content analysis; and (5) reporting descriptive and thematic synthesis results. This section provides information on the conduct of the TLR. Additional information can be obtained in Azevedo et al. (2020).

The TLR outlined was guided by the following RQ: "*How is the state of the art related to literature reviews that address SSCM?*" This overall RQ was divided into three specific ones:

RQ1 - What are the main research topics in SSCM?

RQ2 - What are the main findings and gaps in the SSCM literature?

Firstly, in this research the main keywords were considered related to literature reviews, which were pointed out by Thomé *et al.,* (2016) in their research protocol: "research synthesis", "systematic review", "evidence synthesis", "research review", "literature review", "meta-analysis", "meta-synthesis", "mixed-method synthesis", "narrative reviews", "realist synthesis", "meta-ethnography", "state-of-the-art", "rapid review", "critical review", "expert review" and "conceptual review". Moreover, a few more common keywords were added such as "extensive review", "structured review", "integrative review" and "integrative literature review".

Next, extensive discussions and multiple brainstorming sessions between the researcher, his advisor and his co-advisor were carried out to make a survey of keywords related to the supply chain and their relationship with sustainability, such as: "supply chain", "sustainability", "green supply chain" and "sustainable supply chain". The search process used Scopus (Elsevier) and ISI Web of Science (Thomson Reuters Scientific), using the Boolean logic "AND" and "OR". Two data bases were chosen following the advice of Thomé et al. (2016) and the ones chosen followed Magon et al. (2018) due to being complementary and adequate to sustainability in OM. Although this research focused on the term "sustainable supply chain", the screening process also considered the keyword "green supply chain", since other dimensions of sustainability, such as social, were already implicitly exploited in previous research within the concept of "green". Later, in full-text content analysis it was decided to exclude the green supply chain research that focused exclusively on the environmental dimension. In addition,

bibliographies of all selected papers were scanned for additional papers (snowballing) to go beyond the search keywords and database limitations, as recommended in Thomé et al. (2016). The strings were continuously refined, resulting in 107 reviews found in Scopus and 125 in WoS.

The inclusion / exclusion criteria followed Caiado et al. (2017) being linked to the knowledge area (Environmental Science, Energy, Engineering, Business, Management and Accounting and Chemical Engineering) publication category (Peer-reviewed academic journal) and language (English). The search combined the keywords into title, abstract or keywords, limited to papers published in peer-reviewed journals up to May 23, 2018.

After an analyzing process of abstracts and full text content, 24 reviews complied with the selection criteria. To ensure complete coverage, there was also an inclusion of three articles through snowballing and thus, 27 reviews represent the bibliographic portfolio of this research. Next, the researchers created a database using Microsoft Excel worksheet where the articles were coded according to bibliographic characteristics of the source, type of study, and contextual dimensions like evaluated object, gaps, findings, topics addressed, sustainability dimensions. Then, the technique of content analysis was used, as it is considered by Seuring and Gold (2012) as an effective tool to analyze a bibliographic portfolio in a systematic and rule-governed way. The articles were categorized and organized by concepts, following the subsequent steps (Mayring, 2014): (1) delimitation of the material to be analyzed; (2) descriptive analysis of the formal characteristics: main journals and years of publication; (3) selection and construction of analytical dimensions and categories in an inductive way: thematic synthesis of the content in four categories; (4) evaluation of the material according to the categories: summary of the results and gaps within these categories. An inductive approach was used to categorize the knowledge from the literature, iteratively, testing and revising by constant comparison between the categories and the information collected.

Finally, there was a thematic synthesis analysis, in which individual articles were categorized and organized by concepts. Results are presented in the section 4.1 of this thesis.

3.2.Case Study at Rocinha (Brazil)

Case studies are the preferred strategy when the "how" or "why" questions are being asked, when the researcher has little control over events, and when the focus is on a contemporary phenomenon within some real aspects (Yin, 2014). In this regard, this section describes the research steps oriented to understand the UHSWM in Rocinha through a deep longitudinal case study (2008 - 2018), with a field investigation following the approach of Voss et al. (2002). This research is an extension of the author's Master dissertation (Azevedo, 2008) and additional information on this case study can be obtained in Azevedo et al. (2019).

The research design steps conducted highlight the logical sequence that connects the empirical data to a study's initial RQ and to its conclusion (Yin, 2014) and are presented in Figure 2.

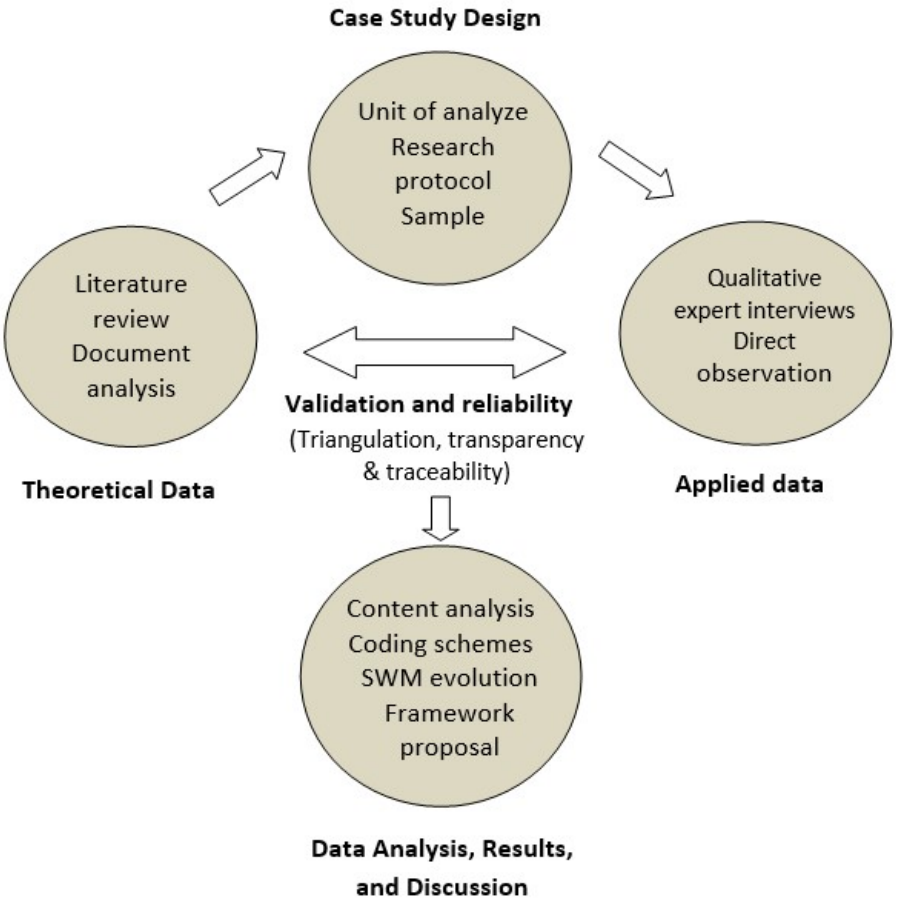

Fig. 3: Case study´s steps (adapted from Azevedo et al., 2019)

To accomplish the first step, data was collected from 2008 until 2018 and then organized into a case study database, keeping separated evidentiary data and individual researcher reports (Yin, 2014). The main sources of evidence were documentary reviews, official public data and literature search in Scopus and Web of Science.

The second step consists of the case study design. The Rocinha community is officially reported as Brazil's most populous urban slum (IBGE, 2011). The lack of reliable data about the place was also a serious constraint, however its geographical position in the middle of the city of Rio de Janeiro, drug dealers' conflicts, access limitations, given its hills and disordered constructions, and population size also contribute to the importance of understanding the research phenomenon through the lens of SSCM. Following the guidelines of Yin (2014), a fieldwork protocol, including case selection and sampling, pre-visit preparations, on-site data collection instruments, contacts, triangulation, recording, analysis, and communications strategies, was performed to guide the author of this thesis during his visits to the community.

At the third step, field visits for direct observation and semi-structured interviews with the primary government and local community stakeholders were conducted. One of the co-authors spent six months visiting the community in 2008, to generate the first diagnostic with some propositions. Given the size of the community, it took many weeks to understand the reality and its particularities. The barrier imposed by violence, which made access to external agents difficult, was the biggest challenge faced during the field research. In this sense, the researcher always had to be accompanied by a resident during the field observations and many times had to deal with the presence of armed men. In 2018, the same researcher spent two more months performing the same process to understand what happened in a ten-year period. In both cases, the leaders of the main organizations involved with SWM at Rocinha were interviewed. The qualitative expert interviews were conducted on-site, and were in-person, with pre-designed questions posed to guide the process. Most interviews were recorded and later transcribed. Finally, to guarantee triangulation of the findings (Yin, 2014), the data collected from the

interviews were compared with those collected during the documentary review and field observations.

The fourth step, the information gathered (e.g., literature review, recorded interviews, field observations, and documents) was analyzed using content analysis (Mayring, 2014). As recommended by Thome et al. (2016), the material was organized with suitable coding schemes following themes related to SWM in Rocinha and the main stakeholders: government participation, which encompasses waste collection, public equipment and public organizations; local community participation, which analyses the population involvement; and industry participation, which analyses the presence of the industry with regard to end-of-life strategies of their products and packages. Next, the evolution of the coded broad themes was evaluated. Finally, proposals to improve SWM in Rocinha were presented in a framework that adapts the SSCM framework offered by Carter and Rogers (2008), with a multi-stakeholder perspective offered in Marshall and Farahbakhsh (2013) and Rebehy et al. (2017), all supported by the enablers presented in Dubey et al. (2017).

In a case study, any discovery or conclusion will be more convincing if it goes through constructs checks (Yin, 2014). The combination of evidence sources, while alternating between analysis and interpretation, usually denotes triangulation (Denzin, 1978; Yin, 2014), and presents itself as an attempt to protect itself against researcher bias and establish a line of evidence during analysis within the case (Taylor and Bogdan, 1998). As a verification of the validity of a construct, this research used a large amount of data sources. For example, the data obtained from the Solid Waste Management Plan of Rocinha - RSWP (Toledo, 2009) were contrasted with the official data researched (IBGE, 2011) and with the field investigation. Results from this case study are reported in section 4.2 of this thesis.

3.3.Within and cross-case analysis – Münster (Germany) and Macaé (Brazil)

The third step of the research consisted of within and cross-case analysis to compare UHSWM from a Brazilian and a German city. The researchers used embedded units of analysis, which means that within each single case (e.g., a

country) attention was given to a subunit (the actual focused city) (Bredenhoff et al., 1978). The chosen German city is Münster, known as the capital of bikes, has around 310.000 inhabitants (Abfallbilanz, 2019), and calls itself ‘‘The World’s Most Liveable City” (Stadt-Münster, 2019). On the other side, the chosen Brazilian city, Macaé, is known as the Brazilian oil capital and has 256.000 inhabitants (IBGE, 2020). Despite having a gross national income GNI per capita similar to those related to high-income economies (IBGE, 2020) Macaé faces all the difficulties related to rapid growth and economic inequality. Both cities were considered equally comparable based on a set of parameters derived from the literature (e.g., population size). Furthermore, focusing on municipalities with less than one million inhabitants is crucial in current urban sustainability discourses since 48% of the world’s urban dwellers reside in urban settlements with less than 500,000 inhabitants, and only 12% live in the megacities of 10 million inhabitants or more (Pojani and Stead, 2015; UN, 2021).

A within-cases analysis and cross-case comparisons grounded a multiple case analysis (Ye et al., 2018), which followed the five steps presented in Figure 3. Furthermore, to guarantee its adequacy, both case studies trailed the methods presented in the section 3.2. Additional information can be obtained in Azevedo et al. (2021a).

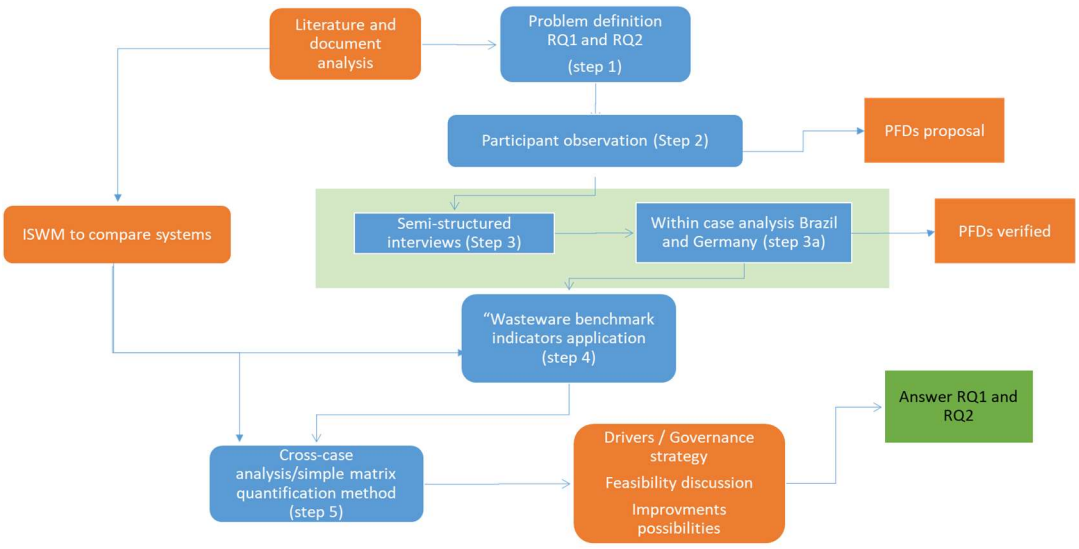

Fig. 4: Cross-case research steps (adapted from Azevedo et al., 2021a)

The first step was based on literature and document analysis, both related to each case study. The literature analysis followed the steps of a scoping review from Armstrong et al. (2011). The document analysis consisted of the review of the Brazilian and the German laws.

At the second step, to develop a holistic understanding of the system in the field, the participant observation method was adopted. This method provides an accurate representation of a culture, improving the knowledge and perception built from the literature. It also increases the study validity if combined with additional strategies such as document analysis and interviews (Kawulich, 2005). In this sense, the author of this thesis lived for at least six months in Münster and Macaé. During this time, besides the personal experience of living as a local citizen, he interacted with local habitants and visited most of the facilities involved with the cities´ UHSWM system to provide primary data collection. As a result, two process flow diagrams - PFDs were developed to represent the flows of the household waste, and picture all the links and transactions between all the stakeholders, including the final destinations of waste materials. (Wilson et al., 2012).

The third step focused on the PFDs validation. To accomplish this, semi structured face-to-face interviews with key experts were conducted. In Münster, the interviewees were the Head of disposal center facilities, the Head of adult education/ networking of the municipal cleaning company (AWM), the Assets and Services supervisor of Remondis, and the Head of Institut für Abfall, Abwasser und Infrastruktur-Management (INFA). In Macaé, the interviewees were the Secretary of municipal infrastructure, the former municipal Secretary of the Environment, a Local entrepreuner in recycling and the operations manager of the municipal cleaning company, Limpatech. The interviews followed a previously established Field Work Protocol, attached as Supplementary Information in Azevedo et al. (2021), encompassing all topics which should be addressed along the interview.

Once the PFDs were approved, the researchers moved to step four and applied the ‘wasteaware’ benchmark indicators (qualitative and quantitative) for ISWM in cities (Wilson et al., 2012). In this method, quantitative indicators comprise of Public Health-collection, Environmental controlled disposal and Resource Management – reuse, reduce and recycling (as percentages) whereas the qualitative

indicators are part of governance covering user and provider inclusivity; financial sustainability; and the national policy framework and local institutions (Wilson et al., 2013). These indicators have already been used in case studies from more than 50 cities around the world, which makes the method convenient for SWM comparison purposes (Wilson et al., 2013). Moreover, the adherence with SSCM pillars (green design, green procurement, green packaging, reverse logistics, social dimensions, public awareness and organizational culture and corporate strategy) was evaluated (Dubey et al., 2017; Azevedo et al., 2019).

In the fifth step, for a better understanding of the existing solid WM systems of the assessed cities, the simple matrix quantification method adopted in Rana et al. (2017), Sharma et al. (2018) and Ali et al., (2019) was used. The proposed grading system used in the 'wasteaware' benchmarks is low (L), Low/Medium (L/M), Medium (M), Medium /High (M/H) and High (H), a certain weightage has been assigned to each of these. The assigned weights are (L = 1, L/M = 2, M = 3, M/H = 4, H = 5).

Finally, to answer the proposed RQs, the feasibility of the German solid waste flow in the Brazilian context was considered. As an example, by using the values of the license calculator offered by the German first dual system company (DerGrünePunkt, 2020), and the numbers of a cooperative presented in Gutberlet (2015), they estimated what could be the improvement of the Brazilian recycling system if the fee applied to the German industry was adopted in Brazil. The values were converted to dollars considering the exchange rate of 03.01.2020, where U$ 1.00 equals R$ 3.75 and 1 Euro equals U$ 1.10. As a first attempt in this direction, the author of this thesis calculated the potential additional income the cooperative would receive if the Brazilian industry had to pay the German fee for its commercialized packaging.

In this exploratory and descriptive research step, the combination of multiple sources of evidence enabled the triangulation of data sources and guaranteed the reliability and validity of the findings constructs (Azevedo et al., 2019). Furthermore, the use of a fieldwork protocol combined with case study documents collected during the study (Yin, 2014), guaranteed the reliability of the data by

providing the necessary transparency and traceability for replicating research procedures. Results from this research step are presented in section 4.3 of this thesis.

3.4.Survey - willingness to pay (WTP)

The fourth step of the thesis aimed to evaluate the feasibility of adopting EPR schemes, such as the one applied in Germany in Brazil by analyzing the Brazilian consumers' willingness to pay to access a formal system for waste recycling. The author understands that the additional costs created by adopting EPR structures would eventually be passed on to consumers. Therefore, it's important to investigate the level of acceptance of these consumers to higher prices. To this end, an exploratory survey (Forza, 2002) was conducted among the population of the metropolitan region of Macaé, considered the oil capital of Brazil. It is located on the coast of the state of Rio de Janeiro and has 416,694 inhabitants (Macaé and Rio das Ostras - IBGE 2020). The research question that guided the research is: Is the local population in Brazil willing to pay to formalize the existing recycling structures towards improving UHSWM? The choice of the region is related to the continuity of the research presented in Azevedo et al. (2021a). Additional information can be obtained in Azevedo et al. (2022).

A great challenge in survey research is determining the appropriate sample size that is representative of the population under study (Bartlett et al., 2001). The research used the Yamane's formula (Challcharoenwattana and Pharino, 2016):

$$n = \frac{N}{1 + N(e)^2}$$

Where:

n= minimum returned sample size =?

N = the population size = 416694

e = margin of error = 0.07

n = 416694/ (1+416694*(0.07) ²)

n = 204

The minimum returned sample size was established in 204 respondents, considering a 7% margin of error.

The first version of questionnaire was built based on other similar studies, such as Challcharoenwattana and Pharino (2016), and Han et al. (2019). To evaluate if the questions were clear and if the answers were sufficient to meet the goals of the research (Forza, 2002), the first version was sent as a pilot version to a small group of people (64 persons among researchers, and regular households of the studied region) by instant messaging apps (Whatsapp). Some changes regarding wording and clarity were necessary to build the final version of the document.

As the survey was realized during the pandemic, the author used as a tool the program "Surveymonkey" to build the final version of the structured questionnaires, and to collect and organize all the answers. The program generates a link that could be shared among the population by using different devices such as social networks (Instagram, Facebook); instant messaging apps (Whatsapp); and, to a lesser extent, mailing lists of the author and his advisors. The result is a non-probability sampling that followed the snowball sampling (Salvia et al., 2019). A filter was applied to guarantee only valid answers from the unit of analysis studied. Furthermore, considering that the biggest challenge of non-probability sampling is to deliver the same kind of non-biased results that probability sampling gives, the socioeconomic characteristics of the respondents were also analyzed (Ezebilo, 2013; Challcharoenwattana and Pharino, 2016; Han et al. 2019).

Table 1 presents the questions adopted in the survey, including the socioeconomic data from the respondents. The first three questions were binary, with two possible answers: yes or no. The fourth question was also closed, however there were five options to choose: R$ 0.00; R$ 10.00; R$ 20.00; R$ 30.00; and beyond R$ 40.00. The fifth question was hybrid, with three closed options (I already pay a lot of taxes; I already have a solution that works for me; I already pay too much taxes), and an open field for other answers. Following, there were seven questions to better understand the socioeconomic profile of the respondents. Table 2 presents the description of the explanatory variables adopted (Ezebilo, 2013). The majority came from the analysis of the studies above cited, except for the one that investigates how dwellers see the working conditions of waste-pickers.

Table 1: Questions of the survey

Questionnaire:
Do you consider that the collection of recyclables in your city is adequate?
How do you dispose of your recyclable waste?
Do you consider the working conditions of the waste-pickers to be adequate?
How much would you be willing to pay per month for a formal company, with formal workers using proper PPE and equipment, to collect recyclables from your doorstep once a week?
If you answered no to the previous question, what would be your main reason for not paying for collection?
Socioeconomic date:
What is your gender?
What is your education level?
What city do you live in?
Which neighborhood?
How many people live in your residence?
What is your age?
What is your monthly family income?

Table 2 - Description of explanatory variables

Variables	**Definition**
Gender	Female, Male
Education level	Lower than college degree; With college degree or higher
Number of residents	One; Two to four; More than four
Age	Less than 18; 19 – 30; 31 – 50; 51 – 60; more than 60
Monthly family income	Up to 2,000 BRL; Between 2,000 and 5,000 BRL; Between 5,001 and 10,000 BRL; More than 10,000 BRL
Considers the collection of recyclables adequate	Yes; no
Destination of recyclable waste	Collector; Conventional collection truck; Recyclable collection Truck; Recyclable collection Truck; Other (specify); Does not separate
Considers the working conditions of recyclable collectors adequate, n (%)	Yes; no

The survey was conducted from September to November of 2021 and was concluded when 214 valid responses were obtained.

To access the WTP of the respondents, a Logistic Regression (Massoud et al., 2021) was performed where the response variable was only "Yes" (agree to pay) and "No" (do not agree to pay). However, in this analysis no variable was significant. Then, a Multinomial Logistic Regression was performed in R Software (R Core Team, 2021) to determine the impact of socioeconomic and demographic factors on participants' WTP (Mavrodi et al., 2021). WTP was set as the dependent variable, and gender, education level, number of residents, age, monthly family income, opinion on the quality of recyclable waste collection and its destination, and working conditions of the waste-pickers were set to be influencing factors. This technique was adopted as logistic regressions are extensively used to analyze the main factors that influenced WTP (Afroz, et al., 2011; Triguero et al., 2016; Hans et al., 2019). Differences among individuals' attitudes were assessed using the Chi-square test, in which the significant values are all smaller than 0.05. Thus, all the independent variables were retained.

4 Research findings

This chapter presents the main results obtained using the multimethod approached described in Chapter 3. Each section addresses one of the specific goals (SGs) of the thesis. Section 4.1 offers main topics, findings, and gaps in SSCM, addressing SG1 “to identify the major topics covered in the SSCM literature, revealing main findings and gaps”. Section 4.2 presents a framework for UHSWM in slums from the SSCM perspective, addressing SG2: “to develop a framework for UHSWM from the SSCM perspective in areas of slums”. Section 4.3 presents the results of the within and cross-case comparison in UHSWM between a Brazilian and a German city, addressing SG3: “to analyze UHSWM from the perspective of two different realities, one from Brazil, representing the case of developing countries, and one from Germany, representing a benchmark case, which can be of practical relevance to improve household recycling in urban areas of developing countries”. Finally, section 4.4 presents the results of the exploratory survey to understand the feasibility of a German UHSWM practice in a real-world scenario in Brazil, addressing SG4: “Analyze the feasibility of implementing a German UHSWM practice in a real-world scenario in Brazil”. SG5 will be addressed in the discussions, presented in Chapter 5.

4.1. Sustainable Supply Chain Management (SCM) as a driver for sustainability

The tertiary LR analyzed 27 reviews in SSCM, identifying the main topics addressed, the main findings and the gaps for future research. The review attested to the evolution of the theme in recent years, with many authors indicating new lines for further research. Despite the misunderstanding in the past, in general, current sustainability comes with a holistic perspective, which includes economics, environmental and social issues as its pillars. Adopting the inductive approach used by Seuring and Muller (2008), the main research topics identified in the review were: (1) dimensions of sustainability; (2) Framework, models, and new definitions; (3) theories in SSCM; (4) managerial aspects aligned with SSCM. This section is organized along these topics. Additional information can be obtained in Azevedo et al. (2020).

One of the most recurrent issues when discussing SSCM is the gap around the social and human dimensions of sustainability (Touboulic and Walker, 2015; Dubey et al., 2017, Köksal et al., 2017, Fiorini and Jabbour, 2017; Ciccullo et al., 2018). Despite many managers having heard of the term sustainability, most supply chain personnel had very different viewpoints of what sustainability really is (Carter and Rogers, 2008) and it is still not clear if it has changed. The prevalence of environmental and economic approaches to SCM given their more quantifiable characteristics, seems to be correlated with the emphasis on performance. In this sense, there is a need to develop key social performance metrics, with a methodology established for their assessment (Martínez-Jurado and Moyano-Fuentes, 2014; Abbasi, 2017). Additionally, it is necessary to address behavioral issues like human resource management and supply chain partner relationship management to reach the goals of SSCM (Singh and Trivedi, 2016).

Many reviews propose new frameworks and/or models and/or definitions for SSCM (Carter and Rogers, 2008; Seuring and Muller, 2008; Ahi and Searcy, 2013; Touboulic and Walker, 2015; Gao et al., 2017; Ansari and Kant, 2017; Dubey et al., 2017; Rajeev et al., 2017; Abbasi, 2017; Gunasekaran et al., 2017; Bastas and Liyanage, 2018). These models/definitions capture all the key characteristics of both business sustainability and SCM (Ahi and Searcy, 2013), serving as a tool to help organizations to diagnose their current situation, to evaluate their SSCM strategies, and to achieve full realization of their plans to gain competitive advantage. (Dubey et al., 2017). Though, for Köksal et al. (2017), since the suppliers are forced to remain competitive and gain orders while simultaneously attempting to reduce costs, these strategies might cause pressure. Once the traditional perspectives had been strongly influenced by neo-classical economics, the competitive paradigm seems to dominate the SSCM field. In this sense, sustainability issues may require a shift in mindsets and business models. This could allow transitioning to new conceptions of consumption and a firm's purpose, as well as developing alternatives to the dominant discourse of growth (Touboulic and Walker, 2015).

The review also attests to the need of more practical studies to test and/or validate the proposed models for SSCM (Carter and Rogers, 2008, Carter end Easton, 2011, Ansari and Kant, 2017, Köksal, et al., 2017, Dubey et al., 2017,

Rajeev, et al., 2017, Ciccullo et al., 2018). As the concept is still evolving, there is a need for both, qualitative and quantitative survey methods, especially at the supplier level located in developing countries (Köksal, et al., 2017, Rajeev, et al., 2017).

Theory-building efforts in SSCM remain scarce, with the predominance of a few popular imported macro theories, having implications on the conceptualization of SSCM and the topics researched to date (Touboulic and Walker, 2015). A theoretical background is often missing (Seuring and Muller, 2008; Abbasi and Nilsson, 2012; Alexander et al., 2014; Dubey et al., 2017) and survey research should follow taking up theoretic conceptualization of SSCM (Gold et al., 2010). Systematic reviews depict that little theoretical research in SSCM are validated with statistical tools, mathematical modeling or at least an empirical study. One possible reason is the fact that companies are not eager to share information related to the environmental and social dimensions, unless it is mandatory by regulatory authorities (Rajeev et al., 2017).

From a theory development perspective, studies are mostly dispersed and are far from reaching a theoretical consolidation (Rajeev et al., 2017). In this sense, there is a huge opportunity to examine current SSCM phenomena by using integrated organizational theories (Dubey et al., 2017).

The review also demonstrated that IT systems gained attention from researchers and practitioners (Singh and Trivedi, 2016), supporting activities in the value chain such as technology development (Carter and Rogers, 2008). To achieve sustainable goals in the lean-agile SSC, distribution and logistics systems must be continually improved and Information and Communication Technologies (ICTs) must be implemented to cooperatively integrate customers and suppliers (Martínez-Jurado and Moyano-Fuentes, 2014). In this sense, the use of new technologies plays a significant role for SSCM, as information systems can bring benefits to organizations, suppliers and customers, acting as an important tool for SSCM (Fiorini and Jabbour, 2017). Big data analytics and data mining can be utilized to assess current practices in terms of their environmental impact, which could further lead to removal of inefficiencies and bottlenecks associated with supply chains (Caiado et al. 2022).

The use of indicators is another topic that comes in the managerial aspects of SSCM. Free market economies with open and active supply chains, should develop globally agreed sustainability norms / standards / requirements / rules (Abbasi, 2017). In this sense, it is urgent to have a set of standardized indicators that guide and help the agents of the chain in measuring sustainability. As instance, Global Reporting Initiative - GRI sustainability indicators, which are developed through multi-stakeholder contributions, can help to structure the performance metrics, including a large part of the supply chain, and not only the first tier (Beske-Janssen et al., 2015).

Finally, sustainability goals require close interaction between all firms involved in the SC to ensure a TBL performance on a product's total life cycle. Valuable and rare resources and capabilities emerging from supply-chain-wide collaboration are prone to become sources of sustained inter-firm competitive advantage (Gold et al., 2010). In this sense, researchers should focus on behavioral aspects like coordination, collaboration and motivation of members in a SC (Singh and Trivedi, 2016).

4.2.Urban Household Solid Waste Management (UHSWM) in slums from the Sustainable Supply Chain Management (SSCM) perspective

Although the literature offers a large and growing number of publications in SSCM and SWM, there are no studies focused on SWM in slums of developing countries from the SSCM perspective. Supported by a ten-year longitudinal case study conducted in the largest slum of Brazil (Rocinha), this section aims to address this gap by developing a framework for SWM in slums from the SSCM perspective. Additional information on this case study can be obtained in Azevedo et al. (2019).

4.2.1.SWM and SSCM at Rocinha

Reported as Brazil's most populous urban slum (IBGE, 2011), and with a daily average garbage production comparable to a medium-sized Brazilian city, Rocinha's community is an interesting starting point for discussing SSCM and SWM. Its geographical position in the heart of the city of Rio de Janeiro, drug dealers' conflicts, access limitations given its hills and disordered constructions, and

population size, legitimize the importance of understanding the phenomenon through the lens of SSCM.

The size and complexity of the community are shocking. According to the local government, Rocinha has several motorcycle taxis, bus lines, supermarkets, and bank branches, with a total of 6,529 companies or entrepreneurs (EGP, 2009). The lack of reliable data is another serious constraint. There are no recent surveys available about government policies, statistics and data about the area. Even the number of inhabitants is not clear, with estimations ranging from 69,161 inhabitants, distributed in 25,352 households (IBGE, 2011), to 116,000 thousand inhabitants (Toledo, 2009). Complementing the barriers brought by Leal Filho et al. (2016) for developing countries, the fieldwork revealed different SWM limitations at Rocinha, among them: absence of traffic control agencies; the local commerce's chaotic system of loading and unloading; the impossibility of night operations due to the violence; the institutionalization of a parallel power with force of law, preventing the inclusion of external agents of change; steep gradient of the hills; high density of houses; lack of streets; disbelief in the state; low educational level of the population. Together with the absence of data, these barriers challenge researchers to develop appropriate SWM strategies that are aligned with the SSCM.

Although SSCM encompasses the three dimensions of sustainable development (Ahi and Searcy, 2013), the reality experienced in Rocinha shows that, in practice, the industry performance is limited to its facilities, not covering downstream members of its supply chain (e.g., points of distribution and sales at Rocinha), as well activities that cover the entire life cycle of its products. No type of action related to the SSCM enablers described by Dubey et al. (2017) in the community was revealed, which leaves a huge liability in fulfilling the social and environmental pillars (Ciccullo et al., 2018), and confirming the lack cited by many authors in the literature (e.g., Köksal et al., 2017).

The situation at the slum demonstrated that industry is fully transferring the responsibility for the end-of life management of its products to the public authorities and to the local community. This practice is contrary to the EPR implemented by some European countries (Da Cruz et al., 2013) and cited in the PNRS, which emphasize the responsibility of the industry for their packaging

waste. The situation gets worse given the fact that the local community in Rocinha have a daily routine surrounded by grave problems, such as high violence, lack of quality education, prejudice, exhausting work routines, aggravated by the lack of good quality public infrastructure. Consequently, the residents normally deny the sense of responsibility for the correct management of the waste they produce (Elgizawy et al., 2016), corroborating the words of the manager of a local project: "There are warnings, but people don't have respect." The result is evident in contaminated ditches, uneven dumps, rivers of packages flowing to the ocean, and rates of bad WM co-related diseases (e.g., dengue and leptospirosis) higher than those found in neighboring areas (SMS, 2018).

4.2.2. Framework for SWM in slums from a SSCM perspective

Even though some progress has been observed in the last ten years, the research findings show that in practice, the performance of SWM stakeholders, particularly industry, is far from fulfilling the social and environmental pillars of SSCM at Rocinha. Towards filling this absence, a framework for SWM from the SSCM perspective in areas of slums is proposed (Figure 4). It adapts the SSCM framework offered by Carter and Rogers (2008), with the multi-stakeholder perspective offered in Marshall and Farahbakhsh (2013) and Rebehy et al. (2017), all supported by SSCM enablers presented in Dubey et al. (2017). Complementing the industrial focus, the framework encompasses government and community viewpoints, reinforcing a holistic and multi-perspective view, and the need for integrated management for better SWM in slum areas. Considering that each stakeholder has to understand their actions over a TBL perspective, every proposal must have an integrated planning perspective. True sustainability occurs at the intersection of all three dimensions (Carter and Rogers, 2008), but it is necessary that all stakeholders involved (i.e., government, local community, and industry) understand the need for sustainable solutions. In this sense, as presented in Azevedo et al. (2019), the four central proposals were those that involve the TBL concept and must have the involvement of all stakeholders, as follows: 1 - Industry, government and residents must develop instruments to make more feasible and attractive the trade of recyclable materials sorted by the local community. This solution is associated with the enablers green procurement, reverse logistics and social dimensions; 2- Industry

and government should assist the local community to develop local workshops for remanufacturing and repair of defective products, as well as the trading of used products. This solution is aligned with the following enablers: reverse logistics, social dimensions, green product design and green procurement; 3- Industry should develop and use alternative packages and materials, which are more environmentally friendly. At the same time, local government need to support this strategy with tax incentives, while the local community must give preference to them when buying. This solution is based on the enablers green packaging; reverse logistics; social dimensions and public awareness; 4 - Industry, government and local organizations must develop educational campaigns to encourage local households to properly dispose of their waste. This strategy can make the collection cheaper, and the work of scavengers present in the community more dignified and healthier. Furthermore, these campaigns must strengthen the proper waste management as an opportunity for income generation and social inclusion. This solution attends to the enablers: green product design; green procurement; green packaging; reverse logistics; social dimensions; public awareness and organizational culture and corporate strategy.

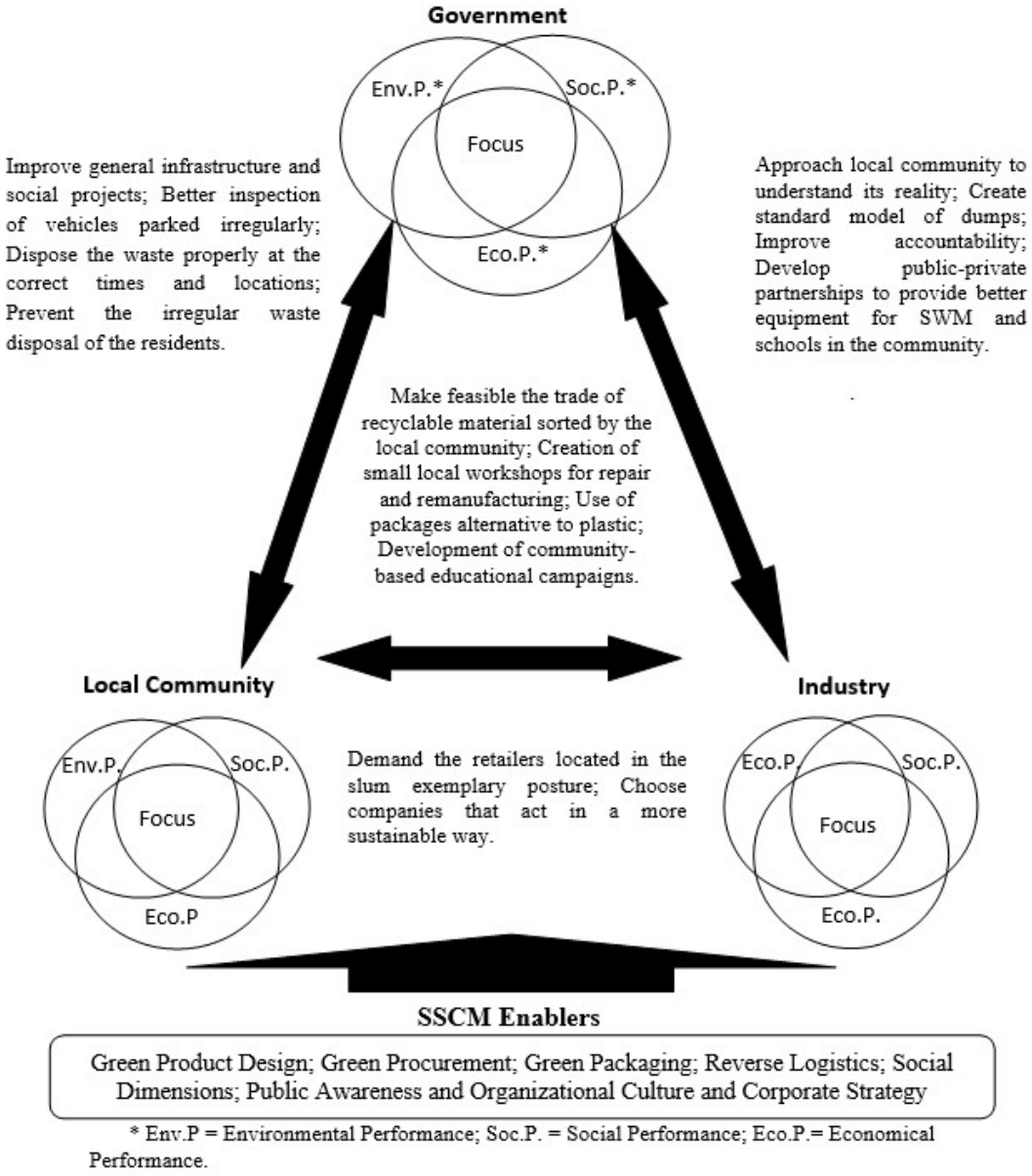

Fig. 5: Framework for SWM at slums (adapted from Azevedo et al., 2019)

4.3.Learning with the German UHSWM practices

This section presents the main results of the within and cross-case analysis between a German and a Brazilian city (Münster and Macaé respectively), which is expected to be of practical relevance to improve UHSWM in developing countries. Additional information in the findings of this comparison is presented in Azevedo et al. (2021a).

4.3.1.UHSWM in Münster and Macaé: a within case analysis perspective

This subsection firstly reports the findings obtained in Münster and the ones obtained in Macaé. The analysis of both cities built the household waste process flow diagram, as displayed in Figure 5.

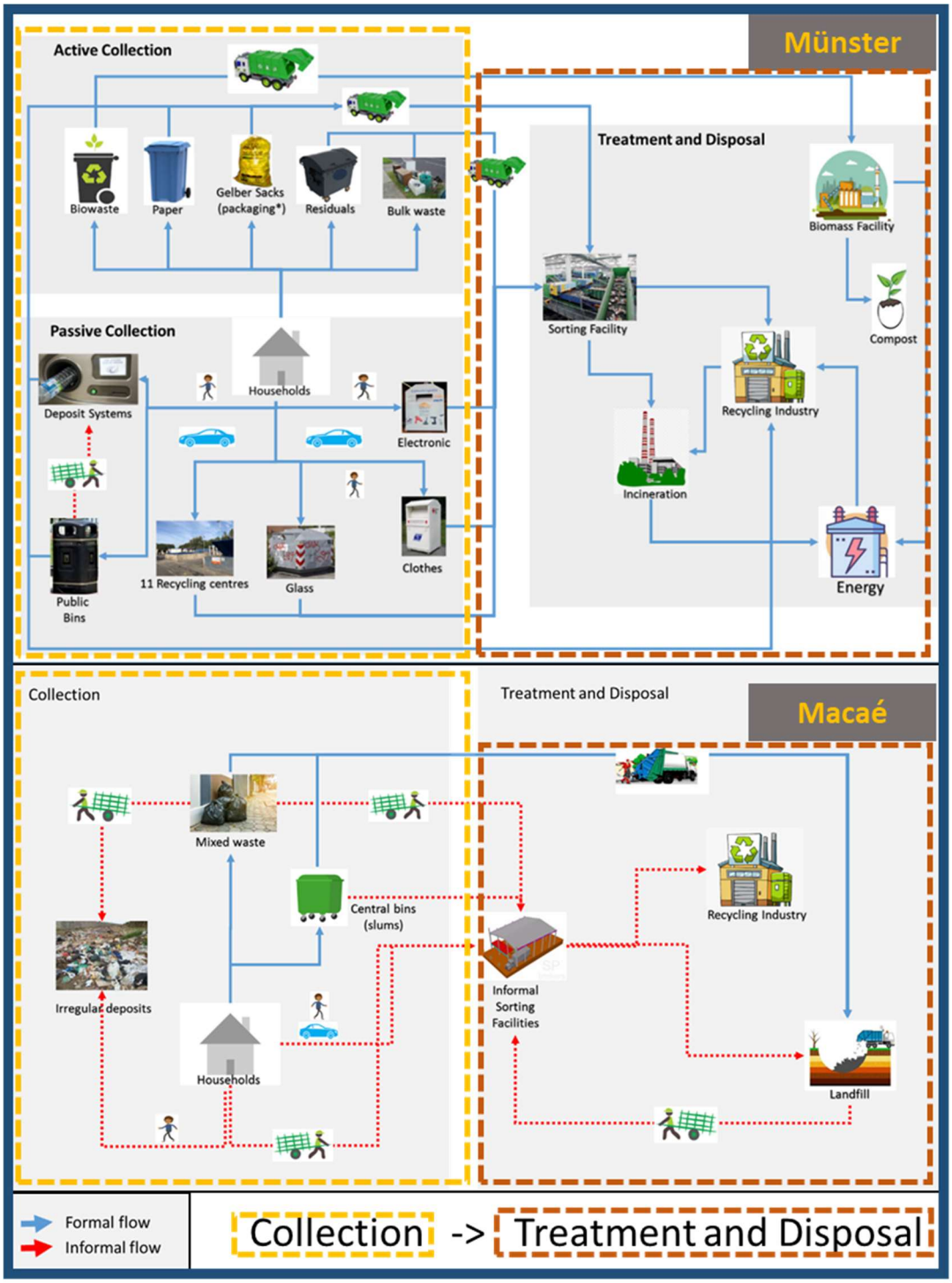

Fig. 6: Household waste process flow diagram of Münster and Macaé
(Adapted from Azevedo et al., 2021a)

Münster has a municipal company responsible for the primary WM services called AWM. The collection system covers 100% of the city and no relations to public health problems were found during the research. The household waste PFD of the city (top part of Figure 5) presents all waste flows, from collection to treatment and disposal. All the flows are formals, with one exception: given the high price of the materials, some waste-pickers were noticed collecting used bottles and cans in public bins.

The cleaning companies in Münster provide different containers in front of the residences, which prevents the spreading of the garbage while protecting the workers responsible for the collection. In the passive collection, AWM offers 290 glass collection banks, 11 recycling centers, plus containers for electronics and clothes scattered throughout the city. In addition to this scheme, the main food markets offer machines to collect bottles and cans licensed by the deposit systems schemes: the single-use containers (Einweg), which have a deposit fee of 25 Euro cents, are destroyed and recycled; and the multiple-use containers (Mehrweg) (e.g., beer bottles), which have a deposit fee that varies from 8 to 15 euro cents and are cleaned up and reused. As the collected material belongs to the company that collects the bottles and cans, the Schwarz Group, a company that owns two big supermarket chains, has become the fifth-largest waste disposal company in Germany (EUWID, 2018). There are many flows concerning treatment and disposal. Clothes, electronics and furniture are collected to be reused and/or dismantled. Biological waste is converted in commercial organic compost and methane gas used to generate energy. All other materials, including the residuals from the non-recycled bins, are sorted to increase the recycling rate to its maximum. Finally, all final residuals with no additional value are then sent to incineration plants, capable of generating electricity. As a highlight, the landfill in Münster has been closed for more than 15 years. The municipal cleaning company also heads many educational programs to motivate children and adults to think and act sustainably, and to understand the benefits of the circular economy.

The system in Münster is sustained financially by the payments made by the industry (DSD), and by the payments from households. The former must comply with two waste fees: a usage fee and a performance fee, which works according to the Pay-As-You-Throw (PAYT) market-based instrument (MBI) (Alzamora and

Barros, 2020; Magrini et al., 2020). The performance rate depends on the size of the waste bins and the frequency of collection. To avoid the deposit of no recyclables in the bins with no charging fee (paper and packaging), AWM estimates a minimum volume per person (10 L) for the residual waste and calculates the minimum fee for each location.

In conclusion, the head of the Institute for Waste, Wastewater and Infrastructure Management GmbH (INFA) stated that the pillars of the German success are clear laws, regular public campaigns and the fees methodology, which was developed to sustain the system integrally.

Findings obtained in Macaé offer a different view. As reported in different studies covering solid WM in developing countries (e.g., Moh and Manaf, 2017; Sharma et al., 2018), obtaining trustful data in Macaé was a challenge. The company responsible for the collection, Limpatech, is not well known by the locals and doesn't even have a website to facilitate communication with the local community. The municipal solid WM plan offered on the city council's website is outdated, and selective collection is no longer carried out (Macaé, 2012). To overcome this situation, most of the data came from field research. Limpatech and the municipal secretary of infrastructure affirmed that the household waste collection covers 100% of the city, however, it is possible to find land with irregular disposal of waste in some areas. The rate of leptospirosis, dengue and other diseases associated with poor UHSWM (DataSUS, 2019; RJ, 2019) are indicate that public health is suffering the consequences of inefficient collection.

The official collection in Macaé is mainly door-to-door, and there is no distinction between the different types of materials. In the slums, as Azevedo et al. (2019), in addition to violence issues that hinder researchers' access, the lack of adequate streets for collection trucks requires the use of central bins. In the whole city, there is no obligation to use containers for waste collection, so most of the waste is disposed in plastic bags on the pathways. According to Limpatech, in the past they tried to adopt containers in specific areas, however, they were all stolen and/or damaged by the population. As Rana et al. (2017), this fact led to the spreading of waste, reproduction of flies and other vectors, floods and to greater physical wear and tear to the garbage collectors.

Since household waste in Macaé is mixed, most of the flows presented in Figure 5 (bottom part) are related to informal waste-pickers collecting recyclable materials from discarded residues, and enthusiastic residents who take their recyclable waste to informal traders distributed around the city (Macaé has no cooperative for waste-pickers). The number of these traders varies constantly. As an example, during the time of the research, one of the biggest collectors had to stop to work because his truck was broken, and he did not have the money to fix it. The great fragility of this system is that traders only accept specific materials, according to their market value. As a result, no one in the city was accepting glass given its low resale price. The formal collection takes all materials directly to a regular landfill, which does not capture the biogas produced.

To finance the system in Macaé, the mayor's office charges the households with a fee that comes together with the land tax. The fee does not vary with the amount of waste produced by each home. Additionally, given the existence of irregular occupations, part of the population does not pay the land tax, so do not pay for the waste collection. Finally, the industry does not pay any specific fee to help to maintain the collection system. Therefore, as Alzamora and Barros (2020), the local government uses the income from other taxes to finance the cleaning company.

As explained by the Secretary of Infrastructure of the city of Macaé, the lack of a budget is the main reason for the failure of recycling programs, including the creation and maintenance of recycling cooperatives. Alternatively, according to the Limpatech' manager, the lack of education and commitment of the population contributes significantly to the failure of the system. However, in the words of the former Secretary of the Environment, the cleaning company has no interest in supporting recycling programs because it receives more money if more waste goes to landfill.

By analyzing the pillars brought by the head of INFA to explain the German success, it becomes clear that they are not adopted in the Brazilian city. The legislation still is not capable to hold all the stakeholders involved in the UHSWM responsible; there are no regular campaigns to improve education of the population towards sustainability; and the charged fees are not sufficient to maintain the system.

4.3.2. Cross-case analysis and the potential impact of the green Dot in Brazil

As presented in Azevedo et al. (2021a), the scores obtained by using the Wasteaware benchmark indicators were 98% to Münster, and only 50% to Macaé. These numbers confirm the German city as a benchmark on solid WM practices, and places Macaé a bit ahead of the Indian cities studied by Rana et al. (2017) and Sharma et al. (2018). The Brazilian city has no formal collection of recyclables and closing the loop of the materials consumed is an unrealistic goal to the near/medium term. The high level of informality corroborates Wilson et al. (2013), who attests that the IRS is subsidizing the collection system of these developing country cities.

The vast difference in the score related to governance factors (100–35%) (Azevedo et al., 2021a), confirms that to improve UHSWM demands policy coherence, engagement of stakeholders (e.g., industries, householders, investors, IRS, and decision-makers) and governance (Ddiba et al., 2020). In this sense, the true application of the German pillars appears to be a feasible strategy to solve this issue. For example, a better fee methodology is needed, given that the fee charged nowadays does not vary according to the amount of waste produced (PAYT) and is not sufficient to cover all the costs related to WM. With this method, the population has no incentive to carry out proper sorting or to reduce the amount of waste produced (Alzamora and Barros, 2020). Besides that, with the current methodology, the cleaning company earns more money if more waste goes to landfill, which goes in the opposite direction regarding the waste hierarchy (Morone et al., 2020). As a result, the lack of financial sources to sustain the recycling system of Macaé is the main reason for the absence of investments in proper equipment and new technologies (e.g., Maroušek et al., 2014), and the lack of public campaigns to improve education towards sustainability (another German pillar). This conclusion corroborates Conke (2018), who named it as an ‘‘unequal sharing of programs’ costs and responsibilities” that contribute to the low recycling rates in Brazil; Rojas et al. (2018), who concluded that per capita spending on waste management is positively and significantly linked to separate collection rates; and Steuer et al. (2018), who stated that any replacement of the IRS would require relatively high

financial investments to create economically favorable conditions to attract the necessary workforce.

Finally, the personal behavior of the citizens is another interesting aspect that emerged from the participatory observation. As stated by Moah and Monaf (2017), one critical challenge in source separation and recycling practice is the public attitude towards making source separation and recycling as a habit. To function well, the German solid WM system demands commitment and confidence of the dwellers. In this sense, the notion of work, discipline, and personal effort appears as a significant differential between the inhabitants of the two studied cities. Generally, Germans seems to have a clearer understanding of the need to comply with daily tasks to have a better society, and to adopt personal abdications to achieve collective benefits. On the other hand, the government delivers the results expected by the population, which creates a positive virtuous cycle.

The last step of the comparison was to understand the results of applying the same fee applied for the German packaging industry in Brazil. Table 2 first presents the amount of collectively commercialized materials by a cooperative of waste-picker presented in Gutberlet (2015) with the prices updated to the market values of 2020 (CEMPRE, 2020). The annual earnings of the cooperative is U$ 216,859.00, which gives each recycler an average monthly income between US$ 120.00 and US$ 241.00. As in Gutberlet (2015), these values are lower than the current minimum salary in Brazil (U$ 277.00). Following, by adopting the values of the license calculator (DerGrüne Punkt, 2020), the author of this thesis calculated the fees industry would need to pay to use in its packaging the same quantity of material commercialized by the presented cooperative. As presented in Table 2, the additional value received per year would be U$ 473,434.00, reaching a total income of U$ 690,293.00. This value represents a 318% increase in the earnings of the cooperative, allowing each recycler to receive between U$ 381.00 and U$ 767.00 per month. This new salary is significantly more than the current minimum salary. Furthermore, this additional gain for the cooperative would enable improvements on the machinery and equipment used by the recyclers, allowing then to take the next step towards the formalization.

Table 3 Commercialized materials COOPCENT (adapted from Gutberlet 2015 and Azevedo et al., 2021a)

Material	Tons/year	Price/ton*	Income	Fee paid per ton / month*	Received Fee/year
Glass	0	-	$0.00	US$9.00	Not available
Plastic	29.20	US$547.00	US$15,979.00	US$113.67	US$40,609.20
Paper/ cardboard	1335.90	US$147.00	US$195,927.00	US$22.68	US$370,301.80
Beverage cartons	74.30	US$67.00	US$4,953.00	US$68.85	US$62522.60
TOTAL	1,439.40		US$216,859.00	Additional Income	US$473,434.00
			Total income (sold material + fees)		**US$ 690,293.00**

*CEMPRE 2020

This comparison has limitations given the present currency-related differences between the countries. The estimation was a first exercise to highlight the need of the Brazilian packaging industry to held responsible for its own product life cycle. As Nwaiwu (2018) concluded in his review about frameworks on digital business transformation, there is not a one size fits all model. As it is already happening with the implementation of advanced technologies within modern industries, the economic reality of each country can be an obstacle to the best performance in UHSWM, but not an inhibitor. Most likely, at least some of this additional cost to industry would be passed on to consumers, which is reasonable given the urgency for consumers to understand packaging as a product that costs money and requires treatment after use. This subject leads to the next subject studied: the WTP of Brazilian consumers for a better UHSWM.

4.4.Survey - willingness to pay (WTP)

This section presents the main results of the survey made to understand the WTP of Macaé dwellers to access a formal structure to collect and treat recyclables. Additional information an analysis can be obtained in Azevedo et al. (2022).

Table 4 presents a descriptive analysis of the distribution of the WTP variables according to the respondents' characteristics. Most responders were female (54%) and had a college degree (71%). The great majority of which live in houses with two to four residents (81%). Sixty-three percent of the respondents were 31-50 years old. The monthly family income of 50% of the respondents was superior to 10,000 BRL, which is superior to the average income of a Brazilian family: 4,002 BRL (IBGE, 2021).

Table 4: Descriptive analysis of the distribution of the WTP

Variables	Total n = 214 (100%)	0 BRL n = 63 (29%)	10 BRL n = 47 (22%)	20 - 30 BRL n = 64 (30%)	More than 40 BRL n = 40 (19%)
Gender, n (%)					
Female	116 (54%)	36 (31%)	28 (24%)	28 (24%)	24 (21%)
Male	98 (46%)	27 (28%)	19 (19%)	36 (37%)	16 (16%)
Education level, n (%)					
Lower than college degree	61 (29%)	20 (33%)	12 (20%)	17 (28%)	12 (20%)
With college degree or higher	153 (71%)	43 (28%)	35 (23%)	47 (31%)	28 (18%)
Number of residents, n (%)					
One	22 (10%)	8 (36%)	6 (27%)	5 (23%)	3 (14%)
Two to four	174 (81%)	50 (29%)	39 (22%)	52 (30%)	33 (19%)
More than four	18 (8%)	5 (28%)	2 (11%)	7 (39%)	4 (22%)
Age, n (%)					
Less than 18	5 (2%)	0 (0%)	1 (20%)	2 (40%)	2 (40%)
19 – 30	27 (13%)	6 (22%)	8 (30%)	10 (37%)	3 (11%)
31 – 50	134 (63%)	36 (27%)	28 (21%)	44 (33%)	26 (19%)
51 – 60	34 (16%)	15 (44%)	7 (21%)	6 (18%)	6 (18%)
More than 60	14 (7%)	6 (43%)	3 (21%)	2 (14%)	3 (21%)
Monthly family income, n (%)					
Up to 2,000 BRL	15 (7%)	8 (53%)	4 (27%)	3 (20%)	0 (0%)
Between 2,000 and 5,000 BRL	43 (20%)	12 (28%)	13 (30%)	16 (37%)	2 (5%)
Between 5,001 and 10,000 BRL	49 (23%)	14 (29%)	15 (31%)	12 (24%)	8 (16%)
More than 10,000 BRL	107 (50%)	29 (27%)	15 (14%)	33 (31%)	30 (28%)
Considers the collection of recyclables adequate, n (%)					
No	199 (93%)	58 (29%)	43 (22%)	61 (31%)	37 (19%)
Yes	15 (7%)	5 (33%)	4 (27%)	3 (20%)	3 (20%)
Destination of recyclable waste, n (%)					
Collector	76 (36%)	28 (37%)	16 (21%)	18 (24%)	14 (18%)
Conventional collection truck	54 (25%)	15 (28%)	14 (26%)	18 (33%)	7 (13%)
Recyclable collection Truck	13 (6%)	5 (38%)	1 (8%)	5 (38%)	2 (15%)
Other (specify)	33 (15%)	7 (21%)	5 (15%)	11 (33%)	10 (30%)
Does not separate	38 (18%)	8 (21%)	11 (29%)	12 (32%)	7 (18%)
Considers the working conditions of recyclable collectors adequate, n (%)					
No	203 (95%)	203 (322%)	203 (432%)	203 (317%)	203 (508%)
Yes	11 (5%)	11 (17%)	11 (23%)	11 (17%)	11 (28%)

Ninety-three percent of the respondents don't consider the collection of recyclables in its own city adequate, and 94,4% believe that the working conditions

of the waste-pickers aren't satisfactory, corroborating findings from Zolnikov et al. (2018) and Azevedo et al. (2019). Thirty-six percent of the respondents send the recyclable waste to informal collectors, while 43% do not separate it and/or send the recyclable to conventional collection trucks.

Table 5 presents the estimated coefficients between the WTP and the respondents' characteristics. The "total" column represents the "traditional" logistic model, where the variable Y is pay or not pay. As explained in Section 3.4, no variable was significant in this analysis. Then, the Multinomial Logistic Regression was performed (columns 0 BRL, 10 BRL, 20-30 BRL and 'More than 40 BRL). In this method the response variable has more than one category, in this case 0, 10, 20-30 or > 40 BRL. Variable 0 BRL was the reference, and all other probabilities were calculated relative to it. The categories 20 BRL and 30 BRL were grouped to run the model. In this analysis, the variable age, monthly income, and adequate work conditions were significant.

Age variable proved to be negatively significant in all classes, which means that older people are less likely to pay than younger people. This finding corroborates (Challcharoenwattana and Pharino, 2016). Among the people who answered 'More than 40 BRL', the family income variable was positively significant, showing that the higher the family income, the more likely the person is to pay 'More than 40 BRL'. However, considering all monthly payment options, the regular income is no longer significant, which corroborates Massoud et al. (2021). Once again for those who answered "More than 40 BRL", the people who consider the working conditions of waste-pickers as adequate, are less willing to pay. The college degree doesn't play an important role in the WTP of the respondents, which indicates that education in schools is sufficient to sensitize the residents about sustainable SWM practices, as observed in Han et al. (2019). Thirty percent of the respondents don't agree to pay any other fee to the government to improve the waste collection/treatment. The main reasons for not paying are related to the high tax rate they already must pay in Brazil. Twenty-two percent agreed to pay 10 BRL (less than U$ 2.00*) per month, 30% agreed to pay 20-30 BRL (U$ 3,6 – U$ 5,5), and 18% agreed to pay more than 40 BRL (U$ 7.2) per month. It gives an average of 17 BRL (U$ 3.09) per month. These values are higher to the ones presented in Challcharoenwattana and Pharino (2016), who noticed a range between U$ 0.73

and U$ 1.95 on the WTP for improving the collection of recyclables in Thailand. Even studies that were analyzing the WTP for general WM services found lower results for WTP: Ezebilo (2013) noticed U$ 1.98 per month in Nigeria, and Han et al. (2019), suggested that the service fee should not exceed U$ 0.80 per month per household in rural areas of China. This difference might be related to the high family income of a great part of the respondents of the survey.

* Exchange rate: 1 USD equals 5.55 BRL

Table 5: Estimated coefficients between the Willingness to Pay variable and the respondents' characteristics

Variables	Total		0 BRL		10 BRL		20 - 30 BRL		More than 40 BRL	
	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
Constant	14,58	1065,76			12,52*	1,22	10,53*	1,20	-18,19*	0,83
Gender, n (%)										
Female	ref				ref		ref		ref	
Male	0,11	0,33			-0,06	0,42	0,41	0,39	-0,15	0,45
Education level, n (%)										
Lower than college degree	ref				ref		ref		ref	
With college degree or higher	0,42	0,39			0,65	0,51	0,71	0,50	-0,35	0,57
Number of residents, n (%)										
One	ref				ref		ref		ref	
Two to four	0,33	0,51			0,07	0,64	0,69	0,67	0,15	0,78
More than four	0,39	0,74			-0,74	1,06	1,08	0,91	0,67	1,06
Age, n (%)										
Less than 18	ref				ref		ref		ref	
19 - 30	-15,21	1065,76			-12,95*	0,98	-12,81*	0,86	-12,99*	0,99
31 - 50	-15,66	1065,76			-13,79*	0,91	-13,46*	0,79	-12,47*	0,85
51 - 60	-16,23	1065,76	ref		-14,21*	0,97	-14,22*	0,87	-13,02*	0,93
More than 60	-16,18	1065,76			-14,06*	1,08	-14,39*	1,07	-12,9*	1,04
Monthly family income, n (%)										
Up to 2,000 BRL	ref				ref		ref		ref	
Between 2,000 and 5,000 BRL	1,18	0,71			0,70	0,83	1,61	0,94	28,78*	0,67
Between 5,001 and 10,000 BRL	1,15	0,70			0,64	0,81	1,11	0,94	30,21*	0,50
More than 10,000 BRL	1,16	0,66			-0,15	0,80	1,30	0,91	30,76*	0,42
Considers the collection of recyclables adequate, n (%)										
No	ref				ref		ref		ref	
Yes	-0,23	0,66			0,26	0,79	-0,78	0,86	0,11	0,91
Destination of recyclable waste, n (%)										
Collector	ref				ref		ref		ref	
Conventional collection truck	0,36	0,42			0,41	0,53	0,45	0,51	0,18	0,61
Recyclable collection Truck	-0,13	0,69			-1,10	1,22	0,33	0,81	-0,20	1,01
Other (specify)	0,51	0,53			-0,27	0,74	0,68	0,63	0,92	0,66
Does not separate	0,66	0,50			0,79	0,61	0,77	0,60	0,37	0,68
Considers the working conditions of recyclable collectors adequate, n (%)										
No	ref				ref		ref		ref	
Yes	0,81	0,87			0,30	1,10	1,58	0,97	-19,49*	0,00

4.4.1. Logistics costs versus WTP

CEMPRE (2020) states that the average cost of collecting recyclables in Brazil is U$ 57.00 per ton collected. ABRELPE (2020) declares that 84,5% of the urban waste generated in Brazil is potentially recyclable – including organics. And literature says that, on average, one Brazilian household produces 0,98 kg of waste per day (Azevedo et al., 2021). Using these variables, it is possible to infer that the average cost per habitant per month (C) for recyclable collection in Brazil is generated by the following formula:

$$C = \frac{p * r * c * d}{1000}$$

Where:

C = Cost for recyclable collection per inhabitant per month
p = waste generated per person per day (kg/day)
r = waste potentially recyclable (%)
c = Cost per ton collected
d = number of days per month

$$0{,}98*0.845*57.00*30 /1000 = U\$\ 1.42$$

IBGE (2020) states that the average number of residents per house in Brazil is 2.90. Hence, it's possible to interpret that each house would need to pay, on average, 2.9 * U$ 1.42 = U$ 4.12 per month to cover the costs of a formal system to collect and treat recyclables.

Comparing this number with the WTP of the households noticed in the survey, it is possible to state that more than 52% of the local population is willing to pay a value lower than the costs involved to formalize the collection of recyclables in Brazil. This fact may hinder the potential acceptance of Brazilian consumers to bear the additional costs that may be charged by companies if they adopt EPR schemes such as the one found in Germany.

It is important to emphasize that this analysis is made as a first step to understand the potential consequences of companies being forced to adopt EPR schemes. It focuses only on recyclable waste, and the effects that this measure could bring to final consumers. It has no relation to the fee already charged by some cities to households who have access to general WM services.

5 Discussion

This chapter first discusses alternatives for UHSWM improvement in Brazil, by integrating the principles of SSCM from the perspective of industry, public sector, and local community, connecting the proposed actions with the German pillars presented in chapter 4 (clear laws, fee methodology, and regular public campaigns). As the solution for UHSWM in developing countries is a holistic and complex process, which involves a revolutionary shift of infrastructural, institutional, and social levels (Morone et al., 2020), the discussions also correlate the actions needed with elements linked to sociotechnical transitions, including policy, consumer practices, technology, markets, infrastructure, cultural meaning, and scientific knowledge (Geels, 2012). Finally, aiming to address SG5, "*To propose a set of guidelines with feasible alternatives in UHSWM to assist cities in developing countries to meet the SDGs"*, and to address the RQ of the research, *"How to improve UHSWM in developing countries such as Brazil by incorporating the SSCM concepts",* section 5.2 offers eight guidelines, which are general recommended directives, to support public authorities in developing countries to improve UHSWM.

5.1. Alternatives for UHSWM improvement in Brazil

The basic premise for proper UHSWM should be shared responsibility (Fuss et al., 2018). This statement is highlighted in the framework presented in figure 5, where the most successful initiatives for UHSWM in developing countries are in the mix of public, private and community involvement (Leal Filho et al., 2016; Azevedo et al., 2019; 2021a). However, the convenient acceptance of the IRS in the Brazilian WM structure, which relies on waste-pickers with no better work option as a solution to household waste recycling, confirms the absence of other stakeholders, and a lack of attention around the social and human dimension of sustainability (Touboulic and Walker, 2015; Dubey et al., 2017, Köksal et al., 2017; Azevedo, 2019; 2021). Therefore, it is reasonable to say that the IRS in Brazil is hindering the responsibility of the main actors in this process: industry, which produces the goods; local community, which buy and use them; and the

government, which must be responsible for the creation and enforcement of fair laws to protect the interests of the population, the society, and the environment.

This fragility is reinforced by the results of the case studies in Rocinha and in the metropolitan region of Macaé, where all recyclables are sorted and collected by informal structures. The results of the survey attested that the population support recycling at the same time they recognize the working conditions of waste-pickers as not appropriated. Yet, most of the households are not willing to pay all the costs related to formalizing recycling chains for their waste. In fact, thirty percent of the respondents don't agree to pay any other fee to the government to improve the waste collection/treatment. The main reasons for not paying are related to the high tax rate they already have to pay in Brazil. As a counterpoint, the survey also brought some positive aspects to be highlighted: 1 – Corroborating Challcharoenwattana and Pharino (2016), older people are less likely to pay than younger people, which may indicate that the subject is getting more attention within the younger generation; 2 - considering all monthly payment options, the regular income is no longer significant, which indicates that the income of the dwellers doesn't hinder the willingness to pay to formalize the recyclable chain; 3 - the college degree doesn't play an important role in the WTP of the respondents, which indicates that education in schools is sufficient to sensitize the residents about sustainable SWM practices, as observed in Han et al. (2019); 4 – the mean WTP found was higher than the ones found in other studies, such as Challcharoenwattana and Pharino (2016).

Regarding industry, although the PNRS is based on the EPR principle, the Brazilian legislation still exempts most of the sector from the obligation to implement adequate reverse logistics channels, which demonstrate non-compliance with the SSCM and German pillars (Ahi and Searcy, 2013; Azevedo et al., 2021a). As consequence, the current packaging design and labelling practices do not facilitate separation and final disposal; reverse logistics are not widely available in many sectors; and as already said, it is mainly the IRS that support urban household recycling (Conke, 2018; Azevedo, 2019; 2021a). It is urgent that these organizations understand that the environmental and social aspects of sustainability go beyond the boundaries of their facilities (Carter and Rogers, 2008) and that the waste generated by their consumers is a liability that requires treatment (Da Cruz et

al., 2013). In this sense, companies must bring to their strategic discussion terms like green product design, green procurement, green packaging, reverse logistics, social dimensions, public awareness and organizational culture and corporate strategy to achieve a sustainable supply chain over the TBL perspective (Dubey et al., 2017; Azevedo et al., 2019). The German case evidence that it is possible to charge industries making profit from the sale of packaged products to cooperate with a system that guarantees recycling and proper treatment. This new posture is needed even more in developing countries, where cities struggle to pay for their solid WM system (Lohri et al., 2014), and where a great part of the households live in places with no structure to deal with the resulting waste. The results presented in section 4.3 attest to the potential for increased earnings for Brazilian cooperatives if the German rate were applied in the country. This additional income would allow waste-pickers to receive a much better salary. It would also allow improvements on the machinery and equipment used by the recyclers, letting them take an important step towards the formalization of their organizations (Azevedo et al., 2021a). On the other hand, if the current attitude does not change, industry will continue to get unacceptable benefits from the informal nature of the recycling chains, based on poverty and on the precarious working conditions of waste-pickers (Yang et al., 2020). Furthermore, it's important to highlight that the IRS heavily depends on the market prices for secondary materials (Steuer et al., 2018), which leads to inefficient results (Azevedo et al., 2021a). For instance, in Macaé, informal collectors say it is not profitable to collect glass given the low price of this material in the recycling market. They also say that it's not worth to collect recyclables in certain locations given the low population density, which corroborates Cervantes et al. (2020). This is the same argument used by Israeli cities (Lavee and Khatib, 2010; Lavee and Nardiya, 2013). In opposition, the German case analysis demonstrated that proper WM, including recycling, is an essential activity that must be done regardless specific market conditions (Azevedo et al., 2021a). In this sense, a new posture of companies that intend to be sustainable could help the IRS to move forward towards formal structures. It is necessary to encourage the creation of partnerships with government and local communities to minimize the social and environmental damage of their products. In slums, which are a sad reality of developing countries, green procurement practices can be applied by purchasing the

recycled materials segregated by the locals in the same way as the "Green Exchange" Program described in Leal Filho et al. (2016). In this program, children could exchange reusable waste to school articles, chocolate, toys, and tickets to entertainment events.

In any case, it is up to the government of these countries to legislate and oversee the industry responsibility for the lifecycle of its products to increase the rate of recovered recyclable materials (Cetrulo et al., 2018). The expansion of EPR schemes in developing countries is more than urgent, and public authorities could learn with the experience from countries like Germany, which announces the existence of clear and effective laws as a pillar of their success. The application of hierarchy of waste represents a relevant and environmentally desirable approach to achieve sustainable UHSWM, based on waste diversion from the landfill to safeguard the environment and human health (Morone et al., 2020). Local governments must also understand the TBL concepts and embrace SSCM enablers in its actions (Azevedo et al., 2019). This can be achieved indirectly, through public-private partnerships, or directly, improving the sustainability of their own supply chain (e.g., biddings including green practices). In addition, their actions must seek to be economically viable, as it is not possible to expropriate thousands of houses in a slum to open new streets for waste collection in the short-term, or to maintain a SWM system without charging the users accordingly. For the latter, cities like Macaé have to change their SWM fee methodology to fulfill to the German pillar. As demonstrated in the German case study, local governments need to charge households and industry according to the amount and type of waste they produce (PAYT), in a way that guarantees income to sustain the system integrally. Otherwise, they have no incentive to carry out proper sorting or to minimize the amount of waste they produce (Alzamora and Barros, 2020).

Finally, local community must reinforce an active posture and develop, together with industry and government, strategies to overcome their social problems. As demonstrated by the cross-case comparison, the German solid WM system demands commitment and confidence of the dwellers as well. Therefore, despite the urgent needs of many inhabitants of developing countries like Brazil, the population must do their part to solve the problem. It is mandatory to adopt personal abdications for the sake of collective benefits. German society, rebuilt after two world wars, is a

great example for the world to learn about the notion of work, discipline, and personal effort to achieve a common good. Nevertheless, the economic disparity that persist in many developing countries such as Brazil, which also carries the cultural heritage of slavery, seems to divide the population in two opposed sides: a burdened class that has to face arduous routines and is discouraged to ‘‘think” or do things in the name of a society that neglects them on a daily basis; and a privileged class that is used to have poor people doing most of the manual labor for them (e.g., cleaning the house, cooking, doing the garden, taking care of their children, waste sorting) (Gomes, 2019; Azevedo et al., 2021a). It appears that both groups find it difficult to understand the need to help to clean up and organize their waste to achieve a common good, especially as they are governed by low credit worthy governors (Azevedo et al., 2021a). As Massoud et al. (2021), it isn’t only a matter of knowing the aspects related to best WM practices it’s also necessary for the residents to believe that they can and should perform it, and that the government will support them. And that the government will support them. The results of the survey where 30% of the respondents do not agree to pay any additional fee to the government to formalize the collection/treatment of recyclables, even though they aren’t satisfied with the service, support this understanding. This number is superior to the 10-13% presented in Challcharoenwattana and Pharino (2016) for Thailand, and the main reasons for not paying are related to the high tax rate they already pay in Brazil. As indicated by Maroušek, (2013), the solution requires a profound transformation in society and must begin with intensive educational campaigns to spread ethical decision-making behavior among the population. In other words, “*it must be sustained by a sociotechnical transition able to encompass the radical changes necessary at the infrastructural, institutional, political, and social levels to achieve the goal of a green waste sector*” (Morone et al., 2020, p.7). Alternatively, in the words of the head of INFA: ‘regular campaigns for better education are essential to convince households, and therefore industry, to contribute to the creation/existence of a sustainable UHSWM”.

All these assumptions are aligned with SDG 4, which states that it is needed to “ensure inclusive and equitable quality education and promote lifelong learning opportunities for all” to guarantee sustainable development (UN, 2015).

5.2.Guidelines for better practices on UHSWM

This section offers a set of eight general directives to aid public authorities in developing countries to improve UHSWM, serving as guidelines for better practices. They were built upon the research findings presented in this thesis and were developed to be concise, clear, and grounded on the literature. The application of these directives aims to surpass the barriers for proper UHSWM, such the ones presented in Conke (2018); Azevedo et al. (2019); and Massoud et al. (2021). There is no necessary order to apply all of them, but the implementation of certain proposals can facilitate the implementation of others. For example, proposals 1 and 2 can be seen as facilitators for all the others that follow.

The application of these guidelines embraces the multi-level perspective view and includes a variety of interacting elements which are enablers to a sociotechnical transition, including industry, technology, markets, policy, culture, and civil society (Geels, 2012). It also considers the pressure made by the landscape on the existent regime (Figure 7). Finally, it encompasses the revolutionary changes needed at the infrastructural, institutional, political, and social levels to achieve the goal of a green waste sector, as cited by Morone et al. (2020).

D.1: All operations related to UHSWM must be integrally financed by its users, with specific fees for that.

This is one of the German pillars for its success, and must have two main drivers:

- Households with door-to-door collection must be charged according to the PAYT method (Alzamora and Barros, 2020; Magrini et al., 2020).
- The packaging industry must comply with and finance a system that ensures its recycling and recovery operations (Da Cruz et al., 2013; (Guarnieri et al., 2015; Ferreira et al., 2017 Rubio et al., 2019).

This directive will first demand changes in policies and legislations, from city to federal level (Moh and Manaf, 2017). Once approved, the increase on financial resources will generate effects on markets related to SWM, allowing the use and the development of new technologies. It will also provide means to improvements

in all infra-structure used in UHSWM. Finally, consumer practices will change the moment they have to pay according to the amount of waste they produce.

D.2: Constant public campaigns to better educate the population on UHSWM aspects is mandatory.

As appointed by UN (2015), Azevedo et al. (2019); Morone et al. (2020), Azevedo et al. (2021a), and by the head of the INFA, better education of people is essential to change UHSWM. Change must start with new policies, which spell out the urgency of explaining UHSWM subjects, and the consequent responsibilities, to every citizen, from kindergarten on. This process is the foundation to change consumer practices, which will allow and encourage improvements in scientific knowledge, and politics. A better educated people will demand better politicians, which will provide better infra-structure, creating a virtuous cycle capable of changing the UHSWM reality. A substantial part of the economic resources generated by P.1 must be applied in this directive.

D.3: In slums areas, the strategy must be tailor made.

The specificities of each slum make it difficult for a one size fits all solution (Coffey and Coad, 2010; Elgizawy et al., 2016; Rashid et al., 2018; Azevedo et al., 2019). There are flat and hilly slums; slums where the access is not so difficult; slums where violence is not an issue, so the trucks can operate during the night; there are really big slums, with thousands of tons of waste being generated daily, and there are small slums, with few hundred of inhabitants. Understanding the scenario has to be the first and mandatory step. Anyhow, the applied strategy should likely include: the creation of central and well-structured collection points; partnership with households' local associations; partnership with Non-Government Organizations (NGOs); and partnership with industry to support the local trade of remanufactured products and recyclables. This approach will have impact in all elements related to sociotechnical transitions, from markets and technology, to policy, infra-structure, cultural meaning, consumer practices, and scientific knowledge. It is important to keep in mind that slums should not exist, as they are

the consequence of much larger problems, such as poor income distribution and lack of access to quality education

D.4: Waste-pickers acting in the informality are not a sustainable solution and do not guarantee the best waste treatment.

It is mandatory to create an alternative where recyclable collection/treatment companies can exist and provide affordable working conditions, including salary, safety, and proper machinery to their employees (Campos 2014; Gutberlet, 2015; Zolnikov et al., 2018; Fuss et al., 2020). The financial income generated by D.1 will create new markets that will allow the use of new technologies for improving recycling rates, and the formalization of the recycling chains structures. Consumer practices and policy must change, to make it clear that to have waste-pickers rummaging through garbage bags on the sidewalks as if they were animals looking for food is not an acceptable solution (Azevedo et al., 2021a).

D.5: Waste hierarchy is mandatory, so landfill must be the last formal option for waste disposal.

Ceasing the dumping of waste in open areas and creating adequate landfill structures is important, however it cannot be seen as the ultimate goal in UHSWM structures (ISLU, 2020; ABRELPE, 2020). The target of waste management practices should be to reduce waste landfills as much as possible, so the focus must rely on strategies such as waste reduction, remanufacturing, and recycling (Morone et al., 2020). In this sense, it makes no sense to pay waste collection companies according to the amount of waste they bury. It is mandatory to create contracts where companies treat residuals by using the waste hierarchy method (Azevedo et al., 2021a).

D.6: It's fundamental to offer different collection points scattered around the city, such as recycling centers, and containers for glass bottles and electronics.

The existence of facilities and areas where households can take their sorted waste for free is welcome in any city (Azevedo et al., 2021). It reduces the cost with collection, as it serves to receive different types of recyclable material brought by dwellers. The waste must be stored in proper containers, and it is important that the area is accessible to cars. It is also important that these structures are monitored and/or have protection to avoid informal collectors mining all the most valuable goods. These collection points cannot receive household waste that is not recyclable. Otherwise, people will bring this type of material to avoid paying for collection at their homes. This attitude would hinder proper sorting, at the same time it would discourage people to reduce waste residuals production (Abfallbilanz, 2019).

D.7: The use of deposit-refund systems is a good option for increasing recycling rates and at the same time for better educating the population.

The creation of a legislation that compels companies to collect their packaging would probably force them to return with deposit fee schemes, such as those used on glass bottles in the past. The application of this method has two main advantages: it allows the scattered waste to return to central points, already sorted and without any contamination, while at the same time it educates consumers, who will perceive the used bottles or packaging as a product with value that must be properly disposed of. The refund given under a deposit/refund system will encourage companies to engineer products that are easier to recycle. Households will demand such products to recycle and receive the refund. This scheme is important since encouraging the recyclability of product design can be managerially difficult (Kinnaman and Fullerton, 1999).

D.8. Composting and bio-digesting schemes are attractive options to treat the organic portion of urban solid waste.

Unfortunately, the great majority of Brazilian cities do not value composting schemes the way they should be (ISLU, 2020). This process permits a sensitive reduction in the amount of waste that goes to landfills, which allows the government to save money, at the same time it complies with the circular economy principles,

allowing the production of fertilizers and energy. The needed structure is mainly related to collection once the composting process is well known. The use of more advanced bio-digesters, such as CSTR, can increase the types of organics to be treated, at the same time it increases energy production. They close the cycle intended by the circular economy with compost and/or energy generation, facilitate the management of recyclable materials, and do not require high investments. This approach also helps to educate people to separate waste properly, which increases the chances of higher recycling rates (Abfallbilanz, 2019; Interview AWM 2019). As a strategy, governors could provide the resulting compost to participants of the program and/or small farmers.

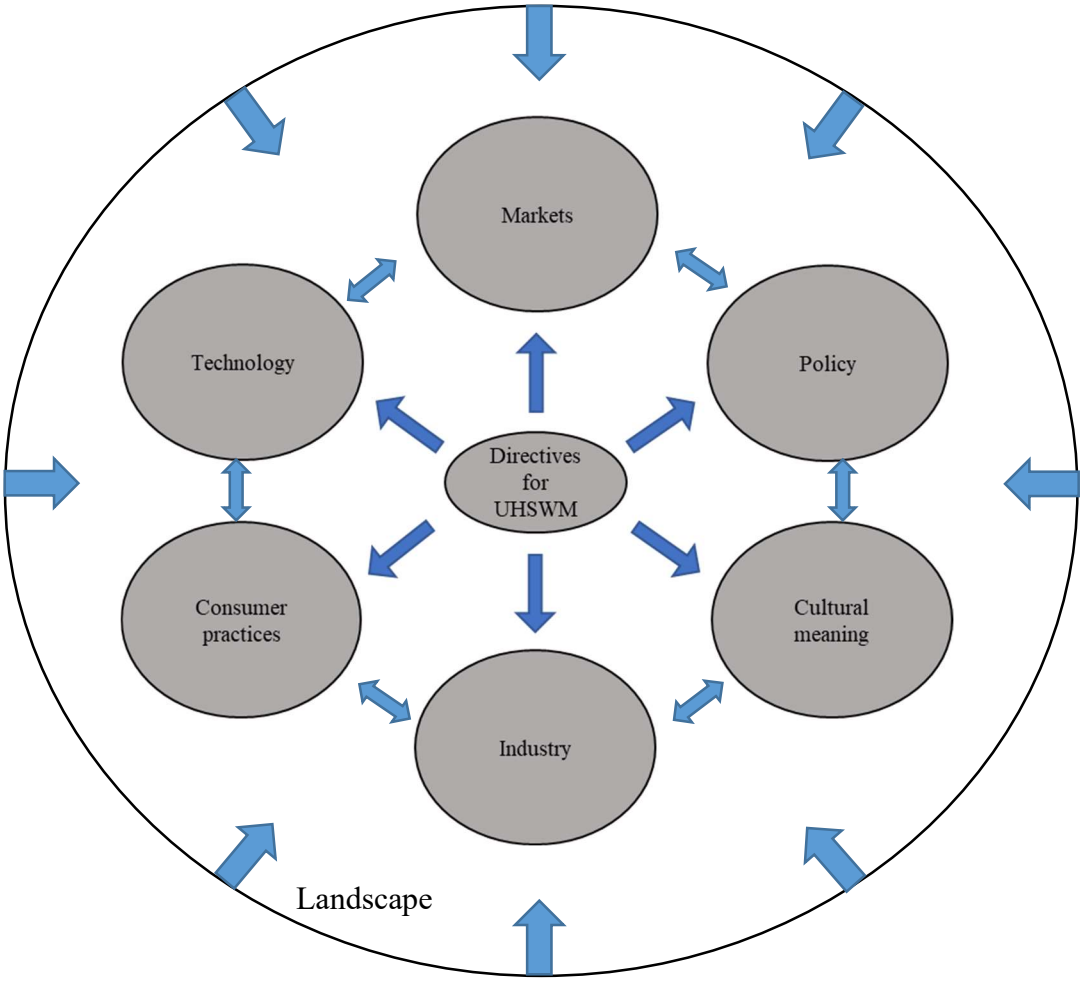

Fig. 7: Interacting elements for UHSWM

6 Conclusion and further developments

This chapter offers first the conclusions of this thesis, together with its main contributions, and then suggestions for future research.

6.1. Final considerations

The present thesis confirms that Brazilian society needs to keep on the search for proper practical results in UHSWM, especially concerning recycling chains. The informality of reverse logistic channels, with low participation of industry and consumers, continuously harms waste-pickers while not solving the problem. To change this scenario, this research aims as its main goal to present alternatives to improve the Brazilian UHSWM, by integrating the principles of SSCM from the perspective of industry, public sector, and local community, through a multimethod approach that embraces a SLR; a case study; a within and cross-case analysis, and an exploratory survey.

Research findings reveal that to achieve a truly sustainable supply chain, companies must include not only the environmental aspects in their business plan, but also the social ones. This new posture must include actions that go beyond the boundaries of their facilities, considering the life cycle analysis of their products, EPR schemes, and the reality of their end consumers. It is also necessary that governments and local communities understand their role in this process, reinforcing a holistic and multi-perspective view, and the need for integrated management for better UHSWM in developing countries. Each stakeholder involved (i.e., government, local community, and industry) must understand the need for sustainable solutions. In this sense, a joint vision of sustainability is mandatory.

The application of the three pillars of the German success model (clear laws, public campaigns, and a fee methodology that entirely sustain the system), merged with the pillars for SSCM (green design, green procurement, green packaging, reverse logistics, social dimensions, public awareness and organizational culture and corporate strategy), can change the reality for UHSWM in developing countries. Considering the inefficiency of local government and the disengagement of the local community, global industries with headquarters in developed nations

could join the leadership in this process, creating niches that will force the other actors to meet the same path. These companies already must comply with EPR schemes in many nations of the world; therefore, it is rational to do the same in nations that have not yet had the time and resources to build a proper WM structure. As demonstrated, if companies operating in Brazil had to pay a similar fee as the ones operating in Germany, the additional income that would be added to the Brazilian recycling chains structures could change the reality of the IRS, providing better salary and working conditions to all involved in the process. However, the results of the exploratory survey indicate that more than half the inhabitants of the region studied are still not willing to pay for all the costs related to the formal collection and treatment of recyclables. This fact can become an obstacle for companies in transferring the costs related to EPR schemes to their products, highlighting the need for more investments in an essential pillar of the process: public campaigns, especially in schools, to increase the educational level of the population to WM matters. These campaigns are essential to convince households to change their attitude and start fulfilling their obligations in the consumption chain. For general WM services, the local government needs to charge households who have access to door-to-door collection, and industry according to the Pay-as-You-Throw method, in a way that guarantees income to sustain the system integrally. Otherwise, these agents will have no incentive to do proper sorting or to minimize the amount of waste they produce. Nevertheless, it's also important to adequate these obligations according to the social reality of the households. In slums, for example, where the great majority of the dwellers don't have access to door-to-door collection, the campaigns should induce a higher commitment of the inhabitants when managing their residuals, avoiding irregular disposal, and encouraging the valorization of waste.

The guidelines presented can help public authorities to implement an agenda with practical measures that enable the construction of a sustainable UHSWM structure in developing countries. They were written to be concise, clear, and grounded in literature, aiming to overcome the barriers to proper UHSWM and enhancing the ongoing social transition to a new regime.

The main contributions of this thesis to the literature are: to improve the comprehension on the impact of UHSWM from the holistic perspective of

sustainability; to provide knowledge about good waste practices, their responsibilities, and consequences of poor WM; to reinforce the need for industries to take more responsibility over the end-of-life of their products (including their packaging); to discuss interventions capable of changing the Brazilian reality on UHSWM, improving the practical application and effectiveness of the PNRS in different regions of the country; to present alternatives to the IRS; to embrace the transdisciplinary aspects of UHSWM and the connections related to global supply chains and circular economy; and to better understand the WTP for WM services of households in developing countries. Additionally, the eight directives can help policy makers in developing countries to deal with the challenges associated to UHSWM. The results obtained support the need for an additional industry tax, which may have a negative political impact in the short term. However, from a holistic perspective, this cost should be offset by avoided expenses that society would have by not dealing with preventable diseases, overexploited resources, waste cleanup, and landfilling.

6.2. Further research

As suggestions for further research, there is a need for more empirical studies about SWM aligned with SSCM' practices and enablers in different developing countries' environments. For example, using multiple real world case studies, combining in-depth qualitative interviews with decision makers and other key actors and questionnaire surveys with quantitative methods might be a way to obtain additional insights and reliable data. In addition, it is expected that the results of this study serve as a basis for comparison with other studies in developing countries. Likewise, as an incentive for new researchers on other fertile areas such as proposing the integration of SSCM enablers with SWM in within a closed-loop supply chain, considering the circular economy as a driver to achieve sustainability and collaboration among the actors of the chain. Another suggestion for future research is to study the influences of Industry 4.0 technologies in the sustainable supply chain, and the ongoing creation of smart cities. It's also recommended to extend the presented guidelines to propose a practical implementation agenda with

clear goals and procedures for a specific developing country. This might lead to a case study and/or a participant observation research.

Finally, research limitations of this study can open avenues for future research. First, the main qualitative nature of the research evidence, especially with the case studies, along with the inductive and iterative process used to identify practical UHSWM characteristics, may be followed by other researchers towards increasing the generalization of the findings. Thus, future research should also include a wider sample of cities and countries to evaluate the offered lessons on UHSWM on a broad scale, and in other contexts, considering other local realities according to ISWM best practices. A larger sample of practitioners covering additional stakeholders involved in the UHSWM could complement and even confirm the lessons offered herein. Additionally, the analysis presented herein can go further on how to adapt the Green Dot approach to the Brazilian packaging industry, to increase the financial resources allocated to the Brazilian recycling actors. It is necessary to adapt the market-based instruments according to the implementation area for viable solutions. Therefore, it would be useful to examine the use of innovative additional financial investments on a longitudinal cross-case study to deepen the comprehension on the impacts of adopting effective charging methods with a holistic, integrated, and participatory perspective. The result of the exploratory survey also opens opportunities for other studies. For example, another survey, with a bigger sample to compare the results, or including new explanatory variables, or another region of the country, is suggested. To include industry executives and public authorities in the research is also recommended. A further option is to use other technic rather than logistic regression, such as contingent valuation, to estimate the WTP of consumers to formalize the recyclable chain. Finally, the analysis could go beyond the TBL approach adopted herein towards a five-dimensional approach, embracing technical and institutional aspects. It would be interesting to compare the results obtained herein to the ones eventually found by using this new approach.

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