UNIVERSIDADE ESTADUAL DE CAMPINAS
Faculdade de Engenharia Civil, Arquitetura e Urbanismo

NATHALIA SILVA DE SOUZA LIMA CANO

A CADEIA PRODUTIVA DE PLÁSTICOS RECICLÁVEIS: O CASO DO PEAD NO SUDESTE DO BRASIL

RECYCLABLE PLASTICS' SUPPLY CHAINS: THE CASE OF HDPE IN SOUTHEAST BRAZIL

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Dissertação de Mestrado apresentada a Faculdade de Engenharia Civil, Arquitetura e Urbanismo da Unicamp, para obtenção do título de Mestra em Engenharia Civil na área de Saneamento e Ambiente.

Dissertation presented to the School of Civil Engineering, Architecture and Urban Design of the University of Campinas in partial fulfilment of the requirements for the degree of master's in civil engineering, in the area of Sanitation and Environment.

Orientadora: Profa. Dra. Emilia Wanda Rutkowski

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Nathalia Silva de Souza Lima Cano

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RESUMO

Uma gestão dos resíduos sólidos adequada é essencial para garantir a sustentabilidade do planeta. A *reciclabilidade* dos materiais desperdiçados pela sociedade faz parte da solução para a promoção de uma economia circular sustentável, mas alguns materiais dificultam isso. O governo brasileiro tem negociado com representantes do setor privado e catadores organizados para criar um sistema de logística reversa eficaz para resíduos de embalagens pós-consumo, para promover a reciclagem e reduzir o desperdício de recursos. Com foco nos resíduos de embalagens plásticas, as cadeias produtivas de materiais recicláveis são complexas de se mapear, devido à composição diversificada do material plástico, alto nível de informalidade na cadeia e alto número de agentes envolvidos. Há uma grande necessidade de mapear e caracterizar os agentes nas cadeias produtivas de plásticos recicláveis e quantificar seus fluxos materiais e monetários, para compreender como funcionam mais profundamente. Esta pesquisa buscará compreender as complexidades da cadeia produtiva de um plástico reciclável no Brasil, enfocando um polímero do tipo Polietileno de Alta Densidade (PEAD), amplamente comercializado no país, a partir de uma central de triagem em Cachoeira de Minas, investigando intermediários até chegar à indústria de reprocessamento. Para tanto, foram utilizadas ferramentas analíticas (Otimização de Valor Complexo para Recuperação de Recursos, Rede Técnica de Resíduos Sólidos e Ferramenta de Análise Custo-Benefício de Resíduos e Reciclagem para Reciclagem Inclusiva). Com este estudo contribuiremos para a gestão de sistemas de logística reversa e reciclagem dos plásticos, acrescentando à base de conhecimento necessária para o aprimoramento de políticas públicas, no Brasil e em outros países em desenvolvimento.

Palavras-chave: reciclagem; setor informal da reciclagem; economia circular; valor complexo; rede técnica.

ABSTRACT

Effective solid waste management is essential to guarantee the sustainability of the planet. The *recyclability* of materials wasted by societies is part of the solution towards promoting a sustainable circular economy, but some materials make this difficult to happen. The Brazilian government has been negotiating with representatives from the private sector and organised waste pickers to create an effective reverse logistics system for post-consumer packaging waste in the country, to promote recycling and reduce resource wastage. Focusing on plastics packaging waste, recyclables' supply chains are complex to map, due to diversified plastic material composition, high level of informality and high number of agents involved. There is a great need for mapping and characterising agents in recyclable plastics' supply chains and quantify their material and monetary flows, to comprehend how they work more deeply. This research will attempt to understand the complexities of a recyclable plastic's supply chain in Brazil, focusing on polymer type High-Density Polyethylene (HDPE), which is widely commercialised in the country, starting from a sorting centre in Cachoeira de Minas, investigating intermediaries until reaching the reprocessing industry. For that, analytical tools were used (*Complex Value Optimisation for Resource Recovery, Solid Waste Technical Network* and *Waste and Recycling Cost-Benefit Analysis Tool for Inclusive Recycling*). With this study, we will contribute to the management of plastics reverse logistics and recycling systems, therefore increasing to the knowledge base required for advocating for efficient public policies, in Brazil and other emerging countries.

Keywords: recycling; informal recycling sector; circular economy; complex value; technical network.

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LIST OF ABBREVIATIONS AND ACRONYMS

ACLAMA – Association of Waste Pickers in Cachoeira de Minas

AIDIS – Interamerican Sanitary and Environmental Engineering Association

CEMPRE – Brazilian Business Commitment for Recycling

CSC – Collector and sorting centre

CVORR – Complex Value Optimisation for Resource Recovery

HDPE – High-Density Polyethylene

IRS – Informal Recycling Sector

LSD – Large scrap dealers

MAN – Transformation subnode; Manufacturers

MFA – Material Flow Analysis

PNRS – Brazilian Solid Waste Policy

PPE – Personal Protective Equipment

REC – Recovery subnode

REP – Reprocessing subnode; Reprocessors

SoCo – Waste and Recycling Cost-Benefit Analysis Tool for Inclusive Recycling

SWM – Solid Waste Management

SWTN – Solid Waste Technical Network

TN – Technical Network

TRA – Trading subnode

UNICAMP – University of Campinas

WG – Waste generation node

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1. Introduction

Driven by resource scarcity and the increasing volumes of waste generated globally, there is now an urgency to promote resource recovery from waste, as a way to prevent greenhouse gas emissions and reduce natural resource (e.g. fossil fuel for energy generation, water, wood, aggregates, etc.) consumption (IACOVIDOU et al., 2017a). Resource recovery from waste refers to establishing processes wherein waste generated at all stages of production and consumption value chains, either in the form of natural resources or man-made materials, components, products, are recovered and maintained in the system, to achieve circular economy (BRAUNGART; MCDONOUGH; BOLLINGER, 2007; VELIS; VRANCKEN, 2015; REIKE; VERMEULEN; WITJES, 2018).

The recovery of resources from waste depends on a *reverse supply chain*, whereby recyclable waste materials are source segregated, collected, sorted by type and removal of contaminants, aggregated, and traded in local and international markets and mechanical processing associated to several industries (POHLEN; FARRIS II, 1992; SCHEINBERG et al., 2011; RAJAGOPAL; SUNDRAM; NAIDU, 2015). This system has also been called “reverse logistics” (SRIVASTAVA, 2007), “green supply chain” (SRIVASTAVA, 2007), “part of the industrial value chain” (SCHEINBERG et al., 2011), “recycling chain” (JALIGOT et al., 2016) and a “closed-loop supply chain” (GUIDE; HARRISON; VAN WASSENHOVE, 2003). This study uses the term “recyclable materials’ supply chain”, because these chains treat recyclable materials as primary source for recycled products, as used in Rutkowski and Rutkowski (2017).

At the same time, there has been increasing global preoccupation with the environmental and social impacts that **plastics** mismanagement are causing (GEYER; JAMBECK; LAW, 2017; LAU et al., 2020). Plastic is a synthetic polymer produced in large scale from 1940s onwards with growing consumption because of its lightness and flexibility and different uses, allowing companies to take advantage of this material in several ways (AL-SALEM; LETTIERI; BAEYENS, 2009; MOURSHED et al., 2017; PIMENTEL PINCELLI et al., 2021). Plastics are now used in many applications and has now become part of daily lives and therefore being largely present in urban waste around the world (PACHECO; RONCHETTI; MASANET, 2012; MOURSHED et al., 2017). However, plastics consumption, can bring about many negative impacts to the environment, economy and society due to its mismanaged and particularly littering to terrestrial and marine environments such as toxic substances, marine litter, ingestion and strangulation in marine life, non-biodegradability when landfilled, urban pollution and recycling without occupational health, environmental and public health standards (UNITED NATIONS ENVIRONMENT PROGRAMME, 2014, 2016; EUROPEAN COMMISSION, 2015; VELIS, 2015b; LAU et al., 2020). Since they are mostly not biodegradable, when plastics are sent to landfill, they will last for years in the environment, or when burned, depending on toxicity and components, they will cause air toxic pollution (PACHECO; RONCHETTI; MASANET, 2012; LAU et al., 2020).

Mechanically reprocessed plastics, i.e. recycling, allows for their useful life to increase, reducing the need for virgin plastics in different products (PACHECO; RONCHETTI; MASANET, 2012). This technological route is widely spread around the world, as a recycling part of circular economy, but other routes exist such as chemical recycling (AL-SALEM; LETTIERI; BAEYENS, 2009; HAHLADAKIS; IACOVIDOU, 2018).

According to Jambeck et al. (2015), Brazil is the 16th country in the world that mismanages plastic waste with approximately 70,000 to 190,000 tonnes that ended up in the Atlantic Ocean in one year. Brazilian waste composition studies have indicated that plastics represent from 11 to 47% in mass for materials that can be recycled (RIBEIRO et al., 2014; CEMPRE, 2016). Rutkowski and Rutkowski (2017) pointed out that paper and plastics represent 79% of waste pickers' income, having a great recycling market demand. Brazil does not export its recyclable plastics, apparently because its domestic market operates under its capacity (RUTKOWSKI; RUTKOWSKI, 2017). Little is known about the plastic recycling industry in the country (PACHECO; RONCHETTI; MASANET, 2012; CAMPOS, 2014; CONKE, 2018; REBEHY et al., 2019) and research in the field is important to support improvements in public policies for reverse logistics systems for post-consumption packaging (DEMAJOROVIC; MASSOTE, 2017; GUARNIERI; CERQUEIRA-STREIT; BATISTA, 2020; PIMENTEL PINCELLI et al., 2021), besides identifying benefits and/or negative impacts in these systems (IACOVIDOU et al., 2017b).

2. Literature review

This section provides an overview of the literature on recyclable materials supply chains, with a focus on **plastics**, undertaken to identify research gaps while writing the rationale for justifying the research, as in Siddaway, Wood and Hedges (2019). It is important to note that several fields of research have been studying the theme, such as engineering, business, and management, environmental, energy, computer, material, and social sciences, among others. Most research on recyclable materials' supply chains around the world shows different ways in which the chains are represented, but also determine the informal sector's contribution and quantify the mass flows. In the next paragraphs, we present a chronological order of different studies around the world, followed by a focus on the Brazilian context, generating a broad picture of what was being researched before we designed our research goals.

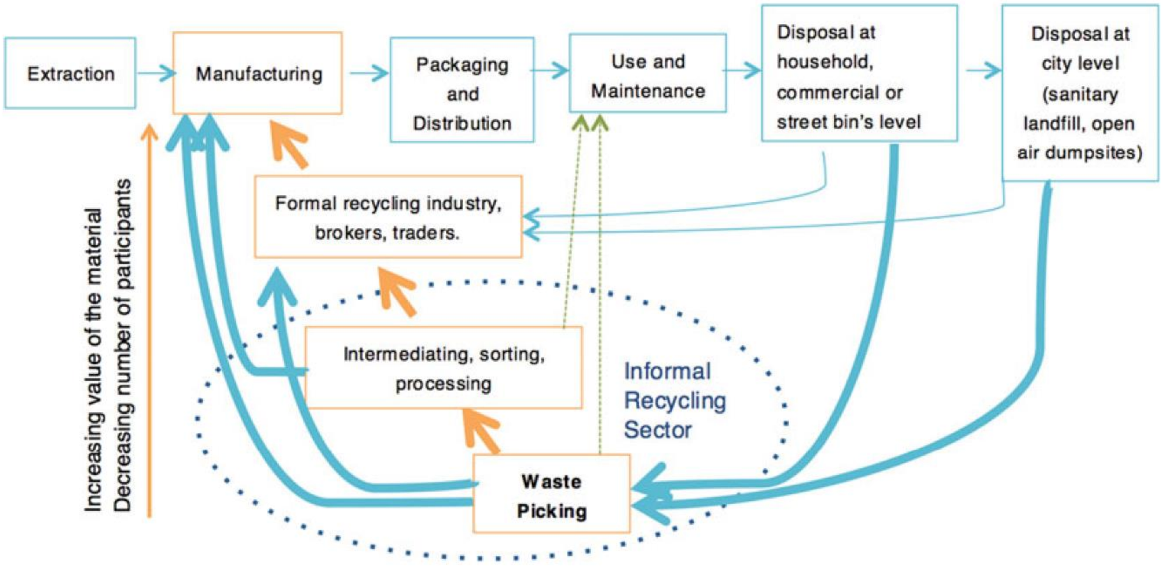
2.1 Global overview of recyclables' supply chains

While in upper-income countries recyclable's supply chains are well-established and organised processes, the situation differs in lower income countries (SCHEINBERG et al., 2011; SUTHAR; RAYAL; AHADA, 2016). Alongside the activities of the formal sector who is responsible for the Solid Waste Management (SWM) system within a municipality, there is also informal recycling agents that often determine the direction of the recycling economy, the so-called "Informal Recycling Sector" (IRS) (WILSON; VELIS; CHEESEMAN, 2006; GUTBERLET, 2012; EZEAH; FAZAKERLEY; ROBERTS, 2013; LEWIS, 2016; STEUER; RAMUSCH; SALHOFER, 2018). The term 'informal' used in this field is different than the economic definition which means unregistered and not paying taxes (SCHEINBERG et al., 2011). Many of the informal recycling agents could even have registration, pay taxes and issue invoices or sales receipts, but are not recognised as operators within the municipal SWM systems (SCHEINBERG et al., 2011).

Different agents are involved in these recyclable materials' supply chains, including manufacturers and producers, waste pickers and collectors (usually from urban marginalised populations, that can be organised in cooperatives or work individually), local public waste companies, material traders (scrap dealers, junkshops, intermediaries, middlemen) and recyclers (WILSON; VELIS; CHEESEMAN, 2006;

VELIS et al., 2012; EZEAH; FAZAKERLEY; ROBERTS, 2013; RUTKOWSKI; VARELLA; CAMPOS, 2014; SCHEINBERG; SIMPSON, 2015; VELIS, 2015a; VELIS; VRANCKEN, 2015; SCHEINBERG et al., 2016; VALENCIA, 2019). Figure 1 shows a typical diagram with a supply chain of recyclable materials in lower income countries around the world.

Figure 1 – Reverse flows of materials through informal recycling sector



Source: VALENCIA (2019).

The following case studies around the world show the type of research on recyclables' supply chains that has been carried out and how it has been a recent field of study.

- SEMBIRING and NITIVATTANANON (2010) mapped the informal recycling sector in Bandung, Indonesia, where waste pickers collected recyclable materials in the streets or at the city dumpsites and landfills, small and large scrap dealers, intermediate enterprises, and the so-called manufacturers were part of the recyclables' supply chain. They showed a simple diagram of the agents and material flows of recyclable waste in that city and discussed the dilemmas faced by decision makers in the field on how to include the informal activities in the SWM system.
- SCHEINBERG et al. (2011) used process flows and materials balance modelling to analyse city level waste management and recycling. She wanted to quantify the economic impacts and activities of the informal sector. She

shows the process flow diagram she created for Quezon City, in the Philippines, being able to map the interactions, transactions, and linkages between formal and informal recycling sectors, including activities, agents and steps of the chain. Besides the visual representation of the chain, she also showed the tonnes of materials exchanged between these agents and financial transactions.

- SCHEINBERG and SIMPSON (2015) created a framework for recycling that shows visually the economic and institutional relations of the service chain within the waste management context and value chain of the recycling market, including five examples of cities around the world to show the different settings they could have.
- SUTHAR; RAYAL and AHADA (2016) captured the complexities of the informal recyclables' supply chains in the city of Dehradun in India, by identifying the main agents and creating a visual diagram for them, including the flow of materials exchanged. They also collected information on quantities and prices of several types of materials traded and found that plastics account for 40% of the waste traded in the city.
- SANDHU et al. (2017) represented the recyclables' supply chain in Amritsar, India, where waste pickers are at the bottom because there are approximately 2,500-3,000 waste pickers in the city. Next, there are itinerant waste buyers, who buy directly from households for a small amount, also estimated at 2,500 people. The small scrap dealers and large junk and scrap dealers are the intermediaries of the chain, which accumulate certain types of materials and sell to recycling units or re-processors.
- STEUER et al. (2017) described what they called the informal trading networks of recyclable waste in Beijing, China. They identified the main agents there as waste pickers, waste merchants and middlemen, estimated at 150,300-170,000 stakeholders in the city in 2013. Additionally, they raised information on monetary transactions within the value chain for several types of materials and the quantities exchanged.
- MOURSHED et al. (2017) described the plastic waste management in Bangladesh, showing what happens to different parts of the chain, from production to final disposal and reprocessing. They concluded with a list of

current challenges of the sector in the country and propositions of improvements.

- OYAKE-OMBIS, VLIET, VAN and MOL (2015) mapped the agents and materials flows of plastic waste in Kenya, in order to study the current regime and innovations in the sector. The characterisation they made for the Kenyan case is different from other places because it depicts waste pickers from yard shop operators and civil society organisations, who collect, clean, and sort the plastics from households and supermarkets for example.
- NANDY et al. (2015) quantified the paper, plastics and glass that is recovered by the informal sector of recycling in India and show the complexity of the chain there. They not only mapped the agents involved but also quantified the plastics exchange between these agents in 2012.
- The report “The New Plastics Economy” (ELLEN MACARTHUR FOUNDATION, 2016) highlighted the material flow of all plastics produced for packaging in 2013, estimating the global quantities that are recycled of 10% (including closed loop and cascaded recycling), while 14% is incinerated, 40% is landfilled and 36% is leaked into the environment with no management. It gave a global overview of the current state of plastics packaging waste management and the importance of the theme globally.
- JALIGOT et al. (2016) developed a method to apply value chain analysis in the informal sector of recycling, and the results include a map of the system dynamics of the recyclables plastics’ supply chains, for the case of the Zabaleen community in Cairo, Egypt. They showed visually the variables influencing plastics recycling, but no quantification was made.
- TORRES and CORNEJO (2016) analysed the plastics recycling industry in Peru and discussed that as the economy of the country grows and work conditions of the informal sector improves, the cost of the recycling structures might increase, therefore, making technical improvements and innovation within the sector necessary.
- KUMAR et al. (2018) evaluated the amount of plastic recovered and revenues generated from the informal recycling in Dhanbad, India. They characterized how the informal recyclers are working, found that 43% of materials recovered are plastics, quantified material, and monetary flows between agents.

2.2 Brazilian context

Before the important legal framework involving waste management was approved in Brazil (National Solid Waste Policy - 2010), COELHO, CASTRO and GOBBO (2011) reported the presence of scrap dealers and waste pickers in the recyclable polyethylene terephthalate (PET) supply chain. Reported by PACHECO; RONCHETTI and MASANET (2012), in 2007 only 16% of plastics coming from municipal solid waste was sent for recycling via waste pickers in the metropolitan region of Rio de Janeiro. At that time, they collected materials at the city's dumpsite and commercialised to the rest of the chain, including dealers, cooperatives of waste pickers and recyclers (PACHECO; RONCHETTI; MASANET, 2012).

The Brazilian Institute for Municipal Administration (IBAM) with the Ministry of Environment (IBAM, 2012) studied the feasibility of reverse logistics for recycling of post-consumer packaging waste. The study shows the recyclables' supply chain with five stages: sorting and primary processing, checking and scale, secondary processing, commercialization, recovery to the sector. However, they did not take into consideration the agents in the informal sector already in place and their connections to the recycling industry. At the same time, the Brazilian Business Commitment for Recycling (CEMPRE, in Portuguese) describe the chain as a pyramid, with recyclers at the top, great dealers (also called scrappers, intermediate recycling agents), small and medium dealers, organisations of waste pickers, usually cooperatives or associations and lastly independent waste pickers. The pyramid shows that there are many independent waste pickers, few organised waste pickers, few intermediaries, and fewer companies who recycle the materials.

One specific study included primary and secondary data from seventy-three agents from the chain representing the five geographic regions of the country (RUTKOWSKI; RUTKOWSKI, 2017). They analysed the recyclable materials supply chains for some plastics and paper packaging waste and represented the supply chains not only from the stage perspective but also from the agent/stakeholder perspective. They also specified from field research the tasks each agent performs in the chain, detailing them much more than previous studies. Recently, PIMENTEL PINCELLI et al. (2021) presented an overview of Brazilian plastic packaging waste management, identifying its general patterns.

2.3 Research gaps and research questions

As presented, research on recyclable materials and specifically plastics supply chains are limited, but they give a general view of stages and possible agents involved. Globally, the studies usually had a qualitative approach and when quantitative, the analyses are disconnected. Decision making, policies and regulations have been created to manage this complex process. However, little is known about the actual material, monetary and technical flows of these chains. Data monitoring through these transactions is exceedingly rare at Municipal, State or National governmental levels.

For developing countries like Brazil to create effective policies on reverse logistics and recycling of plastics, it is essential to understand the complexities of the plastics recovery chains and its benefits and impacts. Not only there is a need to map the agents involved in the chain, but to quantify systematically the mass and monetary flows and to evaluate how value is created and destroyed along the chain with possible interventions. These changes in value could be either in environmental, technical, social, or economic domains (what is called *complex value*), creating potential trade-offs in the system (IACOVIDOU et al., 2017b).

Therefore, this research will intend to answer the following research questions:

- What are the typical agents involved in a recyclable plastic supply chain in Brazil and what are their roles?
- What are the detailed material and monetary flows in this chain?
- How does complex value change throughout the chain in four domains (environmental, technical, social, and economic) and what are the trade-offs?

3. Aim and Objectives

The aim of this research is to illustrate and assess the supply chain of a specific type of recyclable plastic as part of a circular economy system, from waste generation to the production of secondary materials.

The aim was achieved by meeting the following specific objectives:

1. To map the agents involved in the recyclable plastic supply chain by activities and technologies used.
2. To quantify mass and monetary flows of the selected recyclable plastic packaging waste in each step of the supply chain.
3. To identify the trade-offs in the selected chain.
4. To assess the chain's performance as for its impacts in different dimensions.

4. Methods

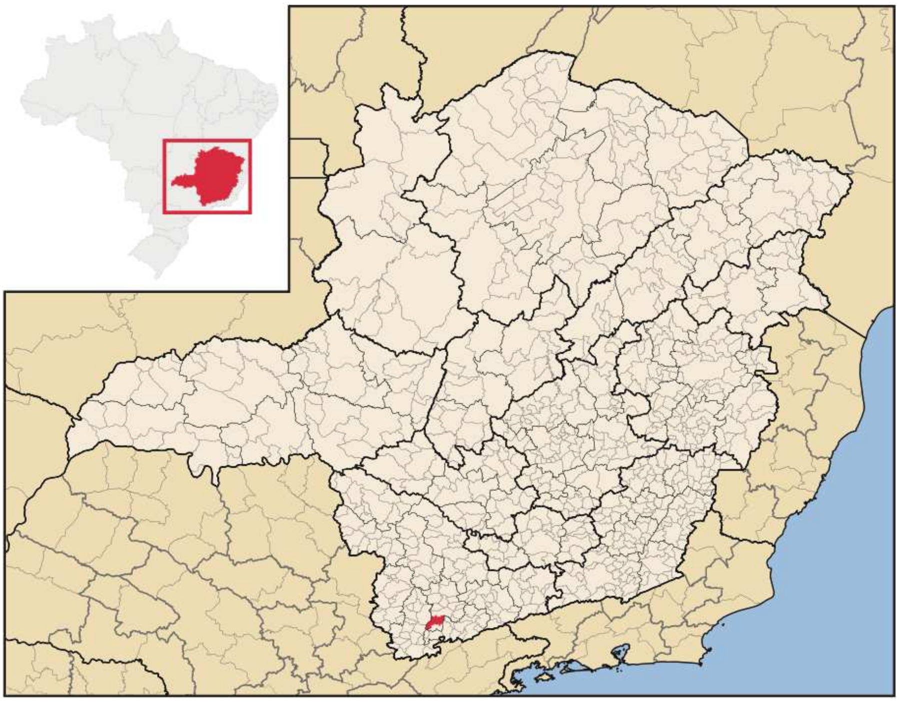
4.1 Overall research strategy

Our methodological strategy was to undertake a single case study of a specific type of polymer, by interpreting data collected through the combination between different analytical tools. Case studies are in-depth studies to comprehend a phenomenon or test specific theories and models (YIN, 2003). It allows the understanding of complex issues through contextual analysis, investigation from various sources, application of theories and extension of methodologies (STAKE, 1995, 2011; YIN, 2003). A mixed-methods paradigm will orientate data collection, analysis, and interpretation. The single case study design was chosen because of the explorative nature in which the theme is being studied and to be able to illustrate the complex dynamics in a particular recyclable plastic supply chain in enough depth and data accessibility, which would be difficult to achieve for multiple cases or a large sample. A case study, with in-depth analysis, interpretation, and discussion of collected evidence often results in new practical implications and reveals hidden problems, evaluate the situation, and identify possible interventions.

4.2 Case study

Plastics recycling industries in Brazil are complex and not deeply studied, therefore one specific area to start and one type of recyclable plastic packaging were chosen for a case study. The specific area was the municipality of **Cachoeira de Minas** because the research group Fluxus from UNICAMP in which the project was inserted had been working there and has good accessibility to waste management agents. The municipality Cachoeira de Minas is in the state of Minas Gerais, in Southeast Brazil (Figure 2).

Figure 2 – Cachoeira de Minas, located in Southeast Brazil



Source: (ABREU, 2006).

Furthermore, a focus on the type of plastic HDPE (high-density polyethylene) rigid plastics waste was chosen. HDPE is widely used in Brazil for multiple applications, such as packaging for food, hygiene and cleaning products, toys, and other domestic products (ABIPLAST, 2019). RUTKOWSKI and RUTKOWSKI (2017) showed that after PET (Polyethylene Terephthalate), HDPE is the biggest recyclable plastic market in Brazil. In addition, previous data collected by Fluxus research group found that, from all urban waste in the year 2016 in Cachoeira de Minas, the plastic type that has the most revenue for the local waste pickers association is the HDPE, proving its importance for the region.

4.3 Data collection

Data were gathered during a 15-month period through desk and field research and were of qualitative and quantitative nature. The desk-based research included a global literature review (Appendix A) and plus literature specific to the case study (i.e., Cachoeira de Minas). Databases for peer-reviewed articles, theses and theme-related reports were used such as Periodicos Capes, Scopus, Repositorio UNICAMP and

Google. As a result of this work, an article was presented at the AIDIS Congress in 2018 (Appendix B).

Field research was conducted during 6 months in the first semester of 2020 and included semi-structured interviews (MANZINI, 2003) by phone to most participants, with exception of two field visits in the Association of Waste Pickers in Cachoeira de Minas (June 2020) and at a reprocessing company in the state of Sao Paulo (July 2020). The semi-structured interview guide used can be seen in Appendix C and was created based on one of the analytical tools to be described in the next section. The data collected concerned activity description, facilities, technologies, mass, and monetary flows, and lastly, related to complex value measurement. This guide has been approved by the UNICAMP's Ethics Committee to comply with international and Brazilian ethical guidelines (Appendix D). In addition, a consent form was signed by all participants and kept with the researcher for record (Appendix E).

Documental research included gathering official records available online from Cachoeira de Minas city council and documents from each agent in the chain to be collected during field visits or by email, for example, internal records, financial documents, activity logs, etc. During field visits in two organisations, observational data were gathered not only for the purpose of understanding the general activity undertaken, but specially for description technologies used in each step of the chain. This was recorded through an observation template by the researcher and with photos (Appendix F).

4.4 Data analysis

All data gathered through literature review, semi-structured interviews, observation, and documents were reviewed, transcribed, and organised into a database. Then, synthesised aiming to perform a *crossover analysis*, when different lens on qualitative and quantitative data sets are used, by mixing different analytical tools, as explained in GRBICH (2013).

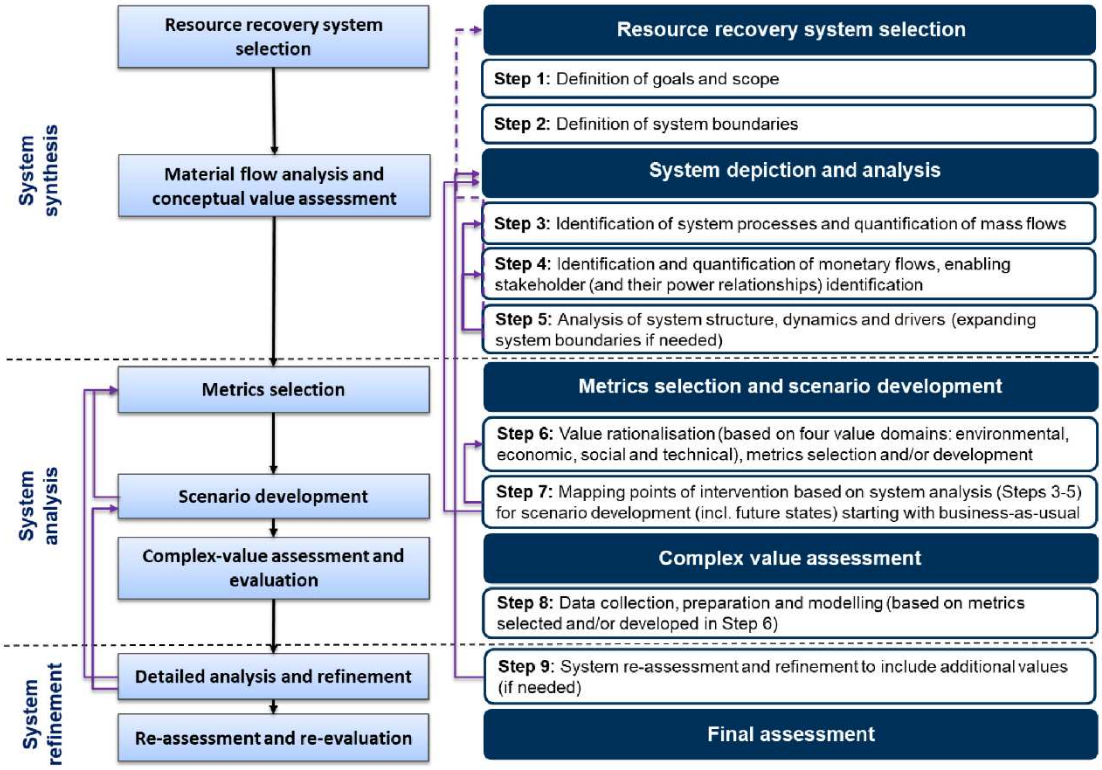
The analytical tools selected have been applied in waste recovery systems before separately. First, we mainly used the *Complex Value Optimisation for Resource Recovery* (CVORR) *approach* (IACOVIDOU et al., 2017b, 2017a) as a general guideline for the whole analytical process, by using some of its steps to understand and evaluate the system in our case study. Then, to complement and enrich the CVORR approach used in our analysis, we have included two other analytical tools. They are: 1. the *Solid Waste Technical Network framework* (FIORE, 2013; FIORE, F. A; RUTKOWSKI, 2017), based on the *Technical Networks* (TN) theory (SANTOS, 1994), which was used in our analysis to help map the agents in the case study and understand the dynamics between them and 2. the *Waste and Recycling Cost-Benefit Analysis Tool for Inclusive Recycling* (SoCo) (VELIS; RUTKOWSKI; RUTKOWSKI, 2016; SAKAMOTO et al., 2021), which was used to inspire the metrics selection to measure complex value in the system from the case study. Section 4.4.1 presents background for all three analytical tools used for our analysis while section 4.4.2 presents more detail on how the analytical process was carried out.

4.4.1 Analytical tools background

Complex Value Optimisation for Resource Recovery (CVORR) approach

The CVORR approach was developed by an interdisciplinary team of researchers from the University of Leeds to assess and optimise complex value in a resource recovery from waste system. It is based on a system thinking approach where value is a complex variable with positive and negative impacts in multiple dimensions that change dynamically within a system. This approach helps to assess and optimise *complex value* of a resource recovery from waste system, holistically, in multiple domains such as environmental, economic, social and technical (IACOVIDOU et al., 2017b). Figure 3 presents the CVORR approach.

Figure 3 – Complex Value Optimisation for Resource Recovery approach



Source: (IACOVIDOU et al., 2020).

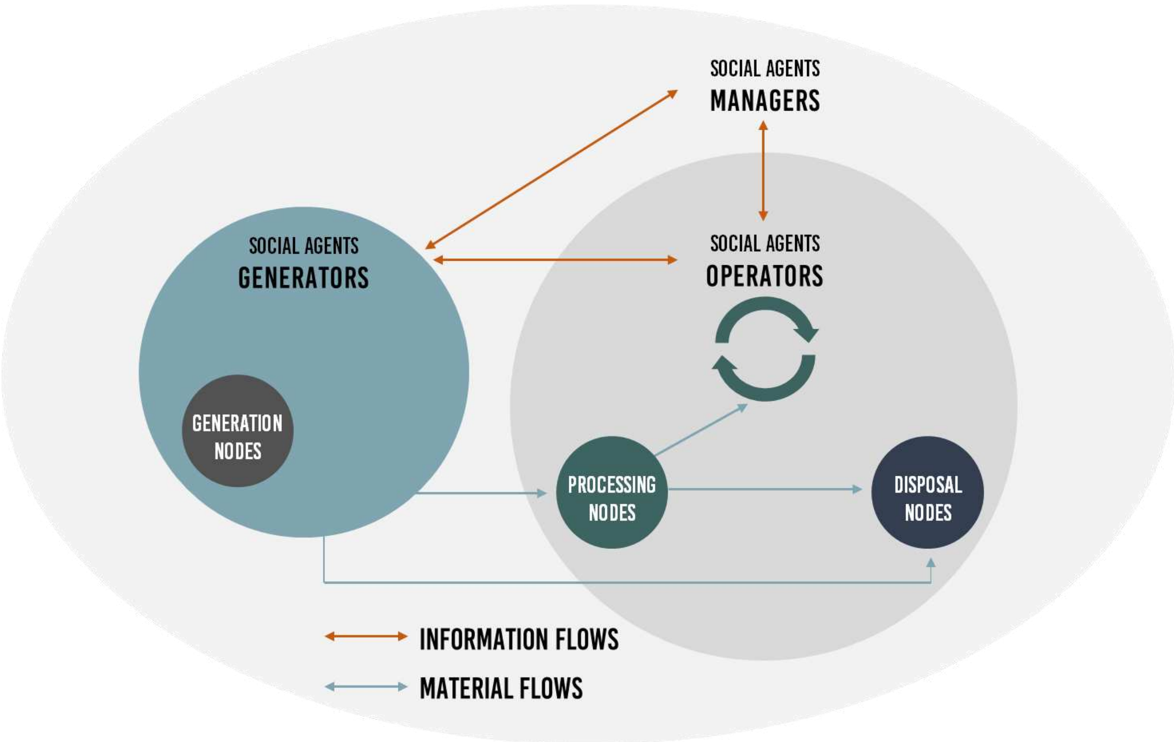
The first part of the CVORR approach is called the *baseline analysis* or *system synthesis*, which includes resource recovery system selection (steps 1-2) and system depiction and analysis (steps 3-5). The second part is the *system analysis,* with the metrics selection and scenario development (steps 6-7) and the complex value assessment (step 8) which is then refined (step 9) (IACOVIDOU et al., 2017b, 2020). CVORR distances from "end-of-pipe" solutions and instead, helps to identify interventions in a systemic way, by recovering value to inform ways by which responsible and sustainable practices can be implemented (IACOVIDOU et al., 2017b, 2017a). It has been used in cases such as pulverised fly ash as concrete additive, coal and steel waste, chemical additives in plastics, biomass, and solid recovered fuel, and plastic packaging (IACOVIDOU et al., 2017b, 2017a, 2020).

Solid Waste Technical Network (SWTN) framework

SWTN was developed by Fiore (2013), who was a PhD student from the Fluxus Research Lab at UNICAMP and it is based on the Technical Networks (TN) theory developed by the Brazilian geographer Milton Santos (SANTOS, 1994). Technical networks' (TNs) theory is one of many theories derived from the *network theory* (BORGATTI; HALGIN, 2011). After the Industrial Revolution, technology started to have a big impact on society and how it was connected (FIORE, 2013). Today, technology in society has not only created new connections locally, but ones that are globalised (FIORE, 2013). These connections are forming TNs which are dynamic but at the same time can describe the political, social, and economic moment of a certain territory (FIORE, 2013).

SWTN can support decision making by coordinating the various waste management activities in a territory, recognizing all the *social agents* who use and operate the systems, locating the facilities (called *nodes*) in a territory and monitoring *flows* that are taking place between nodes, usually material, monetary, and informational flows (FIORE, 2013; FIORE; RUTKOWSKI, 2017; LIMA; MÁRQUEZ; RUTKOWSKI, 2019). Figure 4 presents the SWTN framework. FIORE (2013) defines the SWTN social agents to be generators, operators or managers of the system, nodes to be all possible waste management facilities and flows that can be materials, money, information, and services.

Figure 4 – Solid Waste Technical Network framework



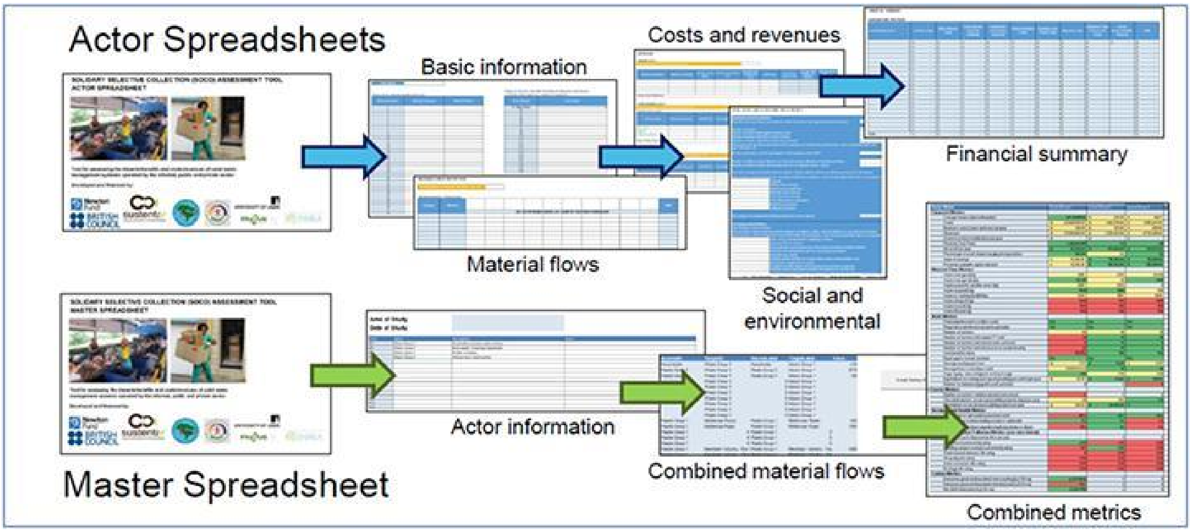
Source: Adapted from Fiore (2013). Graphic design by Jessica Lie Sakamoto.

Waste and Recycling Cost-Benefit Analysis Tool for Inclusive Recycling (SoCo)

SoCo is a methodological tool and training package with two different spreadsheets to more objectively quantify and elaborate potential impacts and benefits of selective waste collection and recycling services within a municipal waste management system (VELIS; RUTKOWSKI; RUTKOWSKI, 2016; INSTITUTO SUSTENTAR, 2018; SAKAMOTO et al., 2021). It has 45 indicators to measure each agent impacts and benefits in 7 categories: material flow, finance, labour, social, occupational health, local environmental pollution, and carbon. The tool is freely available online in English[1] and Portuguese[2]. Figure 5 presents an overview of the SoCo tool.

It was developed in 2016 with participatory methods that included public managers and waste pickers, funded by Newton Fund from the British Council (VELIS; RUTKOWSKI; RUTKOWSKI, 2016; INSTITUTO SUSTENTAR, 2018; SAKAMOTO et al., 2021). The team project was coordinated by the SUSTENTAR Institute for Interdisciplinary Studies and Research in Sustainability / Brazil, in partnership with the School of Civil Engineering / University of Leeds / UK, the FLUXUS Lab / FEC / UNICAMP / Brazil, INSEA Institute for Sustainable Development/Brazil and National Waste Pickers Movement (MNCR) / Brazil (VELIS; RUTKOWSKI; RUTKOWSKI, 2016; INSTITUTO SUSTENTAR, 2018; SAKAMOTO et al., 2021).

Figure 5 – SoCo tool overview



Source: INSTITUTO SUSTENTAR (2018) .

[1] https://soco.leeds.ac.uk/downloads/
[2] http://sustentar.org.br/site/lib/_textEditor/uploads/files/SoCo_Tool.rar

4.4.2 Analytical process

The initial analysis identified and characterised the agents involved in the chain and nodes (facilities) in which HDPE waste is managed, allowing for an initial visualisation of the system. Agents in a SWTN can be generators, operators, or managers. The direct and indirect agents influencing the HDPE chain starting in Cachoeira de Minas were identified, characterised and classified in categories based on the SWTN framework (FIORE, 2013) and on a global literature review of terminology for agents in recyclables' supply chains we did (Appendix A). Nodes are the activities and facilities, which were described according to the participation in the SWTN.

Material Flow Analysis (MFA) is a systematic assessment of stocks and physical flows of resources or materials in a given system in space and time (BRUNNER; RECHBERGER, 2003; CENCIC; RECHBERGER, 2008). Based on the MFA, the HDPE mass stocks at the nodes and flows emitted from nodes were identified, described, and quantified. The MFA is based on the principle of conserving mass, meaning that inputs in the system must equal outputs in the end of its boundaries. The flows were quantified according to data gathered, but assumptions were made to balance the mass when data was not available and are shown in the red colour flows (see also Appendix G for all calculations). A free software called STAN 2.6 was used (CENCIC; RECHBERGER, 2008) to build the diagram.

The monetary flow related to HDPE commerce in each step of the chain was identified, described, and quantified. A diagram showing the monetary values was created to map these flows. Furthermore, informational flows were characterised. After characterising agents, nodes and flows in each stage, the technical network of recyclable HDPE supply chain, from waste generation to production of secondary materials was elaborated. This mapping should show the system under study and its dynamics uncovered.

A metrics selection framework is being developed by the CVORR research team and not ready for use; therefore, in this research, the metrics to be selected were initially inspired by the SoCo tool. The metrics to support the measurement of complex value in each agent of the chain under study belong to each of 4 domains: environmental, social, economic, and technical. After selecting the initial metrics, during data collection for the case study, they were checked with the participants of the research so that the specific metrics for the case studies would be measured. The metrics used and their definitions can be seen in Appendix H.

The measurement of complex value according to IACOVIDOU et al. (2017b, 2020) was then presented on a table by attributing quantitative, qualitative or conceptual values to the metrics selected in the four domains for each agent of the HDPE supply chain. With this, it was possible to identify the trade-offs in value between processes and agents in the system. A trade-off is a balance between incompatible features. For example, there is potential increase in social impacts when trying to achieve higher recycling rates by exporting to places of very low environmental and health standards (IACOVIDOU et al., 2017b). Finally, interventions to improve the system were suggested. Possible interventions could include institutional contexts, operational changes such as collection, processing or disposal of waste, design and production processes and new markets for the material collected for recycling (IACOVIDOU et al., 2017b).

5. Results and Discussion

5.1 Agents in recyclables' supply chains – a global literature review

There is a diversity of agents involved in recyclables' supply chains, and there is an equally diverse terminology used to describe their roles (see Table A1 in the Appendix for a complete list of references we used for this section). Whilst, there are studies that categorise the direct agents involved in the recyclables' supply chains, particularly at the informal recycling sector (WILSON; VELIS; CHEESEMAN, 2006; SCHEINBERG et al., 2011; JALIGOT et al., 2016), there is still a lack of consensus in literature that becomes evident when one scrutinizes the description of the activities performed by the varying categories of agents. The various depictions of recyclables' supply chains from studies carried out around the globe attest also to this discord. Instead, we tried to steer away from communication barriers due to terminology inconsistencies and contradictions and placed attention to categorising agents based on the main activity they perform in the recyclables' supply chains using a global perspective.

With *direct agents* we refer to those who directly affect the generation and management of recyclable waste materials by being involved in their production and recycling and who have vested interest in the success or failure of recyclable waste materials recycling. With *indirect agents* we refer to those who influence (indirectly via decision-making) or are influenced by the generation and management of recyclable waste materials but are not engaged in the mass or monetary transactions accrued in the recyclables' supply chain. These are characteristically called the secondary agents of recyclables' supply chains, and may include national government, and non-governmental organisations, research institutes, local/regional/national/international consultants, and media, among others (SEMBIRING; NITIVATTANANON, 2010; OYAKE-OMBIS; VAN VLIET; MOL, 2015; HAHLADAKIS et al., 2018; DE OLIVEIRA; MÔNICA; CAMPOS, 2019).

To harmonise and simplify the terminology used to describe recyclables' supply chains, we scrutinised the terms used to describe the activities of direct agents involved in recyclable waste materials management and grouped them under six categories corresponding to the main activity performed in the recyclables' supply chain (Table 1).

Table 1 – Direct agents categories operating in the recyclables' supply chains (compiled based on a global literature review; it may not represent an exhaustive list of potential descriptions)

Suggested Category	***Activity***	***Terms used to describe agents that fall under this category***
Waste generators	Primarily generate post-consumers, or similar, recyclable waste materials	Households; Consumers; Consumers on the go; Commercial establishments; Retail and service (hospitality) sectors; industrial sectors producing recyclable waste
Collectors	Primarily collect (or buy) recyclable waste materials from the points of generation and/or disposal (e.g., door-to-door, streets, parks, dumpsites, landfills) and sell them to Sorting centres/ Small scrap dealers, or Brokers / Large scrap Dealers / Semi-reprocessors. *Secondary role(s): sorting, storage and baling of recyclable waste materials*	Municipalities or municipal companies; Private businesses (waste management contractors with a permit); Scavengers; Independent waste pickers; Rag pickers; Itinerant waste buyers or waste merchants
Sorting centres/ Small scrap dealers	Primarily sort recyclable waste materials (incl. baling and storing), and they trade - they buy from Collectors and sell to Brokers/ Large scrap dealers / Semi-reprocessors, or Reprocessors, *Secondary role(s): collection*	Material Recovery Facilities (MRFs); Sorting centres or units; Transfer stations; Cooperatives or associations of waste pickers; Small scrap dealers; Scrap yards, yard shops or junk shops; Buy-back / Drop-off centres
Brokers/ Large scrap dealers/ Semi-reprocessors	Primarily store and trade recyclable waste materials (or recycled materials as secondary commodities) in big quantities – they buy from Collectors and Sorting centres / Small scrap dealers, and sell them to Reprocessors (and from Reprocessors to Manufacturers in the case of recycled materials) *Secondary role(s): sorting and semi-reprocessing (e.g. removal of impurities, cleaning, cutting, crushing)*	Brokers; Middlemen; Intermediaries; Intermediate business firms; Intermediate traders; Medium and big scrap dealers; Intermediate levels of value chain; Intermediate processors; Semi-processors; Industrial semi-processing; Informal pre-processing; aggregators
Reprocessors	Primarily convert materials into secondary commodities and trade them – they buy from Sorting centres / Small scrap dealers, and Brokers / Large scrap dealers / Semi-reprocessors and sell them to Manufacturers (via Brokers or not) *Secondary role(s): sorting*	Reprocessors; Recycling processing industries; Mechanical recycling facilities; Recyclers; Recycling enterprises
Manufacturers	Primarily the end users of secondary materials in the production of new components and products – they buy from Brokers / Large scrap dealers / Semi-reprocessors, and Reprocessors. *Secondary role(s): reprocessing*	Local and foreign manufacturers; remanufacturing/ reprocessing industries; Value recapturing; Applicators or Transformers; End-user or retro-manufacturers; Formal private sector businesses 'higher up' in the industrial value chain

Source: Author (2021) based on global literature review – see Appendix A for a list of references.

We must note that there is a grey area between all categories of agents presented in Table 1. All agents are simultaneously waste generators, as members of the society, and some agents can perform more than one activity (usually two or three, e.g., collection-sorting-processing) in the supply chain. For example, waste collection companies could also be responsible for sorting and storing recyclable waste materials (in developed countries), whilst waste collectors in emerging countries could also be small scrap dealers and even do pre-processing, as it is the case of waste pickers organisations in Latin America (MÁRQUEZ; RUTKOWSKI, 2020; RUTKOWSKI, 2020). However, we decided to not let this diffusion obstruct the development of direct agents' categorisation, and instead used the word *'primarily'* to place emphasis on the agents' group main activity, whilst acknowledging that same agents' activities may also fall into other categories by denoting these as *'secondary role(s)'*.

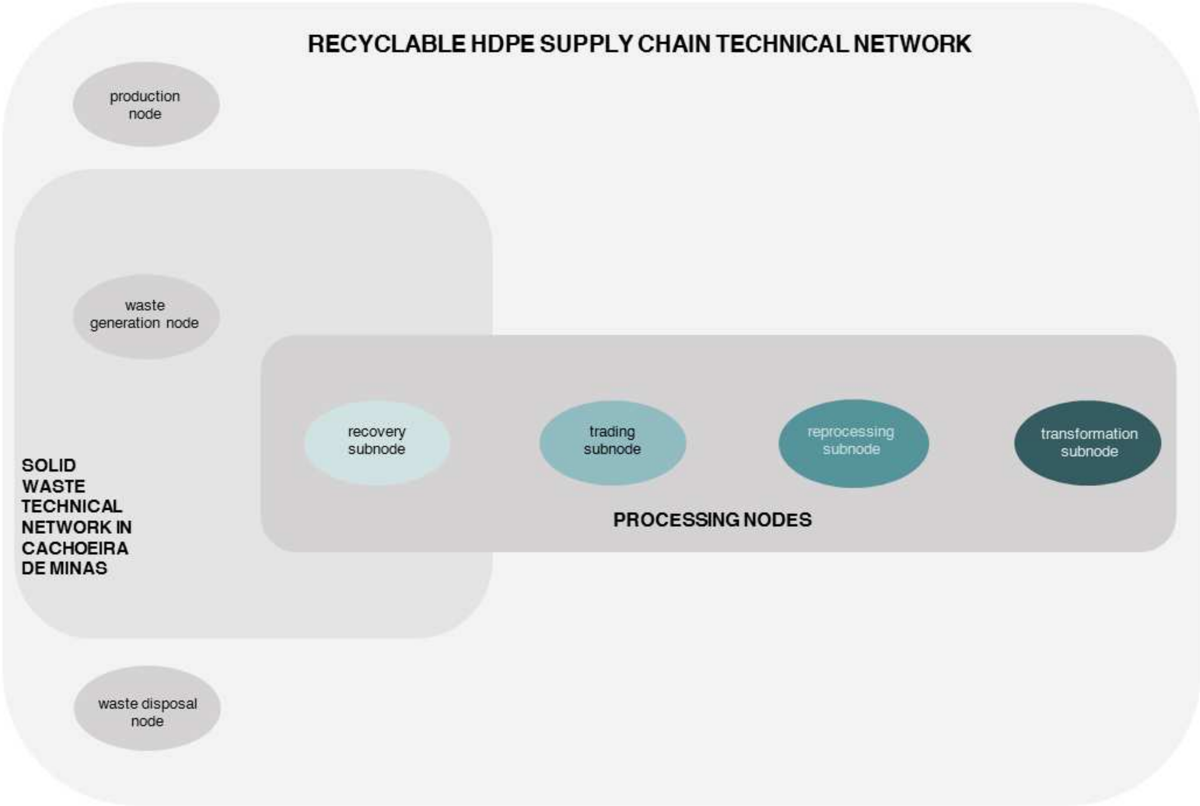
5.2 Technical Network of the recyclable HDPE supply chain starting in Cachoeira de Minas

As mentioned, technical networks are composed of nodes, social agents, and flows. Mapping and understanding nodes, agents and flows of the technical network of the recyclable HDPE supply chain starting in Cachoeira de Minas will support the system synthesis part of CVORR approach.

Nodes

The nodes identified in the recyclable HDPE supply chain technical network can be seen in Figure 6. It must be clear that the recyclable HDPE supply chain technical network contains the Solid Waste Technical Network which starts in Cachoeira de Minas.

Figure 6 – Nodes identified in the recyclable HDPE supply chain technical network

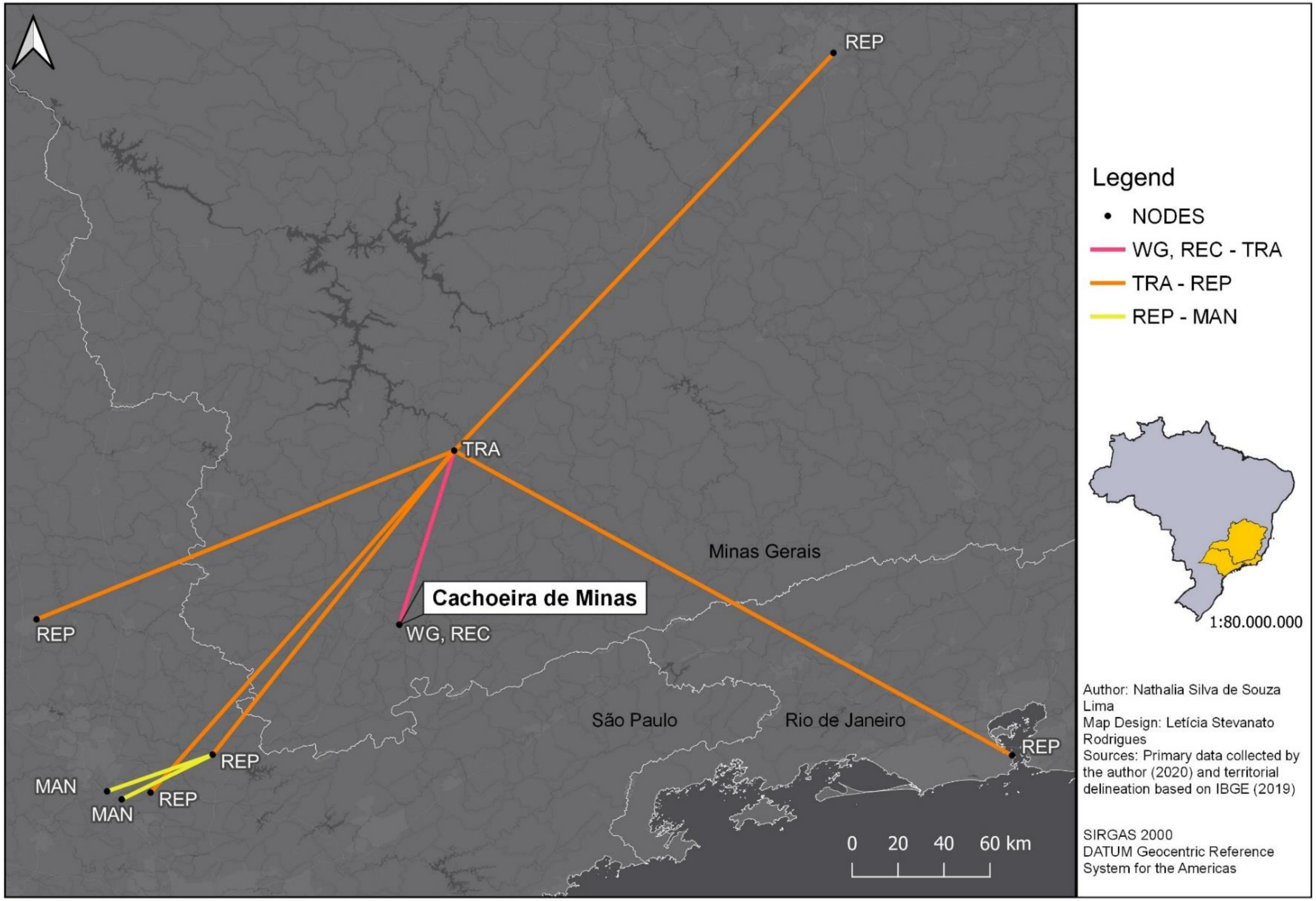


Source: Author (2021). Design by Jessica Lie Sakamoto.

- Production node: production of a diversity of products made of HDPE plastic, most of them being products that use HDPE packaging.
- Waste generation node (WG): HDPE waste are generated by a population.
- Disposal node: waste is collected and disposed of on a sanitary landfill.
- Processing nodes
    - Recovery subnode (REC): selective collection of HDPE together with other recyclables such as paper, cardboard, glass, metals and other plastics; then, materials are sorted from each other and baled separately.
    - Trading subnode (TRA): Reclassification if needed, greater accumulation and storage, and trading HDPE in big quantities.
    - Reprocessing subnode (REP): Cutting, cleaning, and converting HDPE into secondary commodities.
    - Transformation subnode (MAN): manufacturing of new components and products made of recycled HDPE.

Figure 7 presents a map with the nodes identified for the HDPE waste generated in Cachoeira de Minas.

Figure 7 – Map of nodes identified in the recyclable HDPE supply chain technical network starting in Cachoeira da Minas



WG: waste generation node; REC: recovery subnode; TRA: trading subnode; REP: reprocessing subnode; MAN = Transformation subnode.
Sources: Primary data collected by the author (2020) and territorial delineation based on IBGE (2019). Map design by Letícia Stevanato Rodrigues.

Although nodes start in the city of Cachoeira de Minas with the waste generation node, recyclable HDPE waste travels up to radius of 400 km to nodes that come after in the chain. Starting in the State of Minas Gerais, it can go to other states. For this reason, our TN will not have one public manager agent that oversees the whole network, for it surpasses city boundaries. That means that a recyclable waste chain TN applied to a territory possibly will not have its nodes in its own territory, but it will involve other territories and consequently their public managers indirectly. In the next section, we identify all the agents involved in the recyclable HDPE supply chain, but we chose to include only public manager in the city of Cachoeira de Minas to simplify our analysis.

Agents

The direct agents identified, their roles in the recyclable HDPE supply chain and, finally, their classification based on Table 1. There are also indirect agents identified and that play a secondary role in the recyclable HDPE supply chain starting in the Cachoeira de Minas municipality. Table 2 and Figure 8 present all agents identified in the case.

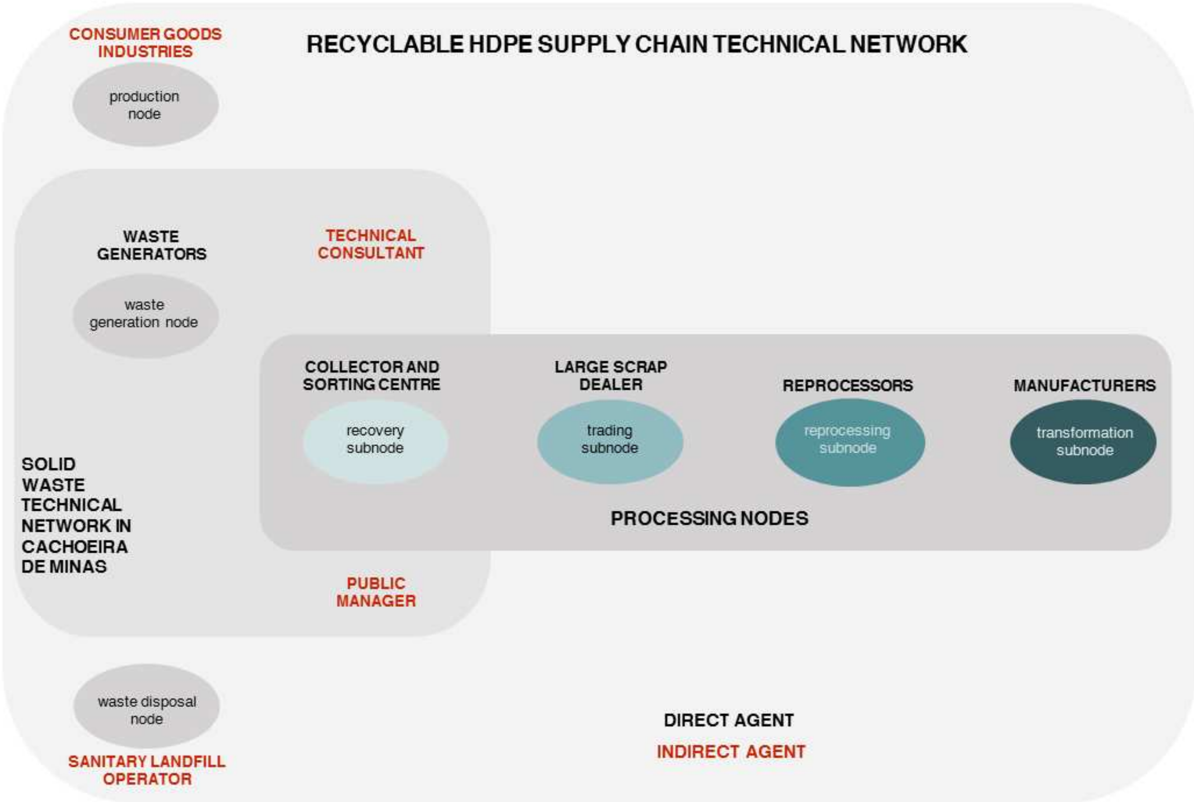
Table 2 – *A*gents identified in the recyclable HDPE supply chain starting in Cachoeira de Minas

Type	Agent	Role	Category Abbreviation
Direct	Households and small commercial enterprises	Waste Generators	GEN
	ACLAMA (Waste Pickers Association)	Collector and Sorting centre	CSC
	Company A[a]	Large scrap dealer	LSD
	Companies B and C[a]	Reprocessors	REP
	Company D[a]	Manufacturer	MAN
Indirect	Cachoeira de Minas local authority	Public manager	PUB
	Sanitary Landfill operator	Land disposal of waste	SL
	NGO	Technical consultant	NGO
	Companies E and F[a]	Consumer goods industry	IND
	Company F[a]	Invests in ACLAMA by paying technical consultant	INV

[a] *For privacy, private sector agents were identified as companies A, B, C, D, E and F.*

Source: Author (2021).

Figure 8 – Agents identified in nodes from the recyclable HDPE supply chain technical network starting in Cachoeira da Minas (direct agents are in black and indirect in red)



Source: Author (2021). Design by Jessica Lie Sakamoto.

In the next part, we will explore each direct agent in the network with further collected information. From all indirect agents, we have only included the sanitary landfill operator because it also receives the HDPE waste flow concerning our case study.

WASTE GENERATORS - Households and small commercial enterprises in the city of Cachoeira de Minas

Cachoeira de Minas (Figure 9) has 11,034 inhabitants (from 2010 IBGE census) (IBGE, 2010). The GDP per capita was R$ 24,207.36 per year (equivalent to US$ 6,247.06[3] per year) in 2018. The Human Development Index of the city in 2010 was of 0.706 (IBGE, 2010).

According to OLIVEIRA (2018), the daily urban waste generation per capita in Cachoeira de Minas was 0.67 kg/day/inhabitant, equivalent to 243.7 kg/year/inhabitant for the year 2016. That is 65% of the Brazilian's average urban waste generation per capita which was estimated at 1.032 kg/day/inhabitant for 2016 (ABRELPE, 2017). Since most of the city's economy concerns services, we assumed that small commercial entreprises who also have their waste collected by the city and ACLAMA, have similar waste generation than households.

Figure 9 – Cachoeira de Minas, Brazil.

Photo: Jessica Lie Sakamoto (2018).

[3] US$ 1.00 = R$ 3.875 (2018).

SANITARY LANDFILL OPERATOR

The sanitary landfill (Figure 10) is owned by local consortium of 10 municipalities (called CIMASAS) which was the first in the country to build a consortium sanitary landfill after the National Solid Waste Policy (MINAS SUSTENTÁVEL, 2011). It is serving around 190,000 people from cities around it (PREFEITURA DE ITAJUBÁ, 2013).

In 2016, 1,420.29 tonnes of urban waste were collected by the municipality to perform the mixed waste collection and transported to the sanitary landfill, equivalent to 76% of the urban waste generated in the city of Cachoeira de Minas (OLIVEIRA, 2018).

The mixed waste collection is done with a compactor truck which can go through the whole city in one day three times a week (OLIVEIRA, 2018). Then, it travels 60 km to arrive at the sanitary landfill in the city of Itajubá (OLIVEIRA, 2018) .

Figure 10 – CIMASAS sanitary landfill

Source: MINAS SUSTENTÁVEL (2011).

COLLECTOR AND SORTING CENTRE AGENT – ACLAMA

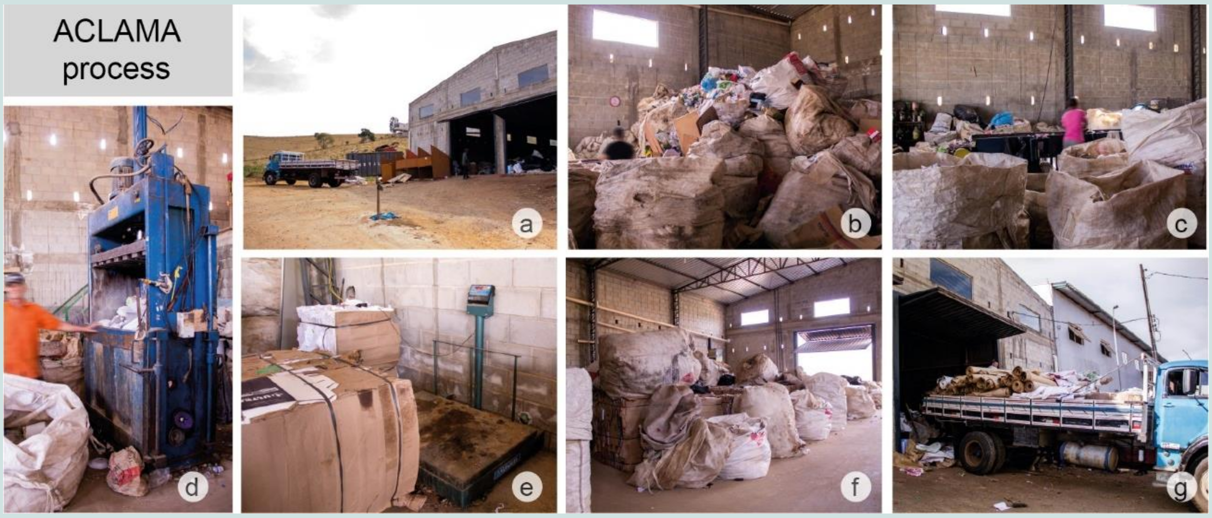
The Association of Waste Pickers in Cachoeira de Minas (ACLAMA) was founded in 2007 with waste pickers that before worked in the city dump (Figure 11). ACLAMA has a partnership with the municipality since its foundation and before the National Solid Waste Policy (2010) which makes it the exclusive provider for recyclable materials' collection and sorting services.

Figure 11 – Members of ACLAMA in January 2019

Source: ACLAMA (2019).

Every Tuesday and Thursday morning, a team of waste pickers distributed big bags on squares and blocks for the citizens to put their recyclables in. In the afternoon, with a truck whose driver is paid by the municipality, they collected the bags and delivered them at ACLAMA. ACLAMA has 9 men and 4 women working daily, amounting to a generation of employment for 13 WPs associates. They constantly change functions between collection and sorting materials, except for the bailer. There are no children working at ACLAMA. All Personal Protective Equipment (PPE) are donated and some pickers do not wear them because they do not have funds for this purpose (OLIVEIRA, 2018). ACLAMA collected 439 tonnes of potential recyclables in 2016 (Sakamoto et al., 2021), equivalent to 24% of urban waste generated in the city of Cachoeira de Minas. Figure 12**Figure 12** presents their production process.

Figure 12 – ACLAMA's production process



(a) Recyclables Arrival; (b) Initial Material Stockage; (c) Sorting Conveyor Area; (d) Pressing and Baling Area; (e) Weighting Area; (f) Stocking Area; (g) Recyclables Commercialisation.
Source: Sakamoto et al. (2021).

They sorted materials in 34 categories, including 14 types of plastics (22%), 8 kinds of paper or cardboard (51%), 7 types of metals (9%), 3 types of electronics (0.2%),1 glass type (2.4%), other types of waste (3.5%) sold to a large scrap dealer (391 tonnes) and rejected waste sent to landfill by the municipality (11% = 48 tonnes) (Sakamoto et al., 2021). The average sorting production was 2.9 tonnes/month per waste pickers (Sakamoto et al., 2021). According to IPEA's production classification, with a study of 70 waste pickers' organisations in Brazil, ACLAMA can be placed as highly efficient, above the national average of 1.5 tonnes/month/waste picker (IPEA 2010).

Most material collected was without impurities (organic or dirt) indicating that environmental education performed by ACLAMA is efficient. However, some materials (rubber, hoses, non-recyclable plastics, and cloths) do not have a market in the region, forcing ACLAMA to send to the sanitary landfill as rejects. This is considered a low reject rate, when compared to others as reported in Dutra et al. (2018) with rejects rates from 4 to 30% or in CEMPRE (2016) with average of 35%. It shows that ACLAMA can recover the majority of collected materials (89%), even though its location can be considered isolated from recycling hubs in the country. ACLAMA does not store bailed materials for a long time. They usually sell all materials to a Large Scrap Dealer once a month, who comes to pick up materials from a distance of 150 km.

LARGE SCRAP DEALER – Company A

Company A is located 160 km from ACLAMA and once a month goes with its own truck to Cachoeira de Minas to buy recyclables from them. They work with all materials sometimes resorting them to improve quality, then, they perform a great accumulation by storing in greater quantities to sell to Reprocessors.

They have been working with 20 types of polymers, and 2 kinds of HDPE: coloured and white. However, it is important to point out that according to Reprocessors demands, they change the types of materials they buy and store, to meet market needs. The company reported to sell HDPE to 5 different Reprocessors but did not disclose which companies exactly (see Figure 7).

Infrastructure includes an area of 7,000 m^2 with a warehouse, a conveyor belt, and some vertical pressing machines to have materials in bales.

It has 22 employees according to the CLT (Consolidated Labour Laws) system in Brazil and that use all PPE necessary. The company has an environmental license, pays all taxes, and emits fiscal receipts (in Portuguese, “nota fiscal”) for all transactions.

One truck load of HDPE is usually 10 tonnes. One cooperative will only store 700 kg/month, which would make it necessary for them to accumulate HDPE for 10 months before selling; hence, the role of a large scrap dealer to buy from several cooperatives and small scrap dealers to accumulate and meet the recycling industry’s requirements for materials.

REPROCESSORS – Companies B and C

One of the companies interviewed started its activities in 2007 and the other in 2013. Both had experiences with other types of plastics such as polypropylene and PET but not successful. They decided to work fully with HDPE, both with the blow-moulded rigid packaging type and with a focus on packaging products.

Rigid HDPE bales come from four to five different suppliers, such as organisations of waste pickers, waste management companies and scrap dealers. Both companies work with four types of HDPE in terms of colour: natural (transparent), white, coloured, and black. Usually, REPs go to their suppliers to pick up the loads, but some suppliers might take it up to REP. The cost for one of the companies to pick up a 7-tonne load is R$ 0.07/kg (US$ 0.02/kg[4]), so it is important that suppliers have a full load before selling. This makes it hard for organisations of waste pickers to sell directly to REPs, because they need to have a great quantity of materials to complete a load.

Companies reported that before buying from suppliers, they look at pictures of materials bales; this way, if quality of the bales is not good enough, they save on logistics. However, if they do get a load with low quality, they will lower the price on the spot, and companies usually have an employee who will perform a visual assessment on the spot. They also reported that the biggest impurity that lowers the price of a load is the presence of black HDPE bottles in the middle of other colours which are more valuable. Even so, comparing to the recyclable PET market, HDPE has stable prices.

Their processes include sorting, shredding, washing and extrusion (Figure 13). First, bales are undone, and materials are **sorted** in a conveyor belt to clean labels and lids made from different plastic types. Occasionally, other materials such as metals, paper, cardboard, and even medical waste are found and sorted out from HDPE. Then, plastics are **shredded** in smaller pieces called flakes. Next, they are **washed** with water only and decanted in a tank. Clean flakes are **extruded** to strands and then **pelletized** (production of pellets). Lastly, they **stored** before sales.

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[4] US$ 1 = R$ 3.816 (2019).

Figure 13 – Company B's process

(a) Sorting; (b) Shredding; (c) Washing; (d) Extrusion; (e) Bagging; (f) Stocking Area.
Source: Author (2021).

When secondary commodities are ready, they are sold to four to five different buyers (manufacturers). Transport is done either by the reprocessor himself, or clients come pick up with their own truck or hire a third to perform this service. Depending on their demands, result from the reprocessor process, pelleted HDPE can have different degrees of quality. For example, if lids and labels made of polypropylene are also processed together with the HDPE, the end pellets have a 10% contamination, therefore, lower prices. For the buyer, the purer the HDPE the better, because contamination with other plastics might affect their machinery and temperature needed for the transformation process. Reprocessors also reported a 20 to 25% loss rate, because of dirt, humidity, other plastics that not HDPE blow-moulded type, metals, paper, and cardboard.

Recycled HDPE prices depend on virgin HDPE resin prices. And these last depend on dollar, petroleum, and plastics markets. Virgin HDPE resins which can be bought at R$ 7.00/kg (US$ 1.83/kg[5]) are better for manufacturers machinery and end products. So, manufacturers claim that recycled HDPE resins that are sold by Reprocessors at R$ 6.30/kg (10% lower than virgin resin) is already considered expensive. Manufacturers

[5] US$ 1 = R$ 3.816 (2019).

in Brazil do not have any fiscal incentives for using recycled content in their products, which makes the main driver for this market, the price of resins themselves. So, Reprocessors sell HDPE recycled resin at average R$ 4.70/kg (US$ 1.23/kg[5]) – R$ 4.40/kg coloured (US$ 1.15/kg[5]); R$ 5.30/kg white (US$ 1.39/kg[5]); R$ 4.00/kg black (US$ 1.05/kg[5]). They buy HDPE waste without taxes and sell them paying all taxes, which explain the high sale price comparing to buying prices (average R$ 1.70/kg - US$ 0.45/kg[5]). If they receive enough amounts of other materials, they accumulate and sell to other companies to reprocess them, for example, injection HDPE, metals, PET, etc. This way they reduce all solid waste in their process.

None of the companies opened the details of their costs, but one of them reported a revenue of around R$ 4.5 million/year (US$ 1,2 million/year or US$ 98,260.00/month[5]). One of the companies is sitting on a 20,000 m^2 lot with a warehouse of 5,000 m^2 (Figure 14). They treat all the water used to wash the HDPE in its own plant, which does not use any detergents. There is no air pollution.

Figure 14 – One of the reprocessors plant (top view)

Source: Company B's website (confidential).

One company has 13 employees and the other 98, most men. All of them according to the CLT (Consolidated Labour Laws) system in Brazil and that use all Personal Protective Equipment (PPE) necessary (mask, gloves, boots, glasses, ear protector). The companies have an environmental permit, Fire Department Inspection Certificate, pay all governmental taxes, and emit fiscal receipts (in Portuguese, "nota fiscal") for all transactions. Both have accidents registry, but only one of them reported one accident in its 8 year-time of existence.

MANUFACTURER – Company D

Company D was founded in 1984, has 10 plants in 7 different states in Brazil and 1,100 employees in total. It reported to produce 1 billion packaging units per year using 12,000 tons of recycled resins per year. Final products include packaging for hygiene products or food products sold to multinational consumer industries. It works with HDPE, PP, LDPE, PET, PVC, and other types of polymers. It also has ISO9000 since 1997, it was the first packaging producer to use recycled resins since 2003 and the first national company to perform Bottle-to-Bottle recycling for PET since 2007. Its process for HDPE packaging production is using the Extrusion Blow Moulding process (Figure 15), with automated technology and highly controlled environment, to produce different sizes packaging from 3 to 30 litters. The company also has a laboratory to test new products and 3D printers. It does not have a significant reject rate (lower than 0.01%) and air pollution is treated with filters.

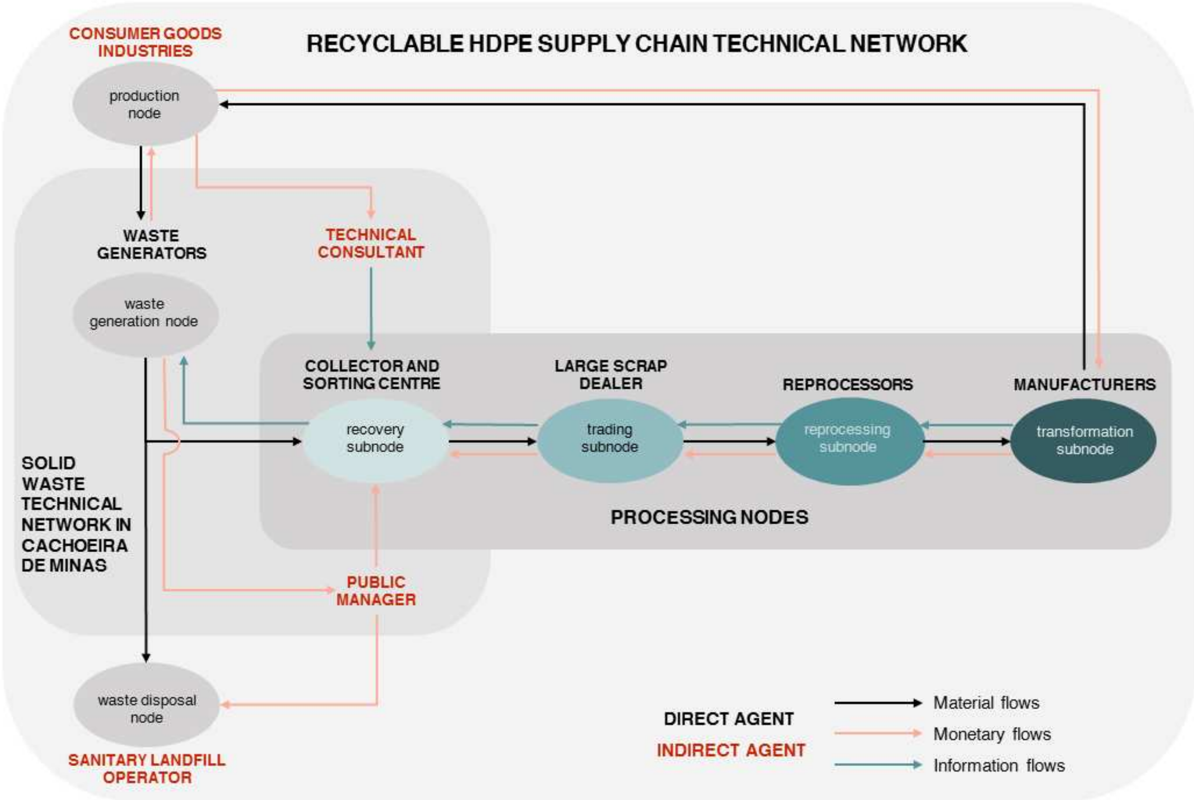
Figure 15 – Extrusion blow moulding machine

Source: Company D’s website (confidential).

Flows

Figure 16**Figure *16*** provides the representation of the complete technical network in the case study, including nodes, agents, and flows.

Figure 16 – Technical network of the recyclable HDPE supply chain starting in Cachoeira da Minas



Source: Author (2021). Design by Jessica Lie Sakamoto.

Flows can be material, monetary and information to be each explained in the next section.

Material flows

To understand the material flows in the case study starting at city level, first we set have the Brazilian context of plastics production and waste management at country level.

Brazilian plastic material flows

In 2017, Brazil generated around 80 million tonnes of urban waste (ABRELPE, 2017). According to a recent academic study (PIMENTEL PINCELLI et al., 2021), in 2017, Brazil generated 12 million tonnes of plastic packaging waste, representing around 15% of all urban waste generated.

In contrast, the chemical industry has declared almost 5 million tonnes per year of the apparent consumption of all types of plastics (not only packaging) for the country in 2008 (see Table 3 for more details). Besides, according to ABIPLAST (2019), apparent consumption of plastics in 2019 was 7.6 million tonnes, a growth of 52% in 11 years. However, supposedly this is not only for packaging, but all applications of plastics industrially and therefore, much below what was estimated by PIMENTEL PINCELLI et al. (2021). This shows how discrepant data is in the plastics industry in Brazil.

Table 3 – Consumption and application with short useful life of plastics in Brazil in 2008

Material	Apparent consumption* (t)	Application in product with short useful life
PP (polypropylene)	1,273,802	Boxes, domestic utilities, lids, pots, trash bags, bottles, gallons, big bags, wrapping tape, packaging filaments, buckets, diapers fibres
HDPE (high-density polyethylene)	676,881	Heavy duty bags, bags, lids, pots, bottles, buckets, boxes, and bottles
LDPE (low-density polyethylene)	531,152	Labels, bags, lids, and bottles
LLDPE (low-density linear polyethylene)	612,373	Labels, lids, bottles, and packaging
PET (polyethylene terephthalate)	530,564	Packaging
PVC (resins) (polyvinyl chloride)	1,026,731	Packaging and film
PS (polystyrene)	337,020	Packaging
Total	4,988,523	

* Apparent consumption was calculated based on the quantity of material produced plus the quantity imported minus the quantity exported.
Source: PACHECO; RONCHETTI; MASANET (2012).

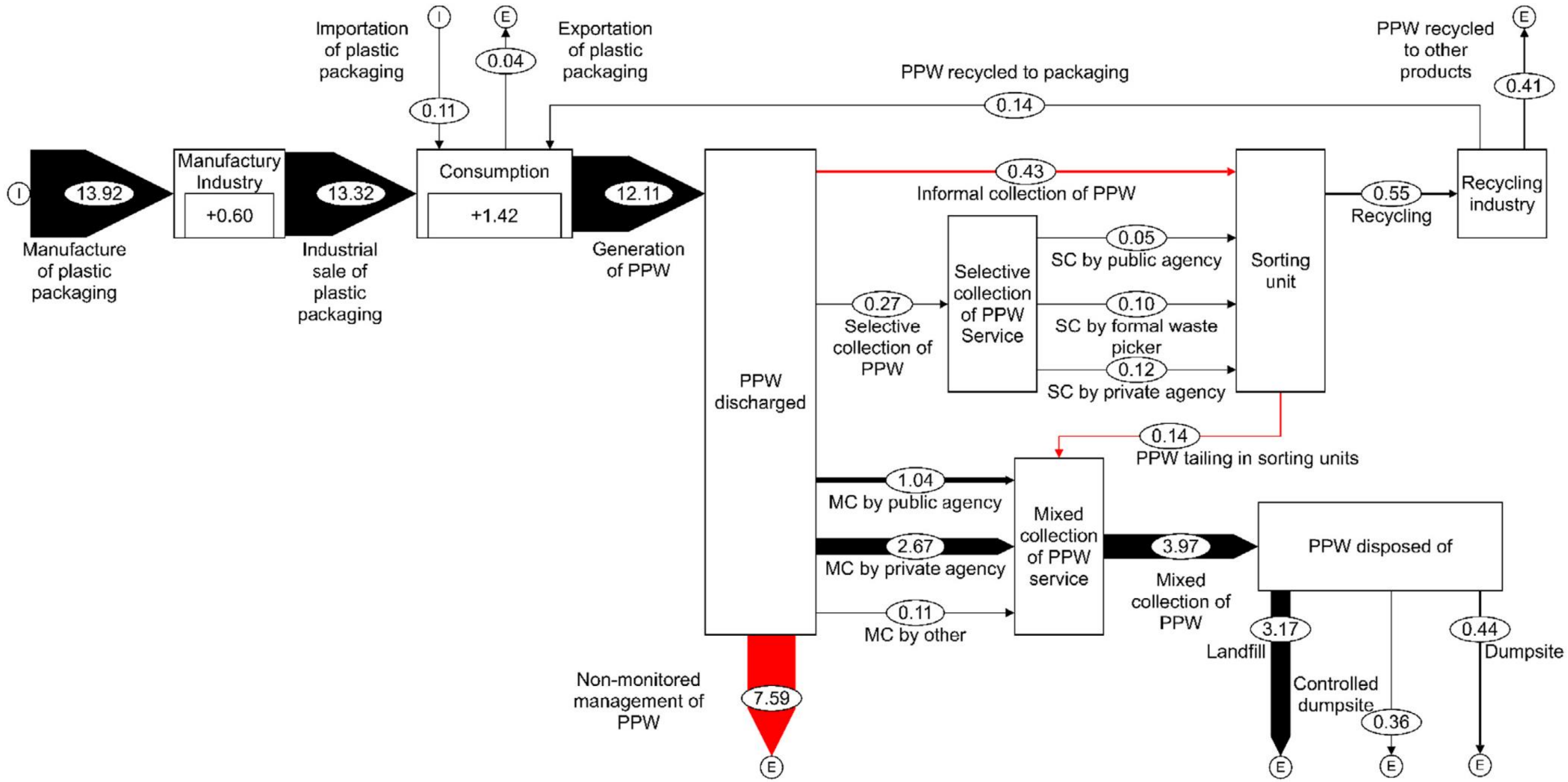
The specified quantity of HDPE type plastic in the composition of Brazilian urban waste is not available but, based on Table 3 where 14% of all plastics is HDPE, we estimate that 1.6 million tonnes of HDPE packaging waste per year are generated for the whole country.

There are 716 active plastics mechanical recycling companies in Brazil (reprocessors and manufacturers together) with approximately 1.8 million tonnes of installed capacity, mostly micro and small enterprises and most (88%) located in the South and Southeast regions (ABIPLAST, 2019). Together they employ 18,662 people and generate R$ 2.4 billion of income (equivalent to US$ 630 million[6]) (ABIPLAST, 2019). The plastics industry does not make available which of these companies are working with only HDPE, but the total quantity of post-consumption plastics that are recycled in the country is accounted at 757 thousand tonnes in the year 2018, and 43% is PET (ABIPLAST, 2019). The second most recycled polymer at 18% is the HDPE, totalling estimated 136,260 tonnes/year of HDPE being recycled in the whole country (ABIPLAST, 2019).

Although it only concerns post-consumer plastic packaging waste, the Material Flow Diagram (Figure 17) made by PIMENTEL PINCELLI et al. (2021) shows a general view of the plastic packaging waste material flow in Brazil in 2017. One of their main findings is that most of the quantity of plastic waste generated was not monitored (PIMENTEL PINCELLI et al., 2021). The solid waste information system in place in Brazil (SNIS) still only includes some agents, it does not include industrial agents such as manufacturers of packaging for example.

[6] US$ 1.00 = R$ 3.816 (2019).

Figure 17 – Material flow analysis for post-consumer plastic packaging waste flow in Brazil for 2017 (in million tonnes)



MC: mixed collection; SC: selective collection; The flows lacking any previous information are highlighted in red.

Source: PIMENTEL PINCELLI et al. (2021).

Case study: Material Flows for Cachoeira de Minas HDPE supply chain

The material flow diagram generated for the case study can be seen in Figure 18. All calculations made by collected data and assumptions based on literature can be seen in Table A2 in the Appendix G.

There are several categories of HDPE materials that are sorted in the generated waste, e.g., blow-moulded rigid, injection rigid, films and coloured, white, natural, or white. The diagram concerns mostly HDPE packaging waste, especially blow-moulded rigid packaging.

With the population of the city, 11% of HDPE products are stored in households. ACLAMA is currently collecting 59% of all HDPE waste generated by the population of Cachoeira de Minas, while 41% goes to the sanitary landfill.

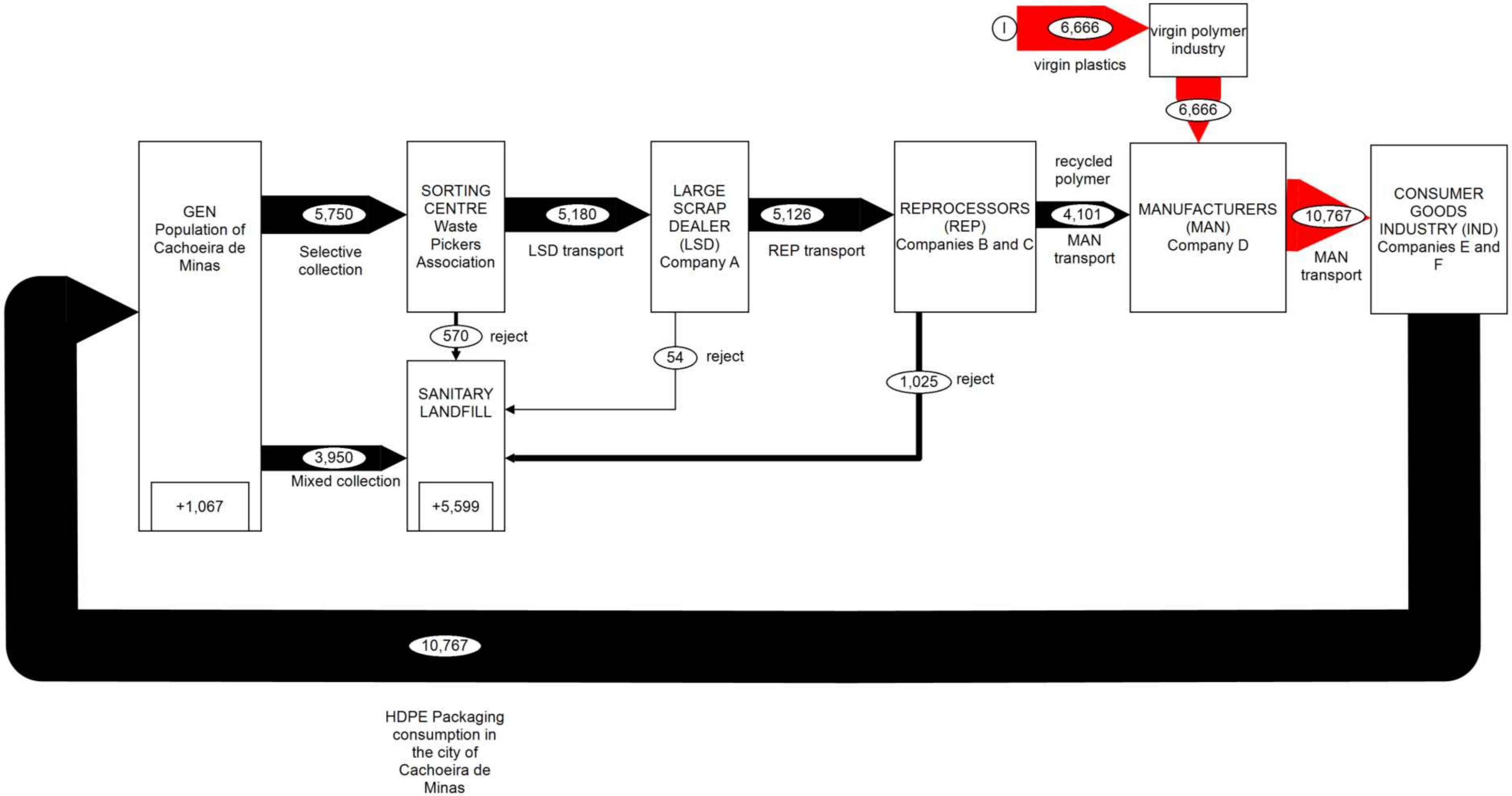
During the sorting process, 11% of materials collected are sent to landfill due to water, impurities (food or other non-recyclable materials such as lids, stickers, and labels) and to the smaller-size pieces of materials (which makes it hard to manually sort them). But ACLAMA sells 89% recyclables collected to the Large Scrap Dealer (LSD), who goes and picks it up with its own truck.

The LSD has a 1% reject rate in its process, according to them it is extremely low because they select well the materials they are buying, and this rate concerns water and small impurities. But we assume that they want to sell as much materials as possible, so some bales can be highly mixed with other rejected materials (such as non-recyclable type of plastics), and even on purpose.

Reprocessors target a specific type of HDPE waste, so they have the highest reject rate in the chain (around 20 to 25%). That is because of dirt, humidity, other plastics that not HDPE blow-moulded type, metals, paper, and cardboard are often in the middle of bales bought from suppliers. According to them, even with a strict quality control for their suppliers, the process still presents losses in terms of mass.

Lastly, reject rate in the transformation stage is negligible at 0.01% according to manufacturers. The virgin resin use is common, but the rate at which it is added with recycled content is variable. Some say from 10% to 90% use of virgin resin, therefore we estimated around 60% of virgin polymer input to produce “recycled” packaging.

Figure 18 – Material flow diagram for HDPE supply chain starting in Cachoeira de Minas, Brazil in 2016 (kg/year)



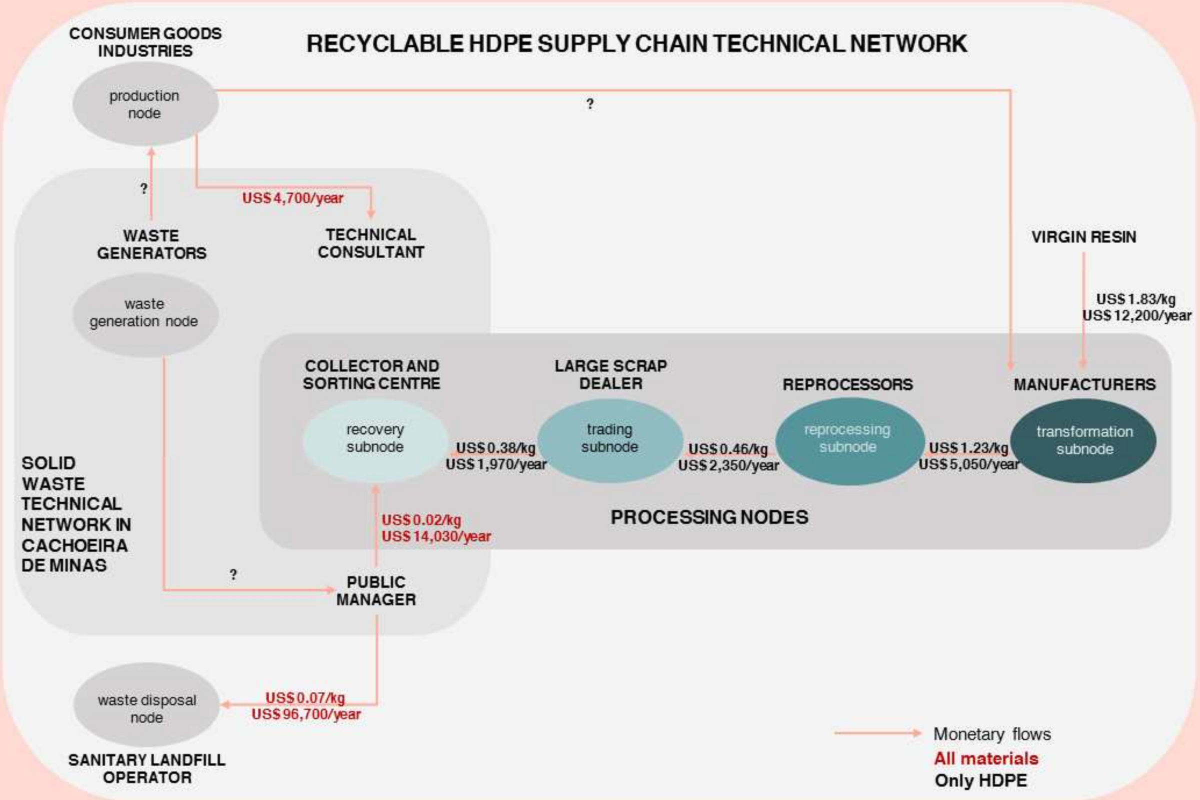
The flows lacking any previous information are highlighted in red.

Source: Author (2021)

Monetary flows

The monetary flows are presented per kg and a yearly estimation in Figure 19.

Figure 19 – Monetary flows for HDPE supply chain starting in Cachoeira de Minas



US$ 1 = R$ 3.816 (2019).

? = flows that were not quantified in this research.

Source: Author (2021). Design by Jessica Lie Sakamoto.

The Cachoeira de Minas municipality paid for ACLAMA urban cleaning services as a subsidy, by paying rent, water and energy bills, the collection driver and sending rejects to landfill, resulting a total of US$ 15,298.52 in 2016[7], besides a donation of a press machine priced at US$ 7,714.29[8]. The municipality does not have a contract with ACLAMA, but the local law 2,496/2017 authorises the city to pay for these expenses.

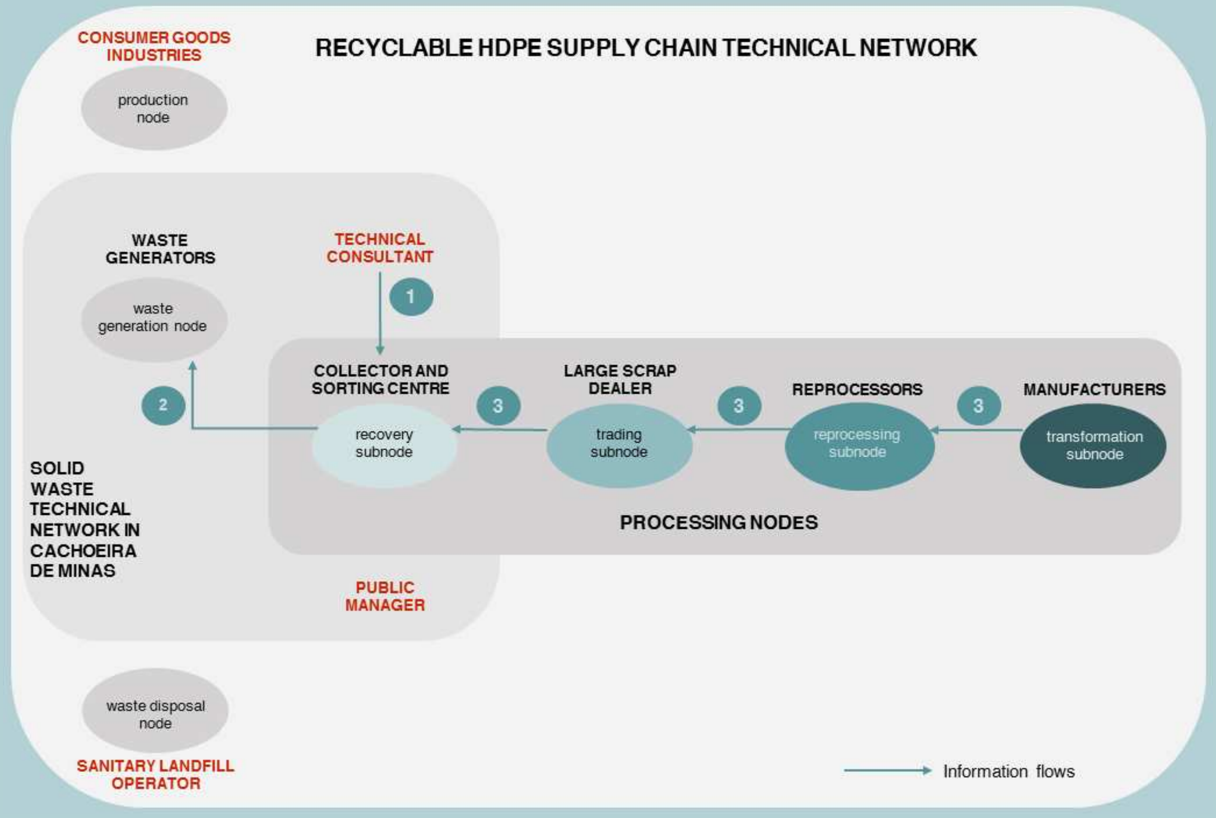
The specific consulting hired by one Producer to advise ACLAMA and other waste pickers organisations in the region are part of a program that invests in reverse logistics of packaging of this Producer.

[7] US$ 1 = R$ 3.352 (2016).
[8] US$ 1 = R$ 3.352 (2016).

Information flows

Information flows were defined in the SWTN with public managers being the main agent responsible for information concerning solid waste management in the technical network (FIORE, 2013). All information concerning the correct destination of all types of municipal solid waste should be clear and transparent for citizens. In our case study, we identified three types of information flows coming from different agents than previewed by Fiore: technical consultancy, environmental education, and material quality demand. Figure 20 shows these flows in the TN of the case study.

Figure 20 – Information flows for HDPE supply chain starting in Cachoeira de Minas



1. *Technical consultancy*: Consulting for waste pickers aims to empower and strengthen the organisations, solidary selective collection programs and communities' sensibilisation.
2. *Environmental education*: when waste pickers perform the waste selective collection door-to-door, they go about explaining how population should segregate their waste to sort for recyclables.
3. *Material quality demanded by industry*: lastly, there is an information flow concerning the quality of HDPE demanded by industry, starting at Manufacturers, going through each stage. In fact, environmental education performed by ACLAMA is also part of this demand to avoid material contamination.

Source: Author (2021). Design by Jessica Lie Sakamoto.

5.3 Recyclable HDPE supply chain’s performance: complex value measurement

The complex value measurement of each agent in the recyclable HDPE supply chain starting in Cachoeira de Minas can be seen in Table 4. First, we laid out the activity, secondary role, and visual representation of HDPE output in each stage of the chain. Then, we depict each complex value metric for each agent in four dimensions. The metrics used and their definitions can be seen in Appendix H.

Table 4 – Recyclable HDPE supply chain's performance: complex value measurement (continues)

Metric	WASTE PICKER AND SORTING CENTER – ACLAMA	LARGE SCRAP DEALER (LSD) – COMPANY A	REPROCESSORS (REP) – COMPANIES B AND C	MANUFACTURER (MAN) – COMPANY D
Activity	Sort recyclable waste materials (incl. baling and storing), and they trade - sell to large scrap dealer	Store and trade recyclable waste materials in big quantities – they buy from Collectors and Sorting centres/Small scrap dealers, and sell them to Reprocessors	Convert materials into secondary commodities and trade them – they buy from Sorting centres/Scrap dealers, and sell them to Manufacturers	The end users of secondary materials in the production of new components and products – they buy from Brokers and Reprocessors
Secondary role(s)	Door-to-door collection	Sorting and semi-reprocessing (e.g., removal of impurities, cleaning, cutting, crushing); logistics	Logistics	Not applicable
Visual representation of material output of each stage [9]				

[9] Image sources:
CSC - https://img.mfrural.com.br/api/image?url=https://s3.amazonaws.com/mfrural-produtos-us/237660-373444-2033628-compro-pp-e-pead-em-fardo-ou-moido-flake-o-melhor-preco-do-brasil.webp&width=800&height=480&mode=4
LSD - https://sc04.alicdn.com/kf/UTB8t707t5aMiuJk43PTq6ySmXXax.jpg
REP - https://gedelplasticos.com.br/wp-content/uploads/2017/03/pead-1600.jpg
MAN - https://www.ecowebdesign.com.br/painel/img/uploads/1540292496_580.jpg

Metric	WASTE PICKER AND SORTING CENTER – ACLAMA	LARGE SCRAP DEALER (LSD) – COMPANY A	REPROCESSORS (REP) – COMPANIES B AND C	MANUFACTURER (MAN) – COMPANY D
Technical dimension				
Technology	Conveyor belt for sorting; Vertical pressing machine	Conveyor belt for sorting; Vertical pressing machine; Fork-lifts	Conveyor belt for sorting with automatic magnet segregators; Shredding machine; Decantation tank; extrusion machine; pelletizer machine; Fork-lifts	Extrusion blow moulding machine; 3D printers
HDPE input (kg/year)	5,750	5,180	5,126	Recycled: 4,101 Virgin: 6,666
Material output (kg/year)	5,180	5,126	4,101	10,767
Loss rate (rejection rate)	11%	1%	20 – 25%	0.01%
HDPE processing capacity (tonnes/year)	6	360	3,600 – 18,000	12,000
Economic dimension[10]				
HDPE Buying prices (US$/kg)	Not applicable	White: US$ 0.41/kg Coloured: US$ 0.35/kg	White: US$ 0.45/kg Coloured: US$ 0.37/kg Black: US$ 0.31/kg	White: US$ 1.39/kg Coloured: US$ 1.15/kg Black: US$ 1.05/kg
Operational and maintenance costs (US$/kg) – for all materials not only HDPE	US$ 0.01/kg	US$ 0.05/kg	Did not reply	Did not reply
Capital cost (US$) – for all materials not only HDPE	US$ 21,818.42	Did not reply	Did not reply	Did not reply
HDPE Sale prices (US$/kg)	White: US$ 0.41/kg Coloured: US$ 0.35/kg	White: US$ 0.48/kg Coloured: US$ 0.43/kg	White: US$ 1.39/kg Coloured: US$ 1.15/kg Black: US$ 1.05/kg	Did not reply
HDPE Revenue (US$/kg)	US$ 0.37/kg	US$ 0.08/kg	White: R$ 3.60/kg Coloured: R$ 3.00/kg Black: R$ 2.80/kg	Did not reply

[10] US$ 1 = R$ 3.816 (2019)

Metric	WASTE PICKER AND SORTING CENTER – ACLAMA	LARGE SCRAP DEALER (LSD) – COMPANY A	REPROCESSORS (REP) – COMPANIES B AND C	MANUFACTURER (MAN) – COMPANY D
Social dimension				
Number of Jobs	13	22	13 - 98	1,100
Gender ratio (M:F)	9:4	Did not reply	12:1	Did not reply
Working Hourly Wage (%)	36%	Did not reply	Did not reply	Did not reply
Type of work	Employees are associates	CLT (Consolidated Labour Laws) system	CLT (Consolidated Labour Laws) system	CLT (Consolidated Labour Laws) system
Use of PPE	Sometimes	Yes	Yes	Yes
Child labour	No	No	No	No
Environmental dimension				
Energy consumption	Low	Medium	High	High
Environmental Impact Assessment (permit)	No	Yes	Yes	Yes
Water quality control [a]	Not applicable	Not applicable	Yes	Yes
Air pollution control [b]	Not applicable	Not applicable	Not applicable	Yes

[a] *If water used is treated in the same facility according to local environmental body's standards.*

[b] *If air pollution is generated and is treated using filters according to environmental body's standards.*

Source: Author (2021).

Material loss rate at reprocessing stage is very high. With the segregating and sorting work from both ACLAMA and the LSD, it would be expected that Reprocessors had a lower reject rate. However, because they wash the plastic and separate materials even further according to manufacturers' demands, the real mass really going through as pellets is only 80% of input material in the beginning of their process.

There are **processing capacity** limitations in the beginning of the chain. ACLAMA is not able to accumulate great quantities or bales of HDPE, because: 1. they do not have fork-lift equipment; 2. it would probably take around 10 months of accumulation to close a full load; 3. waste pickers claim that storage means loss of money; and 4. they urge to be paid fast while Reprocessors might take up to 6 months to pay.

There are increasing **capital costs**. As you go up the chain, the capital cost necessary increases, seen by the level of technology demanded for each stage.

Plastic resins **market** is a chaotic irregulated market. Reprocessors buy HDPE waste without taxes and sell them paying all taxes, which explain the high sale price comparing to buying prices.

Manufacturers in Brazil do not have any **fiscal incentives** for using recycled content in their products, which makes the price of virgin resins the main driver for this market. Virgin HDPE resins which can be bought at R$ 7.00/kg are better for manufacturers machinery and end products. So, manufacturers claim that recycled HDPE resins that are sold by Reprocessors at R$ 6.30/kg (10% lower than virgin resin) is already considered expensive.

As you go up the chain, **jobs** created tend to increase, according to processing capacity. ACLAMA's social regime is an association, so workers are also owners of the business and decide together where they spend their revenue. In this case ACLAMA's associates earned R$ 1,200/month (US$ 358/month[11]) in 2016, 36% above minimum wage in Brazil at that time. We could not verify detailed data from other agents because they did not provide with labour details on wage.

Another aspect we observe is that there is no guarantee that the **water consumption/treatment and air pollution control** at the reprocessing and

[11] US$ 1 = R$ 3.352 (2016).

transformation stages, respectively (even with environmental permits issued by a local authority or environmental body) have adequate efficiency to avoid environmental degradation.

Trade-offs and interventions

Each member of the chain has a role, not always recognised by governmental regulations. If regulations and taxes would be applied, some agents might not be able to continue their activities because they do not have the funds to cover this extra cost.

If ACLAMA would accumulate more materials (or other agents in the sorting category, so to say), LSD category agents would probably lose their market space. One of the proposals would be to create a consortium where LSD could work as 2^{nd} order cooperatives. Large scrap dealers are present in all materials supply chains; however, their role is rarely recognized nor in academy nor by the government, who refers to all the agents after the organisations of waste pickers to the “recycling industry”.

60% of HDPE waste generated in the city of Cachoeira de Minas is still being landfilled, despite efforts toward a selective collection for recyclables. This might happen because:

1. the population might not be sorting their recyclable plastics correctly, therefore the way that educational processes have been developed could be inadequate, so a better environmental education and communication program from the municipality (according to the Brazilian Constitution and the National Environmental Education Policy – Law 9.795/1999 – municipalities are responsible for their territory); and
2. plastics products sold to consumer by the Consumers Goods Industries are likely to have a mixture of polymer types in the packaging (for example, main part made by HDPE, lid made from PP and label from PDV).

In the latter case, the recommendation is of a deeper national (or even international) level discussion on how to regulate packaging production and consumption in a way that it facilitates the recycling later in its life cycle and recycled resins to be cheaper to buy than virgin resins. Today, reprocessors highly depend on the virgin resins mutable prices to set the prices for the recycled resins.

Therefore, economic incentives for recycled resin production such as tax exemptions could be applied for all companies working on the recyclables' supply chains. Today, they are only possible for manufacturers but there has been lobby to improve them (BRAZILIAN SUPREME COURT, 2021).

Another possible regulation could concern the composition of packaging, to use one type of polymer per product to facilitate recycling. Today, most lids and labels are using different polymers than those of the containers, not only in Brazil but worldwide. While in developed countries this is "possible", there is a difficultly for countries such as Brazil to do this. Even if national production conforms to this, it is hard to regulate imported packaging through industrialised products from developed countries.

Comparison with a case study from Cairo, Egypt

As shown in Chapter 2 of this dissertation, there is no study on HDPE waste management nor on its recyclable supply chain, that we could compare our case directly. However, one study applied value chain analysis on PET recycling for the case of the Zabaleen community in Cairo, Egypt (JALIGOT et al., 2016). Although different analytical methods were applied, we were still able to compare some aspects of both case studies.

JALIGOT et al. (2016) map the agents in the chain, depicting 4 types of agents who perform different activities than what we identified in the HDPE chain in Brazil. The 'upstream' chain includes small businesses from the Zabaleen communities who perform collection, sorting and compaction. Collection and what they called "primary sorting" are carried out by Agent 1, "secondary sorting" and compaction of the PET bottles by Agent 2. Linking these two agents there are intermediate traders. The 'downstream' chain includes recyclers performing shredding (Agent 3) and washing/drying (Agent 4), also with more intermediate traders between them. After that PET is sold to either Greater Cairo recycling markets or international markets.

Similar to what we found with Large Scrap Dealers here in Brazil, JALIGOT et al. (2016) identify that "*The niche filled by intermediate traders is essential to deal with relatively small and regular purchases from a large number of collectors/primary sorters and also small secondary sorters. They provide storage space to accumulate larger quantities for which recyclers will pay a higher price.*" (JALIGOT et al., 2016: 83).

They mention two other issues similar to our case, one about the quality demands by, in their case, the international recycling industry and second contamination of PET bottles concerning other plastics, such as collars and caps.

Concerning economic value in each step of the chain, JALIGOT et al. (2016) present the HDPE net value added (%) from one agent to the next in the chain (comparing sales prices between one stage and the next). Table 5 shows a comparison to data from our case study.

Table 5 – HDPE net value added in each step of the chain in Egypt and Brazil

Egypt **JALIGOT et al. (2016)**	**HDPE Net Value added (%)**	**Brazil** **This research**	**HDPE Net Value added (%)**
Agent 1 *Collection/primary sorting*	N/A	Waste Picker Organisation and Sorting Centre *Collection/primary sorting*	N/A
Agent 2 *Secondary sorting/compaction*	15%	Large scrap dealer *Secondary sorting/compaction*	21%
Agent 3 *Shredding*	26%	Reprocessor *Tertiary sorting, shredding, washing, pelletization*	170%
Agent 4 *Washing/drying*	6%		
Agent 5 *Pelletization*	15%		
Sum Agents 3-5	*47%*		
Manufacturer (recycler)	N/A	Manufacturer	N/A

Source: Author (2021).

Comparing the recyclable HDPE chains in both countries, Brazil has a higher net value added between its agents. Especially in the reprocessing stage, where Egypt has a summed 47% net value added and Brazil 170%. That might be because costs in this stage might be higher, including the taxes, which could be studied in future research.

Another difference is that collectors in Egypt receive payment for the collection of waste (because they collect recyclables and organics), while in Brazil, most waste pickers earn with materials' sales only, as it is the case with ACLAMA, but also mentioned by several researchers (RUTKOWSKI; RUTKOWSKI, 2015; MEIRA DE SOUSA DUTRA; HARUE YAMANE; RIBEIRO SIMAN, 2018; SAKAMOTO et al., 2021).

6. Conclusions

This study performed a case study on one type of plastic (HDPE) supply chain starting in a small municipality called Cachoeira de Minas. We achieved our aim with its illustration and assessment using a crossover analysis with three different analytical tools (CVORR, SWTN and SoCo) for the first time. The nodes of the technical network were described in the territory and agents involved were characterised, describing their role and activities. Then, material and monetary flows were quantified, and information flows were described, completing the description of the technical network. Finally, we measured complex value in four domains for four direct agents and we identified interventions to improve the system, the value trade-offs and compared our case with a case from Egypt. Although we have partially used each analytical tool, the combination we did was successful for the objectives of this work.

No other published study has assessed in depth a supply chain case study using HDPE plastic waste; therefore, we hope to publish the results of this research in a scientific journal. With this, we will contribute to the management of plastics reverse logistics and recycling systems, therefore increasing to the knowledge base required for advocating efficient public policies, in Brazil and other emerging countries.

During the execution of this research, some barriers were encountered. The Ethics committee from Unicamp took ten months to approve the project and when we finally got it, the COVID-19 pandemics burst out, which delayed field visits and data collection. Another difficulty was data collection with the agents in the supply chain; as you go up the chain, the harder it becomes to find data and contact companies. Most were not interested in participating (I contacted around 21 companies in total and only had 4 positive responses). This could be because it is still highly informal supply chain and most people do not want their commercial information to be shared. It is important to note that all data collected is very reliant on interviewees declared information.

For future research, we recommend characterising service flows (i.e., mixed and selective collection of recyclables and transportation of recyclables); proposing how public managers from cities other than Cachoeira de Minas could unite to organise and manage the technical network of HDPE recyclable material supply chain; and further studying economic and fiscal incentives for recyclables’ supply chains.

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Appendices

Appendix A – Global literature review on recyclables' supply chains

Table A1 - Global literature review on recyclables' supply chains

References	Region	Country
(MILIOS et al., 2018)	Europe	Denmark, Sweden, Norway
(HAHLADAKIS et al., 2018)		England
(DAHLBO et al., 2018)		Finland
(SHEN; WORRELL, 2014)		EU-15
(BROUWER et al., 2018; VAN ENGELSHOVEN et al., 2019)		The Netherlands
(GUILTINAN; NWOKOYE, 1975; POHLEN; FARRIS II, 1992; CHIKOWORE; KERR, 2020)	North America	USA
(FERRONATO et al., 2021)	Latin America	Bolivia
(VACCARI; PERTEGHELLA, 2016)	Europe	Bosnia and Herzegovina
(SCHEINBERG et al., 2016)		Bulgaria, Greece, Macedonia, Romania, Serbia
(NAVARRETE-HERNANDEZ; NAVARRETE-HERNANDEZ, 2018)	Latin America	Chile
(FEI et al., 2016)	Asia & the Pacific	China
(STEUER et al., 2017)		
(JALIGOT et al., 2016)	Africa	Egypt
(PUTRI; FUJIMORI; TAKAOKA, 2018)	Asia & the Pacific	Indonesia
(SASAKI et al., 2019)		
(SEMBIRING; NITIVATTANANON, 2010)		
(GALL et al., 2020)	Africa	Kenya
(OYAKE-OMBIS; VAN VLIET; MOL, 2015)		
(KASINJA; TILLEY, 2018)		Malawi
(BOTELLO-ÁLVAREZ et al., 2018)	Latin America	Mexico
(AFON, 2012; ADAMA, 2014)	Africa	Nigeria
(ASLAM et al., 2021)	Asia & the Pacific	Pakistan
(MASOOD; BARLOW, 2013)		
(MRKAJIĆ et al., 2018)	Europe	Serbia
(SCHENCK et al., 2019)	Africa	South Africa
(WILSON et al., 2009)	Asia & the Pacific	Thailand
(VILLALBA, 2020)	Latin America	Argentina
(HAMIDUL BARI; MAHBUB HASSAN; EHSANUL HAQUE, 2012)	Asia & the Pacific	Bangladesh
(MATTER; DIETSCHI; ZURBRÜGG, 2013; MOURSHED et al., 2017)		
(GONÇALVES-DIAS; TEODÓSIO, 2006; AQUINO; CASTILHO JR.; PIRES, 2009; COELHO; CASTRO; GOBBO, 2011;	Latin America	Brazil

PACHECO; RONCHETTI; MASANET, 2012; RUTKOWSKI; RUTKOWSKI, 2015, 2017; IBÁÑEZ-FORÉS et al., 2018; MEIRA DE SOUSA DUTRA; HARUE YAMANE; RIBEIRO SIMAN, 2018; SELLITTO, 2018; DE OLIVEIRA; MÔNICA; CAMPOS, 2019; GUARNIERI; CERQUEIRA-STREIT; BATISTA, 2020; RUTKOWSKI, 2020)		
(VALENZUELA-LEVI, 2020)		Colombia
(DIAZ; OTOMA, 2014; TORRES; CORNEJO, 2016)		Peru
(NANDY et al., 2015; SUTHAR; RAYAL; AHADA, 2016; SANDHU; BURTON; DEDEKORKUT-HOWES, 2017; KUMAR et al., 2018)	Asia & the Pacific	India
(SCHEINBERG; SIMPSON, 2015)	International	Several countries
(SCHEINBERG et al., 2011)		
(APARCANA, 2017)		
(AL-SALEM; LETTIERI; BAEYENS, 2009)		
(VALENCIA, 2019)		
(WILSON; VELIS; CHEESEMAN, 2006)		

Appendix B - Article presented at AIDIS Congress

Full Reference: LIMA, N S S; RUTKOWSKI, E W; VELIS, C A. The Plastics Recycling Chain in Brazil: a Review. Oral Presentation, XXXVI Congreso Interamericano de Ingeniería Sanitaria y Ambiental, October 27-31, 2018, Guayaquil, Ecuador.

THE PLASTICS RECYCLING CHAIN IN BRAZIL: A REVIEW

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Abstract

The Brazilian government has been negotiating with representatives from the private sector and organized waste pickers to create an effective reverse logistics for post-consumer packaging waste in the country. However, plastics recycling chains are very complex to map, due to material diversity, high level of informality and high number of actors involved. We have listed 5 different approaches to represent recycling chains in Brazil, which are described by stages and/or actors within the plastics recycling chain. There is great need for mapping and characterizing actors in the plastics recycling chain and, in a further step, quantify their material, financial and technical flows. As a continuation of these frameworks and tools created previously, the next phase of this research will characterize further the plastics recycling chains in Brazil, starting from the generation until recycling, with actors, material, financial and technical flows. We hope to contribute to the improvement of public policies and management of reverse logistics and recycling systems specially in developing countries.

Introduction

Extraction, consumption and disposal of materials characterize the linear economy in which the industrial revolution has been built upon. Increasing economic development coupled with increasing per capita consumption and disposal has led to air, soil and water pollution, threatening environmental and human health. Driven by resource scarcity and an urgency to prevent greenhouse gas emissions and reduction of energy consumption, the concept of resource efficiency has been developed with the aim to reinsert recyclable materials in the economy, hence closing one of the many loops of a circular economy (Velis and Brunner, 2013; Velis, 2015a).

Recycling or valorization of waste depends on a reverse productive chain, with source segregation, collection, sorting, mechanical processing and trading materials in local and international markets (Jaligot et al. 2016). Each of these steps involve different actors, including waste pickers and collectors, governments, transporters, service providers, material traders and recyclers (Velis, 2015b).

While in upper income countries recycling is a well-established and organized process, in the Global South the situation differs. Alongside the activities of the formal sector who is responsible for the solid waste management practices, there is also informal recycling that often determines the direction of the economy (Ezeah et al., 2013; Lewis, 2016).

Most of the recycling in the Global South is supported by labor-intensive activities of urban poor and other marginalized populations, who salvage the most valuable recyclable materials from waste for generating an income, by selling them to other actors in the recycling chain (Velis and Vrancken, 2015; Velis et al., 2012).

In recent years, researchers have raised challenges in creating effective policies that integrate actors in the productive chain to increase materials recycling. Some of them are: real integration of the informal recycling sector in the formal waste management industry, occupational health of workers in the recycling sector, fair trade in global chains of secondary materials, dependency on petroleum markets, articulation with production industries, public participation in recycling programs, political instability, poverty eradication, building inclusive cities (Velis et al., 2012; Velis, 2016; Velis, 2015a; Velis and Vrancken, 2015; Lima and Mancini, 2017).

Brazil has been in the forefront of this formalization process after the Brazilian Solid Waste Policy was approved in 2010 (Brazil, 2010; Lima and Mancini, 2017). The national government has been negotiating with representatives from the private sector and waste pickers to create an effective reverse logistics for post-consumer packaging waste (SNIR, 2015). However, there are other actors in the recycling chain that must be considered when trying to estimate recycling quantities and other benefits and impacts of recycling.

In Brazil, waste composition studies have indicated that plastics represent from 11 to 47% in mass for materials that can be recycled (Ribeiro et al., 2014; CEMPRE, 2016). Rutkowski and Rutkowsi (2017) pointed out that paper and plastics represent 79.3% of waste pickers' income, having a great recycling market demand in Brazil. On the other hand, there is a recent and growing preoccupation with the environmental and social impacts plastics causes, especially its management after consumption. The main impacts are toxic substances in plastics, marine litter, ingestion and strangulation in marine life, non-biodegradability when landfilled, urban pollution and even recycling when done without occupational health, environmental and public health standards (UNEP, 2014; UNEP, 2015; Velis & Brunner, 2013; Velis, 2015a; World Economic Forum et al., 2016; EC, 2015).

Therefore, it is very important to collect this packaging waste, specially plastics, to be directed to recycling; and for this, a reverse logistics and recycling infrastructure must be in place. Understanding the status of plastics recycling chains is fundamental to implement policies that will involve diverse actors in the recycling chains, from generators to recyclers.

Objective

This study will review research that has represented the plastics recycling chains in Brazil and find a research gap. This paper is the first phase of a research project to characterize in depth the plastics recycling chain in Brazil.

Methods

The subject of this study was representations for plastics recycling chains in Brazil. The strategy of research consisted in searching for articles, books and documents that describe and represent the plastics recycling chains in different localities in Brazil. Therefore, a literature review was carried out to encounter different representations. Data was analyzed from 5 studies, carried out from 2012 until 2017.

Results and Discussion

There are five main representations for recycling chains in Brazil, two describing it generally, independent from material type (Figures 1 and 2) and three describing plastics recycling chains (Figures 3 to 5). Two are from reports made by the national government and the private sector recycling association (Figures 1 and 2, respectively), one is from a book made by two specialist professors on plastics and recycling (Figure 3) and two from articles published in scientific journals (Figures 4 and 5). The studies were published between 2012 and 2017, which shows it is a recent theme being discussed in Brazil.

The Brazilian Institute for Municipal Administration (IBAM) published a study together with the national government Ministry of Environment on the feasibility of the reverse logistics for recycling of post-consumer packaging waste. Figure 1 shows the general system for reverse logistics, with 5 stages: sorting and primary processing, checking and scale, secondary processing, commercialization, recovery to sector. It can give us a brief overview of the recycling chains, but this approach is very simplistic in relation to the actors that can be involved in each stage. This study mainly focused on modelling an ideal recovery system for packaging waste in general, by creating a new infrastructure with investment from the private sector and operational support from local governments and cooperatives of waste pickers. It did not take into consideration the informal system already in place and diverse actors and their connections to waste pickers and the recycling industry.

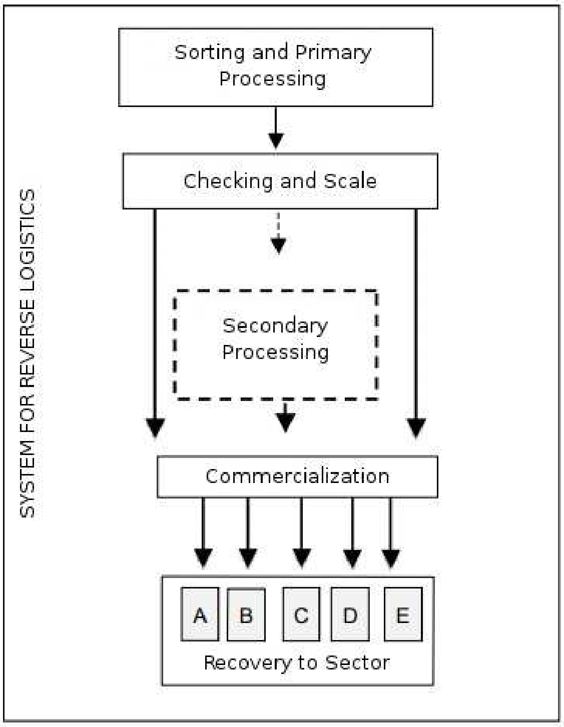

Figure 1. Reverse Logistics System stages. Source: Adapted from IBAM (2012).

The Brazilian Business Commitment for Recycling (CEMPRE) published a guide for selective collection of urban recyclable waste, in which they describe the recycling chain as a pyramid (Figure 2). From top-down, there are the recyclers (4), great accumulators (also called scrappers, intermediaries recycling actors) (3), small and medium accumulators (2), organizations of waste pickers, usually cooperatives or associations (1a) and lastly, autonomous or independent waste pickers (1). This approach shows that the bigger the part of the pyramid, the more actors in numbers we have for each stage of the chain. So, there are many independent waste pickers and few companies who will recycle the materials. However, this is only a visual representation of the chain, it does not quantify material flows or characterize quality of materials in each stage and actor.

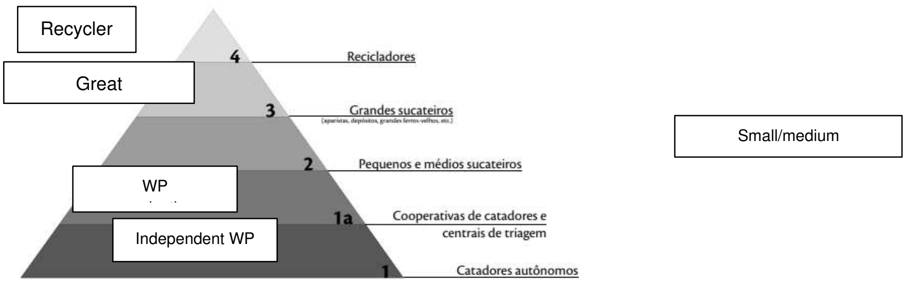

Figure 2. Recycling chain. Source: Adapted from CEMPRE (2014).

Professors Zanin and Mancini (2015) have written a book about plastics and recycling, its general aspects and recycling technologies. They have the most complete representation of the plastics recycling chain as seen in Figure 3. They include stages before generation of waste, such as extraction of resources, production, distribution, transport and consumption. After generating waste, they point out 3 different ways plastics are managed: first, collection for recycling (selective collection) which then goes to mechanical, chemical or energetic recycling; second, mixed collection which then is landfilled; third, hazardous plastics that are sent to incineration or industrial landfills. Each stage is then described from a technology point of view and possible actors are mentioned. This approach is a more holistic approach than others, for it includes stages before generation of waste, connecting the recycling with production of recycled goods. However, as in Figure 1 it focuses on the stages and not actors that might be involved in each of them.

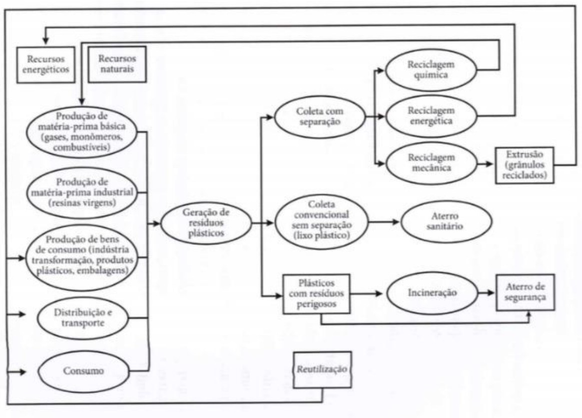

Figure 3. Schematic representation of the post-consumption plastics chain cycle (in Portuguese). Source: Zanin and Mancini (2015).

Rutkowski and Rutkowski (2017) analyzed the recycling chains for some plastics and paper in Brazil, with primary and secondary data from 73 actors from the recycling chain, including informal ones, in the 5 geographic regions of Brazil during 2013 and 2014. They established important nomenclature criteria for actors in the recycling chain:

1- Enterprises Recoverers of recyclable materials (REC) which can be REC T1 - first sorters, usually independent waste pickers or organizations of waste pickers - or REC T2 - buys selected materials from REC T1 and may perform a secondary sorting, usually middlemen and scrap yards;
2- Enterprises Revaluators (REV) of recyclable materials - intermediary industries who produce pellets and flakes;
3- Transformer Enterprises (TRANS) of recycled raw material – diverse industries that produce plastics products made from pellets and flakes

Figure 4 shows a flowchart for the paper and plastics recycling chains in Brazil (Boxes represent: grey—stakeholders; white—production processes; black -material type)

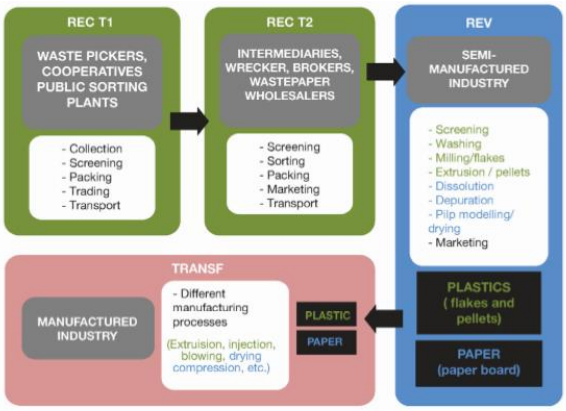

Figure 4. Flowchart of the paper and plastics recycling chains in Brazil (Boxes represent: grey—stakeholders; white—production processes; black -material type). Source: Rutkowski and Rutkowski (2017).

This approach represents the recycling chains not only from the stage perspective but also from the actor/stakeholder perspective. It specifies from field research the tasks each actor performs in the recycling chain, detailing them more than previous studies.

Coelho, Castro and Gobbo Jr. (2011) even though is the oldest study from this list and probably was carried out even before the Brazilian Solid Waste Policy (2010), mapped the Brazilian recycling chain specific for polyethylene terephthalate (PET), a type of plastic that is mainly used for packaging for beverages. Figure 5 shows this recycling chain, which the authors called reintegration system. They have represented the chain, as Zanin and Mancini (2015), holistically from manufacturing until making of new products from recycled PET. They mix stages with actors in the chain but report the presence of scrap dealers and waste pickers (scavengers). From this representation we can infer that all the recycling that happens, goes through these two actors, usually considered informal. If not, is either collected and sent to landfills or not collected and end in the environment with no control. It shows that a system for recycling was existing before legislation and other incentives, but without regulation and informally.

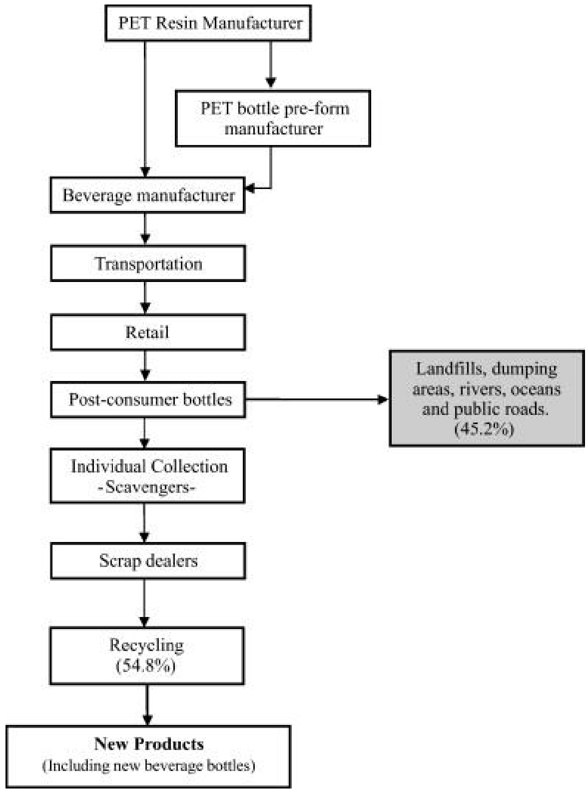

Figure 5. Post-consumer PET reintegration system in Brazil. Source: Coelho, Castro and Gobbo Jr. (2011.)

All these representations for recycling chains are different ways to visualize the systems in place for recovering materials from waste. Some of them represent stages and others use actors to describe the recycling chains. These studies allowed for clarification of how recycling chains work in Brazil, however, the first four generalize materials, either in general (first and second) or for all plastics (third and fourth). Only the fifth one is about one plastic type but is a very simple representation of the chain. Decision making, policies and regulations have been created to manage this complex process. However, little is known about the actual material, financial and technical flows of these chains.

Conclusions

For developing countries to create effective policies on reverse logistics and recycling of the post-consumer plastic packaging waste, it is essential to understand the complexities of the plastics recovery and recycling chains. As shown, research and other studies are usually qualitative, describing stages and possible actors for each stage of the recycling chain in Brazil. There is great need for mapping and characterizing actors in the plastics recycling chain and quantify their flows.

Other studies have started to go in this direction. Scheinberg and Simpson (2015) have created a framework to describe value chains of recycling which gives a visual characterization for recycling chains institutionally; it maps actors and their tasks in the chain. Furthermore, Jaligot et al. (2016) have developed a method for applying Value Chain Analysis (VCA) for the informal sector recycling; they used the Zabaleen, a community of informal recyclers in Cairo, Egypt, as case study and showed at each stage of the recycling chain, what was the value added for each actor, in terms of financial flow. These studies show different perspectives on recycling chains and try to quantify financial flows systematically but could benefit from a more complete analysis.

As a continuation of these frameworks and tools created previously, the next phase of this research will characterize further the plastics recycling chains in Brazil, starting from the generation until recycling, with actors, material, financial and technical flows. We hope to contribute the improvement of public policies and management of reverse logistics and recycling systems specially in developing countries.

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Appendix C - Semi-structured interview guide

1. BASIC INFORMATION *(INFORMAÇÕES BÁSICAS)*

1.1. Organisation/Company (Organização/empresa)

1.2. Address (*Endereço)*

1.3. Date of interview (*Data da entrevista)*

1.4. Name of the person interviewed and function (*Nome da pessoa entrevistada e função)*

1.5. Telefone

1.6. E-mail

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2. **AGENTS AND NODES *(AGENT E FIXOS)***

2.1. When have your activities started? *(Quando as suas atividades tiveram início?)*

2.2. What are the main activities? *(Quais são as principais atividades?)*

2.3. Why do you work with HDPE plastic? *(Por que trabalham com plástico PEAD?)*

2.4. What is the area size? *(Qual a área do local?)*

2.5. The space is owned by the organisation, rented or granted by public sector? If rented, how much do you pay monthly? *(O espaço é próprio, alugado ou cedido pela prefeitura? Se aluguel, qual o valor pago mensalmente?)*

2.6. Machinery and equipment (*Máquinas e Equipamentos)*

Name *(nome)*	Buying date *(data de compra)*	Buy value *(valor de compra)*	Operational cost *(custo operacional) (R$/ton)*	Efficiency *(Eficiência) (ton/dia ou %)*	Life *(Vida-útil) (anos)*	Who bought (*Quem comprou)*

3. FLOWS *(FLUXOS)*

3.1. ***INPUTS (ENTRADAS)***

3.1.1. From whom is the HDPE coming from? *(De quem vem o PEAD?)*

3.1.2. Is it bought or received? (*É comprado ou somente recebido?)*

3.1.3. How much of it comes? (tonnes/month) (*Quanto chega? (toneladas por mês))*

3.1.4. How much you pay if you buy? (*Por quanto compra, se compra?)*

3.1.5. What is the transportation used to bring the material? *(Qual o meio de transporte pelo qual o material chega?)*

3.1.6. How often does the material come? (*Com* q*ual frequência chega o material?)*

3.1.7. How does the organisation define the quality of HDPE that comes? (*Como a organização define a qualidade do PEAD que recebe?)*

3.1.8. In case of intermediaries and recyclers, do the suppliers change with frequency? *(No caso de intermediários e recicladores, os fornecedores mudam com frequência?)*

3.2. ***PROCESSING (PROCESSAMENTO)***

3.2.1. What happens to the HDPE in your organisation's unit? *(O que acontece com o PEAD na unidade da organização?)*

3.2.2. How is it processed and stocked? (*Como é processado e/ou estocado?*)

3.2.3. Plant capacity – how much you process per day? (*Qual a capacidade da planta – quanto PEAD é processado por dia?)*

3.2.4. What chemicals are used and for what purpose? *(Quais substâncias químicas são utilizadas e para quê?)*

3.2.5. How much chemicals are used per kg of plastic waste? (*Qual a quantidade de substâncias químicas utilizadas por quilo de plástico processado?)*

3.3. ***OUTPUTS (SAÍDAS)***

3.3.1. To whom do you sell HDPE? *(Para quem vende o PEAD?)*

3.3.2. How much is sold in terms of mass per month? *(Quanto em termos de massa por mês?)*

3.3.3. What is the transportation used to get to the buyer? *(Qual o meio de transporte utilizado para chegar até o comprador?)*

3.3.4. How often are the sales? *(Qual frequência de venda?)*

3.3.5. How much is it sold for (average price in a year)? *(Por quanto vende (média no preço em um ano e no ano anterior)?)*

3.3.6. How does the organisation define the quality of HDPE that it sells? *(Como a organização define a qualidade do PEAD que vende?)*

3.3.7. Do the HDPE buyers change with frequency? *(Os compradores de PEAD mudam com frequência?)*

3.3.8. How much of PEAD rejects is generated? *(Quanto é gerado de rejeito de PEAD?)*

3.3.9. Where is the HDPE rejects disposed in? *(Onde é destinado o rejeito de PEAD?)*

3.3.10. What is the cost, if there is? *(Tem custo? Qual?)*

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4. COMPLEX-VALUE ASSESSEMENT METRICS (*MÉTRICAS PARA ANÁLISE DO VALOR COMPLEXO)*

4.1. <u>FINANCIAL METRICS *(MÉTRICAS FINANCEIRAS)*</u>

4.1.1. What are the annual fixed and variable costs (last year)? *(Quais são os custos fixos e variáveis anuais (último ano)?)*

4.1.2. What are the annual revenues (last year)? *(Qual o faturamento médio anual (último ano)?)*

4.1.3. How do you set the selling prices? Who is responsible for this? *(Como os preços de venda são determinados? Quem é responsável?)*

4.2. **<u>SOCIAL METRICS *(MÉTRICAS SOCIAIS)*</u>**

4.2.1. How many workers are there? *(Qual o número de trabalhadores?)*

4.2.2. What is the gender proportion? *(Qual a proporção entre homens e mulheres?)*

4.2.3. Are there young people working? Are there specific programs? *(Tem algum jovem trabalhando? Há algum programa como Jovem Aprendiz ou similar?)*

4.2.4. How is the payment made? *(Como é feito o pagamento?)*

4.2.5. Is the payment equal for all? *(O pagamento é igualitário entre homens e mulheres?)*

4.2.6. What is the average income of a worker per month? *(Qual a renda média por mês de um trabalhador?)*

4.2.7. What are the benefits? *(Quais são os benefícios oferecidos?)*

( ) sickness leave/auxilio doença

( ) vacation/férias

( ) maternity leave with remmuneration/licença maternidade e remuneração

( ) paternity leave with remuneraiton/Licença paternidade e remuneração

( ) 13th salary/13º salario

( ) Health plan/plano de saúde

( ) Food stamps/vale alimentação ou refeição

( ) Transport stamps/vale transporte

( ) Insalubrity/insalubridade

( ) Other/Outro____

____

4.2.8. What are the working functions in the organisation concerning HDPE? How many people are there in each? What are each function average salary?(*Quais funções de trabalho que existem na organização relacionadas ao PEAD? Quantas pessoas em cada função? Qual o salário médio de cada função?)*

____

4.2.9. Describe the work environment and safety. (*Descreva o ambiente de trabalho e segurança.)*

4.2.10. Do the workers use protective equipment? Which ones? *(Os trabalhadores utilizam equipamentos de proteção? Quais?)*

4.2.11. Are there driver's license and insurance for all workers driving motorised vehicles? *(Os trabalhadores que dirigem veículos motorizados têm carteira de motorista e seguro?)*

4.2.12. Are there fire emergency procedures? *(Existem procedimentos de emergência para incêndio?)*

4.2.13. Are there pests and animal control? *(Existe controle de pestes e vetores?)*

4.2.14. Are the installations for workers well-being (bathrooms, drinking fountain, etc.) adequate? Do the workers have breaks? (*As instalações de bem-estar estão adequadas para trabalhadores/membros (ex.: banheiros, bebedouros etc.)? Os trabalhadores têm pausas?)*

4.2.15. Are there signs on the floor for each work post? Are there instructions to use machinery and equipment? *(Há demarcações no chão para cada posto de trabalho? Há instruções para uso de maquinários e equipamentos?)*

4.2.16. Is there a vaccine program for workers? *(Existe programa de vacinação para trabalhadores/membros?)*

4.2.17. Is there a registry for accidents and procedures to prevent their reoccurrence? *(Existe registro de acidentes e procedimentos para prevenir recorrência?)*

4.2.18. Is there a first aid kit available? *(Há kit de primeiros socorros disponível no local de trabalho para o uso dos trabalhadores/membros?)*

4.2.19. Is there a system for identifying hazardous materials and procedures to deal with them? *(Há algum sistema de identificação para materiais perigosos e procedimentos adequados para lidar com eles?)*

4.2.20. Are there protection equipment in hazardous places (including height)? *(Há equipamentos de proteção (ex.: guarda corpo) em torno de equipamentos e locais perigosos (incluindo altura)?)*

4.2.21. What is the arrangement of work posts and what are procedures to prevent injuries from excessive effort, repetitive movements and inadequate posture? *(Qual o arranjo de posto de trabalho e procedimentos para prevenir lesões advindas de esforço excessivo, movimentos repetitivos e posturas estereotipadas?)*

4.2.22. Are there any measures to control odor and solid particulate? *(Existem medidas adequadas de controle de odor e particulado sólido?)*

4.2.23. Was there any case of abuse or harassment? *(Já houve algum caso de abuso ou assédio?)*

4.2.24. Are there any workers who feel unsafe at work? *(Há trabalhadores que se sentem inseguros no trabalho?)*

4.2.25. Is there a recognition from authorities and society to see your organization as a service provider? *(Há reconhecimento pelas autoridades e sociedade da sua organização como prestador de serviço?)*

4.3. **ENVIRONMENTAL METRICS *(MÉTRICAS AMBIENTAIS)***

4.3.1. Is there access to potable water? (*Há acesso para água potável?)*

4.3.2. How are the solid waste generated in the facility managed and where are they sent to? (*Como os resíduos sólidos gerados nas instalações são gerenciados e para onde são destinados?*

4.3.3. Do you have air pollution control in your facilities? *(Você tem controle de poluição atmosférica?)*

4.3.4. Do you have wastewater treatment? If not, where does the wastewater go? (*Você tem tratamento de águas residuais? Se não, onde é destinada e tratada?)*

4.4. <u>TECHNICAL METRICS *(MÉTRICAS TÉCNICAS)*</u>

4.4.1. What are the contaminants identified that can make the process in your organization more difficult and maybe reduce the price of the material? (*Você identifica alguma impureza que pode piorar ou inviabilizar seu processo e diminuir o preço de venda do material?)*

4.5. What benefits and impacts do you think are being generated by your organisation? *(Que benefícios e impactos são gerados pelo seu negócio?)*

Benefits – Benefícios:

Impacts – Impactos:

Appendix D - UNICAMP's Ethics Committee approval (in Portuguese)

CEPUNICAMP comitê de ética em pesquisa

UNICAMP - PRÓ-REITORIA DE PESQUISA DA UNIVERSIDADE ESTADUAL DE CAMPINAS - CHS/UNICAMP

Plataforma Brasil

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: A Cadeia Produtiva de Plásticos Recicláveis: o caso do PEAD no Sudeste do Brasil

Pesquisador: NATHALIA SILVA DE SOUZA LIMA
Área Temática:
Versão: 4
CAAE: 15578619.8.0000.8142
Instituição Proponente: Faculdade de Engenharia Civil, Arquitetura e Urbanismo
Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 3.737.254

Apresentação do Projeto:
INFORMAÇÕES FORNECIDAS PELA PESQUISADORA NA PLATAFORMA BRASIL

A reciclagem é parte da solução para uma economia mais circular, um dos desafios globais atualmente. O governo brasileiro em liderança global tem negociado com representantes do setor privado e catadores organizados para que a logística reversa de embalagens em geral se torne realidade no país, a fim de incentivar a indústria da reciclagem e promover a redução do desperdício de recursos. Quando se fala em embalagens plásticas recicláveis, suas cadeias produtivas são complexas de serem mapeadas por sua diversidade de composição material, alto nível de informalidade e grande número de atores envolvidos. Há a necessidade de se caracterizar os atores dessas cadeias e quantificar seus fluxos materiais e monetários a fim de compreender como essa cadeia funciona mais profundamente. Essa pesquisa tem como objetivo compreender as complexidades de uma cadeia produtiva de plástico reciclável, partindo do plástico mais comercializado de uma cooperativa de catadores organizados em Cachoeira de Minas, Minas Gerais, investigando intermediários, até chegar aos recicladores. Para isso, duas ferramentas de análise serão utilizadas (Redes técnicas de Resíduos Sólidos e Otimização de Valor Complexo na Recuperação de Recursos a partir de Resíduos Sólidos). Esperamos contribuir com a gestão de sistemas de logística reversa para a reciclagem e a melhoria de políticas públicas relacionadas a isso no Brasil e outros países.

Objetivo da Pesquisa:

INFORMAÇÕES FORNECIDAS PELA PESQUISADORA NA PLATAFORMA BRASIL

O objetivo geral dessa pesquisa é avaliar detalhadamente a cadeia de suprimentos de um tipo específico de plástico reciclável como parte de um sistema de economia circular, da geração de resíduos à produção de materiais secundários.

Avaliação dos Riscos e Benefícios:

Segundo o pesquisador, "Não há riscos previsíveis para participantes da pesquisa. Os participantes não deverão participar da pesquisa caso não sejam da organização selecionada para o estudo, caso não tenham concordado em serem entrevistados pelo pesquisador ou caso não queiram providenciar documentos da organização a serem analisados."

Quanto aos benefícios, é informado que "s resultados gerados pela pesquisa (dissertação de mestrado e artigo científico) serão divulgados entre os participantes da pesquisa e espera-se que a partir deles, esses atores possam entender melhor as complexidades do contexto em que seus negócios então inseridos, principalmente quanto aos benefícios e impactos presentes, nas áreas ambiental, social, econômica e técnica. Com esse conhecimento, é possível que os atores possam realizar tanto melhorias internas quanto se engajar em melhorias de políticas públicas, se engajando nas discussões em volta de sistemas de logística reversa em embalagens."

Comentários e Considerações sobre a Pesquisa:

Trata-se de uma pesquisa visando obtenção do título de Mestre na Faculdade de Engenharia Civil, Arquitetura e Urbanismo - FEC, da UNICAMP.
A orientação é da Prof. Dra. Emília Wanda Rutkowski.

O início da pesquisa de campo é prevista, nesta resposta à pendência, para 15/01/2020.

Considerações sobre os Termos de apresentação obrigatória:

ver " Conclusões ou Pendências e Lista de Inadequações"

Conclusões ou Pendências e Lista de Inadequações:

O protocolo foi considerado aprovado neste CEP em 01/12/2019 e, caso não tenha autorizações institucionais pendentes ou centros co-participantes, pode ser iniciado A PARTIR DESTA DATA.

Quaisquer dados coletados com humanos ou dados identificados utilizados em data anterior não se encontram no escopo desta apreciação ética.

Considerações Finais a critério do CEP:

- Vale lembrar que a interação com os participantes de pesquisa só pode ser iniciada a partir da aprovação desse protocolo no CEP. Os cronogramas de geração/coleta de dados deve acompanhar os relatórios parcial e final de pesquisa

- Cabe enfatizar que, segundo a Resolução CNS 510/16, Art.28 Inciso IV, o pesquisador é responsável por "(...) manter os dados da pesquisa em arquivo, físico ou digital, sob sua guarda e responsabilidade, por um período mínimo de 5 (cinco) anos após o término da pesquisa.

- O participante da pesquisa tem a liberdade de recusar-se a participar ou de retirar seu consentimento em qualquer fase da pesquisa, sem penalização alguma e sem prejuízo ao seu cuidado (quando aplicável).

- Eventuais modificações ou emendas ao protocolo devem ser apresentadas ao CEP de forma clara e sucinta, identificando a parte do protocolo a ser modificada e suas justificativas e aguardando a aprovação do CEP para continuidade da pesquisa.

- Relatórios parciais e final devem ser apresentados ao CEP, inicialmente seis meses após a data deste parecer de aprovação e ao término do estudo.

- Caso a pesquisa seja realizada ou dependa de dados a serem observados/coletados em uma instituição (ex. empresas, escolas, ONGs, entre outros), essa aprovação não dispensa a autorização dos responsáveis. Caso não conste no protocolo no momento desta aprovação, estas autorizações devem ser submetidas ao CEP em forma de notificação antes do início da pesquisa.

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação

Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_1352742.pdf	27/11/2019 19:48:44		Aceito
Outros	Carta_Reposta3.pdf	27/11/2019 19:48:25	NATHALIA SILVA DE SOUZA LIMA	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	ApendiceB_TCLE.pdf	27/11/2019 19:47:52	NATHALIA SILVA DE SOUZA LIMA	Aceito
Projeto Detalhado / Brochura Investigador	ProjetoemPortugues_111119.pdf	11/11/2019 17:15:07	NATHALIA SILVA DE SOUZA LIMA	Aceito
Outros	DeclaracaoACLAMA.pdf	31/05/2019 10:38:49	NATHALIA SILVA DE SOUZA LIMA	Aceito
Outros	AtestadoMatricula.pdf	21/05/2019 15:33:23	NATHALIA SILVA DE SOUZA LIMA	Aceito
Outros	ApendiceC_GuiaObservacao_port.pdf	21/05/2019 15:26:21	NATHALIA SILVA DE SOUZA LIMA	Aceito
Outros	ApendiceA_RoteirodeEntrevista_port.pdf	21/05/2019 15:25:47	NATHALIA SILVA DE SOUZA LIMA	Aceito
Folha de Rosto	Folhaderostoassinado.pdf	10/05/2019 10:47:17	NATHALIA SILVA DE SOUZA LIMA	Aceito

Situação do Parecer:
Aprovado

Necessita Apreciação da CONEP:
Não

CAMPINAS, 01 de Dezembro de 2019

Assinado por:
Thiago Motta Sampaio
(Coordenador(a))

Appendix E - Consent form to participate in research (in Portuguese)

TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO

A Cadeia Produtiva de Plásticos Recicláveis: o caso do PEAD no Sudeste do Brasil
Nathalia Silva de Souza Lima
Número do CAAE: 15578619.8.0000.8142

Você está sendo convidado a participar de uma pesquisa. Este documento, chamado Termo de Consentimento Livre e Esclarecido, visa assegurar seus direitos como participante da pesquisa e é elaborado em duas vias, assinadas e rubricadas pelo pesquisador e pelo participante/responsável legal, sendo que uma via deverá ficar com você e outra com o pesquisador.

Por favor, leia com atenção e calma, aproveitando para esclarecer suas dúvidas. Se houver perguntas antes ou mesmo depois de assiná-lo, você poderá esclarecê-las com o pesquisador. Se preferir, pode levar este Termo para casa e consultar seus familiares ou outras pessoas antes de decidir participar. Não haverá nenhum tipo de penalização ou prejuízo se você não aceitar participar ou retirar sua autorização em qualquer momento.

Justificativa e objetivos:

Quando se fala em embalagens plásticas recicláveis, suas cadeias produtivas são complexas de serem mapeadas por sua diversidade de composição material, alto nível de informalidade e grande número de atores envolvidos. Há a necessidade de se caracterizar os atores dessas cadeias e quantificar seus fluxos materiais e monetários a fim de compreender como essa cadeia funciona mais profundamente. Essa pesquisa tem como objetivo compreender as complexidades de uma cadeia produtiva de plástico reciclável, partindo do plástico mais comercializado de uma cooperativa de catadores organizados em Cachoeira de Minas, Minas Gerais, intermediários, até chegar nos recicladores.

Procedimentos:

Participando do estudo você está sendo convidado a: acompanhar a pesquisadora em uma visita de campo no local de trabalho a ser observado e ser entrevistado para mapeamento dos atores da cadeia de PEAD reciclável, suas atividades, tecnologias, instalações, fluxos materiais e monetários e, por fim, benefícios e impactos. Estima-se que uma visita incluindo observação, entrevista e coleta de documentos dure entre 2 e 4 horas. As entrevistas serão gravadas em áudio e armazenadas em computador fixo do laboratório de pesquisa protegido por senha (sem riscos de acesso por terceiros, perdas, roubos ou furtos) por pelo menos 5 anos. Não haverá necessidade de deslocamento do participante.

Desconfortos e riscos:

Não há riscos previsíveis para participantes da pesquisa. Você **não** deve participar deste estudo caso não seja da organização selecionada para o estudo, caso não tenha concordado em ser entrevistado pelo pesquisador ou caso não queiram providenciar documentos da organização a serem analisados.

Rubrica do pesquisador: Rubrica do participante:_______________

Benefícios:

Os resultados gerados pela pesquisa (dissertação de mestrado e artigo científico) serão divulgados entre os participantes da pesquisa e espera-se que a partir deles, esses atores possam entender melhor as complexidades do contexto em que seus negócios então inseridos, principalmente quanto aos benefícios e impactos presentes, nas áreas ambiental, social, econômica e técnica. Com esse conhecimento, é possível que os atores possam realizar tanto melhorias internas quanto se engajar em melhorias de políticas públicas, se engajando nas discussões em volta de sistemas de logística reversa em embalagens.

Acompanhamento e assistência:

O participante terá direito ao acesso aos resultados da pesquisa sempre que solicitado.

Sigilo e privacidade:

Você tem a garantia de que sua identidade será mantida em sigilo e nenhuma informação será dada a outras pessoas que não façam parte da equipe de pesquisadores. Na divulgação dos resultados desse estudo, seu nome não será citado. Você autoriza a gravação da entrevista em áudio e armazenamento em computador do pesquisador por pelo menos 5 anos para fins exclusivamente de análise e sem divulgação dos dados.

Ressarcimento e Indenização:

Você terá a garantia ao direito a indenização diante de eventuais danos decorrentes da pesquisa quando comprovados nos termos da legislação vigente.

Contato:

Em caso de dúvidas sobre a pesquisa, você poderá entrar em contato com as pesquisadoras Nathalia Silva de Souza Lima e Emília Wanda Rutkowski (orientadora), Faculdade de Engenharia Civil e Arquitetura e Urbanismo, Unicamp, R. Saturnino de Brito, 224 - Cidade Universitária, Campinas - SP, 13083-889, Brasil, (11) 96479-9665 ou (19) 3521-2372, nathslima@hotmail.com e emilia@fec.unicamp.br

Em caso de denúncias ou reclamações sobre sua participação e sobre questões éticas do estudo, você poderá entrar em contato com a secretaria do Comitê de Ética em Pesquisa em Ciências Humanas e Sociais (CEP-CHS) da UNICAMP das 08h30 às 11h30 e das 13h00 às 17h00 na Rua Bertrand Russell, 801, Bloco C, 2º piso, sala 05, CEP 13083-865, Campinas – SP; telefone (19) 3521-6836; e-mail: cepchs@unicamp.br

O Comitê de Ética em Pesquisa (CEP).

O papel do CEP é avaliar e acompanhar os aspectos éticos de todas as pesquisas envolvendo seres humanos. A Comissão Nacional de Ética em Pesquisa (CONEP), tem por objetivo desenvolver a regulamentação sobre proteção dos seres humanos envolvidos nas pesquisas. Desempenha um papel coordenador da rede de Comitês de Ética em Pesquisa (CEPs) das instituições, além de assumir a função de órgão consultor na área de ética em pesquisas

Rubrica do pesquisador: Rubrica do participante:_______________

Consentimento livre e esclarecido:

Após ter recebido esclarecimentos sobre a natureza da pesquisa, seus objetivos, métodos, benefícios previstos, potenciais riscos e o incômodo que esta possa acarretar, aceito participar:

Nome do (a) participante da pesquisa:

____

____Data: _____/______/_______.
(Assinatura do participante da pesquisa)

Responsabilidade do Pesquisador:

Asseguro ter cumprido as exigências da resolução 510/2016 CNS/MS e complementares na elaboração do protocolo e na obtenção deste Termo de Consentimento Livre e Esclarecido. Asseguro, também, ter explicado e fornecido uma via deste documento ao participante da pesquisa. Informo que o estudo foi aprovado pelo CEP perante o qual o projeto foi apresentado e pela CONEP, quando pertinente. Comprometo-me a utilizar o material e os dados obtidos nesta pesquisa exclusivamente para as finalidades previstas neste documento ou conforme o consentimento dado pelo participante da pesquisa.

____Data:
(Assinatura do pesquisador)

Appendix F - Observation template

1. Observe the work environment – *Observar o ambiente de trabalho.*
2. Observe the material quality (input and output) and identify contaminants – *Observar qualidade do material que chega e sai, e identificar os contaminantes.*
3. Observe the HDPE processing activity undertaken in each organisation and describe it – *Observar o processamento da atividade* de processamento do PEAD em cada organização e descrever.
4. Observe if workers are using protective equipment – *Observar se trabalhadores estão utilizando equipamentos de proteção.*
5. Observe machinery and equipment - *Observar maquinário e equipamentos.*
6. Observe space in diferente work posts (is there enough space for moblity?) - *Observar o espaço nos diferentes locais de trabalho (existe suficiente espaço para sua mobilidade?)*

Appendix G – Material Flow Analysis Calculations

Figure A1 – Material flow diagram without values

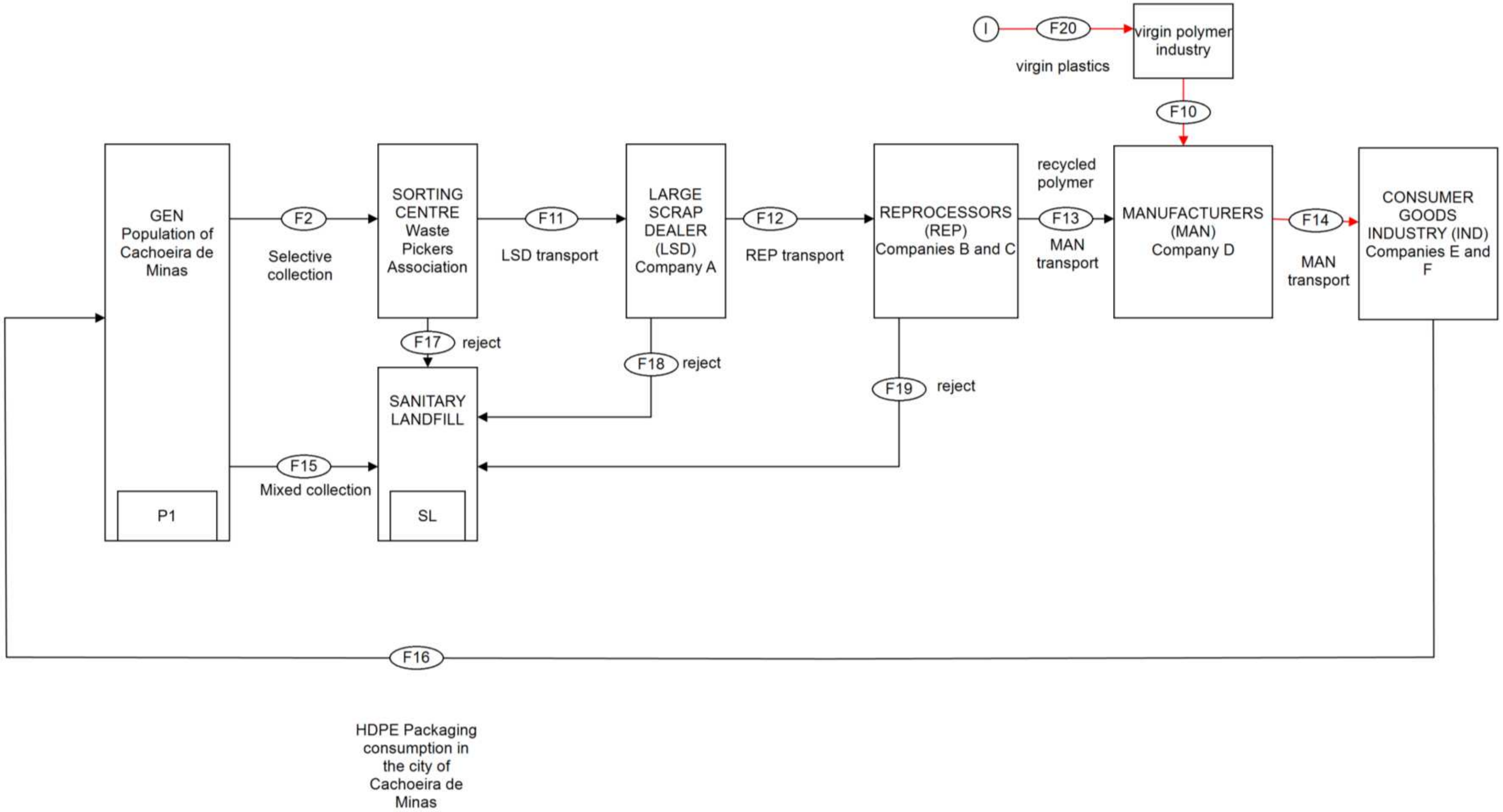

Table A2 – Material flow analysis calculations

Flow	Value (kg/year)	Calculation	Reference
F2	5,750	F2 = F11 + F18	Data collection by author (2021)
F10, F20	6,666	-	Calculated by software
F11	5,180	Reported by agent	Data collection by author (2021)
F12	5,126	F12 = F11 - F18	Data collection by author (2021)
F13	4,101	F13 = F12 - F19	Data collection by author (2021)
F14, F16	10,767	F14 = F16 = F2 + F15	Data collection by author (2021)
F15	3,950	Collected with municipality	Data collection by author (2021)
F17	570	F17 = F2 * 11% (reject rate reported by ACLAMA)	Data collection by author (2021)
F18	54	F18 = F11 * 1% (reject rate reported by LSD agent)	Data collection by author (2021)
F19	1,025	F19 = F12 * 20% (reject rate reported by REP agent)	Data collection by author (2021)
P1	1,067	$P1 = \frac{\text{HDPE generation (Cachoeira de Minas)} * \text{consumption PPW (Brazil)}}{\text{generation of PPW (Brazil)}}$ PPW = plastics packaging waste	Assumption: consumption of plastics packaging waste in Brazil and generation of PPW in Brazil are from (PIMENTEL PINCELLI et al., 2021)
SL	5,599	-	Calculated by software

Appendix H – Metrics selected for complex value measurement

Table A3 – Metrics selected for complex value measurement, with type, description, calculation and reference (continues)

Metric	Type of variable	Description	Calculation	Reference
Technical dimension				
Activity	Descriptive	Description of activities/services performed by agent	-	Author (2021)
Secondary role(s)	Descriptive	Any secondary roles from the agents	-	
Technology	Descriptive	List of all technologies declared by agents	-	
HDPE input (kg/year)	Quantitative	Flow of HDPE waste in each stage of the chain	See Table A2 in Appendix G	(IACOVIDOU et al., 2017a)
Loss rate (rejection rate)	Quantitative	Percentage of material loss in each agent's activity	% = Input bought materials/output sold materials	Author (2021)
HDPE processing capacity (tonnes/year)	Quantitative	Maximum capacity of processing HDPE	Reported by agent	
Material output	Illustration	Picture of the material output for each agent	-	
Economic dimension				
Buying prices (R$/kg)	Quantitative	Prices at which HDPE waste is bought from supplier	Reported by agent	(VELIS; RUTKOWSKI; RUTKOWSKI, 2016; IACOVIDOU et al., 2017a)
Operational and maintenance costs (R$/kg)	Quantitative	Sum of costs including: depreciation of installations, based on expected lifespan (using manufacturing data); running and extraordinary repairs, and inspection costs -may be calculated as percentage of equipment cost; insurance costs calculated as a percentage of fixed capital cost; transportation costs	Reported by agent	
Capital cost (R$)	Quantitative	Sum of costs including: planning costs - costs for planning activities, e.g. engineering design and environmental impact assessment;	Reported by agent	

Metric	Type of variable	Description	Calculation	Reference
		investment costs e costs for providing the infrastructure or services, e.g. bins land costs - land acquisition and site footprints; equipment purchase - cost of equipment needed in the different waste/ resource treatment facilities; setup - site development and equipment installation costs, e.g. civil work, access roads, electrical distribution network, piping and assembly work.		
Sale prices (R$/kg)	Quantitative	Prices at which agent sell to next in the chain	Reported by agent	
Revenue (R$/kg)	Quantitative	Sum of the cash inflow made from the sale of materials minus operational costs	Reported by agent	
Social dimension				
Job creation	Quantitative	Number of jobs in each agent	Reported by agent	(VELIS; RUTKOWSKI; RUTKOWSKI, 2016; IACOVIDOU et al., 2017a)
Gender ratio (M:F)	Quantitative	Number of men versus number of women working in the agent	Number of men/ number of women	Author (2021)
Working Hourly Wage (%)	Quantitative	Measured based on the number of working hours by taking into account, e.g. the living wage in the country, minimum wage in the country, and average wage in the sector	% (paid wage/minimum or liveable wage)	(IACOVIDOU et al., 2017a)
Type of work	Qualitative	If workers are associates to the organisation (in case of associations and cooperatives) or hired according to Brazilian CLT (consolidated labour laws) system	-	Author (2021)
Use of PPE	Qualitative	If workers use personal protective equipment such as gloves, masks, glasses, ear protectors and boots	-	(VELIS; RUTKOWSKI; RUTKOWSKI, 2016)

Metric	Type of variable	Description	Calculation	Reference
Child labour	Qualitative	Employment of children, esp. when in a dangerous or unsuitable environment for them in the system which depends on the child's age, the type and hours of work performed and the conditions under which it is performed		(IACOVIDOU et al., 2017a)
Environmental dimension				
Energy consumption	Qualitative	Since energy matrix is similar for all agents in all supply chains stages, we assumed energy consumption based on machinery employed at each stage as reported by each agent. The more machinery they have, it means that there is higher energy consumption. It can be Low, Medium, or High.	-	Author (2021)
Environmental Impact Assessment (permit)	Qualitative	If the agent's facility has an environmental license (or permit) to operate – usually given by local environmental body	-	Author (2021)
Water quality control	Qualitative	If water used is treated according to local environmental body's standards	-	Author (2021)
Air pollution	Qualitative	If air pollution is generated and is treated according to environmental body's standards	-	Author (2021)