Expanded Polystyrene (EPS) Chain Applied to the Circular Economy Concept in Brazil

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ABSTRACT

Purpose: EPS is responsible for 20% of the total volume of landfills. However, little is known about the members of the distribution and reverse channels and the various logistic activities carried out in the reverse channels of this material in Brazil. For these reasons, the present paper aims to identify the EPS supply and reverse chain structure to verify possibilities to close the loop.

Methods: This qualitative and applied research is limited to post-consumer EPS. We propose a three-step method: (1) characterization and mapping of EPS supply chain; (2) identification and description of the Brazilian organizations or entities involved and logistics activities in reverse channels; (3) identification of aspects related to chain structure and Brazilian legislation.

Results: Among the reverse channels of EPS identified, few are actually used. Importers and distributors of EPS still have an incipient participation in these channels. The difficult to implement a reverse logistics system in Brazil is result of: (a) difficulties of transporting the post-consumer EPS; (b) the lack of knowledge by a large part of the population that EPS is recyclable; and, (c) the low number of collectors and recyclers.

Conclusions: The EPS Reverse Logistics System depends on appropriate solutions considering the Brazilian context, which is characterized by large territorial distances, economic and social differences between regions and the numerous municipalities, the complexity of municipal, state and federal legislations, the different levels of maturity and organization of collectors' cooperatives, the need to change behaviour and habits of the population.

Keywords: EPS, circular economy, supply chain, reverse chain, closed-loop, Brazil.

1. Introduction

Expanded polystyrene (EPS) is an inert, non-toxic thermoplastic with dimensional stability and low cost. EPS offers a combination of strength, lightness (low density), durability, low thermal conductivity, moisture resistance, high acoustic absorption, corrosion resistance, non-degradability and resistance to photolysis [1-6]. For these reasons, EPS is widely used in packaging, electronics, and building materials; it is in high demand in several industries all over the world due to its flexible application. However, EPS products generally have one life cycle, especially in packaging that demands a one-time application; these products are frequently discarded with no reuse value, and that single-use application generates a large amount of waste. Moreover, it takes about 450 years for EPS products to decompose naturally [7]. Because the products are light (98% air in its composition) the transportation cost is high - as it must be done many more times - which limits the commercialization of EPS products and reduces the interest of companies in the reverse chain.

Worldwide, EPS accounts for 0.1% of total municipal solid waste [8]. In Brazil, in 2015, EPS consumption was measured at 93 thousand tons. In other words, each Brazilian citizen consumes about 0.45 kg/year of EPS in average. The growth rate of apparent consumption over a period of 2011 and 2015 was -0.1% per year [9], in other words the market was stable during these years. The amount of EPS discarded in 2013 was 39,340 tons and during 2014, Brazil recycled 15 thousand tons [10]. Despite the generous percentage of recycling, EPS is still responsible for 20% of the total volume of landfills in Brazil [7]. Therefore, EPS organizations and associations from more than thirty countries, including Brazil, have signed an international agreement to maximize the reuse and recycling of EPS in the widest range of possible applications [8].

The objective of managing EPS is part of the larger initiative on waste management. Waste management has gained more attention in public policy; a recent example is the Brazilian National Policy of Solid Waste "*Política Nacional de Resíduos Sólidos* (PNRS)" (Law N^{o} 12305/2010) that came into force at the end of 2010. Considering an approach of shared responsibility, each sector of society has obligations, related to waste generated when products reach the end of their life cycle [11]. Furthermore, in November 2015, the Sectorial Agreement for Implementation of Reverse Logistics System in General Packaging was signed. It aims to ensure the final environmental disposal of packaging. The packaging, which is the subject of the sectorial agreement, can be made up of paper and cardboard, plastic, aluminium, steel, glass, or a combination of these materials. Through this agreement, manufacturers, importers, traders, and distributors of packaging and products sold in packaging undertake to work together to ensure the environmentally appropriate final disposal of the packaging they place on the market. The agreement stipulates that by 2018, there will be a reduction of at least 22% of packaging disposed of in landfills. Therefore, the Packaging Reverse Logistics System should ensure the disposal of environmentally appropriate materials, at least up to the average of 3,815,081 tons of packaging per day [12].

The present paper aims to identify the EPS supply and reverse chain structure in order to verify possibilities to close the loop. That requires an examination of the members of the distribution channels and reverse channels in Brazil and their roles. Moreover, identification, description, and analysis of the various logistic activities carried out in the reverse channels of this material are presented in this work, and we intend to highlight improvements that could make the return process of EPS waste more efficient.

The paper is divided in 6 sections. First, it presents the general aspects of this research. We give a post-consumer EPS background in second section. In section 3, we show the method adopted in this paper. In section 4, we outline the main contribution of our research. We discuss the result in section 5. The conclusion is presented in section 6.

2. Theoretical Background

2.1 Post-consumer EPS

EPS is an inert, non-toxic thermoplastic in the form of very small polystyrene pearls and containing 2-7% blowing agent, usually pentane [13]. The expanded pearls consist of approximately 98% air and 2% polystyrene in mass, becoming extremely light [5, 6, 14-15]. In Brazil, the standard NBR 11752:2016 [16] divides into two classes the EPS: Class P, non-flame retardant, and Class F, flame retardant. The EPS recycling symbol is the same as polystyrene (PS), which uses the number six enclosed by the recycle triangle. The Brazilian Association of Technical Standards "*Associação Brasileira de Normas Técnicas* - ABNT)" recommends this symbol used worldwide through NBR 13230:2008 [17].

The sectors that most use EPS are construction industry and packaging industry. The largest use of EPS in construction industry is in the construction of slabs, 80% of the 53 thousand tons [9]. Regarding packaging, EPS is used in two functions, shims/protection (76% of 26 thousand tons produced) for the transport of fragile products [15] and thermal boxes for packaging of beverages and frozen foods [18-20]. The difference between the construction EPS and the packaging EPS is the majority of EPS of the construction industry remains in ready-made constructions, whereas the EPS of packaging usually has a short first-use cycle. However, this is not only a Brazilian reality, it is estimated that only 1% of the plastics produced are recycled worldwide [1], the other portion may have a different path from the landfill, generating significant economic costs by disturbing and polluting vital natural systems such as ocean.

Many EPS wastes end up in riverbeds and are dumped into the sea, thus becoming floating marine debris (FMD), because they are very light and can be carried by water and wind [15]. When EPS reaches the sea, it can disturb it in two ways: (1) ingestion of debris by animals, which can cause their death [21]; and (2) intoxication of food chain for bioaccumulation, by its ability to absorb toxic pollutants dispersed in the sea [22].

2.2 Post-consumer EPS Reverse Logistics and its Brazilian Legislation

As mentioned above, reverse logistics has gained attention in public policy in recent years with the Brazilian National Policy of Solid Waste (Law N°12305/2010). Among the various concepts introduced in the environmental legislation by this policy are the reverse logistics and the sector agreement concepts. Reverse logistics is defined as:

> An instrument of economic and social development characterized by a set of actions, procedures and means to enable the collection and restitution of solid waste to business sector, for reuse, in its cycle or in other productive cycles, or another environmentally adequate final destination. [11].

In November 2015, the Sectorial Agreement for Implementation of Reverse Logistics System in General Packaging was signed. The agreement provides by 2018 that the packaging disposed in landfills will have a reduction of at least 22%. Therefore, the Reverse Packaging Logistics System should ensure the final destination environmentally adequate of the average of 3,815,081 tons of packaging per day [12]. In the report of the first phase of the Sector Agreement, released in January 2017, the actions of the Sectorial Agreement for the Implementation of the Reverse Packaging Logistics System reached 104,713,430 million inhabitants, representing 51% of the Brazilian population in 25 states and 422 municipalities [23].

Brazilian laws for reverse logistics and development of a reverse logistics system do exist, however there are no laws to discuss the development of the reverse logistics of plastic, let alone EPS. This makes it difficult to develop and apply reverse logistics in the country. Furthermore, the reverse chain is many times more complex than conventional supply chain. An example of its complexity is the cost of transportation, which only valued components or parts are returned to manufacturer or next user to save on transportation costs. The manufacturers recover materials when the cost of customer recovery is significantly lower than transportation costs [24].

Information systems and physical infrastructures are also key factors for the success of reverse chain. Several sources identified opportunities for reverse logistics services. Typical service needs of the reverse logistics include customer service, warehouse repair, end-of-life manufacturing, IT management, recycling, refurbishment/sorting, replacement management, return authorization, spare parts management, transportation, storage and warranty management [25].

Existing Brazilian legislations remain unclear on the issue of what are practices and channels should be implemented in post-consumer EPS and how to develop synergies with the members of supply and reverse chain. Therefore, the intention of this work was to identify the EPS supply and reverse chain structure to improve practices and channels in reverse logistics of post-consumer EPS. The next topic will explain in more detail the methodology adopted.

3. Methods

This is a qualitative and applied research and it is limited to post-consumer EPS. In order to achieve the main objective, we propose a three-step method:

- *Step 1*: characterization and mapping of EPS supply chain, identification of the upstream and downstream links of EPS industry as well as reverse product channels in Brazil. This step was done through interviews with specialists in EPS subject, such as researchers, professors, and a sector reports analysis.
- *Step 2*: identification and description of the Brazilian organizations or entities involved and logistics activities in reverse channels. This step was done through secondary data, such as research papers, thesis, dissertations, reports, and other sources; this data was complemented by analysis of different cases in Brazil through interviews.
- *Step 3*: identification of aspects related to chain structure and Brazilian legislation, which influence the performance of activities developed in reverse channels. This step was achieved through an analysis of Brazilian legislation and policies regarding waste management, class entity data, sector reports, and other sources.

Our intention was to understand how the product distribution chain is configured and, identifying which organizations are involved with physical flow of products in order to figure out how products return to the productive cycle after consumption. Therefore, steps 1 and 2 are intrinsically connected. The identification and characterization of several elements that are part of supply chain of EPS, as well as distribution and reverse channels of these products, allow us to identify which products are commercialized by which members, as well as to identify their functions.

The product generated in a chain link is used as input in the subsequent stage, generating different types of relations between the members that influence directly or indirectly on economic elements involved. These members tend to look for new solutions in search of competitive advantages, thus increasing the complexity of the chain. Therefore, in order to simplify the analysis and to meet the objectives of this work, we take into account the availability of data regarding origins, destinations and volumes of the supply and reverse chain. Our main intention was to establish the state-of-art of EPS as faithful as possible.

4. Results

The data obtained in the research were organized and a representation of the supply chain and the reverse chain of EPS was elaborated, and presented in Fig. 1. The members of the EPS supply and reverse chain are represented in the boxes, and the full and dashed arrows represent respectively the distribution channels and reverse channels.

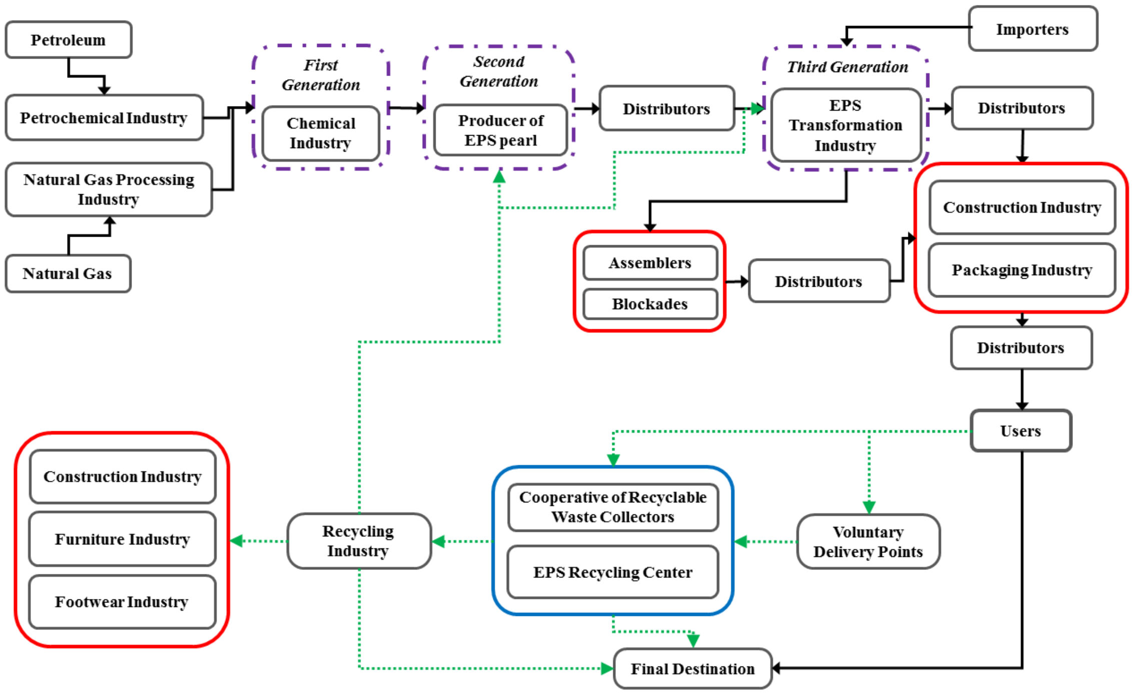

Fig. 1: Supply and reverse chain of EPS.

4.1 Supply Chain

Starting from the supply chain the information gathered from various sources was summarized in Fig. 1 to better express the reality of operations and logistical flows involved among the participating organizations of each link in the EPS supply chain. The production of EPS, being a thermoplastic resin, is divided by generations. Accordingly, we did an analysis of each generation separately described below.

4.1.1 Raw Material and First Generation (Monomers)

Petroleum and natural gas are the EPS raw materials. Ethylene and benzene, the base of the first generation, are produced through the refining of petroleum in naphtha and the processing of natural gas. Ethylene and benzene are converted to styrene monomer during first generation. From the point of view of the circular economy, we verified the irrelevance of the quantification of that chain link by considering there is no known technology that allows the transformation of EPS into petroleum, natural gas, ethylene, benzene or even styrene monomer.

4.1.2 Second Generation – Thermoplastics Resins (Polymers)

The second link in the EPS supply chain is composed of chemical and petrochemical industries located in Brazil. Unlike the subsequent generations with many agents, the second generation currently concentrates its operations on only four companies: "*Styropek*"; "*Videolar-Innova*"; "*Termotécnica*"; and *Contrulev* ("*Polímeros Itaquera*"). The four companies together have installed capacity of 103 thousand tons/year [9], as they have consolidated over time in the national market and due to discontinuation of some production plants. The entry, in June 2016, of "*Videolar-Innova*" in the EPS market provides reduction of imports of EPS resin. Its factory plant has capacity to produce 28 thousand tons/year [9]. Imported EPS represents, since 2011, an average of 43% of all the expanded polystyrene or 40 million tons consumed in Brazil [9].

4.1.3 Third Generation – Plastic Transformers

In the third generation, we describe the organizations responsible for transforming the expanded polystyrene resin into a consumable plastic product, which will later be directed downstream of the supply chain. However, in addition to processing companies, it is mandatory to highlight the logistic flows performed by the traders and distributors of the thermoplastic resin in question, which also play a significant role in this link in EPS supply chain.

From all thermoplastic resins processed in the country, about 2.4% become EPS [26]. There are currently in Brazil about 90 companies in the EPS transformation industry. Considering the EPS blocks industries ("bloqueiras") the total number of companies is estimated at about 200 [9]. Among the 10 largest manufacturing companies, 3 companies produce for the packaging sector and 7 for the construction industry [9]. Commonly, these industries do not consume other resins.

The only distributor of EPS in Brazil is "*BRISCO*". As the demand of manufacturing industries is greater than produced in Brazil, the country imports 44% of what is consumed [9]. In this case, the main exporting countries are China and Taiwan. These countries present a product with competitive price and good quality. The importation takes place, mainly, by the Port of Itajaí in Santa Catarina.

4.1.4 Market

The downstream links of EPS supply chain are the consumers. The Brazilian consume 93 thousand tons of EPS in one year, in a per capita consumption of 0.45 kg per inhabitant, where southeast and south Brazil have more demand of EPS, total of 73% [9]. In spite of the numerous applications of the material, such as stationery, decoration, aero modelling, glasses, buoys, agriculture and refrigeration, the sectors that most consume EPS are construction industry, with 58% of consumption, and the packaging industry with 29% [9]. In the case of construction industry, of the 53 thousand tons of EPS used, 42 thousand tons or 80% become slabs. EPS has the advantage of being light and resistant, as well as requiring less investment in construction time and lower percentage of losses compared to ceramic slabs [27]. The rest of EPS in the construction industry is used in thermal insulation, geosynthetics and construction systems. Regarding packaging industry, of the 26 thousand tons of EPS consumed, 20 thousand tons or 76% are used for shims and protection, the remaining 6 thousand tons are used in thermal boxes [9]. Fig. 2 summarizes information regarding the applications and consumption volumes of EPS in Brazil.

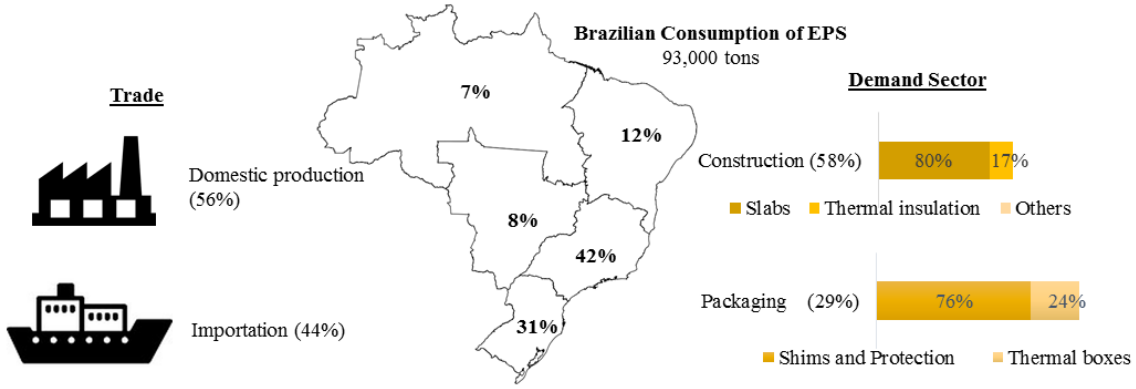

Fig. 2: Consumption of EPS in Brazil

4.2 Reverse Chain

The reverse chain starts with the user, also called generator, who discards EPS after the end of its life cycle (Fig. 1). There are several reverse channels through which post-consumer EPS returns to the production chain and in which they participate: manufacturers; small businesses, which operate on pre-processing of post-consumer EPS; and, recycling cooperatives. To describe the reverse chain of EPS we should briefly discuss the 3Rs: reduction, reuse and recycling.

4.2.1 Reduction and Reuse

The EPS transformation industries try to improve all aspects related to reducing the amount of material used in the production process. To do so, they improve product design and modify the initial properties of EPS [28]. In this way, the smaller, lighter and less material is used in the product, the less waste will be generated at the end of its life cycle, besides being a cost reduction for the EPS industry.

The Brazilian Association of Expanded Polystyrene "*Associação Brasileira do Poliestireno Expandido* (ABRAPEX)" reports that several EPS products can be reused by companies, especially the EPS used as protection for fragile products [28]. However, these reports do not have information on how they collect such material or whether there are voluntary delivery points maintained by these companies. This channel is unknown to most users at our best knowledge.

4.2.3 Recycling

The highest recycling rate is achieved by the southeast and south regions, with 41% and 37.1%, respectively, of all EPS recycled in Brazil [10]. This is because the largest consumer markets and most EPS industries are in those regions, making post-consumer EPS reverse logistics profitable.

Today's recycling technology does not use greasy post-consumer EPS. A lot of post-consumer EPS ends up not being used by the recyclers because they are mixed with greasy materials. The industries together earn 85.6 million reais (R$) or 25 million euros and have an installed capacity of 30,473 tons [10]. Nevertheless, in 2014, only half of the capacity was used, in other words, 15 thousand tons of post-consumer EPS were recycled [9]. Therefore, few of these industries operate at their maximum capacity due to the challenges of selective collection and the recyclable waste arriving as unsorted.

There are two ways of recycling EPS in Brazil: (1) mechanical, when the previously cleaned waste is crushed and used again (EPS waste is added to virgin EPS for building blocks); and, (2) chemical, when the extrusion of the cleaned waste is made to form a ground PS (EPS waste is transformed into polystyrene), and it is destined to polystyrene processing industry. According to NBR 15792 [29], energy recovery is not considered a form of recycling. Most recycling companies in Brazil use mechanical recycling. In mechanical recycling, post-consumer EPS can be used in the manufacture of new EPS elements, soil improvement for agriculture or in addition to other materials for use in construction industry. Construction industry is the largest market for recycled EPS, with about 80% (mortar, lightweight concrete, tiles, thermo acoustic tiles, skirting boards, and pool decks) [10]. The other applications are verified in the footwear industry, furniture industry, household utilities (frames, flower pots), and packaging.

In Brazil, "*Termotécnica*" is considered the largest EPS recycle company, it has been involved in EPS recycling since 2007. Only its reverse chain has about 370 recyclable waste collectors' cooperatives, 121 solid waste generating institutions, 159 transportation customer industries and more than 100 employees directly involved in the project scattered throughout the country [30]. Today, "*Polímeros Itaquara*" also works in recycling. Some products of both "*Termotécnica*" and "*Polímeros Itaquara*" are results of blends of virgin EPS with recycled EPS. They perform from collection to recycling or final disposal, either directly or through third parties.

4.3 Activities of Post-Consumer EPS Reverse Logistics

Throughout the reverse chain, several logistic activities must be carried out, aiming to allow reintroduction of these materials in the productive process, and include: collection, treatment and recovery of post-consumer EPS. These activities are developed by some actors, such as: generators, intermediate companies, recycling industries.

Generators are the ones who discard post-consumer EPS. Results show the largest generators are residences (with many food packaging used in deliveries), public and private institutions, and retailers. Since many generation sites do not have space to store recyclable material, intermediate companies must carry out frequent collections of small volumes, increasing transportation costs. Transportation activities are the largest cost drivers in EPS's reverse logistics, which account for about 29% of total costs [28]. Considering EPS very light and bulky, it occupies a large storage area, each $130m^3$ is approximately equivalent 600 kg of post-consumer EPS only. For this reason, some of these large post-consumer EPS generators have compactors to reduce the volume of the material, making the collection more efficient and attractive.

Intermediate companies are those perform primary collection and sorting of post-consumer EPS. Usually, intermediate companies which perform primary collection are public or private collectors' companies. Intermediate companies which perform sorting of post-consumer EPS are associations or cooperatives of recyclable waste collectors or recyclable waste management companies or even middleman. In the urban centres, the municipality, normally, is responsible for the collection and the delivery of recyclable waste to associations of recyclable waste collectors or middleman. The associations are responsible for sorting the recyclable material. In public and private institutions and retail chains, the process can occur in three ways: (a) operations such as domestic collection, the municipality is responsible to collect; (b) generating centres send to recyclable waste collectors associations or these associations, which have vehicle collection, collect post-consumer EPS; (c) the work of recycling industries is integrated with generating centres and collect post-consumer EPS. Often, post-consumer EPS is milled and compacted by intermediate companies. There are also voluntary delivery points, places where the user can discard post-consumer EPS. They are present in supermarkets, NGOs and public institutions, among other places; however, few are mapped and there is not much disclosure about the voluntary delivery points.

The EPS processing step can happen in recyclable waste collectors' associations or in EPS recycling centres. They operate the EPS processing: weighing; classification if it is EPS or XPS (extruded polystyrene); pre-cleaning (removal of impurities) and/or washing of the residues (washing with water to remove large impurities). In recyclable waste collectors' cooperatives, after pre-cleaning the post-consumer EPS, they storage and sell EPS or send to recyclers. Some intermediate companies have the right machines to start the pre-recycling step, called degassing step, however it normally begins in recycling centres. The degassing system is an industrial process carried out through specialized equipment, which through compression and heat, compacts the waste, removing the gas of EPS, moulding them in form of small billets (similar to bread), which are then milled. After this stage of the process, the post-consumer EPS may have different applications and processes; for example, the material passes through a filter where it is transformed into thin wires, punctured into small pellets. In Fig.3, a scheme is presented containing the activities of reverse logistics and post-consumption EPS flow, from the disposal to the return of the materials for recycling.

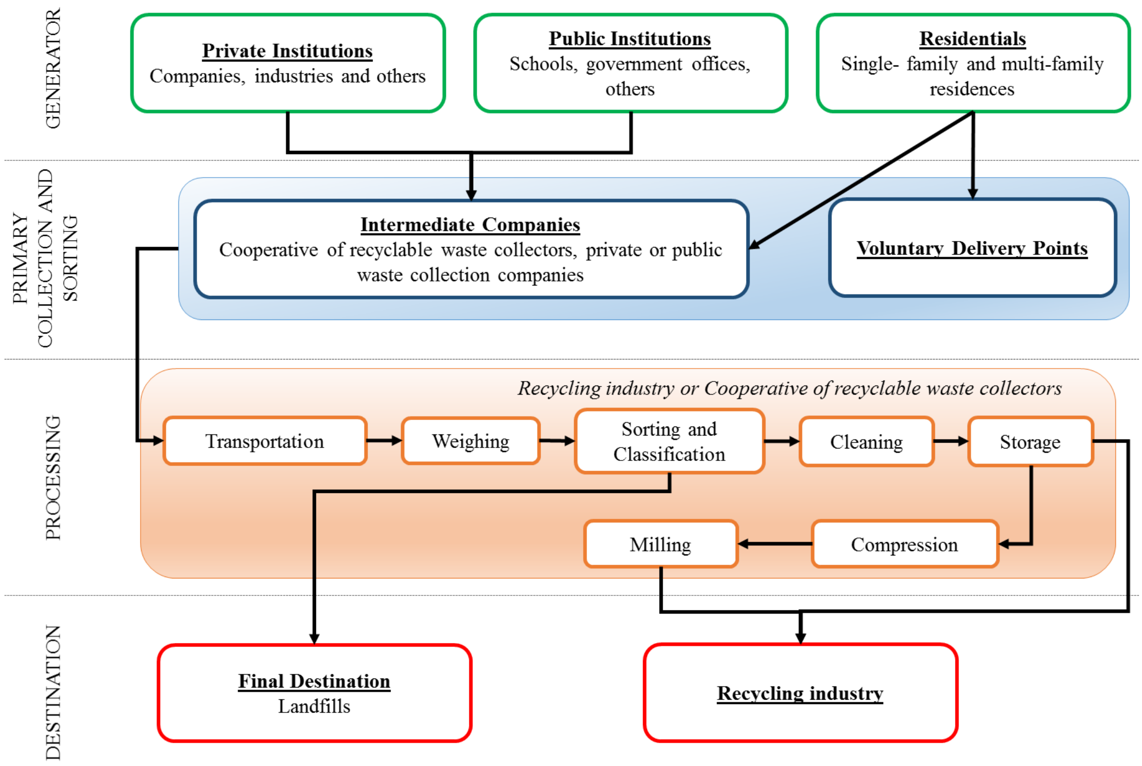

Fig 3.: Activities of reverse logistics and post-consumption EPS flow.

5. Discussion

The implementation of a reverse logistics system of EPS in Brazil has been proceeding slowly, which is confirmed by the fact that, after seven years of the approval of the PNRS, there is still no structured reverse logistics system in Brazil. Nevertheless, the survey of initiatives in relation to reverse logistics of EPS allowed to observe that some manufacturers are developing different actions, but with a structure of reverse channels which counts on the participation of different actors of these chains as foreseen by the PNRS. Brazil has great problems to implement the EPS reverse logistics system, such as the large territorial distances, economic and social differences between regions and the numerous municipalities, the complexity of municipal, state and federal legislations, the different levels of maturity and organization of collectors' cooperatives, the need to change behaviour and habits of the population. Despite these problems, the interest of EPS industry and the existence of intermediaries specialized in reverse logistics activities of EPS prove EPS reverse logistic system can be reached and the processes could be more efficient so the recycling rates can be raised.

The reverse chain of post-consumer EPS is formed by few reverse channels, a factor that makes difficult consolidate logistics processes to reach higher levels of effectiveness and productivity. Few channels reduce transportation costs and other logistics activities because they can store more waste. However, access to correct EPS' disposal is limited to few people e regions and, as mentioned before, few institutions have warehouses to store the EPS. Analysing the reverse chain links, we noticed some barriers to implement a reverse logistics system in the country is result of: (a) transporting cost of post-consumer EPS related to inherent characteristics of this material as its density; (b) lack of knowledge by a large part of population that EPS is recyclable, generating an incorrect disposal of EPS and; (c) low number of collectors and recyclers which result in a small installed capacity of recycling and low levels of post-consumer EPS collected and recycled.

It can also be highlighted that collection in the municipalities is almost non-existent. Several municipalities have not yet implemented the collection services, and others do not offer the collection services to all neighbourhoods. Much of the post-consumer EPS is not collected correctly and, hence, it goes directly to landfills. Besides the need to sort EPS, the movement of this low value-added cargo between cooperatives and recycling industries or middlemen, usually located near urban areas, increases the cost of the process and generates traffic problems, since these vehicles are generally large. The sorting step is carried out by the recyclable waste collectors' associations. These associations have a process defined by the PNRS as a way of generating income for low-income population, which means their work is cited as a social issue. The associations do a manual sorting of recyclable waste, making this process expensive and dangerous. Thus, reverse logistics in Brazil, based on PNRS, is primarily an instrument of social development, which often makes the reverse activities economically unfeasible. Economic return of these workers is also low because they are often at the mercy of middlemen.

In addition, most EPS processing industries do not prioritize non-generation and waste reduction; instead, products are designed for a short life cycle. Reasonably, the little concern with what is written in Article 9o of the PNRS, “non-generation, reduction, reuse, recycling, treatment of solid waste and environmentally appropriate disposal of tailings” [11], on part of the manufacturers is due to the principle of shared responsibility that guides the Brazilian legislation. In fact, the objectives of the producer's extended responsibility are exactly to avoid this problem, as this principle seeks to force industries to invest in development of sustainable products and processes and to avoid as much as possible incineration of tailings or their dumping in landfills [31]. The post-consumer EPS recycling does not achieve a large amount of post-consumer EPS, as there is still the problem of not being able to recycle greasy EPS. However, research and technologies are being developed in Brazil to solve this issue [32].

Although there are some elements of circularity such as recycling in the linear economy of EPS, where progress needs to be maintained, a circular economy goes beyond the pursuit of waste prevention and waste reduction to inspire technological, organizational and social innovation across and within value chains. The EPS reverse chain in Brazil is a small chain, compared to other plastics [33, 34]. For this reason, the EPS chain can become an example of the circular economy in the country if circular strategies are developed.

6. Conclusions

We presented in this paper: i) the description of the supply chain and reverse of EPS, ii) the reverse channels, and iii) the logistics activities performed. We also identified the members involved in the recovery of EPS and its return to productive cycle. Based on the data analysis, the complexity of channels that are part of the EPS reverse logistics system was highlighted.

We concluded that there are still many obstacles to closing the EPS cycle. As the steps are linked, the development of this complex and intricate process to operationalize the EPS Reverse Logistics System depends on overcoming relevant challenges such as the territorial extension of the country, the economic and social differences between the regions and the numerous municipalities, the complexity of municipal, state and federal legislations, the different levels of maturity and organization of collectors' cooperatives, the need to change behaviour and habits of population.

The PNRS instituted shared responsibility for recycling among all participants in the product chain, so identifying the various members of the supply chain as well as the reverse chain of this product is clearly needed. With the description of chain, flows and logistical activities of EPS carried out by the various members are evaluated and possibilities for cooperation and improvements in the processes are identified. However, neither with the PNRS nor with the Sectorial Agreement for Implementation of the Reverse Logistics System in General Packaging there is no clear definition of responsibilities or recycling targets for manufacturers.

Based on the 3Rs principle in circular economy, only a few companies producing EPS consider the principle of reduction, reuse e non-generation. Therefore, there could be stricter rules and incentives to develop technologies and initiatives for the reduction and reuse of post-consumer EPS. Municipal actions of selective collection and education are still precarious and need major overhaul. These educational actions for domestic separation of the recyclable waste and the correct disposal of the waste materials would make the post-consumer EPS reach recyclers with higher quality and thus increase the amount of recycled EPS. The high demand for labour for sorting makes the process very expensive, which becomes a major obstacle.

Nevertheless, the biggest disadvantage to developing EPS reverse-chain into a successful enterprise is the high cost of its transportation; its excessively large volume makes post-consumer transport economically unfeasible. The adoption of a supply chain approach, with cooperation of the members carry out the various logistic activities, may allow the identification of the possibility of obtaining gains of scale to raise the recovery rate of materials, while minimizing environmental impacts and economic factors associated with reverse logistics. Consequently, the EPS supply chain is not yet a closed loop, however it could be.

This work showed a holistic view of supply and reverse chain of EPS in Brazil. Data information about reverse chain of post-consumer EPS is difficult to find. Therefore, for future work, we propose deeper analyses on the members involved with post-consumer EPS. These analyses will provide accurate data information about post-consumer EPS.

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