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System dynamics applied to closed loop supply chains of desktops and laptops in Brazil: A perspective for social inclusion of waste pickers

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ABSTRACT

The structure of reverse logistics for waste electrical and electronic equipment (WEEE) is essential to minimize the impacts of their improper disposal. In this context, the Brazilian Solid Waste Policy (BSWP) was a regulatory milestone in Brazil, submitting WEEE to the mandatory implementation of reverse logistics systems, involving the integration of waste pickers on the shared responsibility for the life cycle of products. This article aims to measure the impact of such legal incentives and the bargaining power obtained by the volume of collected waste on the effective formalization of waste pickers. The proposed model evaluates the sustainability of supply chains in terms of the use of raw materials due to disposal fees, collection, recycling and return of some materials from desktops and laptops using system dynamics methodology. The results show that even in the absence of bargaining power, the formalization of waste pickers occurs due to legal incentives. It is important to ensure the waste pickers cooperatives access to a minimum amount, which requires a level of protection against unfair competition with companies. Regarding the optimal level of environmental policies, even though the formalization time is long, it is still not enough to guarantee the formalization of waste picker cooperatives, which is dependent on their bargaining power. Steel is the material with the largest decrease in acquisition rate of raw material.

1. Introduction

Closed loop supply chain (CLSC) and reverse logistics (RL) concepts have been discussed by different authors (Govindan et al., 2015) as a possible integration in decision-making process for multi objective problems regarding environmental approaches. In this context, Georgiadis and Besiou (2010) presented a system dynamic model applied to a real-world case, through a methodological approach to evaluate regulatory measures and green consumerism. On the other side, it seems that some aspects must be considered in the operational framework. Besiou et al. (2012), for example, analysed the relationship between formal recyclers and waste pickers through a real case study in Greece's Waste Electrical Electronic Equipment (WEEE) management. This study concluded that there is an important role of waste pickers' procedures regulation and conflict mitigation. Sarkis et al. (2010) presented one of the main causes of these conflicts when they emphasized the lack of studies related to social responsibility and RL.

Reverse logistics is a tool for social and economic development characterized by a set of actions, procedures and resources to enable the collection and restitution of solid wastes to the business sector for reuse in either its own cycle or any other production cycles (returning as secondary raw material) or for environmentally appropriate final disposal (Brazil, 2010a). The formalization of BSWP through the sectorial agreement has been delayed due to the complexity in establishing responsibilities associated with reverse logistics activities. According to Chaves et al. (2014), the reverse logistics could be successful by ensuring the Polluter Pays Principle in BSWP as occurred through the European Directives enactment, such as the European Directive 2008/98/CE.

The cooperation between formal and informal waste recovery sectors can help to solve the environmental, social and economic issues concerning sustainability (Ferri et al., 2015; Li and Tee, 2012; Sembiring and Nitivattananon, 2010). However, the informal sector requires more support because it is the most vulnerable link in solid waste management (Paul et al., 2012).

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With technological development, the electrical and electronic equipment (EEE) market has grown considerably worldwide. In Brazil, internal market growth and incentives from credit and tax exemptions have favoured EEE consumption (Migliano et al., 2014). The sector's revenue reached US$ 40.37 billion in 2015, a decrease of 7% compared to 2014 (ABINEE, 2016), due to the economic crisis experienced by the country. Brazil generates the second greatest amount of e-waste among emerging countries (De Oliveira et al., 2012).

This growth, however, raises concern about the generation of waste electric and electronic equipment (WEEE), which grows in amount and variety with market expansion and with its increasingly shorter life cycle (ABDI, 2012; Kiddee et al., 2013; Xavier and Carvalho, 2014). In 2014, Brazil produced approximately 1.4 million tons of WEEE (Baldé et al., 2015) of which only a small portion was recycled (Guarnieri et al., 2016). The reverse flow of these residues add value to the electronic waste, allowing a reduction in mineral extraction and decreasing the high cost associated with the recycling processing, which may exceed the value of the recovered material (Guarnieri et al., 2016; Wakolbinger et al., 2014).

Collection and recovery of WEEE and the agents responsible for its related activities and costs are linked to the relevant regulations in each country (Baldé et al., 2015; Kilic et al., 2015). Reverse logistics can be structured through the country's legislation regulating the waste management by establishing rules and requirements, and defining the agents responsible for its application (Bing et al., 2016; Guarnieri et al., 2016; Chaves et al., 2014).

The Brazilian Solid Waste Management Act (BSWP) was a legal milestone for waste management in Brazil, including WEEE and its components, which involved all links of the production chain, including the waste pickers (Campos, 2014; Migliano et al., 2014; De Oliveira et al., 2012). The waste pickers are people who mostly subsist on the sales of collected recyclable waste (Schenck et al., 2016). At least six categories of informal waste recycling exist: household (door-to-door) waste collector, street pickers, itinerant waste buyers, municipal waste collection crew, dumpsite pickers and intermediate dealers, that compose a hierarchy network (Ezeah et al., 2013). Despite the importance of these actors for the waste management system, the structural gap between the formal and informal waste economy persist (Schenck et al., 2016; De Oliveira et al., 2012; Velis et al., 2012).

The integration of waste pickers into the formal process of waste recovery requires their formalization through cooperatives or other types of organizations (Campos, 2014; Rutkowski and Rutkowski, 2015). Once formalized, waste pickers can demand rights, increase the amount of collected material, and raise their prices, in contrast to informal workers who lack bargaining power or do not have access to a physical structure to store their collected materials, forcing them to accept the prices imposed by the market (Chaves et al., 2014; Oguntoyinbo, 2012). The hiring of waste pickers is a financial alternative for the government since it may reduce the high costs of waste collection in the country (Campos, 2014; Li and Tee, 2012).

However, formalization alone is not sufficient to integrate the waste pickers into the reverse flow of hazardous waste such as WEEE. Proper training for the appropriate handling, storage, transportation, disassembly and sorting of material becomes necessary to guarantee the workers' safety and health (Guarnieri and Streit, 2015; Bleck and Wettberg, 2012; Li and Tee, 2012).

Given the high value added to WEEE, mainly from desktops and laptops, waste pickers target these materials and are exposed to hazards, namely, flammability, corrosiveness, reactivity, toxicity and pathogenicity (Oguchi et al., 2013; Tsydenova and Bengtsson, 2011). These wastes may negatively impact both the environment and human health in the equipments disassembly during management. This process exposes workers to heavy metals, potentially leading to absorption and bioaccumulation (Kiddee et al., 2013). On the other hand, the incineration of these materials produces toxic components and contamination via inhalation (Xavier and Carvalho, 2014). Since 2012, desktops and laptops have been replaced by tablets and iPads (ABINEE, 2015; Kiddee et al., 2013), and proper management of disposed equipment, including collection, disassembly, sorting, recycling and environmentally acceptable disposal of the waste has become necessary.

Thus, this work designs a closed cycle model to manage the reverse logistics of desktop and laptop waste and assesses the impact of Brazilian public policies related to solid waste management on the social inclusion of waste pickers. The influence of these legal motivators as well as the bargaining power of associations and cooperatives on the effective formalization of the waste pickers in the process of WEEE recovery is studied through a dynamic simulation model. Analysing different scenarios, the model shows the impact of these factors on waste picker formalization over time and on the rate of resource acquisition needed for desktop and laptop production.

This study was based on the works of Georgiadis and Vlachos (2004) and Besiou et al. (2012) given their intrinsic characteristics, such as the percent of material collected by the companies in the absence of regulation, the regulatory impositions, and the waste pickers' conditions. However, these factors depend on the country. In developed countries, WEEE is mainly managed by private companies in association with the municipality, and the role of waste pickers is virtually null (Xavier and Carvalho, 2014). In the Indian context, Ardi and Leisten (2016) explain the cause of the informal sector growth in WEEE management system. In Brazil, although the BSWP considers the waste pickers' social inclusion within the waste recovery process, their formalization is difficult. Despite regulation, the country still bears a high number of informal workers: between 400 and 800 thousands (IPEA, 2011; MNCR, 2014).

The assessment of desktop and laptop reverse logistics considering the impact of legal motivators and other factors that interfere with the effective formalization of waste pickers in the recycling process over time is a complex task. System dynamics (SD) is an appropriate tool to model this system and has been applied to a wide variety of problems such as social and economic analyses (Ardi and Leisten, 2016; Nabavi et al., 2016; Pretorius et al., 2015; Senge et al., 2014). In recent years, the complexity of RL has influenced researchers to employ SD modeling (Mafakheri and Nasiri, 2013). However, the number of quantitative research that captured WEEE from informal sectors is still limited (Ardi and Leisten, 2016).

Developed by Forrester, SD studies the behavior changes of complex systems over time based on basic principles such as system, dynamics, structures and behavior, assessing the consequences of the decisions taken (Ardi and Leisten, 2016; Mafakheri and Nasiri, 2013; Karnopp et al., 2012).

2. Materials and methods

2.1. The Brazilian Solid waste policy: The inclusion of waste pickers as a Brazilian legal requirement

Within the context of international pressure on environmental issues and sustainable development, the Brazilian government has sanctioned laws to systematize new procedures concerning solid waste management (Chaves et al., 2014). Enacted in 2010, Law N° 12.305 (Brazil, 2010a) established the Brazilian Solid Waste Policy (BSWP), which encompasses some innovative instruments for developing countries, such as shared responsibility throughout the product life cycle, social inclusion of waste pickers, and the definition and implementation of reverse logistics systems (RLS). The