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ANALYSIS OF THE WASTE MANAGEMENT SYSTEM OF ELECTRICAL AND ELECTRONIC EQUIPMENT IN GERMANY AND ITS INFLUENCE ON THE REVERSE LOGISTICS OF THE MUNICIPALITY OF RIO DE JANEIRO

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ABSTRACT

The contextualization of the study discusses the policies and economies that involve the production, consumption and disposal of electronic products. The sector of production of electronic devices is configured as the one of greater growth within the industry of manufacture in the industrialized countries. The objective of this study is to analyze and compare the waste management systems of electrical and electronic equipment (WEEE) of Germany and Brazil, to point out improvements in the management system of the municipality of Rio de Janeiro, RJ, Brazil. The method used was elaborated in a hypothetical scenario, with the purpose of focusing the generation of WEEE in the city of Rio de Janeiro. For this, data was searched on the internet. One of the main results indicates that Germany has an efficient system, for mapping all points of collection of WEEE per km² and for monitoring the products placed on the market. The municipality of Rio de Janeiro forecasts a generation of 2,655,856.81 tons of WEEE for the year 2018, a calculation obtained through consumption and use of households. The reverse logistics system is considered as an instrument to guarantee the return flow of the waste to the production cycle, to enable its collection and restitution to the business sector (manufacturers, importers), responsible for its environmentally adequate final destination. This study presents in a literary review that consists of identifying data combined with a set of rules to select relevant pieces of literature and map the content of the literature extracting information.

Keywords: Management of Waste Electrical and Electronic Equipment; Sustainability; Recycling; Reuse; Collect.

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1. INTRODUCTION

The contextualization of this study highlights the negative environmental impacts resulting from the inadequate disposal of waste electrical and electronic equipment (WEEE), which causes economic loss due to the non-valuation of recyclable materials. WEEE accounts for most of the total waste produced and have the highest annual growth rate, estimated at 3% to 5%, representing around 20 to 50 million tons discarded (Cucchiella et al., 2015). Compared with traditional waste streams, the management of WEEE presents several challenges, mainly due to its heterogeneity in terms of size, weight, function and composition of the material. If improperly handled, electronic waste can create significant risks to human health and the environment due to the presence of hazardous substances such as heavy metals and flame retardants (Hobohm et al., 2017).

In order to ensure the proper collection and recycling of e-waste, the European Parliament's Directive 2012/19/EU set out general collection requirements for recycling and management purposes and described ten categories of e--waste for the purpose of reducing waste to five until 2018. It also determined the minimum collection rates of WEEE, based on the percentage of products placed on the market in the last three years: 45%, from 2016 to 2019, and 65% from 2019. One of the main changes introduced in this Directive in relation to the previous Directive (2002/96/EC) was the definition of the collection target of 4 kg per inhabitant in relation to products placed on the market. The advantage of the new mechanism of goal setting is the ratio of the actual quantity, which best represents the differences between the socioeconomic conditions of the member states (European Commission, 2018).

National and international regulatory mechanisms play a very important role in the mobilization of the actors involved in the management of the reverse chain of WEEE. Electronic equipment tends to be refurbished and reused in developing countries, including the post-consumer phase. This consumption option is known as cascade consumption, in which the equipment has its use discontinued (whether due to failure or simple replacement by more modern equipment), is reconditioned, and reused in another phase of its useful life. In this way, the life cycle of electrical and electronic equipment can vary according to country, economic situation, technological options, among other criteria (Xavier, 2017).

Even with the worldwide issue on the agenda, Brazil still lacks specific legislation regarding WEEE. Law No. 12,205 of August 2, 2010, which established the National Solid Waste Policy (PNRS, acronym in Portuguese) was enacted only in 2010. In the same year, the above-mentioned law was regulated by Decree No. 7,404, dated December 23, 2010. However, no other legal instruments were created to define what exactly should be done with scrap electronics in the national scope (Guerra, 2012). In common, such waste may be composed of equipment or parts thereof, which become obsolete, have ceased to function or are defective during their production.

In this study, it is verified that the current management of the subject aims at sustainability and minimization of environmental and social impacts and, therefore, determines that WEEE should be destined to reuse and recycling, and when the possibilities are exhausted the resulting waste should be treated to be disposed in landfills (Flandinet et al., 2012). With this, the recycling of WEEE aims at sustainability by minimizing the environmental impacts caused by the primary extraction of the metal; the reduction of waste to be disposed of in landfills and the consequent reduction of the contamination of the soil and groundwater caused by the percolation of the bleach; and compliance with current legislation (Brierley et Brierley, 2013).

The present article is an attempt to estimate the influence of the management system of the European Union (EU), with emphasis on the management of WEEE from Germany; compare the collection system, the goals to be achieved, and the procedures adopted by the responsible bodies; and compare this model with the existing system in Brazil, using as a representative scenario the municipality of Rio de Janeiro, with the purpose of elaborating improvements to the management system.

2. 2 LITERATURE REVISION

In recent years the EU has sought to lay the foundations for the development of a circular economy for which waste would be considered as resource and therefore used more efficiently and sustainably (European Commission, 2014). To this end, the WEEE Directive (2012/19/EU), which identifies the management of WEEE at the end of its useful life, has been established and the RoHS Directive (Directive 2011/65/EU), which defines the restriction on the use of certain substances in electrical and electronic equipment (Smol et al., 2016). Among all the different waste streams, the attention of the European Commission was particularly focused on the treatment of WEEE due to a series of explicit warnings. In addition, these wastes contain very important components that are on the list of critical raw materials in the EU, representing the largest source of waste and the highest growth rate (European Commission, 2014).

Therefore, the recovery of expensive and scarce resources such as precious metals and critical materials of these products represents a significant economic opportunity. However, current recycling technologies and business mo-

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dels have limited our ability to recover these resources as recovery rates remain relatively low (European Commission, 2018). In addition, the recycling of electronic waste is more complex than the recycling of solid household waste, because of the high concentration of toxic compounds prevalent in electronic devices (Smol et al., 2016). Figure 1 shows the trends in the quantity of electro-electronic equipment placed on the market and the percentage of WEEE collected and treated in the EU between the periods 2010 to 2015. The missing data for some Member States were estimated to be able to show development across the region. The time interval between the year in which the electronic equipment is placed on the market and the year in which it becomes waste is not taken into account in the monitoring of the WEEE collection goal.

Between 2010 and 2013, the amount of electronic equipment placed on the market fell by almost 0.7 million tons, resulting in less than 8.8 million tons in 2013. This reduction (7.2%) is seen as more likely due to recession following the global financial and economic crisis but was offset between 2013 and 2015. This amount increased again in 2014 and 2015 to 9.3 million tons and 9.8 million tons respectively (European Commission, 2018).

When discussing the policies and economies that involve the production, consumption and disposal of electrical and electronic products, it is inevitable that there will be a junction between developed and developing countries (Silvas, 2014). Extraction, production and high energy consumption activities are preferably transferred to developing countries due to low wage costs, lack of or weak environmental and labor legislation, incentives from governments and manufacturers, and the disposal of waste produced in production processes and in post-consumption. Some European countries already had WEEE management systems prior to Directive 2002/96/EC, but since their entry they have had to make some adaptations (Huisman et al., 2008).

2.1 Legislation in Germany

The Federal States Task Force (LAGA) in Germany created the Elektro-Altgeräte-Richtline Directive (EAG) in November 2000, the first to offer a broad and environmentally friendly professional technical standard for the treatment of electronic equipment (UmweltBundesamt, 2017). Waste management in Germany adopts the "Closed substances Cycle and Waste Management Act" (Krw-/Abfg) model, which came into force in 1996, establishing the new product liability approach, in which manufacturers and traders have an obligation to meet the targets.

On October 20, 2015 ElektroG was implemented. This law transposes Directive 2012/19/EC into the European Directive, which in turn replaced Directive 2002/96/EC, with changes in the definition of the collection target of 4 kg/inhabi-

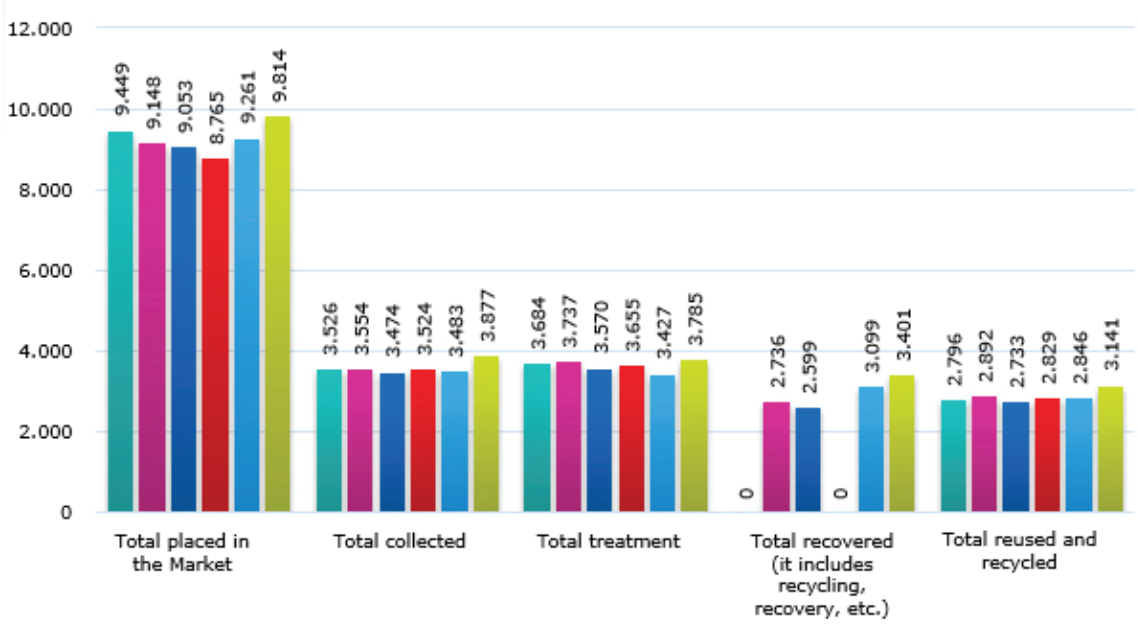

Figure 1. Electrical and electronic equipment placed on the market and the resulting waste that is collected and treated. European Union, 2010-2015 (1000 t)

Source: Prepared from the European Commission, 2018

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tants for an approach based on the percentage of sales of products placed on the market. The objective of the law is to prevent or reduce the harmful effects of the generation and management of WEEE, reduce the overall impact of resource use, and increase the efficiency of resource use (UmweltBundesamt, 2017). Figure 2 shows the cycle of specific obligations for product manufacturers, trade, municipalities and disposal companies and citizens, who are required by ElektroG to transfer their WEEE to a separate collection of municipal waste.

Process description

- Legal basis: law on the sale, return and ecological disposal of electrical and electronic equipment (EEE--ElektroG, March 16, 2005).
- Transposition of Directives 2002/95/EC (RoHS) and 2002/96/EC (WEEE) into national law.
- Ecological objectives: prevention of waste, reduction of inputs, pollutants to the environment, conservation of resources and promotion of producer responsibility.
- Loan Act: as of July 6, 2005;
- Loan: Federal Environment Agency as the competent authority;
- Responsibility: responsible industry, register in Electrical and Electronic (EAR);
- Objective: deregulation by submitting sovereign tasks to the responsibility of the economy.
- Responsibility of the industries: registration of manufacturers and quantity of new equipment placed on the market by manufacturer; verify guarantees of disposal by issuing orders of supply.
- Tasks: supervision against illegal activity by EAR; transfer of loans.
- Technical supervision: evaluation of legal complaints from third parties that ensure the internal legal compliance of process and protection of data and regulations, examination of areas financed by EAR.

Thus, we have all the support for the implementation of the law that prints the performance of important functions, from the registration of producers until considering the guarantee of disposal, the collection of all necessary data, the equipment of the municipalities with the pick-up containers, and calculating the manufacturer's pick-up quantities for the collection company's arrangement (Stiftung EAR,

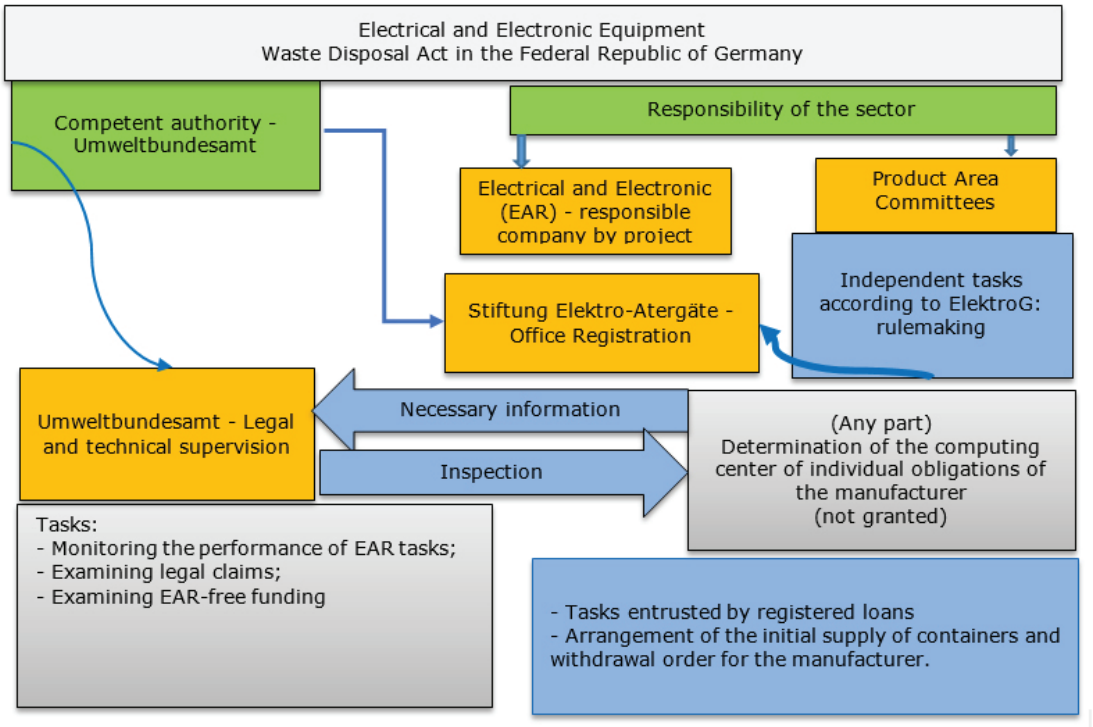

Figure 2. German Waste Electrical and Electronic Equipment Act
Source: Prepared from UmweltBundesamt, 2017

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2018). Figure 3 demonstrates the operation of ElektroG: (1) electronics manufacturers register in the organization; (2) private households dispose of their electrical and electronic equipment at municipal collection facilities (or retailers); (3) municipal collection transfers the segregated waste to the organization when the containers are full; and (4) the organization decides which company will be responsible for the proper destination of the container.

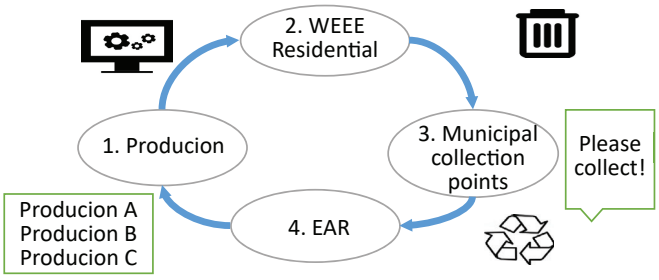

Figure 3. German System
Source: Prepared from UmweltBundesamt, 2017

In this system, the electronic equipment is labeled with information for its disposal at the end of its useful life and with the objective of influencing consumers to dispose of the electronic waste properly at strategic disposal points. ElektroG collects data from registered producers, disposal sites, and treatment facilities. (Stiftung EAR, 2018). With this information, EAR ensures the presence of an adequate number of containers for each category of WEEE at specific collection sites and coordinates the process. Those responsible for the management of public waste manage the collection, in the case of producers related to the individual collection system, or operate a collective system; in any case, producers will cover all additional collection costs.

ElektroG does not place any direct financial liability on producers for equipment placed on the market before 13 August 2005, making WEEE owners responsible for disposal. ElektroG regulates the system of withdrawal of the dealers, who have gone from a voluntary basis to a compulsory action (UmweltBundesamt, 2017). As of July 24, 2016, online distributors or resellers must accept WEEE with or without the purchase of new equipment. The German systems are described below:

- **The drop-off system:** the collection is performed through storage in containers; the citizens take their old electronic equipment, without any cost, to one of the municipal collection points or to stores of distributors and resellers;
- **The collection system:** consists in the collection of electronic waste directly in family condominiums (with a cost of 35 €);
- **Distribution of containers**: near shopping centers and residential areas, for segregation, where citizens can leave small electronic waste (dimensions <50 cm). These containers are emptied approximately every two weeks by those responsible for public waste management.

2.2 Legislation in Brazil

In order to have an effective WEEE management system, it is necessary to establish responsibilities regarding the product. Directive 2002/96/EC establishes the extended responsibility of the producer, who is responsible for the management of his post-consumer product, being able to opt for an individual management system or a shared management system (Huisman et al., 2008). In the individual management system, the producer assumes, individually, responsibility for the organization and financing of his own WEEE management system (Silvas, 2014). In the shared system, responsibility for the management of WEEE is shared with a duly licensed management entity.

Because there are no regulations in Brazil that oblige manufacturers and importers of electrical and electronic equipment to take responsibility for their post-consumer products, an adaptation of the shared management system between manufacturers, municipalities, and consumers is used. The life cycle of electronic equipment has decreased due to technological advances, providing a significant amount of waste in this sector; with this, the exchange of devices and equipment is increasingly frequent due to the rapid level of technological innovation and programmed obsolescence. Brazil generates about 680,000 tons of WEEE annually, characterized as the largest generator of this type of waste among emerging countries (Silva et al., 2015). Table 1 shows the categories of products, weight and life cycle and their variations according to consumption.

In this context, the need for adequate management of WEEE is created, based on the existing management regulation standard in Brazil, called PNRS; however, the management system after the use of electronic material is inefficient and there is still no specific regulation in the PNRS under the treatment of such waste. The PNRS establishes that the service providers that generate hazardous waste are subject to the preparation of the Solid Waste Management Plan (PGRS, acronym in Portuguese) (Art. 20), which is a tool that seeks to ensure the traceability of waste, from its generation to the final destination, and must contain the following information: generator identification; diagnosis of the existing

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situation; conditioning, collection, internal transportation, temporary storage, segregation, pre-treatment and treatment within the organization; collection, external transportation and final disposal of waste; and source reduction, reuse and recycling programs, and environmental education programs (Silva et al., 2015).

Table 1. Categorization of electrical and electronic equipment in Brazil

Categories	Product	Average weight (kg)	Life cycle (year)
White line	Refrigerators	57,95	15
	Fireplaces	44,292	12
	Washing machines	36,512	11
	Air conditioning	8	9
Brown Line	TV/monitor	37,234	10
	LCD/Plasma	12	7
	DVD/VHS	3,374	7
	Audio Products	10,4	7
Green Line	Desktop	24,283	7
	Notebooks	2,368	4
	Printers	6,312	6
	Mobile phones	0,124	3
Blue line	Drums	2,9	5
	Blender	2,65	5
	Electric iron	1,177	5
	Drilling machine	1,7	5
		251,276	7,375

Source: Prepared from Xavier et Lins, 2018

The design and implementation of a PGRS is essential to reduce the costs associated with waste management, as well as ensuring that all waste generated by the company is managed safely and properly. They are defined as electrical and electronic equipment "all those products whose operation depends on the use of electric current or electromagnetic fields" (Xavier, 2017).

The necessary conditions for its success were not all established by law and, therefore, are being structured through the regulation of federal decrees, resolutions of the National Environmental Council (CONAMA) and management plans. The PNRS is the public policy that brings together a set of principles, goals and actions developed by the Federal Government on its own or through the cooperation regime with the States, Federal District, Municipalities or individuals, with a view to integrated management and environmentally sound management of solid waste and the adoption of sustainable patterns of production and consumption of goods and services in order to meet the needs of the current generations and to allow better living conditions without compromising environmental quality and meeting the needs of future generations (MMA, 2010).

The law governing the PNRS encourages manufacturers to adopt adequate procedures for the production of non-environmentally and human health-endangering products and for the environmentally sound final disposal of waste in order to avoid damage or risks to public health and safety and to minimize adverse environmental impacts (MMA, 2010). The law also differentiates waste (that which has economic value and can be recycled or reused) of waste (any material considered useless after exhausting the possibilities of treatment and recovery by available and economically viable technological processes), and treats all types of waste, including domestic, industrial and construction, except for radioactive waste.

One of the paths foreseen in the PNRS, which will guarantee the increase of recycling in Brazil, is that of the selective collection. Increasing recycling will also have the effect of preventing such waste from reaching landfills. Recycling can make it possible to recycle materials, as well as being an opportunity to generate work and income and social inclusion. After regulation, through Decree 7,404/2010, solid waste policy entered a new phase that depends on sectoral agreements and a proposal that includes targets and operating rules for reduction, recycling, reverse logistics, and other instruments (MMA, 2010). The law gives due importance to hazardous waste by predicting the requirement of reverse logistics, which is the case of WEEEs.

3. CHARACTERIZATION OF THE MUNICIPALITY OF RIO DE JANEIRO

Rio de Janeiro, the capital of the state of Rio de Janeiro, is one of the main cities in economic development in the country. It stands out in the generation of waste because it has an urban population density with purchasing power, characteristic of the main centers of consumption and, consequently, the disposal center for post-consumer products and materials. These areas can be understood as points of collection and recovery of secondary resources from urban mining, which includes the economic exploitation of resources of the "surplus" resulting from the generation of waste of diverse characteristics, by the discarding of products and materials after consumption. Similarly to conventional mining, urban mining can recover rare and common metal materials and non-metallic materials such as WEEE (Xavier et Lins, 2018).

The Municipal Law No. 4,969/2008, in its annex, the Federal Law 12,305/2010, in its Article 3, item XII, and the recent State Law no. 6.805/2014, which includes Art. 22-A, 22 -B and 22-C in Law No. 4,191/2003, define the Reverse

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Logistics System as an instrument to guarantee the return flow of the waste to the production cycle, making possible its final environmentally adequate destination. According to the aforementioned laws, manufacturers, importers, distributors and merchants of WEEE are required to structure and implement reverse logistics systems, upon return of the products after use by the consumer, independently of the urban cleaning and solid waste management service (Rio de Janeiro Municipality, 2013).

Figure 4 shows the sectors that represent the terms of commitment that must be signed by the Government, manufacturers, importers, distributors and traders. It is the responsibility of the State Environmental Institute (INEA) to supervise the actions for the disposal related to waste management in the state of Rio de Janeiro, with responsibility for the environmental agencies in their respective instances (Rio de Janeiro Municipality, 2013). This survey intends to indicate in an illustrative way some sectors responsible for supervising the management of this waste and to point out the behavior of the private consumers in relation to the possibilities of disposal of some electronic equipment. According to the analyzes carried out in this study, the WEEEs of the city of Rio de Janeiro need adequate management that can outline their management.

Minimizing the damage or negative impacts of waste to the environment, through these agreements, could make these rules applied to the target audience to help with the organization of waste disposal. Involving specific technologies for the recovery of certain components of the electronics industry becomes increasingly important (Rio de Janeiro Municipality, 2013). The household collection service in the city of Rio de Janeiro is calculated through the divisible fraction of urban cleaning services, and is paid for by the Household Collection Fee, under the terms of Municipal Law No. 2,687, dated November 27, 1998. As for the non-divisible fraction of services, such as the collection, transfer and disposal of public waste, it is funded by other municipal taxes.

Table 2 shows the mapping of the districts of Rio de Janeiro, the number of the resident population by occupied private households and the percentage of these households with the number of residues generated by residences.

The diagnosis indicates that private consumers will have a large volume of electronic waste, which, if not properly disposed of, will have a great impact on the environment.

This mapping was done for a better understanding in the context of the estimation of generation of computer waste. However, it was not possible to accurately perform the flow of such equipment throughout the municipality, only in part of the municipality, due to the various limitations of existing information, citing:

- The lack of historical sales data by region of WEEE;

Table 2 Estimation of waste electrical and electronic equipment (WEEE) in households in Rio de Janeiro (%)

District	Resident population	Occupied private households (%)	(%)	WEEE (n)
Lagoa	167.774	67.914	85.08	57.781
Botafogo	102.618	82.890	83.7	85.891
Tijuca	163.805	68.332	80.98	55.335
Copacabana	146.392	72.293	79.64	57.574
Vila Isabel	135.924	69.856	77.54	54.166
Barra da Tijuca	86.018	106.262	79.11	83.984
Méier	49.828	137.616	70.96	97.652
Ilha do Governador	212.574	71.786	68.97	49.510
Irajá	202.952	69.121	67.76	46.836
Jacarepaguá	572.617	191.859	65.76	126.166
Cidade de Deus	97.823	11.391	51.74	5.893
São Cristóvão	26.510	26.906	51.09	13.746
Rocinha	69.356	23.404	49.83	11.662
Santa Cruz	368.534	112.689	45.18	50.912
Guaratiba	110.049	37.699	44.74	16.866
Maré	129.770	41.750	43.97	18.357
Jacarezinho	37.839	11.368	43.69	4.966
Complexo do Alemão	69.143	21.048	45.096	10.157
Total	2.688.218	1.224.184	63.46	926.784

Source: Author (2018)

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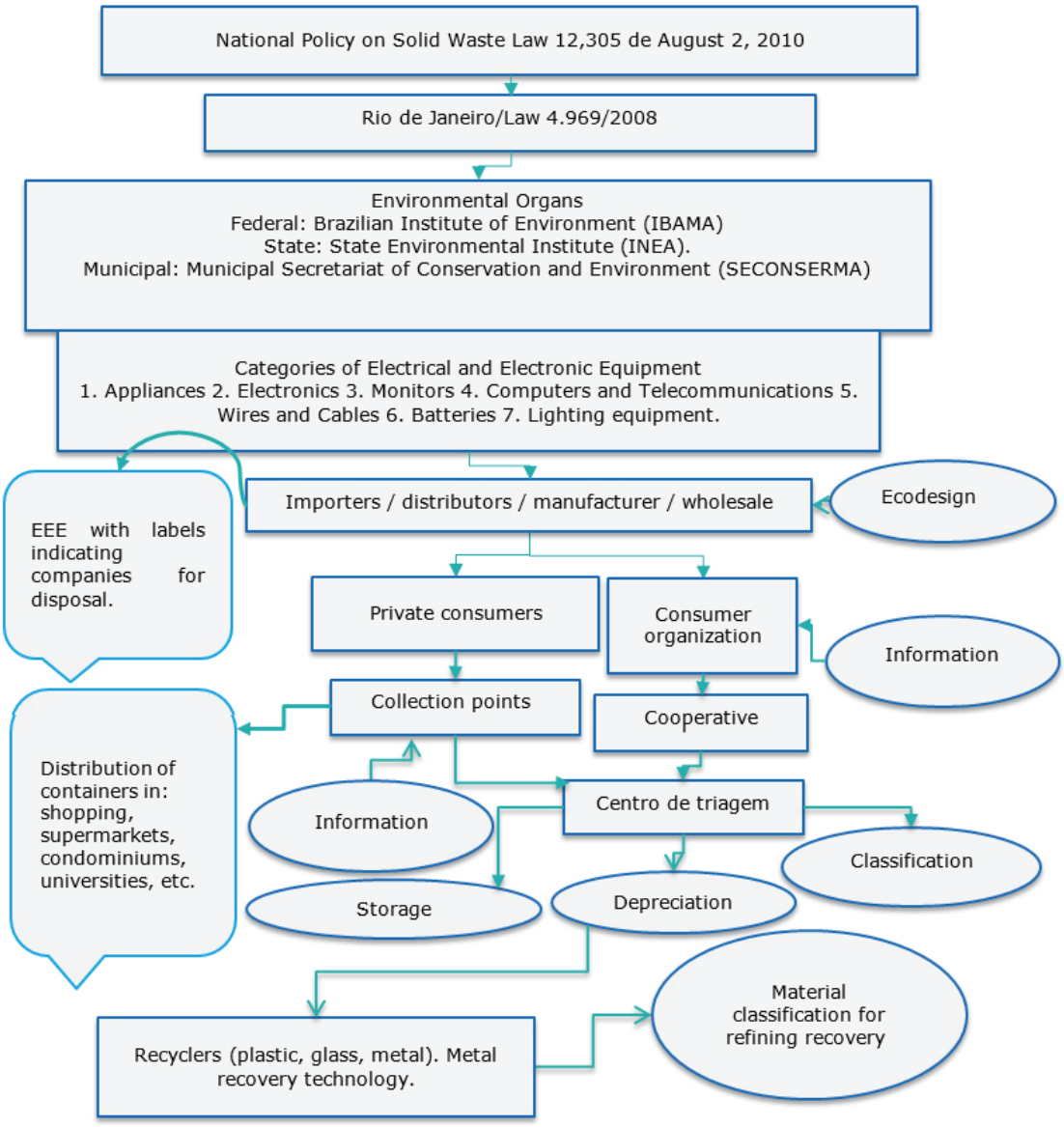

Figure 4. Waste management system for electrical and electronic equipment
Source: The author himself (2018)

- Absence in the number of flows of the entrance of this equipment in the municipality;
- Absence of recycling data of this equipment, as it is a recent practice and is done by informal means;
- Disposal of such waste together with household waste;
- Storage of these products in homes.

4. SCIENTIFIC METHOD

The methodological procedures section presents the scenario, the method, the steps of research, data collection, and analysis.

4.1 Scenario

The present study was elaborated in a hypothetical scenario, with the intention of mapping an important scenario, focusing the generation of WEEE in the city of Rio de Janeiro. For this, we used the data obtained through Internet sear-

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ches, based on the Digital Inclusion Map report presented by the Getúlio Vargas Foundation (FGV, acronym in Portuguese) team (Neri, 2012). The city of Rio was highlighted, pointing out some sub-districts of Rio de Janeiro with the largest number of computer access. In this way, a survey was developed through an exploratory research (Gil, 2002), in order to identify and investigate the behavior of WEEE in the city of Rio de Janeiro. For comparative and referential analysis, Germany is used because it stands out in the efficiency of the collection and the treatment of these residues. Due to questions related to data collection, this study is limited by the lack of data in the literature.

The Brazilian Association of the Electrical and Electronic Industry (ABINEE, 2017) states that in the Brazilian scenario, this sector of the economy presented in the year 2016 an annual turnover of R$ 131.2 billion, with a generation of 1.4 million tons/year of WEEE and less than 3% of it was recycled. It is estimated that 10% or 140,000 tons/year are of information technology (IT) and telecommunications equipment.

4.2 Research method

This research is classified as a bibliographical nature because it intends to acquire knowledge in order to be applied in a real context (Gil, 2002). As for the objectives, it is classified as exploratory, because it aims to make the problem more explicit, with greater familiarity and understanding. As for the technical procedures, it is a selective reading, since it covers a data survey, with the objective of contributing information to a researched universe. As for the research approach, it is qualitative, considering that there is a relationship that cannot be translated into numbers. Regarding the research method, it is inductive because it will start from particular questions to conclude questions related to the generation of WEEE in the city of Rio de Janeiro.

Bibliographic research can be understood as a process involving different steps, according to Figure 5.

4.3 Stages of research

The present study followed the sequence of introduction, methodological procedures, literature review, results, discussions and conclusion. The first step was to approach the topic definition, with the objectives and delineation of the motivation of questions that contributed to the research and keywords. Thus, as envisaged by the European Union (European Commission, 2014), the increase in recycling targets is seen as an important ally for a circular economy. From the point of view of the WEEE recycler, however, WEEE recycling is becoming increasingly challenging as device innovations lead to a highly complex and heterogeneous waste stream (Cucchiella et al., 2015).

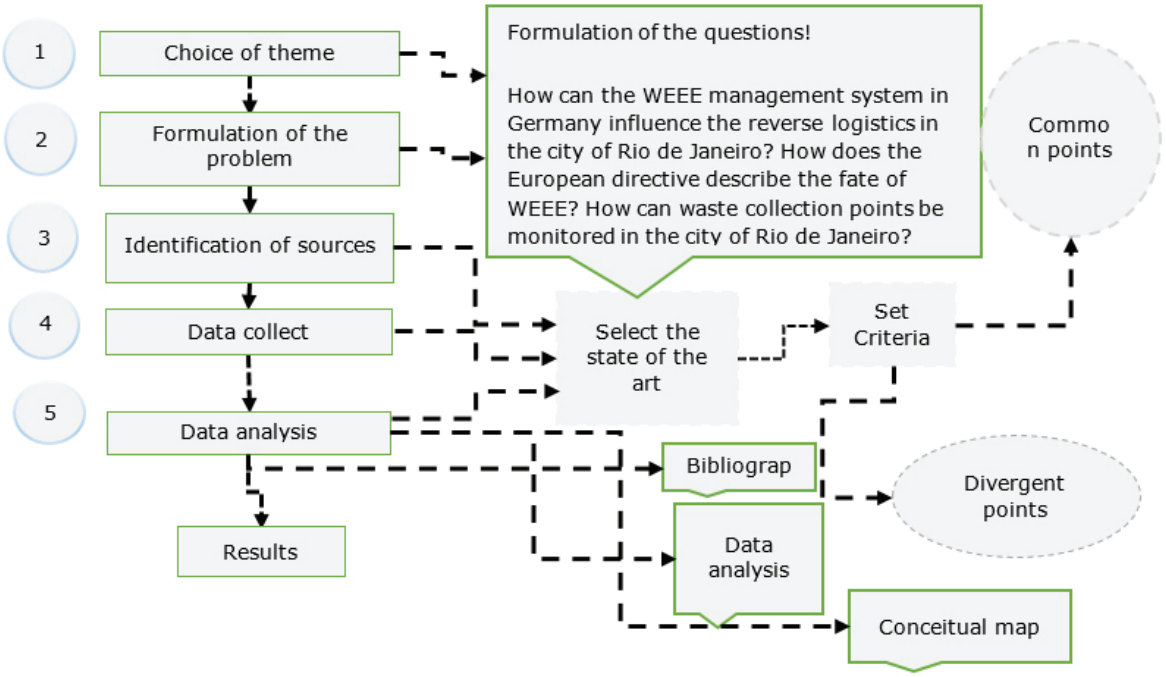

Figure 5. Conceptual map of the research
Source: Prepared from (Gil, 2002)

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The second step was the literature review, which implies searching for information about definitions and applications correlated with the research problem. Subsequently, in the third section, the characterization of the article analysis and data collection of the research was carried out and, sequentially, the elaboration of the method of data collection and the research instrument. Then, the validation of the procedure developed from the discussions carried out, with the exchange of e-mails between the participants, was carried out. In the fourth stage, the analyses of the results were performed. Finally, in the fifth stage, the work was concluded from the data obtained.

The data presented in this study show an expressive number of durable consumer goods, which induces questions about the fate given to these products when they are no longer useful to their possessors - post consumer, on how these wastes were being managed, and on why these waste need special management (Franco et Lange, 2011). In this way, the present study aimed to obtain an analysis of the electronic waste collection system in Germany and the generation of WEEE in the city of Rio de Janeiro, which has a population of 6.3 million (IBGE, 2017).

Therefore, the research was subdivided into two phases: (i) to analyze how the WEEE collection system works in Germany, to present this reference of success by having an organized system and comparing the benefits to the country's economy, with the possibility of minimizing environmental impacts caused by improper disposal; and (ii) to estimate the generation of WEEE in the city of Rio de Janeiro, which to date does not have an adequate collection system for these wastes. The approach considers the regulations, classification and management systems of WEEE.

4.4 Data collection

The international electronic database Google has been defined. Through this base, specific works that approach the industrial sectors of the economy were selected, in an intentional and non-probabilistic way. Figure 6 presents the key words chosen for this research: electronics industry; waste electrical and electronic equipment; electrical appliances and materials; Waste Management; recycling; reuse; collection; final destination; national and international policies; circular economy; sustainability; post-consumer products; trash; solid waste; and environment.

4.5 Data analysis

For the preparation of the study, a practical study schedule was created with the purpose of organizing the sequence of activities that were performed until the completion of this study. With this, the research by academic material provided scientific articles that delineated the research (Table 3).

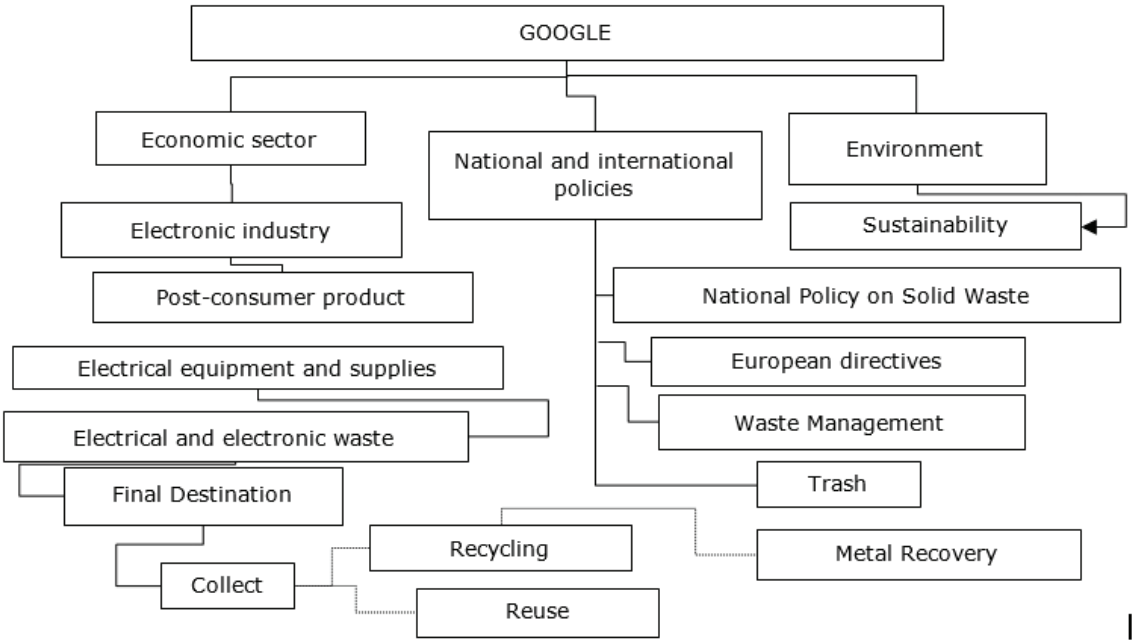

Figure 6. Word tree
Source: The Author (2018)

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Table 3. Study schedule

Activities	Start	Duration/ day	End
a) choice of theme;	29.06.18	1	30.06.18
b) formulation of the problem;	30.06.18	2	02.07.18
c) identification of sources;	05.07.18	5	10.07.18
d) sample selection;	10.07.18	10	20.07.18
e) data collection;	20.07.18	10	30.07.18
f) data analysis;	07.08.18	23	30.08.18
g) results.	30.08.18	15	15.09.18

Source: The Author (2018)

12 articles that were submitted to the complete reading in order to absorb information important for the research were considered, according to Figure 7.

There are several studies on WEEE management systems applied to recycling processes and their influence and benefits in reducing environmental impacts, especially Afroz et al. (2013), Biganzoli et al. (2015), Brierley et Brierley (2013), Silva et al. (2015), Silvas (2014), Cucchiella et al. (2015), Flandinet et al. (2012), Hobohm et al. (2017), Ziglio (2005), Zhou et al. (2011), Smol et al. (2016) and Franco et Lange (2011).

With the valorization of the end of the useful life and the time of recycling of electrical and electronic equipment, the sustainability system is reached, considering it valid for the whole process. In this sense, there is a need for more studies and generation of more inventory data, particularly on the collection, sorting, recycling of monomers and recycling of polymers and the generation of these residues by region. Figure 8 shows the counting of articles, highlighting Brazil in studies related to WEEE.

5. ANALYSIS OF RESULTS

5.1 1st Phase - Analysis of the German system

The registration system in the German responsible environmental agencies (UmweltBundesamt, 2017) demands all municipalities to provide points for waste disposal. With these disposal points, the waste is classified by categories and segregated and, sequentially, the collection, with all the supporting documentation for the registration in the system. Municipalities may also dispose of waste equipment or have them disposed of through third parties; Another way would be to announce the waste to a mixed unit six months in advance so that they can remove all the waste from a group in a period of two years to be made available for collection. In this case, the authorities should also ensure that the requirements for treatment and recycling are complied with and

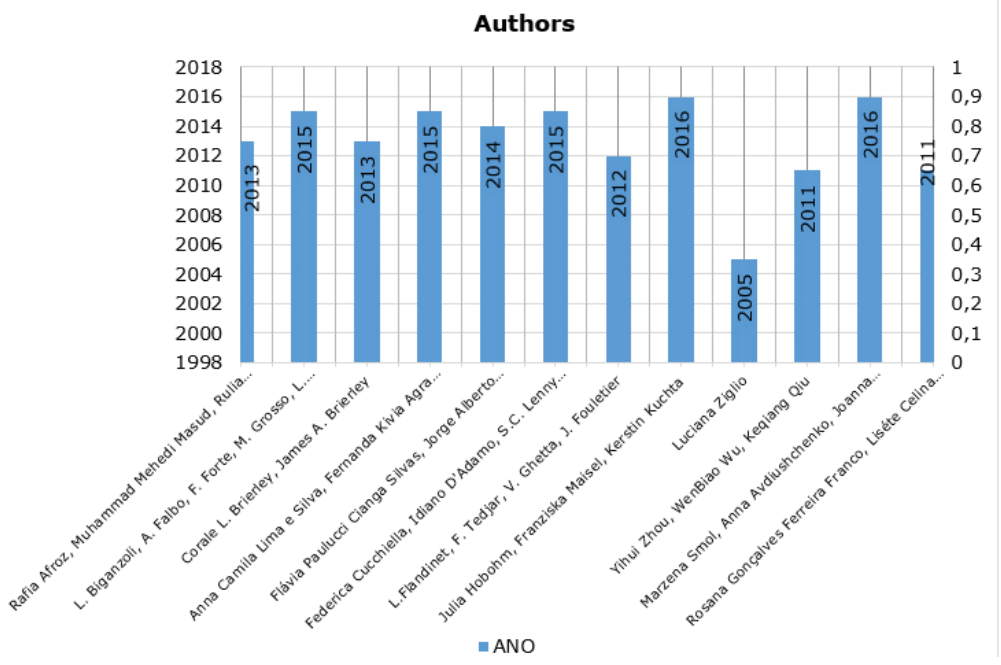

Figure 7. Selected articles
Source: The Author (2018)
Legend: Ano – Year

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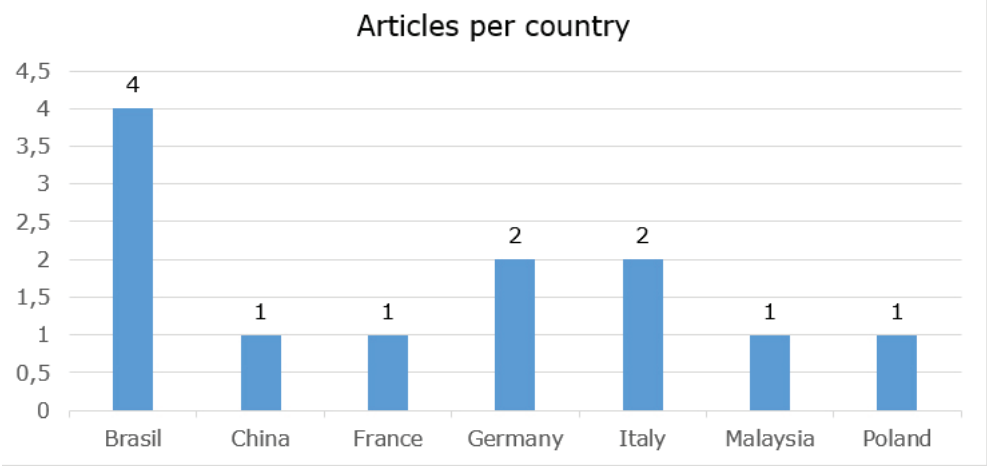

Figura 8. Artigos por países
Source: Prepared from the European Commission, 2018

that the corresponding reporting requirements can be met.

WEEEs are categorized into: 1. Large appliances; 2. Small household appliances; 3. IT and telecommunications; 4. Consumer equipment and photovoltaic panels; 5. others.

Figure 9 shows, for the year 2015, the estimate of products put up for sale and later collected and prepared for treatment. It is verified that 42.23% of the products collected were made available for sale.

For Hobohm et al. (2017), the changes in the definition of the collection target of 4 kg/inhabitants for an approach based on the percentage of sales of products placed on the market, using as a reference the European Directive 2012/19/EC, aims to reduce the harmful effects of the generation and management of WEEE. This reduces the overall impact of resource use and increases the efficiency of resource use. In addition, the Directive proposes the creation of collection points per km², in order to facilitate the collection system and for citizens to dispose of their waste efficiently.

5.2 2nd Phase - Generation of WEEE in the city of Rio de Janeiro

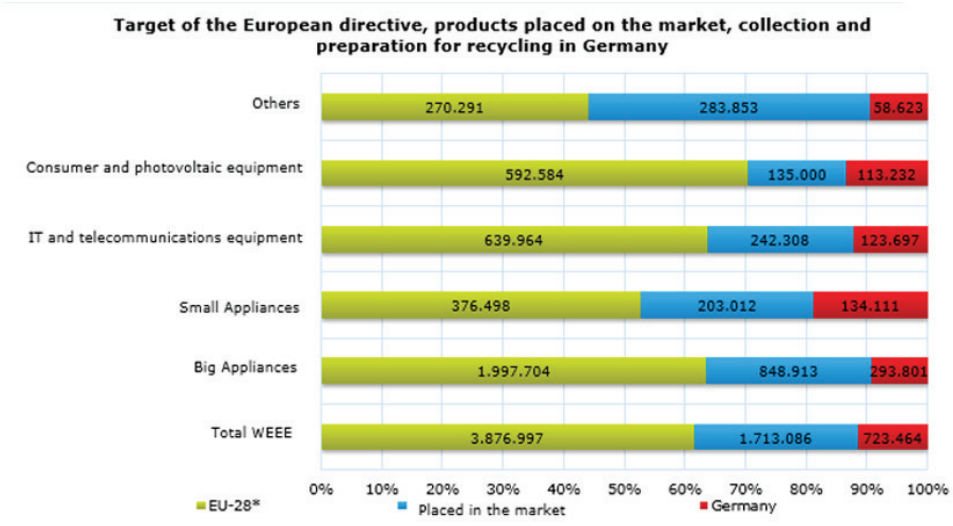

Figure 9. Comparison of waste collection of electrical and electronic equipment in Germany and the European Union (EU)
Fonte: Elaborado a partir de European Commission, 2018

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To carry out the study, a mapping work was done on the districts of Rio de Janeiro, presented in Table 2. With this database, information was obtained on the categories of the products, the average weight of each of them and the life cycle. The survey indicated that each household will discard 16 devices over the years, with a total weight of 251,276 kg. The calculation of the average lifecycle of all equipment, with variations of time and use, resulted in 5 to 7 years, with the probability of decreasing due to the technology exchange. With these results, it was possible to size the volume of electrical and electronic waste in the city of Rio de Janeiro using the consumption and use method (ABDI, 2012), which can calculate the volume of WEEE without sales data. Despite its simplification, the method is based on the two variables of greater imprecision: useful life and saturation level of the market, according to Figure 10.

It is not intended to make a representative analysis with this survey, but to indicate in an illustrative way some behavior of the WEEE situation in relation to its disposal. The average weight of the electronic equipment was determined by means of a search in the technical datasheets of products, available in the manufacturers' websites; it was considered that the useful life of all equipment is approximately five years. It can be considered that by the year 2023 there will be 2,989,190.24 tons of WEEE.

Figure 11 presents an analysis of the proposed study, with emphasis on Germany, with 57% of the equipment offered for sale collected and made available for recycling. The United Nations (UN) highlighted Brazil for its generation of WEEE: of the 1.4 million tons of WEEE, only 3% were recycled and only 10% are waste in the area of information technology. It is estimated that in Rio de Janeiro, 2,655,856 million devices can be generated, of which 531 thousand tons per equipment category (Figure 11).

From the increase in the quantity and diversity of post-consumer products, it is necessary to implement efficient collection and separation systems for products and materials. In this way, the demand for coordinated logistics actions is increased for the transportation and packaging of materials and products that will be destined in an environmentally adequate way, according to legal requirements. Although there is still no established system for the management of electrical and electronic waste in the city of Rio de Janeiro, it is observed the consolidation of procedures for the effectiveness in the management of this category of waste. Thus, it is expected that in Brazil/Rio de Janeiro, the WEEE management system can be coordinated in a way that electronic equipment is monitored until its final destination.

6. CONCLUSION

The best WEEE management practices are being developed in first world countries. In this study, Germany was used as an example, following the standards of the European Directives (European Commission, 2000) which determine the waste collection targets.

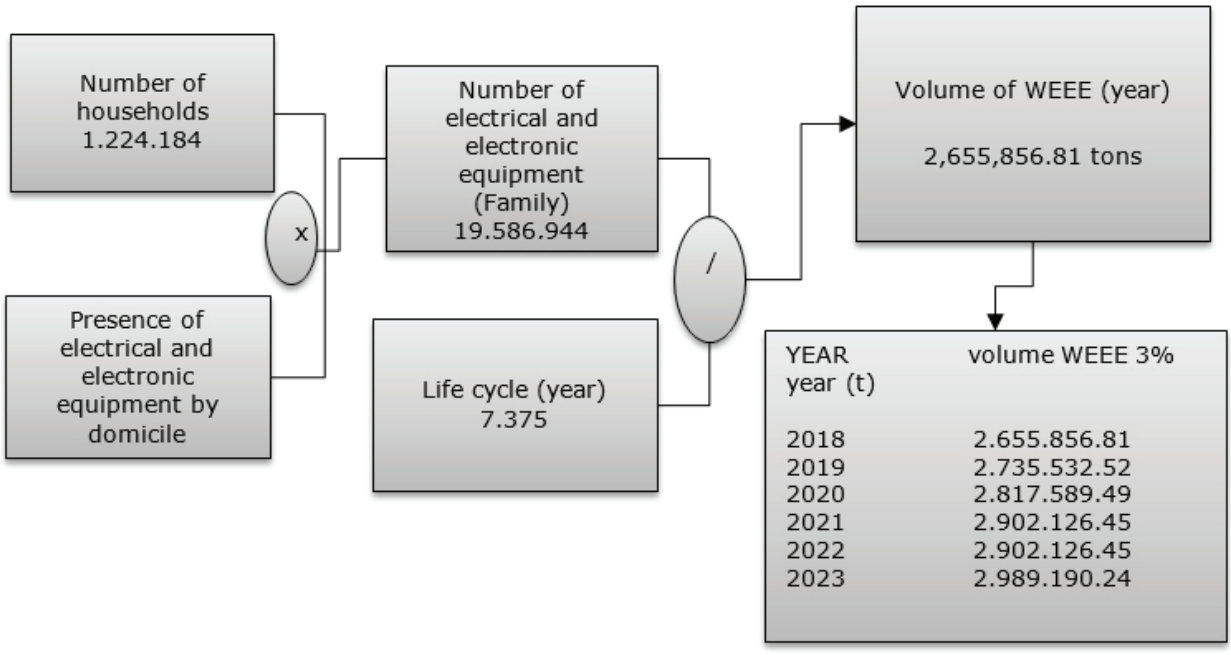

Figure 10. Estimation of the volume of waste electrical and electronic equipment in Rio de Janeiro
Source: Prepared from ABDI, 2012

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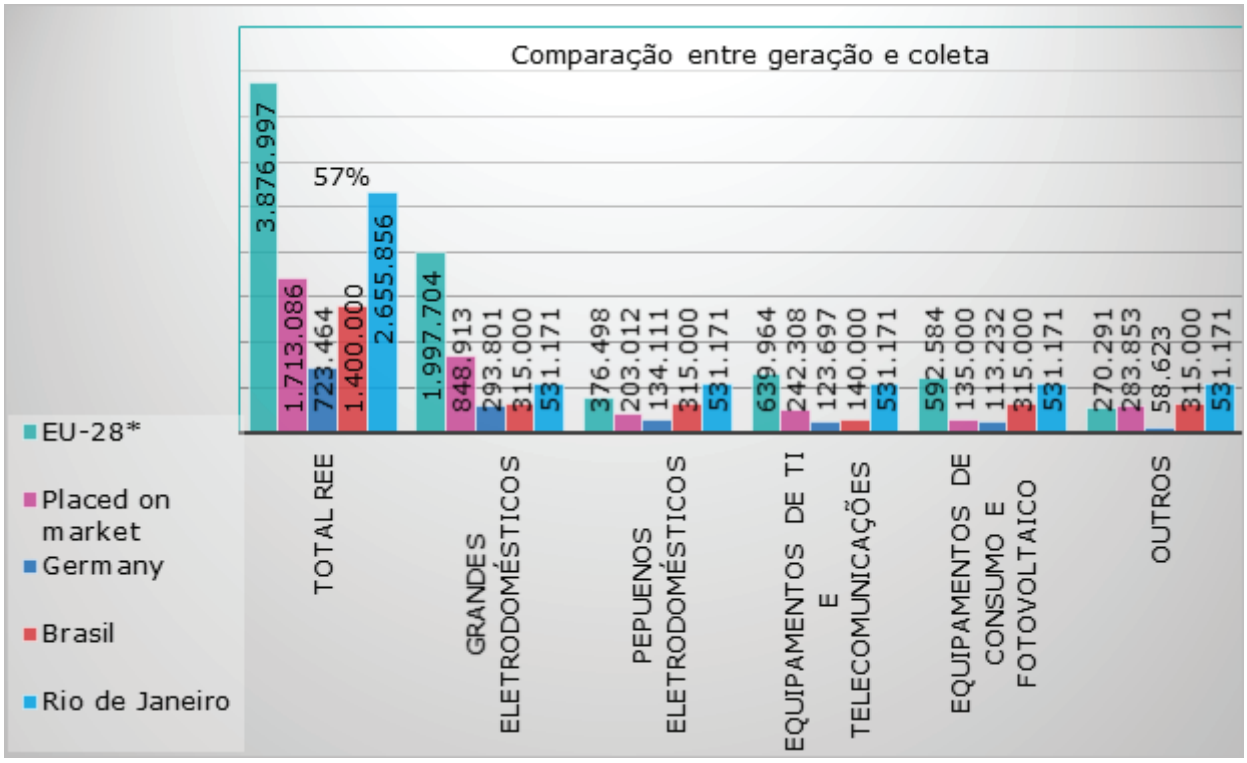

Figure 11. Generation of electrical and electronic equipment and waste collection (WEEE)
Source: Elaborated from European Commission, 2018

It is concluded that:

- The Government is responsible for licensing managers, for setting targets and updating legislation, and also for ensuring selective collection; the reuse and recycling targets are defined by legislation according to the type of product;
- The distributor acts as a point of receipt of WEEE for the consumer in exchange for new equipment;
- The manufacturer is responsible for the management of waste reception facilities, treatment facilities and waste recovery. They must operate individually through management, integrated recycling management systems and final disposal of WEEE, with consumer orientation.
- Each producer or manufacturer shall, when placing the product on the market, provide a financial guarantee to ensure that the costs of the management of WEEE from orphan products fall on the remaining company or producers;
- Manufacturers bear the cost of collecting, transporting, recycling and disposing of products placed on the market and also in case of replacing WEEE with a new product or fulfilling the same functions. Each manufacturer must give the proper destination for its products.

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