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MODELING OF THE GENERATION OF URBAN ELECTRONIC WASTE: CHARACTERIZATION OF THE HOUSEHOLD FLOW IN THE CITY OF CAMPOS-RJ

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Abstract

The management of Waste Electrical and Electronic Equipment (WEEE) has become a major concern for urban communities due to the large volumes of waste generated. In this context, this work seeks to gather information for the implementation of a Reverse Logistics system that is comprehensive and regular for WEEE in Campos - RJ and can be intended as a prototype to be adapted to the reality of other cities in the country. These information correspond to obtaining an estimate of the potential of generating WEEE (such as, cell phones, computers and tablets), characterizing the home flow and its peculiarities. Therefore, an estimation model was proposed based on the indicator of devices present with the users. The data needed for this work were collected through the application of a questionnaire to a sample, random and representative of citizens. It was noticed that the results found would support the decisions to be taken in the design of an efficient management system for WEEE. It is also worth mentioning that this research was carried out under the current considerations of sustainability according to what determines the Brazilian legislation on Solid Waste.

The results approximate the global estimates of the specific, researched electronic residues.

Keywords: Electronic Waste; Reverse Logistics; Modeling.

1. Introduction

The competitive environment in which companies find themselves fosters the search for technological innovation aimed at ensuring market survival and better profit rates. In this sense, the rapid technological development embedded in new products, precisely with a wish, sometimes induced by media, of consumers in acquiring newly launched products, is leading to the environmental problem: the generation of more waste and its inadequate disposal, because products are discarded prematurely even before they lose their functionality (POCHAMAMPALL, NUKALA AND GUPTA, 2009; VICTOR AND KUMAR, 2012).

This fact is more preponderant when we consider the sector of the electronics industry, which now clearly illustrates this production dynamics, consumption and generation of waste. This is mainly due to shortening the life cycle of products or Electronic Electrical Equipment - EEE, causing them to have planned or calculated obsolescence, aiming their quick replacement and, thus, turning the wheel of the consumer society (OLIVEIRA DA SILVA, 2012); adding up the fact that they have very low recycling rates (VICTOR AND KUMAR, 2012).

Waste Electrical and Electronic Equipment (WEEE) corresponds to EEE discarded by users and includes components, subsets and materials that are part of the product at the time of disposal (TSYDENOVA AND BENGTSSON, 2011; RODRIGUES, 2012). The increasing volume of generation of these wastes combined with their high-risk composition, due, in large part, to the heavy metals (such as mercury, cadmium and lead) required in their manufacture, until now, implicate to difficulties in their proper disposal and treatment.

As pointed out in the article by Cox et al. (2013), most of small electronics (such as cell phones, computers, etc.) are considered to have an expected life cycle of less than five years. In addition, these products are easily disposed before the end of their useful life, in order to remain in line with technological advances.

Due to the diversified composition, the management of the WEEE recycling chain becomes complex, for example, the collection and treatment activities of WEEE are costly and require good planning. Hence, it became important to formulate and implement specific legislation in order to equate the logistics required for recycling, which involves the environmentally safe collection, sorting, transportation and disposal of the same. For instance, it's used the extension of responsibility of producing and / or trading companies for the disposal of products manufactured and / or marketed.

Li et al. (2012) commented that developed countries have been leading the way in establishing formal systems for the treatment of WEEE since the early 1990s, starting with the European Union's granting of directives for the treatment of WEEE. In Brazil, Federal Law No. 12,305 / 2010 found the National Solid Waste Policy (PNRS, 2010), which set up principles, objectives and directions for the integrated management of solid waste in the country (Article 1), sharing responsibilities among manufacturers, consumers and public authority responsible for urban cleaning (Item XVII, Art. 3). Rodrigues (2016) highlights the existence of a fourth stakeholder, represented by companies (or collector cooperatives) that manage recyclable waste.

The PNRS (2010) also talks about the obligation of consumers to adequately make available their solid waste for collection and return, whenever there is a municipal selective collection system, consequently an established Reverse Logistics system (ABDI, 2013).

In the city of Campos, as in most Brazilian cities, there is still no Reverse Logistics system for WEEE, as it is already the case for agrochemical packaging, for example. The National Institute for the Processing of Empty Packaging (INPEV) is responsible for the management of the reverse logistics system for empty packaging of pesticides; created in compliance with Federal Law 9.974 / 2000 and Decree 4.074 / 2002 (INPEV, 2015). Likewise, in the same direction, there is a national program for collecting and disposing of waste tires, the Reciclanip Program, which activities comply the CONAMA Resolution 416 / 09, this program was created by tire manufacturers operating in Brazil. A management model for WEEE requires a diagnosis that regards the specific characteristics of the institutional and household information flows, equivalent to EEE production and disposal flows.

In particular, home flow has specific characteristics, such as diffuse generation given mainly by the EEE lifetime factor, in other words, predicting when and how the products will be disposed, in addition there are difficulties related to consumers' behavior and practice.

The lack of environmental concern of citizens and recycling channels in the city contributed to the inadequate disposal of EEE, demanding an urgent need to establish a WEEE management system that uses Reverse Logistics processes.

In this context, this work aims to characterize the generation of WEEE in the city of Campos dos Goytacazes, a medium-sized town located in the north of the state of Rio de Janeiro with a population estimated at more than 490 thousand inhabitants, distributed a total of 150 neighborhoods, being the 6th most populous city in the state, with an average density of 115 hab./km^2 (IBGE, 2018), and with a high concentration of Universities in the municipality. It has been selected for the research, an accurate estimated sample in order to provide subsidies for the implementation of a Reverse Logistics model for WEEE in the city, which could be intended as a prototype to be adapted to other realities of the country.

Having a more accurate prediction about the current and future generation of WEEE is important to quantify the waste potential and to estimate the toxic content generated by the disposal (ZENG et al., 2017). The results of this research are intended to provide a basis to optimize and support the policy planning for WEEE that looks for improvement the waste management systems, reinforcing the need for recycling industries and their supply chain. Moreover, it's for monitoring the federal, state and municipal legislative implementation.

2. Bibliographic Review

2.1 Reverse and Closed Cycle Supply Chain

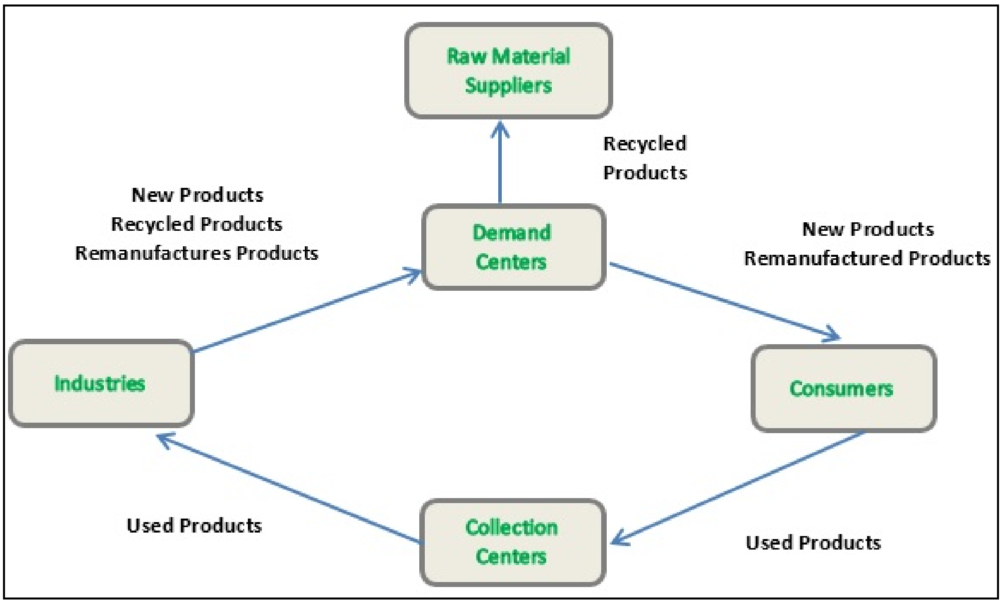
Environmental awareness has become an obligation for most companies within the traditional Supply Chain (CS) or direct CS (it means, the chain which includes all activities necessary for the production of new products from raw materials and their distribution to consumers) due the legislation and growth of the present environmental concern from users (SAVASKAN, BHATTACHARYA AND WASSENHOVE, 2004; LAMBERT AND GUPTA, 2005).

Sustainable Supply Chain Management has been developed by manufacturing companies not only as a response to external pressures, as previously reported, but also as a strategic business vision, with the objective of obtaining better environmental and commercial results, such as reduction in manufacturing costs of products from reprocessing materials and components (FIGUEIRÓ, 2010).

Reverse Logistics (LR) consists of a series of activities required to collect a product from the consumer. Leite (2009) presents two types of LR, the first called post-consumer LR that concerns itself with the reverse flow of discarded products at the end of its useful life. In the other hand, after-sales LR deals with products with little or no use, for example, for quality problems. The LR proposed by the PNRS is the post-consumption and applies to the discarded products after their use by the consumer.

For Pochamampall, Nukala and Gupta (2009), the reverse supply chain involves post-consumer LR operations in order to reprocess products both to recover their market value and to discard them appropriately. The combination of direct and reverse supply chains is called the Closed-Cycle Supply Chain (POCHAMAMPALL, NUKALA AND GUPTA, 2009), not considering the post-sale LR, as it is generically represented in Fig. 1.

Figure 1: Generic representation of a Closed Cycle Supply Chain or Network



Source: Adapted from Pochamampall, Nukala and Gupta (2009)

The Closed Cycle Supply Chain or Network has the application of most industries, including automotive, chemical, clothing, electronics, among others.

As it has been seen, the Closed Cycle Supply Chain or Network requires an expansion of direct supply chain management, emphasizing economic, ecological and social aspects in business practices, such as: social responsibility, green purchasing strategies, life cycle analysis of the product, substitution and reutilization of inputs, Reverse Logistics, correct disposal of waste, among others (SVENSSON, 2007).

2.2 Models for Estimation of Generation of WEEE

The inherent difficulties in obtaining data on WEEE and the possible ways of estimating its generation were themes of several studies found in the literature. The complexity of estimating more accurately generation of electronic waste is mainly due to the lack of information, caused by the market dynamics and socio-economic aspects. These difficulties are circumvented by the use of suitable mathematical models in order to increase the quality of the data and, consequently, to improve the estimation.

In the work of Wang et al. (2013), for example, it is stated that in the literature there are a series of evaluation methods used to quantify the generation of WEEE (WALK, 2004; YU et al., 2010; ARAÚJO et al. 2012; LAU et al., 2013). These methods were classified into four groups: Analysis related to the disposal of WEEE (it uses e-waste images obtained from collection channels, treatment facilities and disposal sites), time series analysis (projections using data from previous occurrences), and the input-output analysis (WALK, 2004; BEIGL et al., 2008; CHUNG, 2011).

The IOA is the most widely used method with multiple model variations, which are applied to estimate the generation of electronic waste in many regional and national studies (CHUNG et al., 2011; ARAÚJO et al., 2012; POLÁK AND DRÁPALOVÁ, 2012). Such method considers mathematical relations (model) among three variables: product sales information; size of stock, products in use and inoperative, in the environment where they remain and the period of useful life of the equipment.

In particular, the research by Araújo et al. (2012), considering the lack of infra-structure in Brazil to treat solid waste, proposes two models for the estimation of WEEE generation. The results showed the importance of the precise dimensioning of the life time variable of the equipment, which requires a complete knowledge of the consumer's behavior.

Variations of the IOA model are given below, which consider the following varia-bles: EEA sales, inventory and lifetime:

Time step model - In this model the change of stock within a period is equal to the difference between the total of the inputs and outputs. The method needs two types of data entry: sales in the evaluation year and record information for two consecutive years. The model is represented by (ARAÚJO ET AL., 2012, WANG et al., 2013):

$$W(n) = POM(n) - [S(n) - S(n-1)] \quad (1)$$

Where, W (n) is the generation of electronic waste in the evaluation of year *n*; POM (*n*) represents the quantity of sales of equipment in year *n*; S (*n*) and S (*n*-1) are the quantities of appliances in stock in year **n** and year **n**-1, respectively.

It is important to highlight that these models use officially released sales information, without consider the electronics which are sold in parallel markets (without fiscal control), which makes it difficult to implement an LR system for these materials.

Market Supply Model – in this model it is estimated the generation of e-waste by sales of products in all historical years with their respective obsolescence rate in the year of evaluation (OGUCHI et al, 2010; DWIVEDY AND MITTAL, 2010; WANG et al., 2013).

$$W(n) = \sum_{t=t_0}^{n} POM(t) \cdot L^{(p)}(t,n) \quad (2)$$

Where POM (*t*) represents the sales history of an equipment in year *t* and *t0* the initial year, in which the product was released on the market. L^{p} (*t, n*) represents the probabilistic obsolescence rate for the products batch sold in year *t*, evaluated in year *n* (out of use equipment in percentage for total sales in year **t**).

Filter Model (leaching) - This model calculates the generation of electronic waste as a fixed percentage of the total stock divided by the average of product lifetime (CHUNG et al., 2011; ARAÚJO et al., 2012). As proposed in Wang et al. (2013), we have:

$$W(n) = S(n)/L^{(av.)} \quad (3)$$

In which, W (*n*) is the generation of electronic waste in the evaluation of year *n*; S(*n*) is the quantity of products in stock in year **n**; $L^{(av.)}$ is the average lifespan that represents the most likely time of the product to become obsolete. It is assumed that this model can only be used for products with a relatively short lifespan (WALK, 2004).

In Rodrigues (2012) the generation estimate is made using a similar model that considers a proportion among the number of discarded equipment, the number of households in the studied city (São Paulo) and the size of the sample considered in the survey. The proposed model uses information on the amount of discarded EEE and it is equated as:

$$Q = \frac{q \times D}{395} \quad (4)$$

Where *Q* represents the units discarded in the city under study; *q* units discarded in the sample searched; *D* number of households in the city under study; and 395 domiciles that represented the sample size.

The common approach is to select a corresponding estimation method with available database. Consequently, the estimated result is potentially sensitive to data quality, especially in the case of an assumed or non-validated life distribution (JAIN AND SAREEN, 2006).

3. Method

In order to collect the data needed for this research, the country's size and the nature of scientific research were considered. Then it was chosen by a geographical cut, treating the case of Campos dos Goytacazes in the state of Rio de Janeiro. A city with a population estimated by the IBGE (2018) of 490 thousand inhabitants, with specific cultural characteristics, considered as a university campus in the north of the State, and which coexists with a large supply and demand of consumer goods.

The instrument developed for this study was based on a questionnaire established by the authors according to the research objective. In this questionnaire the following EEE were investigated: cell phones, computers (portable and personal) and tablets belonging to the Information Technology and Telecommunications Equipment category, specified in Directive 2012/19/EU.

This questionnaire was structured with questions that aim, primarily, to define the profile of the respondents, posteriorly, it has been asked about the amount of EEE in use and stored in their homes, in addition, the time of acquisition and brand of the manufacturer. It was also identified the reason for the purchase and it was requested them to opt among the disposal possibilities (for example, "disposing in the common trash").

In the case of residues, which there is no necessary information (DIAS et al., 2017) for decision making regarding the management of a reverse chain (defined in section 2.1), the act of knowing, describing or characterizing its generation needs additional information that precedes its destination phase. Furthermore what is currently generated, in terms of quantity and type of EEE, it is necessary to apprise accurately the future generation potential, because according to the literature, this type of waste goes through the storage phenomenon that concerns the pre- consumer's willingness to keep EEE's, even when judged obsolete, for many reasons, including the lack of viable alternatives for proper disposal (RODRIGUES, 2012).

Such phenomenon varies according to socioeconomic and cultural aspects that can be observed in the population studied here. As a consequence, in order to estimate the potential for the generation of electronic waste, the quantities of EEE in use and stored in the households were investigated.

The information on sales volume are not available for the city evaluated in this work, mainly in relation to products of the gray market or parallel market (unknown origin products and without knowledge of the used technology), which are representative when considered the sales in the electronics market.

Therefore, it’s proposed the model inspired on the Filtering model and on the proposed model by Rodrigues (2012), formulated as follows:

$$W(n) = \frac{S(n) \times P}{z} \tag{5}$$

In this relation W(*n*) represents the generation of electronic waste in year *n*; S(*n*) is the average quantity of stocked products (in use and/or stored) per inhabitant, in year *n*; and *P* represents the population of the city under study and *z* the size of the sample used.

To estimate the volume of WEEE, information on the average weight of the equipment were also collected, based on the work of Oguchi et al. (2010) and analysis of the product datasheet available on electronic selling websites, considering different brands and models.

4. Results

The results of this research were obtained through the application of the questionnaires from July to December, in 2016. 328 valid questionnaires were applied, which 14% represent those applied online.

From the data tabulation, it was possible to construct Table 1 that shows the characteristics of the respondents.

Table 1: General characteristics of respondents

Education		**Age**		**Gender**	
Don't read or write	0.6%	From 15 to 25 years old:	55.9%	Male:	42.8%
Basic Education	11.8%	From 26 to 35 years old:	24.8%	Famale:	57.2%
High School	37.6%	From 36 to 45 years old:	13.3%		
College	37.3%	From 46 to 55 years old:	5.4%		
Postgraduate	12.7%	Over 56 years old:	0.6%		

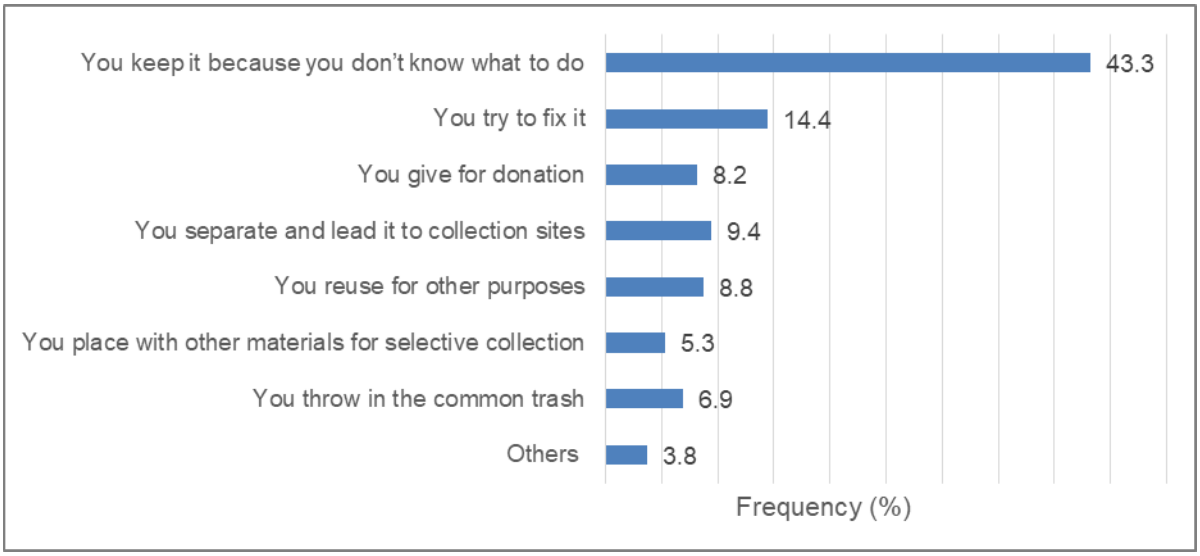
Source: The authors

As it can be observed, the majority of respondents are between 15 and 25 years old (55.9%) and it is verified that the level of schooling in High School and higher education (college and Postgraduate) are the most frequent, 37.6% and 37.3%, respectively.

When asked about the means of purchase of the investigated equipment (cell phone, computer and tablet), 53.5% of them have affirmed they had bought their equipment in a physical store, 24.4% bought through the internet and 22.1% bought both in physical store and through the Internet. These data collection were obtained considering the total number of respondents who answered this question (n=271). The above mentioned collection becomes relevant when it is wanted to know the volume of sales of these products, a variable that has a strong connection with the accuracy of an estimation model of WEEE generation.

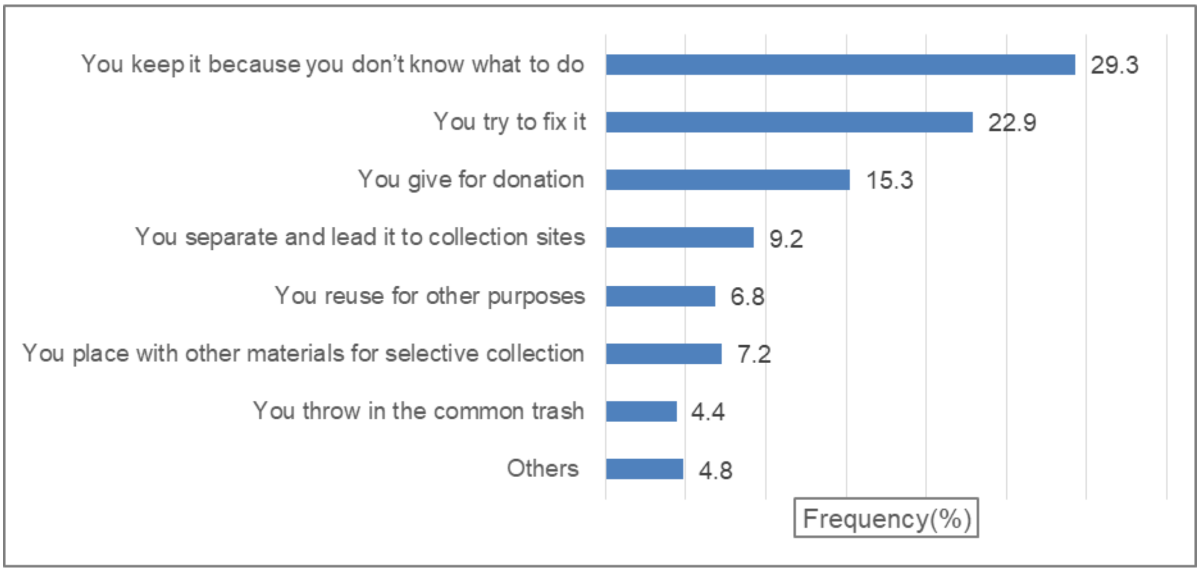
The option that the consumer ponders at the time when the EEE considered here is out of use has been investigated. The graphs below (Fig. 2, Fig. 3 and Fig. 4) present the results. Through them, we can identify the number *n* of validated responses to this questioning. In case of tablet the low number of answers can be justified because many respondents don't have this equipment and therefore didn't feel able to evaluate it.

Figure 2: Graph of options considered for cell phones out of use (n=319)



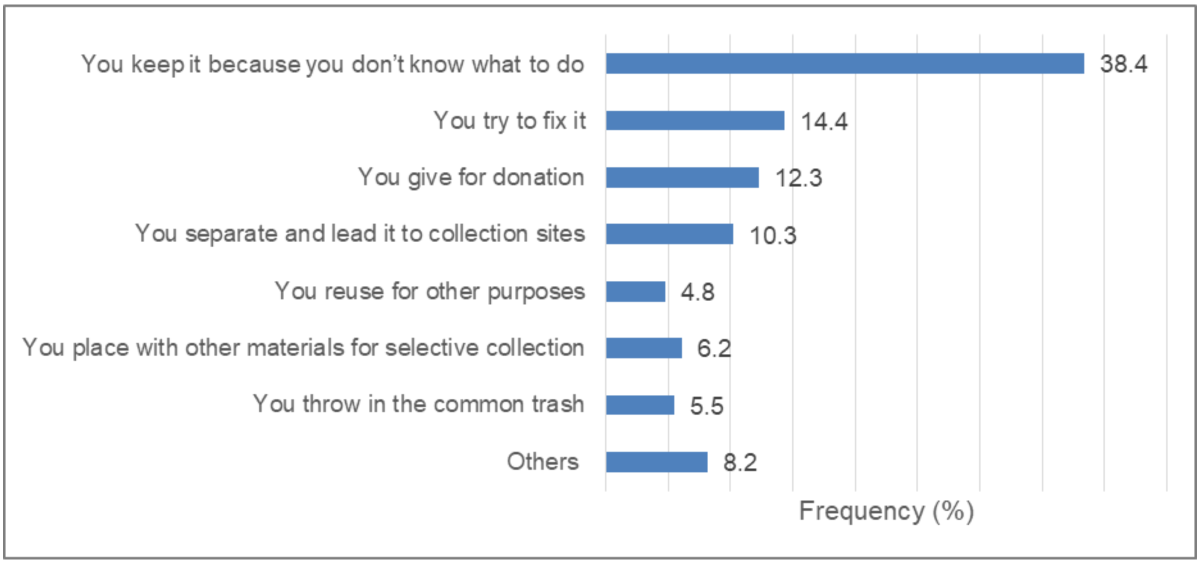
Source: The authors

Figure.3 - Graph of options considered for computers out of use (n=249)



Source: The authors

Figure 4: Graph of options considered for tablets out of use (n=146)



Source: The authors

As it can be observed, the most considered option by consumers for the three products is to store the equipment because they don't know what to do (43.3% for cell phones, 29.3% for computers, and 38.4% for tablets). This conclusion demonstrates the predisposition of consumers to keep such equipment stored for several and particular reasons, such as affection to the good that had a high acquisition cost. Thus, for an accurate estimation of the WEEE generation, the importance of the stock variable investigation, defined as the sum of the equipment in use and stored by the consumers, is reinforced.

Those interviewed, who have chosen "Other" option, most indicate that they intend to sell the EEE when they are out of use.

When questioned about the possibility of free collection or delivery in specific places, of those out of use equipment, 96.9% of the respondents intend to deliver their equipment, which reinforces Dias et al. (2017) about the positive intention of the Brazilian population for recycling, despite few practical actions in this sense.

Another important result is that only 17.4% of respondents have heard about e-waste collection in Campos-RJ.

4.1 WEEE Generation Estimating Model

In order to estimate the volume of WEEE that can be generated from equipment owned by consumers in 2016, the model proposed in this work was used. The following table presents these estimations. It was considered the city population *P*=487.186 inhabitants. The generation of WEEE given in kg/year was calculated by *estimated WEEE x Average Weight*.

Table 2: Estimation of WEEE generation, city of Campos-RJ

Equipment		Average amount/inh.	Estimated WEEE (unit/year)	Average weight (kg/unit)	Estimated WEEE (kg/year)	WEEE generation *per capita*(kg/inh.)
Cell phones		1.8	2,674	0.1	267	0.18
Computers	*Desktops*	0.5	743	15.0	11,145	7.50
	Laptop	0.9	1,337	2.6	3,476	2.34
	Netbook	0.1	149	1.3	193	0.13
Tablets		0.4	594	0.3	178	0.12
TOTAL			5,497		15,259	10.27

Source: The authors

As it can be observed, the total estimated WEEE is 5,497 in units/year with a total weight of 15,259kg annually. The WEEE generation per capita was estimated by the product *Average Quantity x Average Weight*, totaling 10.27kg/inhabitant.

In addition, it was also calculated the per capita average of the out of use equipment, it means, stored at consumers' houses, it was found that for cell phones the average was 0.6 cell/inhab.; 0.1 desktops/inh.; 0.2 laptops/inh.**;** 0,04 netbooks/inh.; and 0.08 tablets/inh.

The average amount of 0.1 netbooks per inhabitant can be explained by the ending of the production of this equipment, as pointed out by IHS Markit (2013) netbooks had a 72% reduction in their sales volume in 2013 and in that same year the manufacturers Asus© and Acer© have announced the ending of production of these items.

For cell phones, data from ANATEL (2017) indicate in the state of Rio de Janeiro a density of cell phones, per 100 inhabitants, of 129.43 or 1.29 cell phones/inhabitant. The data collected in this study show that or the city of Campos the average found is 1.8 cell/inhabitant.

5. Final considerations

This research aimed to gather relevant information about the home flow of WEEE, considering the consumer is an important link within the reverse chain. Consumer studies indicate that most of them are concerned about the correct disposal of EEE, but few know what to do with this material, either because of lack of information or because of the absence of appropriate disposal sites, as it happens city under study and a large portion of Brazilian cities.

As it has been pointed out, the consumers interviewed here tend to keep the EEE because they don't know what to do with them, when the equipments are out of use and 96.9% of those interviewed intend to deliver their equipment, reinforcing the necessity to have collection sites for WEEE that guarantees, including the flow of the received material, completing the activities of an efficient Reverse Logistics system.

Moreover, it was estimated a total volume of 15,259kg of WEEE (cell phones, computers and tablets) generated in the city of Campos - RJ in 2016. The results found in this research allow us to infer a WEEE generation of 10.27kg/inhabitant, for the equipment considered here. According to the UNU (2015), a generation of 8.3kg/inhabitant is expected in Brazil in 2018, this estimation has considered information on sales and distribution of life time and regarded other types of EEE, such as televisions, refrigerators, etc. Similarly, in Baldé et al. (2015) it was estimated that in Brazil in 2014, 7.0 kg/inhabitant of domestic electronic waste was generated. These and other estimates of WEEE generation can be used to provide information and important indicatives in the design of a reverse chain in the city**.**

There are difficulties related to the precise quantification of WEEE generation, due, as well to other factors, to the uncertainties associated with the variables of a model. In the case of this work, sales information are not available for the evaluated city. However, the results found with the proposed model demonstrate the possibility of making estimations even when there isn't total availability of information. There are, though, opportunities for future searches in order to seek new rounds for the proposed model (using data from other regions, for example), as well as its improvement with the inclusion of new variables and parameters.

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