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Artigos

Forecasting methods of generation of waste electrical and electronic equipment: a systematic review

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Abstract
In recent decades there have been a significant increase in the use of electronic equipment in homes, offices and industries. When these equipment are discarded after have been used they become Waste of Electric and Electronic Equipment (WEEE). To know how the forecasting of WEEE´s generation were made, it was necessary to carry out a systematic review. The search was done in 5 databases by using the key words "electronic waste" or "WEEE" or "e-waste" and "forecasting" and it was found 854 articles. After applying the inclusion and exclusion criteria 28 articles were reached. As a result, it is noted that the selected articles are concentrated in the USA and China and in a few newspapers. The most independent variable used was the dada about the commercialization of the equipment. The majority of the articles have as variable response the unit and weight. There was also strong use of statistical tools and forecasting methods, especially the regression and the MFA (Material Flow Analysis).

Keywords: Forecasting; Waste electric and electronic equipment; WEEE; Systematic review.

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1 Introduction

The equipment that rely on electric current or electromagnetic fields, which does not exceed the rated voltage of 1,000 V for alternating current and 1,500 V for direct current, is called electrical and electronic equipment (EEE), according to Directive 2012/19/EU of the European Parliament (EU, 2012). These devices are increasingly present in people's lives, regardless of age, education or social class. In Brazil, according to TELECO (2015), in 2013, 97.2% of homes had television sets, 92.5% had a telephone, and 48.9% had computers.

These devices can help in professional and domestic works, improve communication and enable access to information about the world, but they also become waste of electrical and electronic equipment (WEEE) at the end of their life cycle. This waste – if disposed incorrectly – may cause damage to human beings and the environment, as they have hazardous chemical elements in their compositions such as lead and cadmium. Disposal of EEE occurs mainly due to loss of functionality, emergence of new technologies, aesthetic issues, emotional value or repair infeasibility (Osibanjo, Nnorom, & Ogbonna, 2008; Franco, 2008).

The United Nations Environment Program (UNEP, 2015) estimates that 90% of WEEE is traded or discarded in landfills illegally. Although the countries that most manage with this type of waste are concentrated in Europe and North America, the most frequent destination for disposal of them are the poorer or less developed countries in Africa and Asia, such as Ghana, Nigeria and Pakistan. Ghana, according to Hoeltl, Brandtweinder and Müller (2017), imported a considerable EEE volume from Europe, Asia and the USA in 2009 and 15% of these equipments could not be reused. The underdeveloped countries suffer with illegal recycling deposits and unhealthy and poorly paid work.

In China, Habuer and Moriguchi (2014) have got as result of their research that between 4.8 and 5.1 billion units of household´s appliances (mainly computers and air conditioners) will be discarded in the next 20 year. The amount expected of the Latin America's WEEE is near to 4800 kilotonnes in 2018 (Magalini, Kuehr, & Baldé, 2015). In Brazil, Araújo, Magrini, Mahler and Bilitewski (2012) estimated the generation of 3.8 kg per person per year of WEEE from 7 types of equipment. There are more than 790 million kg of WEEE generated per year considering this rate in relation to the Brazilian population of approximately 209 million people (IBGE, 2018).

However, there is paucity of data on lifespan and disposal of electrical and electronic equipment in Brazil, essentials informations to make estimates of WEEE, according to Polák and Drápalová (2012). Some papers, such as the one by Franco and Lange (2011), adopt standards and terms of US agencies or present empirical estimate of a given region. B.M.M. Aguiar, Melo, A.V.M. Aguiar, Silva and Maracajá (2010) present the estimate of Mossoró/RN where 10% of collected household waste is consumer electronics, with no description of how this value was reached. Similarly, an estimate of the number of mobile phones to be disposed in two or three years, considering data on sales at stores in the city of Carazinho/RS in a given period, was presented in a paper by Padilha, Quadros, Mattos and Rodrigues (2009).

There is not a consensus about forecasting method to estimate of WEEE generation. With reliable information about quantities, types and location of WEEE, it is possible to plan actions for their treatment and correct destination. Thus, the research question is: "How were the forecasts of generation of waste electrical and electronic equipment performed?" The purpose of this article is to know the methods that were used to perform forecasts in relation to generation of waste electrical and electronic equipment, as well as to identify models, variables and tools that were used to do this.

2 Waste Electrical and Electronic Equipment (WEEE)

Electronic equipment in Brazil is classified as per ABDI (2015) in four lines: (i) White Line – large equipment, such as refrigerators, freezers, washing machines and electric stoves; (ii) Brown Line – equipment such as stereos, television sets, DVD players and telephones; (iii) Blue Line – portable medium and small equipment: vacuum cleaners, hair dryers, coffee makers, blenders; and (iv) Green Line – information technology equipment: computers, peripherals and the like.

During the manufacturing process of EEE energy, water and various chemicals are used. According to Oliveira, Chiesi and Barbieri (2012), the most commonly materials or chemical elements found are epoxy resin, fiberglass, PCB (polychlorinated biphenyls), PVC (polyvinyl chloride), lead, tin, copper, silicon, beryllium, carbon, iron and aluminium. Others are found in much lower amounts, such as gold, silver, titanium, arsenic, boron, cobalt, indium, lithium, manganese, selenium and platinum. Hagelüken and Corti (2010) affirm that the concentration of gold in mobile phones is between 300 and 350 gram/ton, and this justify recycling and recovery processes of raw material to production.

Some of these elements are heavy metals, which are bioaccumulative, i.e., if ingested, the body cannot eliminate them. Risks to humans who handle, transport or store waste with heavy metals range from skin diseases to problems in the nervous system and cancer, according to J.M.B. Ferreira and A.C. Ferreira (2008). Regarding the environment, such waste can contaminate soil, water and air with heavy metals and toxic fume. In addition, this waste represents a misuse of non-renewable natural resources, because if this waste was recycled, there would be no need for extraction of some metals, saving the natural resources and energy that would be required for extraction (Oliveira et al., 2012).

For these reasons, the European Parliament created the RoHS directive (Restriction of the Use of certain Hazardous Substances in Electrical and Electronic Equipment), which aims at eliminating and/or reducing chemicals as lead, cadmium, mercury, chromium and flame retardants (PBB – polybrominated biphenyls – and PBDE – polybrominated diphenyl ethers). These restrictions are mandatory for commercialization and production of equipment in the European Union, and certificates that prove compliance to the RoHS are required and such action has an impact on the design and production of equipment in several countries, including Brazil (EU, 2011).

It is necessary to change the materials and the methods of EEE´s production to meet the requirements of the RoHS directive, creating new forms of production that reduce the energy consumed during the process, minimizing packaging, maximizing the lifespan of products, and using materials that are renewable, recyclable and less harmful to the environment. For this purpose, Wang and Gupta (2001) present "green" materials that can be used in the EEE´s manufacture, listing their advantages, disadvantages and impact on the environment. For example, metals such as aluminium and titanium are strong and durable, can be manufactured and recycled and there are already mature infrastructure for recovery of these materials; however, they are prone to corrosion and have low resistance to weight, features that hinder their use in some applications.

Disposal of electrical and electronic equipment is due to obsolescence. According to Osibanjo et al. (2008), this obsolescence can be: (i) due to technical reasons, when the product no longer has the desired functionality; (ii) due to the introduction of new technologies, offering new features and facilities to users; (iii) due to aesthetic reasons, providing more modern and attractive design; (iv) due to psychological reasons related to the emotional product value. Franco (2008) and Leite (2009) add the financial impossibility of repair to the reasons for obsolescence, either for lacking of spare parts on the market or for the comparison between repair costs and the price of new products. In Brazil, the subjective obsolescence is the main motivation to replace EEE and the Brazilian´s consumers seem no condemn the programed obsolescence of these equipment (Echegaray, 2016).

Brazil established the National Policy on Solid Waste (PNRS) through Law no. 12,305 on August 2, 2010. The PNRS´s article 33 establishes the manufacturers, importers, distributors and retailers have obligation to provide reverse logistics to electrical and electronic products and their components (Brasil, 2010). Reverse logistics is a system (actions, procedures and means) that aims at facilitating the return of goods or their constituent materials to the production cycle for reuse or proper disposal (Brasil, 2010; Leite, 2009). Gutiérrez, Adenso-Diaz, Lozano and Gonzalez-Torre (2010) emphasize that the most important goals of reverse logistics depend, in practice, on the disposal habits of consumers.

In Brazil, the Electric and Electronic Equipment Sector Agreement is being coordinated by the Environment Ministry which has set up a working group to draft proposals for the implementation of reverse logistics in 2011 and submitted a technical feasibility study in 2012. In 2013 proposals were received for agreement. Since then, the public consultation and subsequent signing of the sectorial agreement are in standby (SINIR, 2017).

Dias, Machado, Huda and Bernardes (2018) affirm the most of Brazilian´s WEEE recycling companies does only sort and dismantling parts and exports complex and value components to be processed in others countries. Furthermore, the authors present that federal and local governments do not have effective control about this companies and its operation licenses.

3 Forecasting

Making a forecast is to predict future events, according to Abraham and Ledolter (2013). Organizations, for example, use forecasts to identify possible problems and/or demands, scale their production, develop action plans and make decisions in all relevant areas based on such information (Krajewski, Ritzman, & Malhotra, 2009).

Historically, in the late 1930s, some demand forecasting methods were already known, such as the method of least squares, moving averages, the decomposition of time series and regression (Makridakis, 1986). After the 2nd World War there were great theoretical and practical advances in forecasting in several areas such as the development of econometric models, ARIMA models used by statisticians to model time series, techniques of decomposition of macroeconomic components of time series used by governments, noise filter methods used by engineers, and the exponential smoothing method used by company researchers to predict demand and production. In the 1970s, with the help of computers, forecasting became popular.

Forecasting methods can be qualitative, quantitative or a combination thereof (Armstrong, 2001). Qualitative models are based on human judgment and are subjective, however can be useful when there are no adequate historical data or at the launch of new products. Peinado and Graeml (2007) affirm that these methods generally rely on professionals with expertise in the study area and need to be well structured to do not privilege the information from talkative people or holding higher-ranked positions people. The Delphi method and focus groups are examples of qualitative methods.

Quantitative methods involve mathematical models and data. They can be classified as causal models or time series (Morettin & Toloi, 2004). The advantage of these methods is the possibility of error estimation, providing information for selection of the best methods for each situation. However it is necessary to be aware of the data behaviour in the past, which may not be applicable in some cases. Examples of quantitative methods include: exponential smoothing models, linear regression and autoregressive models of moving averages. The model´s choice should consider the data behaviour under analysis and characteristics such as seasonality, trend and randomness.

The combination of qualitative and quantitative methods is an alternative to generate forecasts more accurately, as per Costantini and Pappalardo (2010). This gain in accuracy, according to Armstrong (2001), occurs because the combination of forecasts incorporate various features collected from different individual's forecasts. There is an interest from researchers studying demand forecast in applying mathematical models allied to human judgment. Apparently, the most important reason is to incorporate more knowledge regarding the forecast environment into the forecast itself.

The methods based on demand forecasting are used to know the quantities of WEEE´s generation. Potdar and Rogers (2012) affirm that the important aspect to reverse logistics is to use robust forecasting methods for obtaining reliable estimates of WEEE´s generation amount. Araújo et al (2012) developed a mathematic model to preview the quantities of e-waste for seven equipment in Brazil. Habuer and Moriguchi (2014) applied time-series to estimate the amount of generation of equipment´s end-of-life in China. Temur, Balcilar and Bolat (2014) design robust forecast of returning quantity e-waste of all electrical and electronic equipment using Fuzzi expert system. Nguyen, Yamasue, Okumura and Ishihara (2009) estimated the e-waste´s quantities using a model that combines a mathematic model and a population survey in Vietnam.

4 Material and methods

This article is a systematic review. According to Moher, Liberati, Tetzlaff and Altman (2009), a systematic review has a clearly defined research question and uses a systematic method to identify, select and critically evaluate the studies included in such review. This article adopts the recommendations of PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses).

The purpose of this systematic review is to know methods that were used to perform forecasts related to waste electrical and electronic equipment. More specifically, this review seeks to verify the variables considered, the tools used and the assumptions and restrictions of each method. Thus, the research question used in this systematic review was: "How were the forecasts of generation of waste electrical and electronic equipment performed?"

In order to answer this question, keywords related to "forecasting" and "waste electrical and electronic equipment" as well as its synonyms were chosen. The following logic was used to search in the databases: {[("electronic waste") OR WEEE OR ("e-waste")] AND "forecasting"}.

The selected databases include journals of engineering, statistics or environment. The keywords were searched in five databases: Science Direct, ProQuest, Scopus, Emerald and ISI Web of Science. The language adopted was English, and the chosen articles had to be published in scientific journals. As an example, Figure 1 displays the search strategy in the Science Direct database using the search logic and limiting the search to articles.

Figure 1 – Search strategy in the Science Direct database

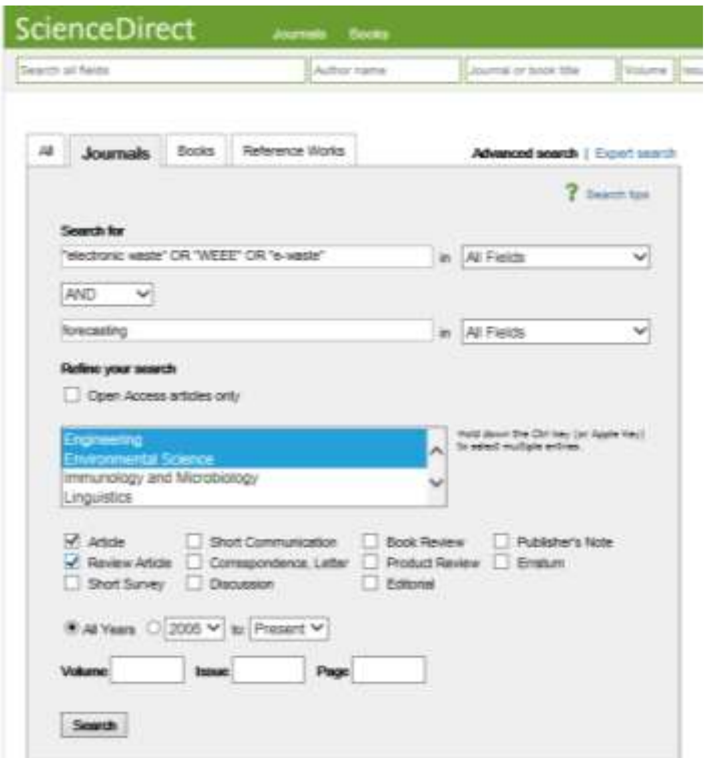
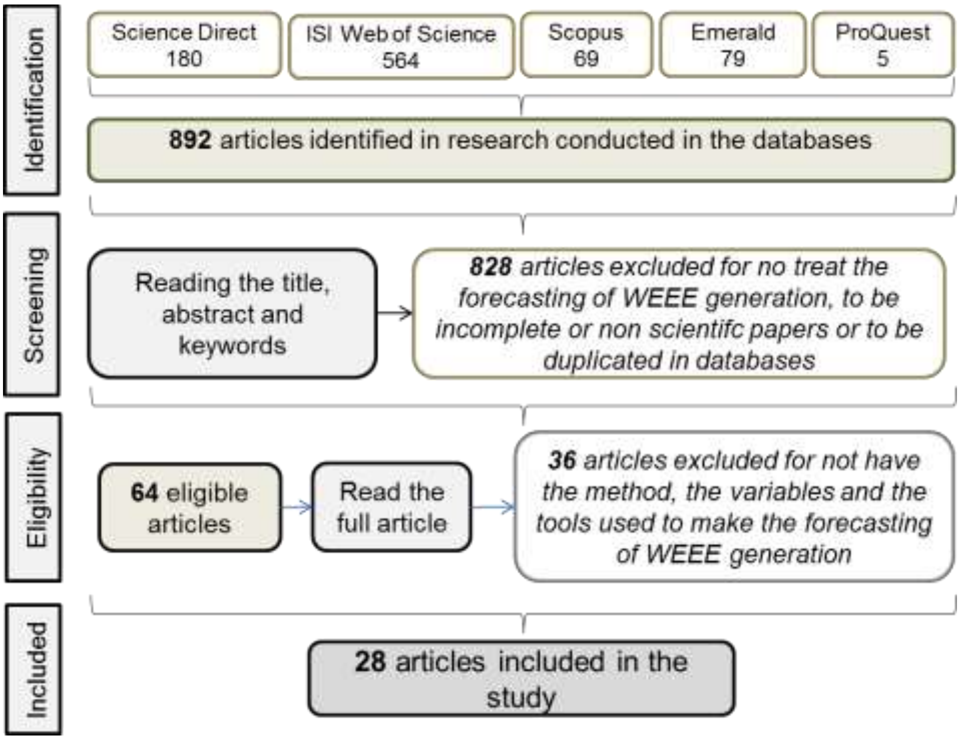


Figure 2 shows the flow of systematic review information, based on the model proposed by Moher et al. (2009), which features four phases: identification, screening, eligibility and inclusion. In searches conducted between June and August 2012 in the databases, and updated in February 2015, were found 892 articles.

At the screening stage, were evaluated titles, keywords and summaries of the articles found. The articles that would be analysed in next step had to be the complete text of scientific articles.

At this stage, papers presented in conferences, theses and dissertations, abstracts, and non-scientific publications were excluded because the complete text was not available. Also, the articles from the Scopus database, published in the Journal of the Air and Waste Management Association that did not deal with forecasts of WEEE´s generation were discarded, such as Environmental issues and management strategies for waste electronic and electrical equipment (Hidy, Alcorn, Clarke, Smith, & Thomas, 2011). Additionally, it was checked whether the paper was available in more than one database and was considered only once in the final list. After the screening stage, 64 articles remained.

Figure 2 – Flow of information of the systematic review



Next step was to read each one of the 64 articles to identify the ones that really had a detailed description of forecasting method of WEEE´s generation and not only third-party of the results. For this reason, at this stage articles such as Forecasting product returns in closed-loop supply chains (Krapp, Nebel, & Sahamie, 2013), the ones from the Emerald database were excluded. After this analysis, 28 articles remained.

The following details were collected from the 28 articles selected for further analysis: information about the author, country where the research was conducted, journal in which the article was published, methods, tools used, variables considered in the research, and other data which were considered relevant. Tables and graphs were prepared with this information in order to enable the analysis.

5 Results

The articles that were selected after the application of this systematic review method are show in the Figure 3.

Figure 3 – Selected articles

Authors	Title	Year
Agrawal S.; Singh, R. K.; Murtaza, Q.	Forecasting product returns for recycling in Indian electronics industry	2014
Araújo, M.G.; Magrini, A.; Mahler, C.F.; Bilitewski, B.	A model for estimation of potential generation of waste electrical and electronic equipment in Brazil	2012
Babbitt, C.W.; Kahhat, R.; Williams, E.; Babbitt,G.A.	Evolution of Product Lifespan and Implications for Environmental Assessment and Management: A Case Study of Personal Computers in Higher Education	2009
Dwivedy M.; Mittal R. K.	Estimation of future outflows of e-waste in India	2010
Dwivedy, M., Mittal, R.K.	Future trends in computer waste generation in India	2010
Feszty, K.; Murchison, C.; Baird, J.; Jamnejad, G.	Assessment of the quantities of Waste Electrical and Electronic Equipment (WEEE) in Scotland	2003
Gutierrez, E.; Adenso-Diaz, B.; Lozano, S.; Gonzalez-Torre, P.	A competing risks approach for time estimation of household WEEE disposal	2010
Habuer; Nakatani J.; Moriguchi Y.	Time-series product and substance flow analyses of end-of-life electrical and electronic equipment in China	2014
Kang H.Y.;. Schoenung J.M.	Estimation of future outflows and infrastructure needed to recycle personal computer systems in California	2006
Lee, J.C.; Song, H.T.; Yoo, J.M.	Present status of the recycling of waste electrical and electronic equipment in Korea	2007
Leigh, N.G.; Realff, M.J.; Ai N.; French, S. P.; Ross, C. R.;Bras, B.	Modeling obsolete computer stock under regional data constraints: An Atlanta case study	2007
Li, J., Tian, B., Liu, T., Liu, H., Wen, X., Honda, S.	Status quo of e-waste management in mainland China	2006
Linton, J.D., Yeomans, J.S., Yoogalingam, R.	Enabling industrial ecology through the forecasting of durable goods disposal: Televisions as an exemplar case study	2004
Liu, X. B.; Tanaka, M.; Matsui, Y.	Generation amount prediction and material flow analysis of electronic waste: a case study in Beijing, China	2006
Nguyen, D.Q.; Yamasue, E.; Okumura, H.; Ishihara, K.N.	Use and disposal of large home electronic appliances in Vietnam	2009
Ongondo, F.O.; Williams, I.D.; Keynes, S.	Estimating the impact of the "digital switchover" on disposal of WEEE at household waste recycling centres in England	2011
Osibanjo, O.; Nnorom, I.C.; Ogbonna, K.C.	Modelling waste generation by the telecom sector in Nigeria: the grey side of the impressive outing	2008
Polák, M.; Drápalová, L	Estimation of end of life mobile phones generation: The case study of the Czech Republic	2012
Potdar, A.; Rogers J.	Reason-code based model to forecast product returns	2012
Rahmania, M.; Nabizadehb, R.; Yaghmaeiana, K.; Mahvia, A. H.; Yunesianb, M.	Estimation of waste from computers and mobile phones in Iran	2014

Saphores J.D.M.; Nixon H.; Ogunseitan, O.A.; Shapiro, A.A.	How much e-waste is there in US basements and attics? Results from a national survey	2009
Schumacher, K.A.; Schumacher T.; Agbemabiese, L.	Quantification and probabilistic modeling of CRT obsolescence for the State of Delaware	2014
Temur, G. I. T.; Balcilar, M.; Bolat B.	A fuzzy expert system design for forecasting return quantity in reverse logistics network	2014
Walk, W.	Forecasting quantities of disused household CRT appliances - A regional case study approach and its application to Baden-Württemberg	2009
Yang, Yan; Williams, Eric	Logistic model-based forecast of sales and generation of obsolete computers in the USA	2009
Yu, J., Williams, E., Ju, M.	Analysis of material and energy consumption of mobile phones in China	2010
Yu, J.L.; Williams, E.; Ju, M.T.; Yang, Y.	Forecasting Global Generation of Obsolete Personal Computers	2010
Zhang, L., Yuan, Z., Bi, J.	Predicting future quantities of obsolete household appliances in Nanjing by a stock-based model	2011

After the stage of selection of articles that included methods and models to carry out forecast of WEEE´s generation, the data were organized and analyzed. Figure 4 shows that the subject is still incipient and the number of papers is very diverse over the years.

Figure 4 – Year of publication of the selected articles

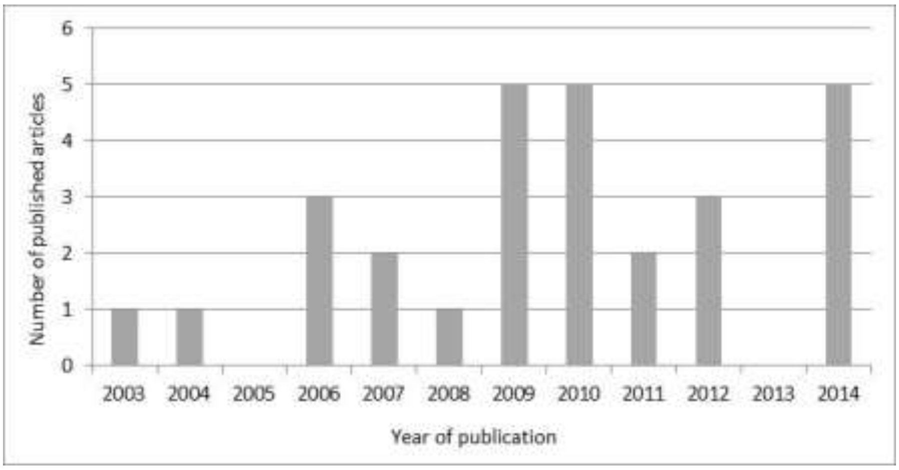


Table 1 presents the number of articles by country and continent, showing the higher concentration of studies in Asia and America, although Europe has pioneering legislation for the treatment of electrical and electronic waste. Turkey was considered a European country, even though most of its territory is in Asia.

Table 1 – Data on where the papers were written

Continent	Country	Number of articles	Total	%
Europe	Germany	1	6	21%
	Scotland	1		
	Spain	1		
	England	1		
	Czech Republic	1		
	Turkey	1		
Americas	Brazil	1	10	36%
	Canada	1		
	United States	8		
Asia	China	5	11	39%
	South Korea	1		
	India	3		
	Iran	1		
	Vietnam	1		
Africa	Nigeria	1	1	4%

The journal in which nine of the 28 selected articles were found was Waste Management. Table 2 shows the concentration of selected articles in a few journals, with 57% of the selected papers published in three journals.

Table 2 – Journals in which the selected articles were published

Journal	Number of articles	% of selected articles
Waste Management	9	32.1
Resources, Conservation and Recycling	4	14.3
Waste Management & Research	3	10.7
Journal of Material Cycles and Waste Management	2	7.1
Environmental Science & Technology	2	7.1
Journal of Hazardous Materials	1	3.6
Journal of Environmental Management	1	3.6
Energy Policy	1	3.6
Canadian Journal of Administrative Sciences	1	3.6
Technological Forecasting and Social Change	1	3.6
Journal of Enterprise Information Management	1	3.6
Journal of Advances in Management Research	1	3.6
Foresight	1	3.6

The waste generated by computers that is theme in most of the papers assessed, according to this EEE was detected in residences, academic environment and companies. Television sets were also object of more than half of the articles evaluated, and some articles focused on this device due to the change from analogy to digital transmission systems that happened in some countries. Table 3 shows the number of articles for each type of equipment to which some kind of forecasting of WEEE generation was performed. Note that some articles performed forecast in relation to more than one device.

Table 3 – Number of articles that contain forecasts for each EEE type

Electrical / Electronic Equipment	Number of articles	% of articles
Computer	18	64.3%
Television set	15	53.6%
Refrigerator	10	35.7%
Washing machine	9	32.1%
Air conditioning unit	8	28.6%
Mobile phone	8	28.6%
Freezer, microwave oven and clothes iron	2	7.1%
Printer, camera, fax machine, video camera	3	10.7%
Generic	2	7.1%

In eight articles the survey method was used for data collection. The idea was to obtain information about the consumer such as what equipment they had in their homes and how long they had been using these devices. Therewith it was possible to estimate the equipment´s lifespan and also know what it is done with it after its obsolescence. Most of the articles used data from secondary sources, such as research institutes, manufacturers associations, government agencies and information included in research from other authors.

Concerning the explanatory variables used, it is possible to separate them into groups according to their similarities. The most commonly used variables were those relating to EEE commercial data, which include information about sales, production, export and import. These variables were used in 20 of the 28 articles. Data on disposal of equipment after use, such as the percentage sent to recycling or the percentage stored at home, were used in 16 articles, as well as the life cycle average of such equipment. Table 4 details these information.

Table 4 – Number of articles for each type of independent variable for the forecast of WEEE generation

Type of data / variables used	Number of articles	% of articles
Data of the equipment commercialization (production, sale, import, export, growth rates)	20	71.4%
Action applied after use (disposal, reuse, donation, recycling, sale)	16	57.1%
Average equipment life cycle / probability or time of use	16	57.1%
Equipment´s data (quantity, type, weight)	11	39.3%
Data of the consumer (age, education, financial situation...)	8	28.6%
Others	4	14.3%

The Unit, which represents the amount of equipment no longer used and that have become waste, was the dependent variable (response) used in 18 of the 28 articles analyzed. In addition, some papers used derived units, such as Units per capita or units/year. The dependent variable Weight and its variances are important data to size these EEE´s disassembly, storage and transportation to a reverse logistics system. Table 5 presents information on the response variables grouped according to similarity. Note that some articles presented results with more than one response variable and the "Time" refers to how much time the device takes to become obsolete or be disposed.

Table 5 –Number of articles for each type of Response variable for the forecast of WEEE generation

Response variable	Number of articles	% of articles
Units; Units per capita; Units/year	20	71.4%
Weight; Weight per capita; Weight/year	10	35.7%
Time	4	14.3%
% return; % recycled	3	10.7%
Cost ($) / year	1	3.6%

The relationship between the independent and response variables used to forecasting the WEEE generation is shown in Table 6. It can be noted that half of the articles analysed (14 of 28) used equipment commercialization data as independent variables and the unit as variable response. Several articles used more than one type of independent variable to perform the forecasting, as well as many articles presented the results using more than one response variable. Its justifies the sum of some rows and columns of table 6 being greater than the total number of articles analyzed in this work.

Table 6 – Number of articles for the relation between independent variable and response variable for the forecast of WEEE generation

	Response variable				
Type of data / variables used	Units; Units per capita; Units/year	Weight; Weight per capita; Weight/year	Time	% return; % recycled	Cost ($) / year
Data of the equipment commercialization	14	6	2	2	0
Action applied after use	11	6	3	2	1
Average life cycle / probability or time of use	9	5	2	1	1
Data of the equipment	7	4	2	1	0
Data of the consumer	6	2	1	0	0
Others	2	2	0	0	1

Regarding the methods and tools used to performing the forecast of electrical and electronic waste generation, it is possible to see that in eight of the 28 articles the method used was Regression – simple or logistic. The Material Flow Analysis (MFA) method, which consists in describing, investigating and evaluating the changes that occurred in systems according to Brunner and Rechberger (2005), was used in six articles. These two methods were used in 14 articles, representing 50% of the selected articles. The simulation was used in six articles as a primary or secondary method. One article (Linton, Yeomans, & Yoogalingam, 2004) cited Monte Carlo simulation. Others articles mentioned that some scenarios were simulated, like as Ongondo, Williams and Keynes (2011) and Dwivedy and Mittal (2010a).

It is also noted that two articles presented specific formulas for forecasting calculation, relating commercial data of EEE, life cycle and information on consumers: Araujo et al. (2012) and Feszty, Murchison, Baird and Jamnejad (2003). Other articles used descriptive statistical tools to performing the forecast or other techniques such as Return Reason Code and Fuzzy Logic, for example , Potgar and Rogers (2012) and Temur et al. (2014), respectively.

Regarding the probabilities of distribution, seven articles mentioned some probability model for waste disposal, with the Weibull distribution model being highlighted, as it was used in four articles, for example, Polák and Drápalová (2012). Sensitivity analysis was performed in six articles. Table 7 shows the number of articles by methods or tools used to forecast of WEEE generation. The total of articles are more than 28 because many articles use two or more methods or tools.

Table 7 – Method or tools used to forecasting of WEEE generation

Method or tools	Number of articles
Regression – simple or logistic	8
Probabilities distribution model	7
Material Flow Analysis (MFA)	6
Simulation	6
Sensitivity analysis	6
Specific formulas	2
Descriptive statistical tools	2
Market Supply Method	2
Others models (Fuzzy Logic, Return Reason Code, Gompertz, Leight and Realff´s, Fischer-Pry, GERT)	6

Most articles did not mention whether any software was used, but Matlab was referred to in two articles, whereas Visual Basic (Excel), SPSS, Excel and Stata 9.1 were mentioned in one article each.

6 Discussion

The study of forecasting of the WEEE´s generation is an incipient subject, but still with few studies realized. The area has been attracting more interest from researchers, especially from the USA and China, which have had almost half of all the selected articles (13 of 28). It shows that these countries conduct researches and have intense activity in this area.

Regarding variables, many papers chose to seek historical sale´s data and the amount of existing equipment in homes as well as time estimates of using and reusing included in documents of research institutions or government agencies. Dwivedy and Mittal (2010a) affirm that the estimates are strongly affected by sale´s data and by the first user´s decisions about the end of the equipment lifespan. However, Leigh, Realff, French, Ross and Bras (2007) consider important to know the information about the product lifespan, discard rate, WEEE´s volume and its geographical distribution, but they affirm these data are not usually collected systematically.

By carrying out surveys it is possible to learn about the consumer's behaviours in the region under analysis regarding electrical and electronic waste and to try to find out the way and how long it takes for a device to be discarded or recycled. However, large-scale surveys are expensive and time-consuming (Leigh et al, 2007). Data such as the life cycle of the equipment may vary depending on the country or region, as they are subjective in nature, according to Dwivedy and Mittal (2010b).

Regarding methods, it is possible to see that Regression, MFA and scenario simulation can be a way of performing significant estimates of the WEEE´s generation. Statistical tools are essential and should be used, as should be statistical software for forecasts and simulation. Potdar and Rogers (2012) reinforce the need for robust methods to make accurate forecasts. It seems recommendable to use combinations of types of forecastings to estimate the e-waste generation.

There seem to be differences in people's behaviour in relation to large devices such as refrigerators, washing machines and television sets. It is feasible to think of different models for each type of equipment, similarly to what was carried out by Araújo et al. (2012) and Gutiérrez et al (2010).

7 Conclusions

It is difficult to estimate when Electrical and Electronic Equipments will be effectively discarded, because they can be sold to a second user or simply stored at home as backup equipment, for example. By observing the information gathered in the selected articles, it is possible to note that there are no consensus about the variables, methods and tools to be used to determine the amount of e-waste generation. There are only predominance.

If you intend to develop a model of forecasting of WEEE´s generation based on the selected articles, it is important to emphasize some results. It seems correct to use equipment´s data about commercialization and average EEE´s lifespan as independent variables. Still, it seems interesting to investigate the behavior of the consumer about the action applied after using these equipment in a research about geographical areas. Brazilian consumers are different from the European or Asiatic consumers because of their culture and purchasing power, among other factors. According to Rodrigues, Gunther and Boscov (2015) knowledge of the WEEE´s generation and disposal profile is fundamental to an effective reverse logistics system and it is influenced by technological development, government policies and consumer's behavior. It seems practicable to use as response variable to the number of devices that became WEEE at some time and location.

An idea for future research is to create specific models for each product line, considering data on Brazilian consumers and allowing adaptations according to the type of equipment and the region of the country under study. It is interesting to evaluate the use of regression method, MFA and simulation to do this forecasting.

Another interesting point is to analyse how companies will comply with the new National Policy on Solid Waste of Brazil, which was approved in 2010 and requires reverse logistics of electrical and electronic equipment. The sectorial agreement is in standby but it is expected to be finalized in next years (SINIR, 2017). To implement reverse logistics is important to forecast the amount of equipment to be discarded and when and where it will be done, so that it is possible to determine the necessary infrastructure for this system, as highlighted by Kang and Schoenung (2006).

References

ABDI. Agência Brasileira de Desenvolvimento Industrial (2015). Logística reversa de equipamentos eletroeletrônicos - Análise de viabilidade técnica e econômica. Retrieved May 28, 2015 from http://www.mdic.gov.br/arquivos/dwnl_1362058667.pdf

Abraham, B., & Ledolter, J. (2013). Statistical methods for forecasting. New Jersey: Wiley.

Agrawal, S., Singh, R. K., & Murtaza, Q. (2014). Forecasting product returns for recycling in Indian electronics industry. Journal of Advances in Management Research, 11(1), 102 – 114.

Aguiar, B.M.M., Melo, K.K.P., Aguiar, A.V.M., Silva, R.M., & Maracajá, P.B. (2010). Resíduos eletrônicos no município de Mossoró-RN. Revista Brasileira de Gestão Ambiental, 4(1), 74-78.

Araújo, M.G., Magrini, A., Mahler, C.F., & Bilitewski, B. (2012). A model for estimation of potential generation of waste electrical and electronic equipment in Brazil. Waste Management, 32 (2), 335–342.

Armstrong, J. S. (2001). Principles of forecasting: A handbook for researchers and practitioners. Norwel: Kluwer Academic Publishers.

Babbitt, C.W., Kahhat, R., Williams, E., & Babbitt, G.A. (2009). Evolution of product lifespan and implications for environmental assessment and management: A case study of personal computers in higher education. Environmental Science & Technology, 43(13), 5106–5112.

Brasil, 2010. Lei nº 12.305 - Política Nacional de Resíduos Sólidos. Retrieved from http://www.planalto.gov.br/ccivil_03/_ato2007-2010/2010/lei/l12305.htm

Brunner, P.H., & Rechberger, H. (2005). Practical handbook of material flow analysis. New York: Taylor & Francis.

Costantini, C., & Pappalardo, C. (2010). A hierarchical procedure for combination of forecasts. International journal of forecasting, 26(4), 725-743.

Dias, P.; Machado, A.; Huda, N.; & Bernardes, A.M. (2018). Waste electric and electronic equipment (WEEE) management: A study on the Brazilian recycling routes. Journal of Cleaner Production, 174, 7-16.

Dwivedy M., & Mittal R. K. (2010a). Estimation of future outflows of e-waste in India. Waste Management, 30(1), 83 – 491.

Dwivedy M., & Mittal R. K. (2010b). Future trends in computer waste generation in India. Waste Management, 30(11), 2265-2277.

Echegaray, F. (2016). Consumers' reactions to product obsolescence in emerging markets: the case of Brazil. Journal of Cleaner Production, 134(Part A), 191 - 203.

EU - European Union (2011). Directive 2011/65/EU - Restriction of the use of certain hazardous substances in electrical and electronic equipment (Recast). Retrieved from http://www.eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32011L0065

EU - European Union (2012). Directive 2012/19/EU - Waste electrical and electronic equipment (WEEE) (Recast). Retrieved from http://www.eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32012L0019

Ferreira, J.M.B., & Ferreira, A.C. (2008). A sociedade da informação e o desafio da sucata eletrônica. Revista de Ciências Exatas e Tecnologia, 3(3), 157-170 .

Feszty, K., Murchison, C., Baird, J., & Jamnejad, G. (2003). Assessment of the quantities of waste electrical and electronic equipment (WEEE) in Scotland. Waste Management & Research, 21(3), 207-217.

Franco, R. G.P., & Lange, L.C. (2011). Estimativa do fluxo de resíduos de equipamentos elétricos e eletrônicos no município de Belo Horizonte, Minas Gerais, Brasil. Engenharia Sanitária e Ambiental, 16(1), 73-82.

Franco, R.G.F. (2008). Protocolo de referência para Gestão de Resíduos de Equipamentos Elétricos e Eletrônicos domésticos para o município de Belo Horizonte/MG (Master's thesis, Universidade Federal de Minas Gerais. Retrieved from http://www.smarh.eng.ufmg.br/defesas/428M.PDF

Gutiérrez, E., Adenso-Diaz, B., Lozano, S., & Gonzalez-Torre, P. (2010). A competing risks approach for time estimation of household WEEE disposal. Waste Management, 30(8-9), 1643–1652.

Habuer, Nakatani, J., & Moriguchi, Y. (2014). Time-series product and substance flow analyses of end-of-life electrical and electronic equipment in China. Waste Management, 34(2), 489 – 497.

Hagelüken, C., & Corti, C. (2010). Recycling of gold from electronics: Cost effective use through 'design for recycling'. Gold Bull, 43(3), 209–220.

Hidy, G.M., Alcorn, W., Clarke, R., Smith, D., & Thomas, V. (2011). Environmental issues and management strategies for waste electronic and electrical equipment. Journal of the Air and Waste Management Association, 61(10), 990-995.

Hoeltl, A., Brandtweinder, R., Müller , R. (2017). Approach to solving the e-waste problem – case study Ghana. International Journal of Sustainable Development and Planning, 12 (6), 1050–1060

IBGE. Instituto Brasileiro de Geografia e Estatística (2018). Projeção da população do Brasil e das Unidades da Federação. Retrieved May 28, 2018 from https://www.ibge.gov.br/apps/populacao/projecao/

Kang H., & Schoenung J.M. (2006). Estimation of future outflows and infrastructure needed to recycle personal computer systems in California. Journal of Hazardous Materials, 137(2), 1165 – 1174.

Krajewski, L., Ritzman. L., & Malhotra, M. (2009). Administração de produção e operações, São Paulo: Pearson.

Krapp, M., Nebel, J., & Sahamie, R. (2013). Forecasting product returns in closed-loop supply chains. International Journal of Physical Distribution & Logistics Management, 43 (8), 614 – 637.

Lee, J.C., Song, H.T., & Yoo, J.M. (2007). Present status of the recycling of waste electrical and electronic equipment in Korea. Resources, Conservation and Recycling, 50(4), 380–397.

Leigh, N.G., Realff, M.J., Ai N., French, S. P., Ross, C. R., & Bras, B. (2007). Modeling obsolete computer stock under regional data constraints: An Atlanta case study. Resources, Conservation and Recycling, 51(4), 847–869.

Leite, P.R. (2009). Logística reversa: Meio ambiente e competitividade. São Paulo: Pearson.

Li, J., Tian, B., Liu, T., Liu, H., Wen, X., & Honda, S. (2006). Status quo of e-waste management in mainland China. Journal of Material Cycles and Waste Management, 8(1), 13-20.

Linton, J.D., Yeomans, J.S., & Yoogalingam, R. (2004). Enabling industrial ecology through the forecasting of durable goods disposal: Televisions as an exemplar case study. Canadian Journal of Administrative Sciences, 21(2), 190-207.

Liu, X. , Tanaka, M., & Matsui, Y. (2006). Generation amount prediction and material flow analysis of electronic waste: a case study in Beijing, China. Waste Management & Research, 24(5), 434-445.

Magalini, F., Kuehr, R., & Baldé, C. P. (2015) eWaste in Latin America: Statistical analysis and policy recommendations. United Nations University (UNU). Retrieved May 28, 2018 from https://www.gsma.com/publicpolicy/wp-content/uploads/2015/11/GSMA2015_Report_eWasteInLatinAmerica_English.pdf

Makridakis, S. (1986). The art and science of forecasting: An assessment and future direction. International Journal of forecasting, 2(1), 15-39.

Moher D., Liberati A., Tetzlaff J., Altman D. & the PRISMA group (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. PLoS Med 6(7), e1000097.

Morettin, P.A., & Toloi, C.M. (2004). Análise de séries temporais São Paulo: Edgar Blucher.

Nguyen, D.Q., Yamasue, E., Okumura, H., & Ishihara, K.N. (2009). Use and disposal of large home electronic appliances in Vietnam. Journal of Material Cycles and Waste Management, 11(4), 358–366.

Oliveira, L.H., Chiesi, F.K., & Barbieri, J.C. (2012, October). Manufatura reversa e gerenciamento de resíduos eletroeletrônicos: o Caso da Oxil. Proceedings of the Encontro Nacional dos Cursos de Graduação em Administração, Bento Gonçalves, RS, Brazil, 23.

Ongondo, F.O., Williams, I.D., & Keynes, S. (2011). Estimating the impact of the "digital switchover" on disposal of WEEE at household waste recycling centers in England. Waste Management 31(4), 743–753.

Osibanjo, O., Nnorom, I.C., & Ogbonna, K.C. (2008). Modelling waste generation by the telecom sector in Nigeria: The grey side of the impressive outing. Waste Management & Research, 26(4), 317-326.

Padilha, A.C.M., Quadros, V.D., Mattos, P., & Rodrigues, R.G. (2009). A equação tecnologia e a gestão de resíduos sólidos: uma análise do descarte de telefones celulares no município de Carazinho-RS. Revista Brasileira de Gestão Ambiental 3(1), 1-12.

Peinado, J., & Graeml, A.R. (2007). Administração da produção: Operações industriais e de serviços. Curitiba: UnicenP.

Polák, M., & Drápalová, L. (2012). Estimation of end of life mobile phones generation: The case study of the Czech Republic. Waste Management, 32(8), 1583–1591.

Potdar, A., & Rogers, J. (2012). Reason-code based model to forecast product returns. Foresight 14(2), 105 – 120.

Rahmania, M., Nabizadehb, R., Yaghmaeiana, K., Mahvia, A. H., & Yunesianb, M. (2014). Estimation of waste from computers and mobile phones in Iran. Resources, Conservation and Recycling, 87, 21–29.

Rodrigues, A.C., Gunther, W.M.R., & Boscov, M.E.G. (2015) Estimativa da geração de resíduos de equipamentos elétricos e eletrônicos de origem domiciliar: proposição de método de aplicação ao município de São Paulo, São Paulo, Brasil. Engenharia Sanitária e Ambiental, 20(3), 437-447.

Saphores, J. M., Nixon, H., Ogunseitan, O. A., & Shapiro, A.A. (2009). How much e-waste is there in US basements and attics? Results from a national survey. Journal of Environmental Management, 90(11), 3322–3331.

Schumacher, K.A., Schumacher, T., & Agbemabiese, L. (2014). Quantification and probabilistic modeling of CRT obsolescence for the State of Delaware. Waste Management 34 (11), 2321–2326.

SINIR. Sistema Nacional de Informações sobre a Gestão dos Resíduos Sólidos (2017). Logística Reversa. Retrieved August 28, 2017 from http://sinir.gov.br/ web/guest/logistica-reversa.

TELECO (2015). Estatísticas de domicílios brasileiros (IBGE - PNAD). Retrieved January 14, 2015 from http://www.teleco.com.br/pnad.asp

Temur, G. I. T., Balcilar, M., & Bolat, B. (2014). A fuzzy expert system design for forecasting return quantity in reverse logistics network. Journal of Enterprise Information Management, 27(3), 316 – 328.

UNEP. United Nations Environment Program (2015). Illegally traded and dumped e-waste worth up to $19 billion annually poses risks to health, deprives countries of resources. Retrieved May 29, 2015 from https://www.unenvironment.org/news-and-stories/press-release/illegally-traded-and-dumped-e-waste-worth-19-billion-annually-poses.

US EPA (2012). Fact sheet: Management of electronic waste in the US - 2008. Retrieved September 17, 2012 from http://www.epa.gov/osw/conserve/materials/ecycling/docs/fact7-08.pdf

Walk, W. (2009). Forecasting quantities of disused household CRT appliances - A regional case study approach and its application to Baden-Württemberg. Waste Management, 29 (2), 945–951.

Wang, H.F., & Gupta, S. M. (2001). Green supply chain management product life cycle approach. Columbus: McGrawHill.

Yang, Y., & Williams, E. (2009). Logistic model-based forecast of sales and generation of obsolete computers in the USA. Technological Forecasting and Social Change, 76(8), 1105–1114.

Yu, J., Williams, E., & Ju, M. (2010). Analysis of material and energy consumption of mobile phones in China. Energy Policy, 38(8), 4135–4141.

Yu, J., Williams, E., Ju, M., & Yang, Y. (2010). Forecasting global generation of obsolete personal computers. Environmental Science & Technology, 44(9), 3232–3237.

Zhang, L., Yuan, Z., & Bi, J. (2011). Predicting future quantities of obsolete household appliances in Nanjing by a stock-based model. Resources, Conservation and Recycling, 55(11), 1087– 1094.

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