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PATENT TECHNOMETRY BY MIND MAPS: A STUDY ON THE RECYCLING OF WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT

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ABSTRACT

Objective: To demonstrate the possibility of relating bibliographical review and patent technometry in a study on the recycling of waste electrical and electronic equipment (WEEE).

Method: Technometry in patents using a mind map generated from the classification of 466 patent registers. The prospecting of patents was carried out through the software Patent2Net accessing the database of the European Patent Office (EPO).

Originality/Relevance: Research in patent databases as a source of information has been growing substantially with advances in information technology, but the identification of relevant records in a given context from the large volume of data available is still a challenge. In this work, we have analysed a method that has not yet been published, which deals with patent technometry with the use of mind maps.

Results: The patent records found were related to the main problems mentioned in the literature on WEEE recycling, involving the following aspects: a) separation of high-value components from other elements. b) reduction of the environmental impact of battery recycling; c) transformation of solid waste into material useful or harmless to the environment; d) separation of metals from plastic waste; e) solutions for the adequate collection of residues from the domestic environment; and e) techniques to reduce the health impact of recycling professionals.

Theoretical/methodological contributions: Presentation of the method of patent analysis by mind maps as a complementary resource to bibliographic research in studies aimed at technological innovation.

Keywords: Technometry. Patents. Recycling. Waste electrical and electronic equipment.

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TECNOMETRIA EM PATENTES POR MAPAS MENTAIS: ESTUDO APLICADO À RECICLAGEM DE RESÍDUOS DE EQUIPAMENTOS ELÉTRICOS E ELETRÔNICOS

RESUMO

Objetivo: Demonstrar a possibilidade de se relacionar a revisão bibliográfica e a tecnometria em patentes em um estudo sobre a reciclagem de resíduos de equipamentos elétricos e eletrônicos (WEEE).

Método: Tecnometria em patentes com uso de um mapa mental gerado a partir da classificação de 466 registros de patentes. A prospecção das patentes foi realizada por meio do software Patent2Net acessando a base de dados do Escritório Europeu de Patentes (EPO).

Originalidade / Relevância: A pesquisa em bases de dados de patentes como fonte de informação vem crescendo substancialmente com os avanços da tecnologia da informação, porém a identificação de registros relevantes em um determinado contexto a partir do grande volume de dados disponível ainda é um desafio. Neste trabalho analisou-se um método ainda pouco divulgado que trata da tecnometria em patentes com o uso de mapas mentais.

Resultados: Os registros de patentes encontrados foram relacionados aos principais problemas citados na literatura sobre a reciclagem WEEE, envolvendo os seguintes aspectos: a) separação de componentes de alto valor de outros elementos; b) diminuição do impacto ambiental da reciclagem de baterias; c) transformação de resíduos sólidos em material útil ou inofensivo ao ambiente; d) separação de metais de resíduos plásticos; e) soluções para a coleta adequada de resíduos do ambiente doméstico; e e) técnicas para diminuir o impacto a saúde dos profissionais de reciclagem.

Contribuições teóricas / metodológicas: Apresentação do método de análise de patentes por mapas mentais como um recurso complementar à pesquisa bibliográfica em estudos que visem à inovação tecnológica.

Palavras-chave: Tecnometria. Patentes. Reciclagem. Resíduos de equipamentos elétricos e eletrônicos.

Introduction

Patent databases have played an important role as a source of information for research in several areas of knowledge, as demonstrated by Quoniam, Kniess and Mazieri (2014). Only based on the European Patent Office used in this research are more than 100 million records of inventions claimed over the last 170 years (EPO, 2018). In addition to volume, other features make these bases relevant from a technological innovation point of view, for example, they have complete, technically detailed documents with information not generally available in other ways, and because they are free sources of knowledge and without costs (Quoniam *et al.*, 2014).

An important element of patent bases is the international patent classification (International Patent Classification - IPC), which similarly to the documentary classification systems used in librarianship, such as the Dewey Decimal Classification - CDD (Slavic, 2006), aims to facilitate indexing and search of records. Although searches on patent bases are carried out initially by words or search expressions, the classification system allows the in-depth analysis of the returned records, which often represent large volumes of information (Ferraz, Quoniam, Reymond, & Maccari, 2016).

An issue that emerges from the observation of studies based on patent technology (Di Petta, Ferraz, Pedron, & Quoniam, 2018; Kobayashi, Kniess, Serra, Ferraz, & Ruiz, 2017) is how to relate information from patent databases to

bibliographic references. Among the various techniques and tools for data mining in patents currently available, we have identified the use of mind maps available in the software Patent2Net as a potentially useful resource for achieving this goal (Reymond & Quoniam, 2016). These induced the following research question: can patent maps analysis be considered as a complementary resource to bibliographic research in studies in the area of technological innovation?

In this research, we used a feature of the Patent2Net data mining system (http://patent2net.vlab4u.info/), which allows the selective search of patents in the Espacenet database (Zaions, Ferraz, Quoniam, & Mazieri, 2018), and among other resources, generates, in an automated way, mind maps of the set of patents returned from a search expression, based on the IPC classification of the records found. This resource applied in a study of the area of sustainable innovation related to the recycling of waste electrical and electronic equipment (Waste Electric and Electronic Equipment - WEEE). The objective of the research was to demonstrate the possibility of relating bibliographical research and technometry in patents in a topic of technological innovation. The main contribution of the research is the exploration of the method used as an alternative for the collection and analysis of technological information in patent bases in a way complementary to the bibliographical research in studies of technological innovation.

This article is composed of six more sections besides this introduction. The following two sections provide the theoretical reference of the research on the analysis of patents as a source of information and the recycling of waste electrical and electronic equipment. Subsequently, the method used, the results obtained and a brief discussion about the implications of these results was presented, concluding with the final considerations.

Patent analysis as a source of information

The granting of patents is a concept created in the fifteenth century to guarantee to its owner the return of the investment made in the development of an invention of public interest. The concession is generally valid for 20 years, depending on the country of registration, on the other hand, the company may benefit from the knowledge disclosed by the registration of the invention (Nilsiam & Pearce, 2016). To preserve industrial property, the inventor must pay periodic maintenance fees, which often does not occur. In the US it is estimated that 50% of patents become public domain before they turn 20 for failure to pay fees due (Nilsiam & Pearce, 2016).

An important challenge for anyone who proposes to search for patent registrations is the amount of data available. Although this is a motivating factor for the research, because of the universe of knowledge they represent, extracting useful information on specific topics is not a trivial task, so the adoption of data science technologies for patent analysis has been growing rapidly in recent years under the name of "patent mining" (Madani & Weber, 2016).

The technologies for analysing large volumes of data that have become popular in recent years have brought new possibilities for patent analysis. Data and text mining techniques, which are part of the concept of data science, allow for several statistical analyzes for the discovery of knowledge. Some of these possibilities are the observations of technological trends; the analysis of networks of relationships between inventors and between companies; identification of innovations; and chronological analyses of several aspects related to the topics researched (Abbas, Zhang, & Khan, 2014).

Patent searches can be carried out by various specialized search engines, including Google Patents (Google, 2018), the Patentscope from Word Intellectual Property Organization - WIPO (WIPO, 2018)

and the Espacenet from the European Patent Office - EPO (EPO, 2018). The latter two have their own patent search mechanisms, which concentrate registers of several patent offices around the world through collaboration agreements. Other international databases available for research online are the US Patent and Trademark Office (USPTO, 2017) and the Japanese Patent Office (JPO, 2017). An extensive list of systems for data mining in patents with various graphical features and statistical analysis functions is presented in Han *et al*. (2017). In most cases, these are paid tools, but are also on the Internet some free and open source options such as Patzilla (Motl, 2018) and Patent2Net (Patent2Net, 2018), the one used in this research.

In addition to the traditional techniques of mining and data science, the concept of mind maps can also be applied to analyse the universe of patents on a given theme (Dirnberger, 2016). Automatically generated mind maps from patent subgroups selected by keywords allow a comprehensive view of the areas of knowledge involved, and selective navigation through the records to find the most relevant ones in relation to the research objective (Reymond & Quoniam, 2016). The mind maps still allow the researcher to interact with the data through notes and highlights that can be inserted into the mind maps associated with the analysed records.

Due to an international agreement promoted by WIPO since the 1970s, the world's leading patent registration systems follow a coding standard called IPC (International Patent Classification) (WIPO, 2015). Another classification also used internationally is the CPC (Cooperative Patent Classification), created in 2013 from the cooperation between the European Patent Office (EPO) and the US Patent and Trademark Office (USPTO) (Leydesdorff, Kushnir, & Rafols, 2014). In Brazil, the National Institute of Industrial Property (INPI) follows most of the countries that participate in international intellectual property protection agreements and adopts the two classifications (INPI, 2017).

The IPC code represents a hierarchical structure of the areas of knowledge and application to which the inventions belong. Many inventions, because they fit more than one area of knowledge and application, receive more than one IPC code. This information is one of the key elements for the researcher that allows analysing to which technologies a certain invention is related (WIPO, 2004). Researchers such as Adams (2006) and Leydesdorff, Kushnir and Rafols (2014) recommend the use of IPC codes as a way of analysing what has been produced in a specific subclass of patents. In these cases, instead of starting keyword research, all patents for specific classification groups are analysed.

In the hierarchical structure of the IPC, the first symbol of the code is a letter from A to H, called the section and represents the large area of knowledge to which the patent refers. A two-digit number representing the specific class of invention with respect to that section follows this letter. The fourth symbol is another letter that can range from A to Z indicating a subclass. Then the code contains one or two digits representing the group, followed by a forward slash ("/") and a two-digit number for the subgroup (WIPO, 2015). For each of these levels (section, class, subclass, group, and subgroup) there are detailed descriptions of the technologies in which they fall, allowing only by the dismemberment of the classification code to be able to identify the nature of the invention.

To exemplify the interpretation of an IPC code from its hierarchical structure, Table 1 shows the breakdown of the IPC code C22B7 / 02, used in the classification of the invention of a technique for treating zinc ashes.

Table 1 - Example of interpretation of IPC classification code C22B7 / 02

Hierarchical element of the IPC	Description
Section: C	Chemicals and metallurgy
Class: C22	Metallurgy; ferrous or non-ferrous alloys; treatment of alloys or non-ferrous metals
Subclass: C22B	Production or refining of metals; pre-treatment of raw materials
Group: C22B7	Production of raw materials other than ores, eg.: scrap, to produce non-ferrous metals or their compounds
Subgroup: C22B7 / 02	Treatment of chimney dust

Source: Espacenet (2015)

The various possibilities of consulting international patent databases have been considered as a major advance in the policies of access to information (Ferraz *et al.*, 2016), especially for developing countries, where access to technological information is scarce and costly (Dou, 2004). This feature makes the use of patent databases even more significant in the study of the recycling of waste electrical and electronic equipment, which, as can be seen in the bibliographical references discussed in the following topic. It is a problem that mainly affects the underdeveloped or in developing countries, in which this activity is a source of income for many people from less favoured social groups and low access to technology.

The software Patent2Net adopted in this research has been used and cited by several Brazilian researchers in the field of patent mining, for example, Di Petta *et al.* (2018) suggest the use of the tool in work on patent mining and open innovation applied to small companies; Ferraz *et al.* (2016) used the tool to demonstrate patent mining in a study on dengue fever, a topic that was also addressed by Nigro *et al.* (2018); Kobayashi *et al.* (2017) associated mining and patents using Patent2Net with bibliometric research in a work on smart cities; Silva *et al.* (2018) researched patents on assistive technologies; and Zaions *et al.* (2018) investigated the Brazilian participation in the development of technologies related to the treatment of pulmonary tuberculosis based on patent mining with Patent2Net.

Recycling of electric and electronic waste

The significant increase in the production of electrical and electronic equipment caused by the constant technological innovations also provokes the growth of the generation of residues that represent a challenge for the modern society on what to do with this material (Tuncuk, Stazi, Akcil, Yazici, & Deveci, 2012). By 2017 it was estimated that some 50 million tonnes of WEEE would be generated worldwide during the year 2018 (Parajuly, Habib, & Liu, 2017), and in the European Union there is a constant increase in the generation of this waste in the range of 3 to 5% per year (Eurostat, 2017). Of course, the slowdown in technology evolution or technology consumption is not in line with the economic goals of nations in general, so concern for environmental sustainability becomes a dilemma for most economies. What is often discussed in this scenario is the need to develop more environmentally efficient business and production models (Duflou *et al.*, 2008; Nguyen, Stuchtey, & Zils, 2014).

There are several ways of recovering materials from discarded or out of use products, often referenced in the literature by the term EoL - End of Life,

including direct reuse for other purposes, remanufacturing and recycling. Reuse has utility limitations and remanufacturing is not always economically feasible, including because most products are not designed to be remanufactured (Duflou *et al.*, 2008). The focus of recycling is the reuse of materials without the need to preserve any structure of the original product (Duflou *et al.*, 2008).

Recycling of WEEE brings the expectation of a reduction in the volume of solid waste to be treated, which is a problem for most countries, as well as greater efficiency in the consumption of natural resources (Gu, Wu, Xu, Mu, & Zuo, 2016). Recycling metals such as aluminium, copper and iron, for example, can save up to 95% energy compared to the extraction of nature (Kahhat *et al.*, 2008). The environmental impact of metal recycling is generally considered to be very insignificant compared to the primary production of these same materials (Khetriwal, Kraeuchi, & Widmer, 2009).

Some raw materials used in the electronics industry are still at risk of scarcity in nature, such as gallium and indium which are estimated to end completely in 20 years (Li, Zeng, Chen, Ogunseitan, & Stevels, 2015). Other metals of high commercial value and also with limited sources such as platinum and ruthenium are increasingly used in electronic equipment (Heacock *et al.*, 2016).

Compared with other methods of material recovery, recycling is less environmentally efficient due to the generation of waste inherent in the recycling process (Duflou *et al.*, 2008), which include the dispersion of various chemical components by land and water, as well as contamination of plantations and air around industrial recycling centres. This is a problem that is not observed in economically developed countries such as USA, Canada and most European countries, which in general tend not to recycle WEEE (Robinson, 2009), but to ship their waste to developing countries such as China and Malaysia (Afroz, Masud, Akhtar, & Duasa, 2013; Gu *et al.*, 2016). In 2016, the Institute of Scrap Recycling Industries (ISRI) estimated a total of US$ 5.6 billion in solid waste exports to China (Waste Dive, 2017).

Virtually every electronic waste contains materials of high commercial value, especially copper, which makes recycling attractive for many low-income populations (Heacock *et al.*, 2016). However, this activity when performed improperly, is more conducive to generate environmental pollution and risks to human health (Garlapati, 2016; Robinson, 2009), including for children living in these areas and who are naturally more vulnerable to poisoning (Heacock *et al.*, 2016; Zeng, Xu, Boezen, & Huo, 2016). This situation is aggravated in developing countries where the amateur recovery of small quantities of valuable metals has been expanding, generating a parallel market and, due to the informality of the processes, increasing the environmental pollution in these countries (Li *et al.*, 2015).

Widmer *et al.* (2005) analysed the impact of WEEE recycling in China, India and South Africa, and identified that recycling in these regions plays an important role as a source of income for many households, but due to the lack of technology and labour standards, these people are exposed to various risks. Afroz *et al.* (2013) identified the same problem in Malaysia and Gu *et al.* (2016) show that this is still the reality in China. Due to the social importance of recycling activity for large population groups in these countries, it is essential that there be public policies that absorb and formalize this activity, instead of simply eliminating this sector due to its informality (Garlapati, 2016; Sepúlveda *et al.*, 2010; Yu, Williams, Ju, & Shao, 2010).

Although most of the discussions on recycling of WEEE are mainly about the recovery of metals, the recycling of the plastics contained in this equipment is also an important issue. Wäger *et al.* (2012)

identified various concentrations of heavy metals in plastic compounds used in electronic devices such as cadmium, chromium, mercury and lead. The treatment of these materials requires specific techniques to avoid contamination of the environment and the health risks of recycling workers, which is often neglected (European Commission, 2016). Zhao *et al*. (2010) identified high concentrations of cadmium, copper, lead and zinc in rice plantations close to the predominant regions of WEEE recycling industries in China. Cui *et al*. (2017) deepened this study demonstrating the remaining copper, zinc and lead levels after a period of 2.5 years. In another study of Chinese soil, Luo *et al*. (2009) concentrations of polybrominated diphenyl ethers (PBDE) around WEEE recycling regions. This class of chemical compounds is known for its harmful effects on human health, often cited in research on the impact of WEEE recycling on the environment (Garlapati, 2016; Li *et al.*, 2015).

Industrialized countries have been adopting several measures to control the impacts of the generation of WEEE, these actions were analysed by Kahhat *et al*. (2008). In 2003, the European Union adopted regulations related to the design of electronic products that favour recycling, collection and recovery of WEEE, treatment and economic feasibility of recycling WEEE, and guidelines for the use of electronic equipment (Eurostat, 2017). The design of products with guidance to facilitate disassembly is already a practice adopted in Japan a few years ago (Duflou *et al.*, 2008). Another key action in Japan is laws requiring manufacturers and importers of electronic equipment to collect and recycle their products after the end of their useful life. On the other hand, consumers pay an extra fee on the value of the products to cover the costs of collecting and recycling the materials (Kahhat *et al.*, 2008). In South Korea, recycling targets have been set that need to be met by product manufacturers such as microcomputers, air conditioners and televisions. If targets are not met, industries are financially penalized (Kahhat *et al.*, 2008).

Method

This research had an exploratory character and sought to identify new possibilities of sources of information that help to solve known problems, but that remain in discussion in the academic circles. The exploratory approach in this context is appropriate because it is a situation that seeks information that allows complete future research for specific cases (Sampieri, Collado, & Lucio, 2013).

The research is essentially based on the analysis of patent records, which, because they are public documents, are considered secondary data (Marconi & Lakatos, 2010). One of the techniques used was the frequency analysis of patent classifications, which is a quantitative method, but the answer to the main objective of the research reflects an interpretive approach of the data by a qualitative method. In this way, the research was classified, as to its nature, in qualitative and quantitative, or mixed method (Sampieri *et al.*, 2013). By including the quantitative analysis of data related to technology, this research also falls within the concept of technometry (Reymond & Quoniam, 2016; Santos, 2003).

The software Patent2Net

To carry out the research was used the software Patent2Net (Reymond & Quoniam, 2016), which is a system developed collaboratively in open source and free access. The Patent2Net system enables the research, local storage and analysis of patent data extracted from the European Patent Office system known as Espacenet (EPO, 2018), and therefore, the user of the software Patent2Net must register with the website of Espacenet and

generate an access key that will be used in the configuration of Patent2Net. This registration is done through the following steps:

1. Access the Espacenet registration page at the following Internet address: https://www.epo.org/searching-for-patents/technical/espacenet/ops.html#tab1
2. Click on the button "Register" and fill out the form provided by the system.
3. Wait for the registration confirmation email to be received.
4. Access the Espacenet system developer page at: https://developers.epo.org/user and enter the registered user name and password.
5. Select the "My Apps" and then click the "Add a new App".
6. In the form that will be presented, enter the name of the software Patent2Net.
7. After confirmation that a new application has been registered, click on the name Patent2Net, the system will present two codes identified by "Consumer Key" and "Consumer Secret Key", copy these codes to a text file using, for example, Windows Notepad and save the file named "cles-epo.txt ". The file should only contain codes separated by a comma, for example:

vmrr7AaAGll794E6VunJ6PzjbkfajwLW,KHzH4fGM7opMhDDD

The software Patent2Net can be installed on a microcomputer with Windows operating system from the web page http://patent2netv2.vlab4u.info/dokuwiki/doku.php?id=user_manual:download_install, in which the researcher-user finds a detailed step-by-step for the installation of the software, as well as the other components needed to use the system and information on how to perform the searches.

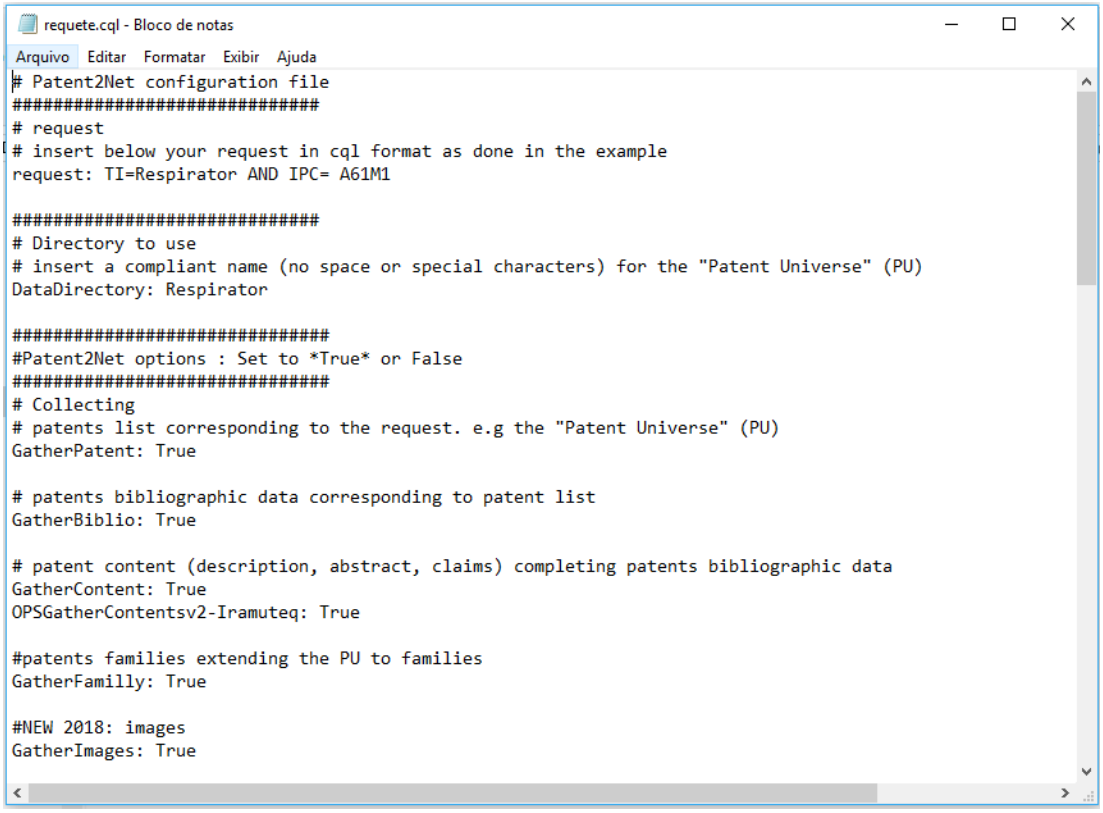
The software Patent2Net, up to the time of the development of this research, did not have a graphical interface for installation. After downloading the software in a compressed file (.zip extension), the researcher must decompress it into a workbook, in which a structure with four subfolders and seven files will be created. In the subfolder "REQUESTS" is the file "requete.cql" that must be edited according to the research to be performed, for this, the searcher must find the line that starts with "request:", and insert the expression search ahead. In the example of **Erro! Fonte de referência não encontrada.**, the file is being set up to search for patents that the title of the record contains the word "Respirator" (TI = *Respirator)* and are rated with IPC codes initiated by A61M1 (AND IPC = A6AM1).

The term "TI =" of the search expression specifies that if you want to retrieve the documents that have a certain keyword in the title, other commonly used terms are "TA =" to search the title or summary of documents, "TXT =" to search anywhere in the text. A complete list of valid terms with use examples can be found on the help page of the Espacenet system: (https://worldwide.espacenet.com/help?topic=fieldidentifier&locale=en_EP&method=handleHelpTopic).

Research can be done by constructing expressions with keyword combinations and by other criteria, such as the name of the inventor, country of origin

of the patent, name of the organization holding the patent, date of registration or international classification code of the patent. It is recommended that expressions be tested on web page of Espacenet (https://worldwide.espacenet.com/) so that you can quickly ascertain approximately how many records will meet the criteria and if they match the researcher's expectations.

Figure 1 - Editing the Patent2Net configuration file



Source: Sample file provided with the software Patent2Net (2018)

Another important configuration is the line that starts with “DataDirectory: "For which you must assign a name to the project. This name will be used to identify the folders and files generated by processing that specific case. The project name must be assigned in a single word, with no spaces, in this example it was given the name “Respirator”.

Throughout the file there are several other optional parameters that allow choosing what resources the researcher wants the system to process from the recovered patent records. The resources are selected by assigning the value “True” in each one. Once the settings have been made, the file should be saved.

The searcher then returns to the main folder where the software Patent2Net was installed, append the previously generated "cles-epo.txt" file from the user's registration in the Espacenet system and run the "CollectETraite.bat" file. After processing, the search data will be written to a Patent2Net subfolder named DATA, in which a subfolder with the name assigned to the project and a file with the same name and extension “.HTML” will be created. To access the results of the search and processing of patents, the researcher must open the file with

extension "HTML" with the Firefox browser (until the development of this search other browsers were not supported) that will give access to the data and graphics collected in the processing of the stipulated search key and that are now stored locally in the researcher's computer.

More detailed information on the use of the Patent2Net system can be found from the main system page (http://patent2netv2.vlab4u.info/) and examples of recent studies that have used it in the works of Ferraz et al. (2016), Kobayashi et al. (2017), Nigro et al. (2018), Zaions et al. (2018), Silva et al. (2018) and Di Petta et al (2018).

Search procedures performed

In order to recover patents specifically related to the recycling of waste electrical and electronic equipment, search simulations were carried out with different combinations of terms found in the literature to designate this industrial activity. The simulations were performed on 12/28/2018 using the Espacenet system's own search functionality.

In the first simulation, the criterion was the search for patents that had the word “weee” or the words “recy *” and “electr *” simultaneously in titles or abstracts. The mask character “ * ” (asterisk) was used for the system to consider the variations "recycle" or "recycling", as "electrical", "electronic" or "electronically", for the defined search terms, resulting in the following expression:

ta = weee OR (ta = recy * AND ta = electr *)

This research indicated the existence of more than 10 thousand records that met the criterion (from 10 thousand, the Espacenet system does not inform the exact number of records), and analysing by sampling, it was noticed that the majority dealt with the recycling of energy power. On the other hand, this expression did not contemplate records that referred to electrical waste like “ewaste" rather than “weee". To correct these distortions a new simulation was made with the following expression:

(ta = ewaste OR ta = weee) OR (ta = waste AND ta = electr*)) AND ta = recy*)

In that case, the search also included patents that contained the term "ewaste", Besides "weee", or a combination of the terms "waste", "electr*" and "recyc* ", returning 9562 records. By observing a sample of the recovered records, it was noticed that the result brought many patents related to the recycling of diverse materials that cited some type of electrical component, for example, recycling hospital material.

A new simulation was made keeping the same terms, but restricting the search to consider only patent titles, thus ensuring that only specific patents for the recycling of electrical and electronic equipment were returned. The new expression is as follows:

(ti = ewaste OR ti = weee) OR (ti = waste AND ti = electr*)) AND ti = recy*)

This expression resulted in 465 patents, and the records verified by sampling were satisfactory in relation to the research theme.

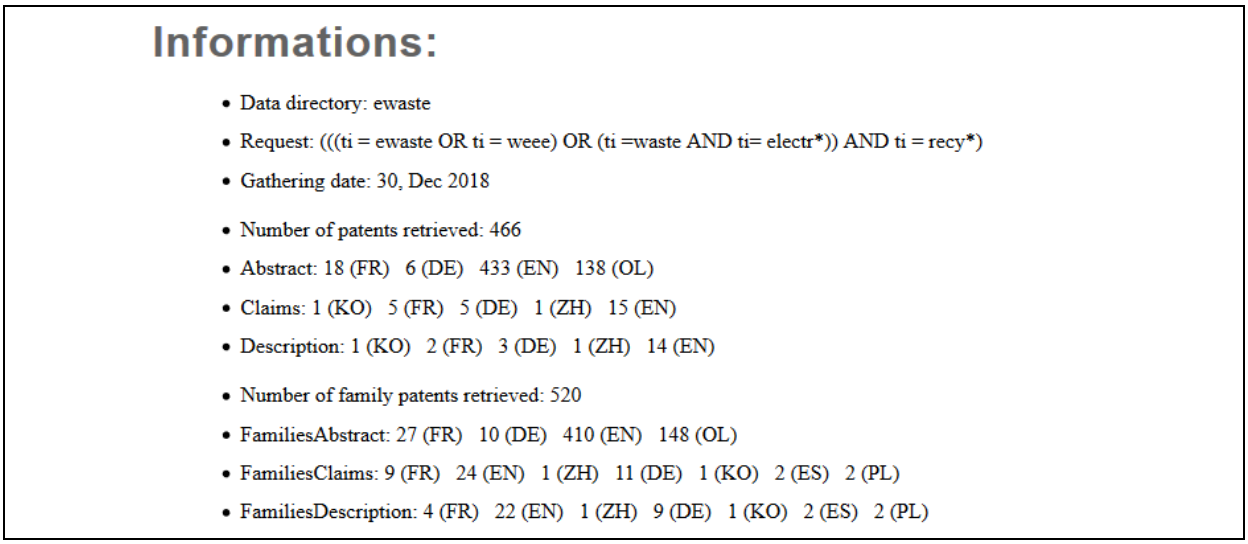
For the analysis of the results, with the objective of associating the patents with the problems identified in the literature review, one of the functionalities of the Patent2Net system was used, which constructs a mind map of the set of patents found from the IPC classification of the registries. In this way, it was possible to perform the analysis of the results from the hierarchical structure of IPC classification, observing the frequency of the classifications used in the set of patents found and observing the solutions by technological areas.

Results

The effective processing of the defined search expression occurred between December 29th and December 30th, 2018, resulting in 466 patents, 595 abstracts (some patents provide the

abstract in more than one language) and 520 patent families. **Erro! Fonte de referência não encontrada.** shows the summary table of the recovered data, this information is part of the results presentation of Patent2Net.

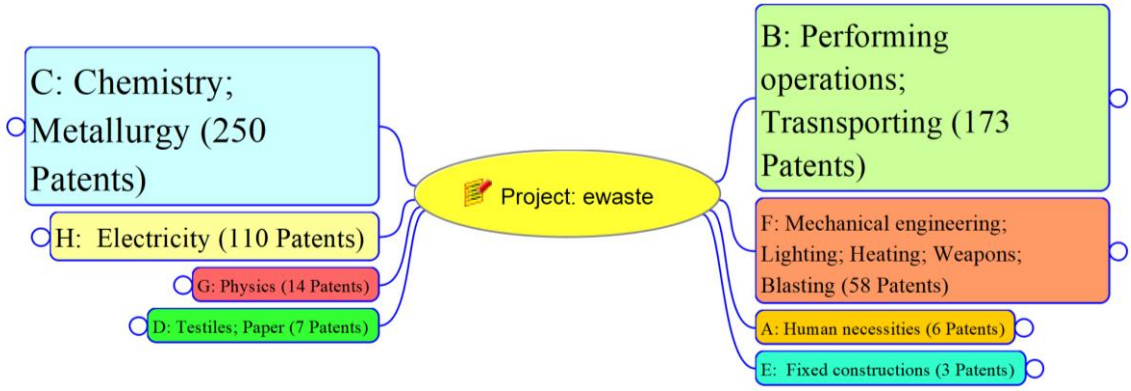
Figure 2 - Summary table of data collected by the Patent2Net system



Source: Research data obtained from the use of software Patent2Net (2018)

In the initial view of the mind map of the patents found by the search expression (**Erro! Fonte de referência não encontrada.**), it is possible to identify the distribution of patents in sections. In which the concentration of inventions related to chemical and metallurgical products are observed, followed in order of frequency by the sections related to the execution of operations and transportation; inventions involving electricity; mechanical engineering, lighting, heating, weapons and explosions; physical inventions; textiles and paper; human needs; and for fixed construction.

Figure 3 - Initial view of the mind map of selected records



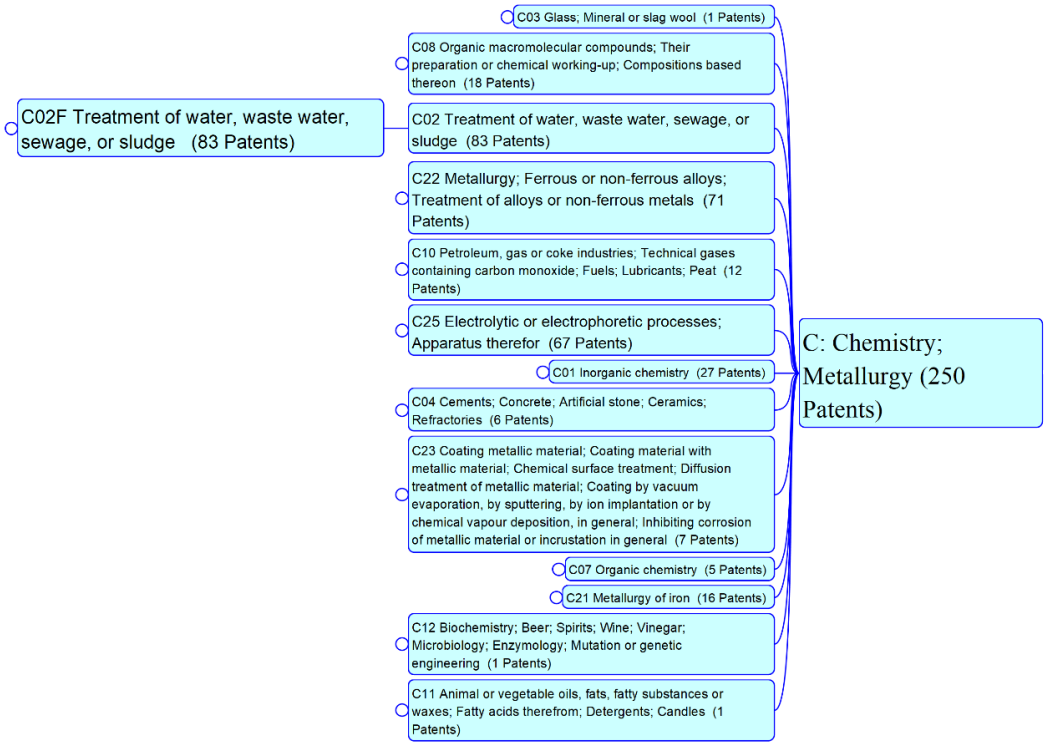
Source: Research data obtained from the use of software Patent2Net (2018)

Mind maps allow the exploration of the data by several criteria; the researcher can choose a path from the classifications that judge the greatest potential to find the information sought and then try other paths to reach their goals. In this case, the researcher could be, for example, analysed the patents of section H, because he is in search of solutions directly related to the separation of components by the use of electrical processes, and then to choose between the classes available, again to which aroused more interest. In this work, because we are not looking for a solution to a specific problem, but rather to observe the relationship between patents and the problems pointed out in the literature in general, we opted to start the analysis by the higher frequency classifications.

Section C - Chemistry and Metallurgy

Following this line of reasoning, we began the analysis by the expansion of section C - "Chemistry and metallurgy", then to class C02 - "Treatment of water, waste water, sewage or sludge" and subclass C02F that maintains the same description of the corresponding class (**Erro! Fonte de referência não encontrada.**).

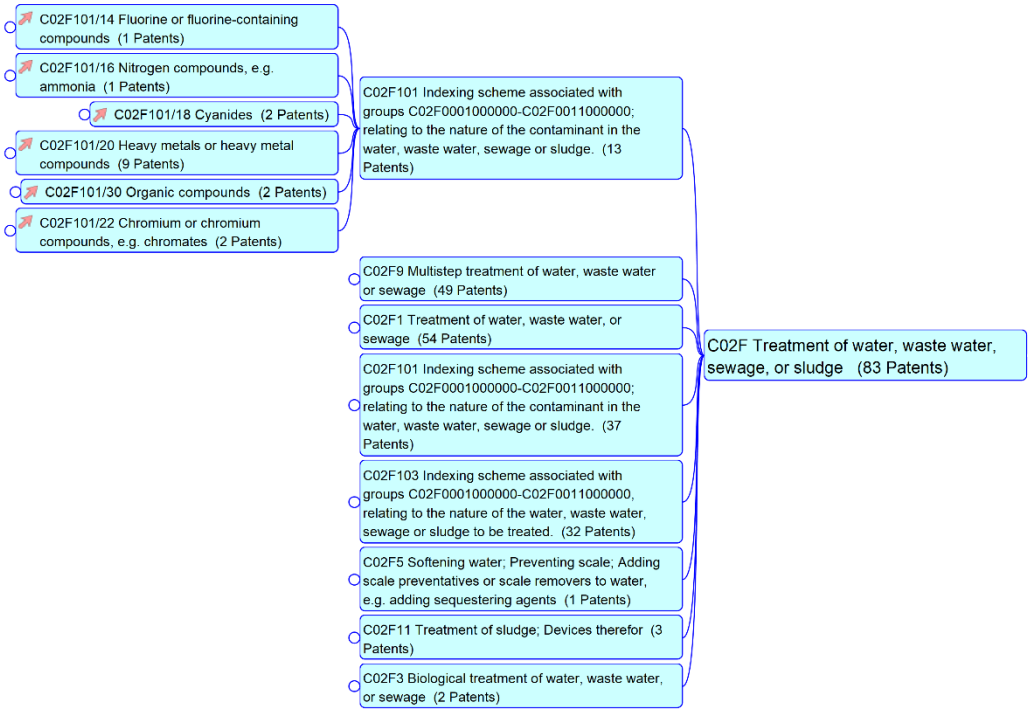
Figure 4 - Expansion of the highest frequency section for class and subclass levels



Source: Research data obtained using the software Patent2Net (2018)

By further expanding the subclass C02F, there are eight groups, each group being expanded once again to the corresponding subgroups representing the complete IPCs codes used in the classification of these patents. To facilitate the demonstration of this resource, at this point instead of expanding the most frequent, the group C02F101 was expanded showing the six subgroups of corresponding IPCs codes (Figure 5).

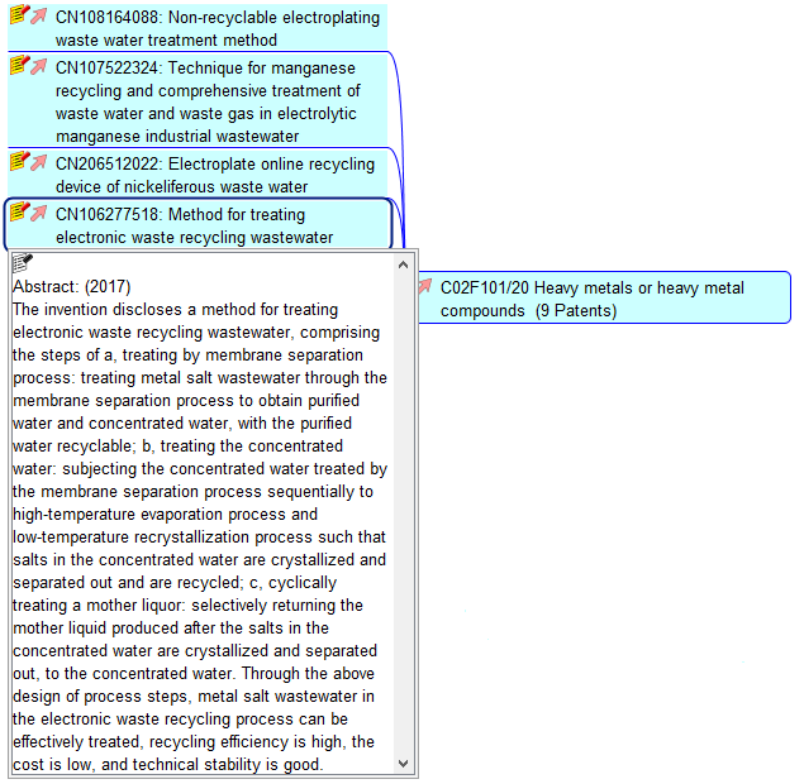
Figure 5 - Expansion of subclass C02F and group C02F101



Source: Research data obtained using the software Patent2Net (2018)

The patent map of the Patent2Net system can be expand once again by revealing the code and description of patents classified in each subgroup, and allows the visualization of the request year and the summary of each record (Figure 6).

Figure 6 - Expansion of the mind map to the summary view of a patent



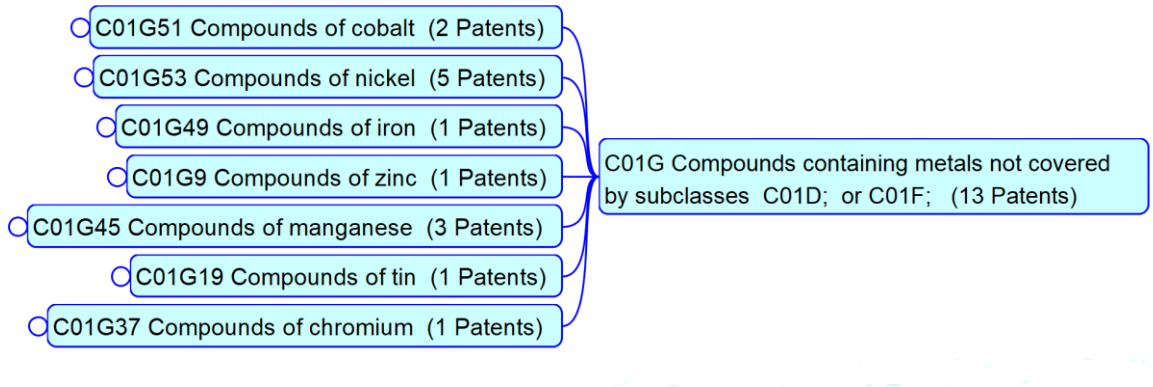
Source: Research data obtained from the use of software Patent2Net (2018)

By observing subclass C02F, now independent of patent frequency, but considering the classificatory descriptions, a variety of possibilities exploited by inventions for wastewater treatment of industrial processes was noted.

Also in section C - "Chemistry and Metallurgy", class C01 - "Inorganic chemistry", subclass C01G - "Compounds containing metals", 13 patents distributed in seven groups were found (**Erro! Fonte de referência não encontrada.**), each related to the treatment of a specific metal. They are patents of physical and chemical processes for the segregation of these metals from their compounds. They may contain relevant information both for the recovery of commercially valuable materials and for the treatment of recycling waste (Robinson, 2009).

In subclass C01B - "Non-metallic element compounds", 13 patents distributed in groups related to the treatment of halogens, hydrogens, sulphur, carbon and phosphorus were found. In this category there is, for example, a patent for the treatment of gases generated in the combustion of waste.

Figure 7 - Subclass C01G and corresponding groups



Source: research data obtained from the use of the software Patent2Net (2018)

Section B – Performing Operations and Transporting

Section B - "Performing operations and Transporting" also returned a significant number of patents, 173 records in total. Patents in this category relate primarily to mechanical component separation processes, for example, the 27 patents in subclass B02C - "Crushing, pulverizing or disintegrating in general; Grinding grain", which refer to the techniques cited by Tuncuk *et al*. (2012).

In subclass B03B - "Separating solid materials using liquids or using pneumatic tables or jigs", 25 patents were classified, most of them 16 patents, in group B03B9 - "General layout of the separation plant, e.g. flow sheets" and subgroup B03B9 / 06 - "specially adapted for scrap". A peculiar feature of this set of patents is that ten registrations refer to inventions from the late 1990s and early 2000s, i.e., patents that have already become public domain or are about to enter this condition.

In subclass B09B - "Disposal of solid waste", 74 patents were found, 67 in the group B09B3 - "Destruction of solid waste or transformation of solid waste into something useful or harmless". The patents of this group are predominantly recent, 30 registrations refer to requests between 2014 and 2018, among which are several inventions related to the separation of recyclable materials in forms less aggressive to the environment.

Regarding the treatment of plastic waste, 42 patents were found in subclass B29B - "Preparation or pre-treatment of the material to be molded; Making granules or preforms; Recovery of plastics or other constituents of waste containing plastics", all in-group B29B17 “Recovery of plastics or other constituents of waste containing plastics".

Section H - Electricity

In section H - "Electricity", 110 patents were found, mainly concentrated in class H01 - "Basic electrical elements" (72 patents), and subclass H01M - "Processes or means, example: Batteries, for the direct conversion of chemical energy (53 patents) of battery recycling inventions that suggest various techniques for recovering lithium, lead and other materials. Many of these inventions seek greater efficiency for material and decrease of environmental impacts, for example, the patent identified by the code CN10839012.

This section also contains patents related to processes for the recovery of peripheral parts of batteries, such as CN106992283, on the removal of positive electrodes from lithium batteries, classified as IPC H01M4/58 - "inorganic compounds other than oxides or

hydroxides, and sulphides, selenides, tellurides, halides or polyanionic structures, example: phosphates, silicates or borates".

Investigating a subclass of patents parallel to that of batteries, identified by H01B - "Cables; Conductors; Insulators; Selection of materials for their conductive, insulating or dielectric properties" was found another potentially significant group, H01B15 - "Apparatus or processes for recovering material from cables", with 17 records related to the techniques of recovery of the metals of electric cables.

Section F - Mechanical Engineering, Lighting, Heating, Weapons and Blasting

In the last section of the four most frequently recorded sections, section F - "Mechanical Engineering, Lighting, Heating, Weapons and Blasting" with 58 patents, the distribution of records was less concentrated, notably classes F27 - "Furnaces and Retorts" with 21 patents, F23 - "Combustion apparatus; Combustion processes" with 13 patents, F01 - "Machines or motors in general; Engine plants in general; Steam Engines" with 11 patents, plus seven classes with less than 10 patents in each classification.

Some relevant examples of patents found in this path are CN207703015, on a metal recycling furnace capable of reusing the heat produced by the process, the CN107270725 patent proposing a system for the recovery of aluminium by electrolysis, and the patent JP2000205528 on a system combination of crushing and thermal decomposition of electronic devices for metal recovery. The latter is a Japanese patent of the year 2000 and, therefore, about to become a public domain.

Section G - Physics

The first of the four sections with the least frequency of registers is section G - "Physics", with 14 patents distributed in seven classes, with more frequent G06 - "Computing; Calculation; and Count" with seven records. The patents found along this path are characterized by suggesting systems for controlling the collection of electrical and electronic waste, for example, Japanese patents JP2002230153, JP2000289807 and German patent DE19944688.

Section D - Textiles and Paper

In section D - "Textiles and Papers" among the seven patents found, there is a system for recycling washing machines, and other patents not directly related to the research topic, such as an industrial dryer with recycled heat produced and a system for recycling of fabric manufacturing process components. Coincidentally using the terms “recycle” and “electric” in their definitions aggregated these records.

Section A - Human Necessities

Section A - "Human necessities" found six patents, four in the A62D3 group - "Processes for the production of harmful, harmless or less harmful chemical substances in chemical substances", which deal with recycling processes involving high-risk chemicals to human health. In these cases, related patents were also classified into other sections such as chemicals (C) and electrical (H).

Section E - Fixed Construction

Finally, three patents were identified in section E - "Fixed Construction", one being Korean on the recycling of electric poles, a German patent on recycled material flooring with spacing for electric cables, and the third, also of German origin, on a disposal system of a lavatory with an electric actuator. In such cases, as occurred with section D, the patents returned by the search expression can be considered with search noise.

Discussion

The universe of patents observed in the mind map generated from the search expression defined for this research allows us to make some considerations, both from the point of view of the area of recycling of waste electrical and electronic equipment, and in relation to the possibilities that the method offers for research in the area of technological innovation.

The initial condition of the mind map, in which the distribution of the patents found by large areas of knowledge, or sections, as the first level of IPC classification is observed, coincides with the concentration of the themes observed in the literature, being the main focus the chemical and metallurgical issues, in which there are several discussions on the environmental aspects of recycling (Jin-li Cui *et al.*, 2017; Garlapati, 2016; Zhao *et al.*, 2010); secondly, the operational problems of the dismantling of these equipment, which are often performed inappropriately as informal activities in various low-income social groups (Gu *et al.*, 2016; Li *et al.*, 2015; Widmer *et al.*, 2005); and third, electricity, as it is the recycling of electrical equipment.

From the economic point of view, metal recovery is one of the main drivers of the WEEE recycling industry due to the high concentration of electronic components (Tuncuk *et al.*, 2012), but the difficulties to recover them represent great challenges, and when they are performed in an inadequate manner, they generate several problems including public health (Sepúlveda *et al.*, 2010). Patents found in the B02C subclass may be especially relevant in studies that address the difficulties of separating high commercial value metal components from other elements. Since this subclass belongs to the operational patents section, much can be learned about non-chemical processes that assist in this activity, such as electrolysis separation methods.

An example of a consequence of the lack of adequate technology is the waste of materials of high commercial value, as occurs with the recovery of copper in China, which in the cases of informal organizations, cannot generate electric copper requiring 99.95% purity, only the secondary copper (Gu et al., 2016). Only in the subgroup B03B9/06 were 16 patents dealing with the industrial processes applied in the recycling industry suggested by Tuncuk *et al.* (2012). Depending on the type of equipment to be recycled, section H patents may be an important source of knowledge for classifying patents by specific material types or equipment, for example, subclass H01M for battery treatment, subclass H01B for cables and subclass H01K for printed circuit boards. Among these groups, batteries receive special attention in the literature due to the high environmental exposure of their recycling process (da Silva Santos, de Souza Santos, & de Souza, 2011).

The negative counterpart of the economic value of recycling is in environmental pollution. The case of water, for example, is cited in the literature as one of the major problems of WEEE recycling that makes this activity often a threat to the environment rather than contributing to its preservation (AFROZ *et al.*, 2013), especially in developing countries (Gu et al., 2016). Patent analysis by classification can also help with this problem, for example, by observing the considerable number of patents, most published in recent years, from group B09B3 that propose solutions for the destruction or transformation of solid waste into something useful or harmless. The timeliness of these records can be interpreted as reflecting increased attention to environmental issues of recent years in patent registrations.

The observation of patents found in subclass B29B refers to the discussion about the difficulties encountered in separating metals from plastic waste (Wäger *et al.*, 2012), which generate environmental problems and limitations in

the recovery of financial value. The volume of patents found under this classification indicates that there are technical solutions for this, but in developing countries, which receive large volumes of electronic waste from richer countries to recycle, they still find it difficult to do this properly, causing waste metals and dumping contaminated plastics into landfills.

The literature review also pointed to discussions on the policies adopted in several countries to enable the adequate collection of end-of-life equipment (Afroz *et al.*, 2013; Duflou *et al.*, 2008; Kahhat *et al.*, 2008). These policies imply the development of specific systems, and on this, potentially relevant patents have also been found. For example, in group G, a patent was found related to a selective waste collection system that assists the user in choosing the correct container (Patent CN103440607); a system that allows the paid collection of waste (patent CN202351953); and also a system for separating components from printed circuit boards (patent CN103293018). In the same line, Japanese patents JP2002230153, JP2000289807 and German DE19944688, which refer to e-waste collection systems, can be studied both for developing public policies and for expanding the view on possibilities in this area.

Many of the processes and techniques found in patent registrations fall under the concept of Best Environmental Practices (BEP) (Li *et al.*, 2015), widely adopted in industrialized countries, but still ignored in developing countries. The practice of observing patent databases as a source of knowledge in this area could help organizations established in these countries to evolve gradually towards the use of processes and techniques with better environmental cost and lower human health risk.

The main recycling techniques cited by Garlapati (2016) as possible solutions to reduce the environmental and human health impacts of recycling processes are referenced in patents found in the search. Some examples: for reverse osmosis, the patents identified by CN207671826, CN106517604 and CN205874067 were found; for processes based on electrolysis, patents CN104030481, CN203781954 and TW201311570; for electrolytic recovery, patents CN106583423, CN106180118, CN102009062 and CN103304838; and by pyrolysis, the patents CN104624605, KR20130061418 and EP2628809. Pyrolysis, besides helping to separate the plastic from the metals, can also generate synthetic fuels as a by-product (Garlapati, 2016). Techniques such as these can be adopted to stimulate innovations in a business segment with high demand in developing countries, reducing the informality of the activity (Garlapati, 2016), since economic viability is a key point for the regularization of recycling processes in an environmentally appropriate way (Parajuly *et al.*, 2017).

As well as Garlapati (2016), Li *et al.* (1985) also suggests several techniques for separating materials contained in WEEE, but it is not the responsibility of authors of scientific articles to teach how to do, including space limitations, and in this regard, patent records are a source of important complementary knowledge, because they effectively teach various possible ways of performing these activities. What might be a useful combination if the scientific papers on technology included patent mining related to the topics discussed and cited these documents, just as patent records are cited among each other to substantiate the technologies applied in new inventions.

In general, it is possible to observe that the main problems discussed in the literature on the recycling of waste electrical and electronic equipment are dealt with by several patent applications, although rarely scientific articles in this area mention any patent. In 25 articles analysed among the most cited in the period 2008 to 2017, citations were identified to patents only in Robinson (2009) and Cui and Zhang (2008). One of

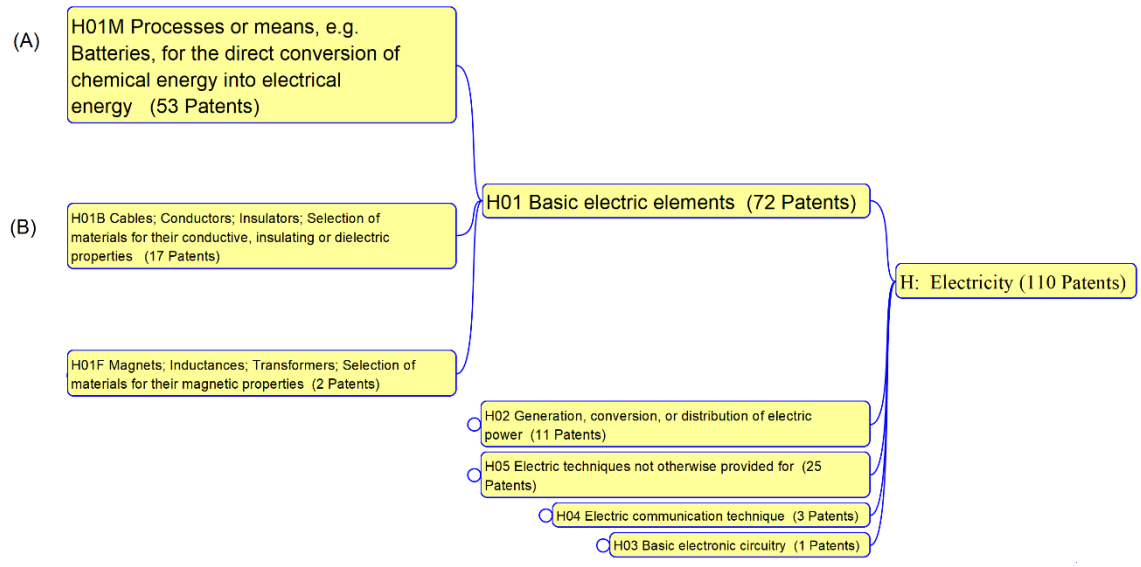
the probable reasons for this phenomenon of the low reference to patents in technological research, despite the volume and completeness of the available information, is explained by Ferraz *et al*. (2016), and consists mainly of the difficulty in finding and organizing the records relevant to each case.

For Zeng *et al*. (2016), due to the socioeconomic importance of recycling activity in developing countries and its consequences when carried out inappropriately, it is important to discuss an international agenda for technical capacity building in these sectors. Patenting can be one of the ways to do this, since this knowledge is available in the open patent databases, free of charge, and in most cases free to be reused, because they are patents that have not been granted in countries where they are required or even no longer protected due to the expiration of the request by time limit or non-renewal of maintenance fees (Nilsiam & Pearce, 2016).

In relation to the objective of the research, it is important to note that the diverse relationships established between the problems of recycling WEEE found in the literature with patents that deal with the subjects were carried out totally based on the use of the mind map of patents generated with software Patent2Net.

A situation that allows observing the facility provided by the use of a visual tool in the analysis of the patents was the form that came to the patents of recycling of electrical cables. Initially, Section H was expanded so that it could check the patents related to electricity in general, the class that stood out in patent frequency, as would be expected, was that of electrical elements and then the subclass for recovery of batteries (Figure 8A). However, the underlying subclass, with a less expressive number of records (Figure 8B), also referred to an important issue that is the recovery of electric cables, mainly due to the strong propensity for air pollution caused by the irregular performance of this activity. The visual proximity between the two subclasses motivated the sequential analysis of the two paths in the exploration of related patents.

Figure 8 - Visual proximity between two subclasses of relevant patents in the study



Source: research data obtained from the use of the software Patent2Net (2018)

Final considerations

This study demonstrates that it is possible to relate bibliographical studies and technometry in patents in the development of scientific research involving topics of technological innovation, for which the patent databases represent a significant source of information. Consideration of these sources is an important factor in ensuring the completeness of technological research, since the descriptions of inventions submitted to patent applications often correspond to important technological knowledge that is not available from other sources and should therefore not be neglected in these discussions.

Information technology, through data mining tools, graphical analysis and statistics contributes significantly to the evolution of patent research methods, and the use of analysis by mind maps generated automatically from the classification of records, functionality available in the Patent2Net system, is another alternative in this sense, not in substitution of other techniques, but in a complementary way, mainly in relation to the use of IPC classification of the registries as a facilitator for locating relevant information.

Specifically in relation to the search for patents on the recycling of waste electrical and electronic equipment, this work allowed to identify classifications and patent records directly related to the main problems identified in the literature, namely: a) the separation of high value components from other elements; b) reduction of the environmental impact of battery recycling; c) transformation of solid waste into material useful or harmless to the environment; d) separation of metals from plastic waste; e) solutions for the adequate collection of these residues from the domestic environment; and e) techniques to reduce the health impact of recycling professionals.

However, it is important to point out that the work was limited to use the subject only as an example of applying the method of patent analysis by mind maps in researches of technological innovation, not proposing to validate the solutions to the problems discussed. Specific study on this topic, to be conclusive about any of the mentioned problems, should have the parameters for the search of patents, for the bibliographic survey and the analysis of the results reviewed by specialists of other areas of knowledge involved, such as Engineering Chemistry, Production Engineering and Environmental Management. The analysis of the patent records to establish the relationship with the recycling problems was based only on the reading of the abstracts, each of the cited cases, to confirm the contribution of the patents found with the solution of the related problems, also requires in-depth studies of the available documents and possibly application tests.

These limitations suggest new studies addressing in-depth each of the cited problems - environmental pollution; separation of valuable materials; safety of work in recycling. These studies may be based on experiments or case studies in which the solutions found in patent registrations can be effectively tested.

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