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A PATENT VIEW IN DEVELOPMENT AND RECYCLING OF EEE IN THE CONTEXT OF CIRCULAR ECONOMY

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Abstract

The continuous development of technologies that incorporate new functions into electronic equipment has led to increased demand for such products and therefore increased levels of disposals. The application of concepts from the circular economy to the development of new electronic equipment could help resolve the problems caused by the unceasing demand for new technologies. This article aimed to map the progress of circular technologies in the production chain for electronic equipment, for which there is high demand or have a complex design. The analysis of the patent documents revealed that the main patent applicants are from Asia and the USA and the technologies are mainly from the first and the fourth link in the production chain, raw materials end recycling processes, respectively. The proposed solutions are geared toward equipment efficiency, reduced energy consumption, design and more efficient recycling processes.

Keywords: equipment; Circular economy; Patents; Recycling; E-waste

1. Introduction

Growing demand for electronic equipment and the associated disposal of used equipment poses risks and challenges of a social, economic, and environmental nature, as well as for public health. Shortages of raw materials, such as rare earth metals, lithium, indium, and gold (European Commission, 2017; UNEP, 2013; World Gold Council, 2020), soil contamination, water, and air pollution, and respiratory diseases are some of the adverse consequences of inadequate disposal and recycling of EEE. In 2019, an estimated 53.6 million tonnes (Mt) of waste from Electrical and Electronic Equipment (WEEE) were generated globally, up 21% in 5 years. Only 17.4% of this WEEE was collected and recycled, an increase of 0.4% compared to 2014. The volume of end-of-life electro electronic equipment (EEE) without proper processing also influences the supply of raw materials that use noble metals in their composition (Li et al., 2015; UNEP, 2013). In a conservative analysis, it is estimated that $57 billion worth of gold, silver, copper, and other high-value materials were disposed of or burned rather than collected and treated for reuse.

The never-ending technology development cycle means the life cycles of EEE are increasingly shorter, pushing demand for new equipment and the corresponding disposal of used equipment

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(Balde et al., 2017, 2015; Li et al., 2015). Even where public opinion is in favor of adopting sustainable behaviors, consistent recycling programs are not observed. This is due in part to how management policies are developed: there should be a link between manufacturers and recyclers (Dalrymple et al., 2007). The increase in the consumption of EEE without the proportional increase in recycling shows the need to seek alternative solutions for the management of EEE throughout its life cycle with actions aimed at the initial stages of the development of electronic equipment that favor recycling activities, thus as post-consumer technologies.

Thus, this article aims to ascertain whether, through the patent applications, if the technological advances being in the EEE production chain seek to improve the electronic equipment within the concepts of circularity to remedy the deficiencies that make them potential pollutants, when presenting a complex design or reduced useful life and what solutions are being proposed for the electronic equipment recycling stage. Therefore, will be presented links in the production chains, government policies for EEE management, concepts of circular economy and information about industrial property.

1.1 Links in the EEE production chain

The production chain constitutes a set of operational stages. In a linear process, the stage of transforming the raw material into the final product is considered from the extraction and handling of materials, the distribution of the products to consumers and disposal, but it does not consider what happens to the product when is discarded.

The concept of the circular economy offers an alternative to this linear model. The circular economy is one weapon in the effort to combat the damage caused by inadequate disposal of WEEE such as soil, air and water pollution and material depletion. A circular supply chain allows to eliminate or reduce waste generation along the entire supply chain. In order for this objective to be achieved it is necessary that all stages of the life cycle of the equipment are considered at the time of its development.

For this study, the links in the circular supply chain for EEE were divided into: raw materials, systems development, final product, and post-consumption. Raw materials constitute all the materials used to make EEE, components and other materials and processes used in the manufacture of electronic equipment. The inputs, processes, and design of products are decided on at the project stage, which influences the characteristics of the final EEE.

The “systems development” link includes the systems and software that enhance the functionality of EEE. They may even increase its useful life or influence its energy efficiency. The “final product” link constitutes the EEE per se, while “post-consumption” relates to the processes and equipment used for managing WEEE. As shown above, this link feeds into the “raw materials” link but is also heavily influenced by it.

1.2 Circular Economy

The circular economy has among its objectives the elimination or reduction of waste generation throughout the entire production chain. Therefore, it is necessary that all stages of the equipment's life cycle are considered during the design of product stage. In circular economy, the

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industrial system must be restorative or regenerative.

The idea is that there is no "end" to a product's useful life or its components. Products and materials are maintained within the economic system to preserve their value. One recovery method involves repairing equipment by replacing or configuring its parts. Material design can develop products that are easier to repair and have replaceable parts. Recycling processes are employed when product recovery is no longer feasible (Bakhiyi et al., 2018).

The introduction of the circular economy into manufacturing processes could be driven by several factors, such as consumer demand for products and brands that incorporate such processes, government policies, and increased added value of products and/or brands. Furthermore, new laws to foster the circularity of the EEE production system, together with their effective enforcement, would make companies rethink their products in such a way as to consider the whole life cycle to meet legal and consumer demands (Kane et al., 2018).

1.3 EEE Management Policies

The recycling policies drive the development of circular manufacturing and recycling processes. In 2019, 78 countries had some legislation for the management of WEEE and 71% of the world population was covered by some type of regulation focused on the subject. The main countries that manufacture EEE, as well as the main consuming countries, have policies for the management of WEEE, many of which are based on the principle of extended producer responsibility (EPR) and the 3Rs (reduce, reuse, recycle).

The USA does not have a federal-level regulatory system for WEEE, but 25 of the 50 states do have some legislation of their own. The National Strategy for Electronic Stewardship was introduced in 2011 by the Environmental Protection Agency (EPA) and provides recommendations on measures that the federal government, companies, and individuals can take to attain the goals identified in Executive Order 13693 (Interagency Task Force on Electronics Stewardship, 2011; Schumacher and Agbemabiese, 2019).

In Japan, there have been specific laws for e-waste management since 1991. One of the most recent pieces of legislation is the 2012 Act on Promotion of Recycling of Small Waste Electrical and Electronic Equipment, which sets forth measures for promoting the recycling of small electrical and electronic devices (Home Appliance Recycling Law, 2001; Japonese Act, 2013; OECD, 2014). The country's WEEE laws have similarities with the attributes of extended responsibility for consumers and manufacturers. They encourage the 3Rs and form a legal framework that covers the entire EEE life cycle.

China has had legislation on the circular economy since 2009, one of which goals is to improve the efficiency of resource utilization, protect the environment, and foster sustainable development. The Circular Economy Promotion Law applies the principles of the 3Rs and, in its scope, it encompasses all the aspects of a circular economy (People's Republic of China, 2008). The Administrative Measures for the Restriction of the Use of Hazardous Substances in Electrical and Electronic Products, also known as China's RoHS2 (named after the EU's RoHS2 directive), came into effect in 2016, regulating the same six substances as the EU legislation (People's Republic of China, 2006). The country has set a goal of obtaining 20% of raw

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materials for new electronic products from recycled content and recycling 50% of electronic waste by 2025 (Kaya, 2016).

In 1998, Taiwan introduced the Recycling Fund Management Committee to reduce waste, promote the recycling of hard-to-process products, hazardous materials, and items with high recovery value, and assure the efficient use of resources. Under this system, manufacturers are responsible simply for paying a charge, not for collecting or recycling the electronic waste (Chung and Murakami-Suzuki, 2008; Fan et al., 2005).

In South Korea, EPR was introduced in 2003, stressing the role of manufacturers in the recycling of e-waste. Additional legislation in the country establishes the duties and responsibilities of producers and importers of different EEE, including restrictions on the use of hazardous substances, and the collection and recycling of products at the end of their useful life (OECD, 2014).

In the EU, the first directive on WEEE (Directive 2002/96/EC) came into effect in 2003. Revised legislation entered into force in 2012 (Directive 2012/19/EU) and became effective in 2014 (European Commission, 2003; Europen Commission, 2012). The new directive is design to prevent or reduce the negative environmental impacts of the generation and management of WEEE and regulate resource use by drawing on EPR and targets to be transposed and met by EU member-states (European Commission, 2015; Europen Commission, 2012; Véronique Monier; Mathieu Hestin; Jérémie Cavé; Ilse Laureysens; Emma Watkins; Hubert Reisinger; Lucas Porsch, 2014).

As for hazardous substances, Directive RoHS 2011/65/EU came into effect in 2013. It sets the maximum values tolerated for some heavy metals and polybrominated flame retardants, and applies to a variety of EEE (Europen Commission, 2017).

The European Commission's new Circular Economy Action Plan proposes measures to be applied throughout product lifecycles, promoting the circular economy and sustainable consumption, and assuring that the resources utilized are maintained within the EU economy as long as possible. The action plan proposes several initiatives covering the whole life cycle, from the design and manufacture of products to their consumption, repair, reuse, and recycling, reintroducing resources into the economic cycle. For EEE, the plan proposes the creation of an initiative to extend the useful life of products by enhancing the possibilities for reuse and repair and also increasing the capacity for upgrading components and software in order to avoid premature obsolescence (European Commission, 2019, 2017).

Alongside local policies, there are also cross-border agreements, such as the Basel Convention, an international treaty designed to reduce the movement of hazardous waste between nations. The treaty also envisages minimizing the quantity and toxicity of waste generated to assure its environmentally friendly management as close as possible to the point of generation (UNEP, 2020).

1.4 Patent Documents

Patent documents are assets that represent industrial property, an indicator of R&D performance

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and a source of technological information, which, when channeled into the market, generates innovation. These documents can be seen as a source of knowledge transfer and as providing support for policymakers, favoring promising technologies (Aldieri et al., 2020; Lee and Lee, 2019).

The information obtained from patent documents can be used to map certain aspects of the dynamic of innovation processes, such as research cooperation, the spread of technologies, business strategies, leadership or positioning in a given area, market strategies, etc. The choice of where to file a patent application is made according to its market potential for the company. Variables such as cost, protection received, and risks are considered when filing a patent. The number of priority patent applications a country receives is indicative of the attractiveness of its patenting process, as well as general characteristics like the size and relevance of the market for that technology. Graham et al. (2002) provide evidence that patents that belong to large international patent families are more strongly associated with economic value. The geographic scope of protection provided by a patent is a strategic decision, but also a value indicator. When a patent applicant requests protection for their invention abroad, this already constitutes a sign of economic value, commercial potential, and greater market coverage for the invention (Graham et al., 2002; OECD, 2009).

Patent documents are indexed using the International Patent Classification[1] (IPC), which classifies them per area of knowledge, making their retrieval easier. Furthermore, the IPC means patent documents can be organized in such a way as to facilitate access to the information they contain. The IPC has been in use since 1975 and establishes a common classification for patents for inventions, which is divided into eight main sections, A to H. These sections are then subdivided hierarchically into subsections, classes, subclasses, groups, and subgroups (International Patent Classification (IPC), n.d.).

Patent records can be used to identify the companies and countries involved in developing electronic equipment and the solutions proposed to reduce the problems caused by the high demand for and disposal of EEE.

2. Methodology

A patent document search was conducted to ascertaining the existence of more sustainable technologies using new raw materials, different processes and designs, projects to extend equipment's useful life, as well as the technologies developed for recycling EEE when they are disposed of.

The equipment considered for this study was: mobile devices such as cell phones, smartphones, laptops and notebooks, tablets, smart watches, LCDs and CRT screens (for monitors and television sets), printed circuit boards (PCBs), integrated circuits, and thin-film integrated circuits. These products were chosen because they are in high demand on the market, they quickly become obsolete, since updated products are constantly being launched, and they often have a complex design, limited modularity, and are hard to disassemble. PCBs were included in

[1] Details on the IPC system can be accessed at: https://www.wipo.int/classifications/ipc/

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this study because they are a constant presence in EEE and are very heterogeneous in their composition, appearing in different shapes, sizes, colors, and compositions, while also being very complex to recycle because of how they are made.

Patent documents were searched on the commercial platform Derwent Innovation, run by Clarivate Analytics, a company that provides a subscription service for the research of different kinds of documents, such as scientific articles and patent records. The time period encompassed by the search ran from the 1970s, when the first patent applications were filed in this area, until the end of 2017. This latter date is because of the confidentiality period, as well as the time it takes to index documents on the database.

The search strategies were developed from the combination of terms that characterize electronic equipment, electronic waste, circular economy, post-consumption and terms related to the EEE of interest, as shown:

- Group I: terms to describe the electronic equipment, such as “electronic equipment”, “electronic device”, and “electronic component”;
- Grupo II: terms to describe electronic equipment waste such as “electronic waste”, “weee” and “e-waste”.
- Group III: terms related to the circular economy focused on the beginning of the life cycle of electronic equipment, so that the use and end-of-life of products are facilitated, less polluting, or more economically attractive, such as: design for disassembly, design for environment, design for recovery, design for recycling, design for sustainability, durable use, e-product design, easier disposal, easy or easier disassembly, easier reuse, energy efficiency, green design, manual disassembly, lean design, life cycle thinking, low environmental impact, reduction energy user, reduction toxicity, regenerative design, reparability, restricted hazardous substances, sustainable, toxicity, waste reduction, cradle-to-cradle;
- Group IV: terms related to recycling process such as: reclaiming, reclamation, recovery, scrap, garbage, trash, waste, recycling, disposal, decontamination, dismantling, disassembly, end-of-life.
- Group V: terms related to the equipment of interest and the IPC codes for the different kinds of EEE (see Table 1).

The search was divided into two blocks and was performed from the following combinations:

- Block I - Development of electronic equipment: Group I + Group III + Group V

- Block II - Post-consumption: End of life: Group I + Group II + Group IV + Group V

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Table 1 - Classifications used in the search for patent documents (WIPO, 2020).

International Patent Classification	
B09B	Disposal of solid waste
G02F	Devices or arrangements, the optical operation of which is modified by changing the optical properties of the medium of the devices or arrangements for the control of the intensity, color, phase, polarization or direction of light
G06F	Electric digital data processing
G09G	Arrangements or circuits for control of indicating devices using static means to present variable information
H01L	Semiconductor devices
H02J	Circuit arrangements or systems for supplying or distributing electric power; systems for storing electric energy
H04M	Telephonic communication
H04N	Pictorial communication
H05B	Electric heating
H05K	Printed circuits; casings or constructional details of electric apparatus; manufacture of assemblages of electrical components

Once the documents were retrieved, the duplicates were eliminated, then the information was refined as shown in Figure 1.

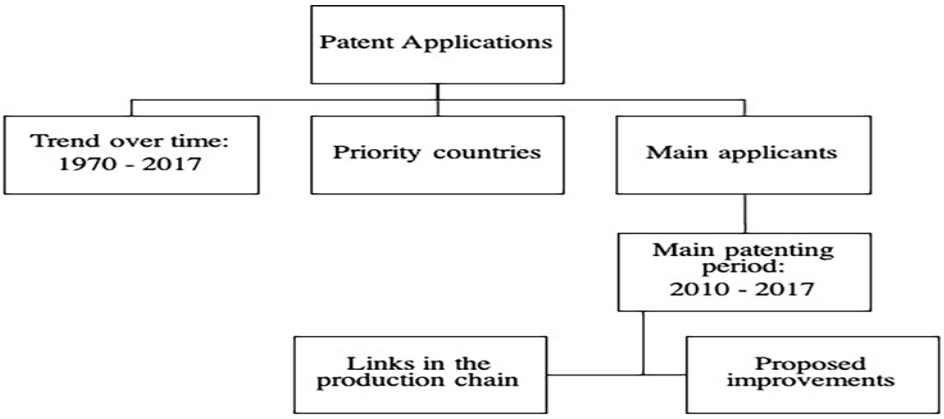

Figure 1. Information extracted from patent documents and analyses conducted.

The following links were considered in the production analysis:

- raw materials: documents related to the variables that compose a given EEE, such as metals, plastics, ceramics, components, other materials and processes for obtaining electronic equipment;
- systems development: documents concerning processes, systems, and software to improve the functionalities of electronic equipment;
- final products: documents related to electronic equipment per se;
- post-consumption: documents related to processes and equipment for the end of the useful life of electronic equipment.

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The "raw material", "system development" and "product" links belong to Block I - Development of electronic equipment, while the "post-consumption" link is considered to belong to Block II. After the analysis of the production chain, the solutions the companies were seeking to provide with their inventions were identified, as well as whether these were connected to the development of more sustainable electronic equipment.

3. Results and Discussion

3.1 Trends over time in patenting for EEE

The patenting trends demonstrate how new technologies started to be developed tentatively as of the 1970s, starting to rise more significantly as of the 1990s, albeit still in relatively low numbers. It was only at the turn of the century that research into new technologies really took off. As shown in Figure 2, at the beginning of the 21st century, the development of technologies grew strongly, mainly in the development of new EEE and their respective manufacturing processes.

The search identified 3238 patent documents dating from 1970 to 2017. A total of 2594 (80%) geared to the development of electronic equipment and 644 (20%) geared to the post-consumption of EEE. The 120% leap in patent applications filed in 2003 in comparison to 2002 is indicative of industry's interest in developing new technologies related to the development of electronic equipment, even if since then there have been some slight reductions year-on-year.

It is important to note that 61% of the documents geared to the development of EEE and 65% of the documents were related to the post-consumption of EEE were filed from 2010 to 2017. During this period, it was observed that in 2015 there was an increase of 91% in the number of patent applications filed for post-consumer EEE.

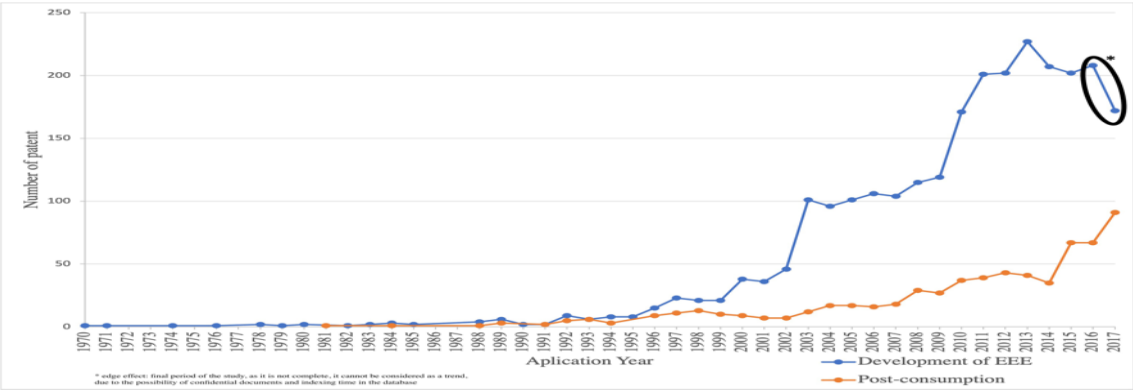

Figure 2. Temporal evolution of patenting.

3.2 Priority Countries

The patent applications geared to the development of EEE and dating from 1970 to 2017 were filed in 32 countries, which the main ones are USA, Japan and China. As the patent applications to the post-consumption of EEE, in the same period, were filed in 27 countries. For both, the 6

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countries that received the most filings of patent applications are responsible for more than 88% of all filings made in the period.

The patent applications retrieved from the search for Block I – Development of EEE were filed mainly in the USA, followed by Japan, China, South Korea, Taiwan and Germany, as shown Figure 3. Japan was the country with most priority filings in the 1990s but was overtaken by the USA in the subsequent decade, which saw a significant increase in patenting as of 2010. Similar growth rates can be seen elsewhere, such as South Korea, Taiwan, and China, which will likely overtake Japan in the total number of priority filings in the areas of interest soon. Figure 3 also shows that the USA commands a significant proportion of all the protected intellectual property in this area in the world, accounting for 39% of all the patent filings, followed by Japan, with 19%, and China, with 17%.

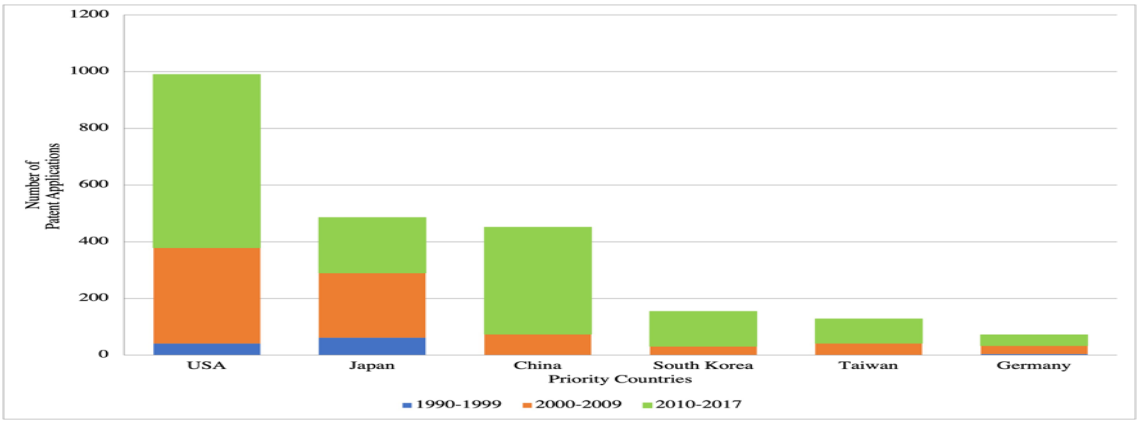

Figure 3. Priority countries for filing patent applications – Development of EEE.

The patent applications resulted from the search for Block II – post-consumption were filed mainly in the China, followed by Japan, USA, Germany and South Korea, as shown in Figure 4. To the applications to post-consumption Japan was also the country with most priority filings in the 1990s and the 2000s, but in this case, Japan was overtaken by the China in the subsequent decade, which saw a significant increase in patenting as of 2010. For the patent applications geared to the post-consumption of EEE, China is the country that commands a significant proportion of all the protected intellectual property in this area in the world, accounting for 36% of all the patent filings, followed by Japan, with 25%, and USA, with 13%.

This scenario is consistent with the level of interest of countries that have considerable demand for electronic equipment, host the headquarters of major transnational corporations, have a large technology manufacturing industry, and/or a robust intellectual property culture (IP5 co-operation, 2020).

The USA, which received the most priority patent applications for technologies geared to the development of EEE, has not present the same outcome for technologies geared to the post-consumption of EEE. This could be explained because, despite being one of the largest consumer markets in the world, the USA does not have a well-defined recycling policy and is known as an

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exporter of waste to less developed countries, which can make the country less attractive for the development and implementation of recycling and material recovery technologies.

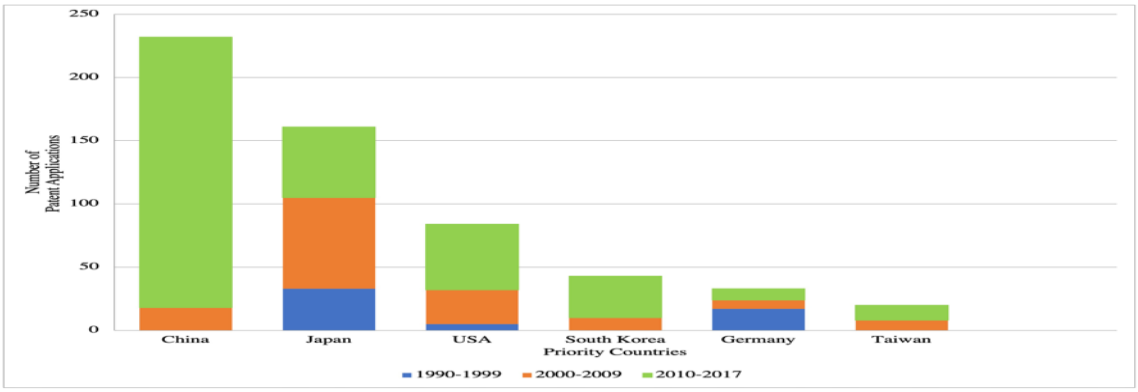

Figure 4. Priority countries for filing patent applications – Post-consumption.

3.3 Main patent applicants

The patent documents identified in the search reveal that many companies engage in technologies to the development of electronic equipment (Block I), insofar as over 3000 companies filed at least one patent application between 1970 and 2017. For study purposes, the applications filed by companies with more than 30 inventions were analyzed, jointly accounting for 519 patent documents, or 20% of all the documents identified in the search.

The leading patent applicants are companies headquartered in USA (55%), while the other leading applicants are headquartered Asia (South Korea, Japan, and Taiwan), as shown in Table 2. On average, 68% of technologies were developed between 2010 and 2017, which is consistent with the overall trend in patenting in the area (Figure 2). All companies chose to file their priority patent applications in their home country (Figure 3).

Table 2 - Patent applications made by the leading applicants – Development of EEE.

Company	Headquarters	Total no. of filings	Filings in 2010-2017	Leading priority countries	Filings in other countries (2010-2017)
Samsung	South Korea	84	77 (92%)	South Korea	88%
Hon Hai	Taiwan	71	43 (61%)	China	88%
SEL	Japan	68	55 (81%)	Japan	95%
IBM	USA	73	46 (63%)	USA	15%
Apple	USA	58	49 (84%)	USA	29%
Sony	Japan	47	21 (45%)	Japan / China	81%
Cadence	USA	40	17 (43%)	USA	12%
Intel	USA	43	38 (88%)	USA	63%
Microsoft	USA	35	20 (57%)	USA	45%

In the period between 1970 and 2017, almost 900 applicants filed at least one patent application geared to the post-consumption of electronic equipment (Block II). For study purposes, the

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applications filed by companies with more than 5 inventions were analyzed, jointly accounting for 108 patent documents, or 16% of all the documents retrieved in the search.

As shown in Table 3, the leading patent applicants are headquartered in Asia, in countries such as Japan (50%), China (33%), South Korea (8%), and Taiwan (8%). On average, 58% of technologies were developed between 2010 and 2017, which is consistent with the overall trend in patenting in the area (Figure 2). All companies decided to file their priority patent applications in their home country (Figure 4). From the Figure 4, it would be expected that american companies would appear among the main applicants, however, north american applicants with technologies geared to post-consumption are very diffused. Similar behavior is found for patent applications filled in Germany both for development of EEE and for the technologies of post-consumption of electronic equipment.

Table 3 - Patent applications made by the leading applicants – Post-consumption.

Company	Headquarters	Total no. of filings	Filings in 2010-2017	Leading priority countries	Filings in other countries (2010-2017)
Lenovo	China	12	12 (100%)	China	33%
Sharp	Japan	12	3 (25%)	Japan	33%
GEM CO	China	11	10 (91%)	China	0%
Samsung	South Korea	10	7 (70%)	South Korea	57%
Panasonic	Japan	10	1 (10%)	Japan	0%
Shenwu Technology	China	9	9 (100%)	China	0%
Hon Hai	Taiwan	9	5 (56%)	China	100%
Pan Pacific Copper	Japan	8	4 (50%)	Japan	25%
Dowa	Japan	8	2 (25%)	Japan	0%
Beijing University of Technology	China	7	6 (86%)	China	0%
Mitsubishi Materials	Japan	7	3 (43%)	Japan	67%
Toshiba	Japan	5	2 (40%)	Japan	0%

3.4 Patent applications made by the leading applicants per link in the production chain

The reading and analysis of patent applications filed between 2010 and 2017 allowed for the categorization of inventions in the links of the production chain.

The most effort of companies is geared to the development of new materials, manufacturing processes, new components and the different designs for electronic equipment, indicating a focus on the start of the production process, which is what was expected, considering the search strategy used, as can be seen in Table 4. The development of systems and software in the manufacturing of EEE is the link in the chain with the second most inventions, although for Cadence, IBM, Microsoft and Lenovo this is the link where most of its research efforts are focused.

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Claims for new products (e.g., smartphones, computers, tablets, PCBs, screens, and smartwatches) were not expected in any significant number given that most of these products are assembled by combining different inventions and technologies that can be patented individually. The documents classified as final products were mainly ones for PCBs and liquid crystal displays (LCDs). Although not many patents for final products were expected, it is important to record the few that were retrieved.

Table 4 - Patent applications made by the leading applicants in the development of EEE per link in the production chain.

Applicant	Link in Production Chain		
	Raw Materials	Systems development	Final Products
Samsung	68%	21%	11%
Hon Hai	83%	14%	2%
SEL	98%	2%	-
IBM	18%	80%	2%
Apple	57%	37%	6%
Sony	71%	14%	14%
Cadence	-	100%	-
Intel	71%	14%	-
Microsoft	25%	75%	-
Lenovo	17%	75%	8%
Sharp	50%	50%	-
Toshiba	100%	-	-

In the study of patent applications geared to the post-consumption of EEE, the inventions were divided into documents geared to recycling processes and documents geared to recycling equipment, as shown in Table 5. Among the main applicants, it is observed that GEM CO, Shenwu Technology and Beijing University of Technology put most of their efforts on the development of recycling equipment, while Sharp, Panasonic, Pan Pacific Copper, Dowa, Mitsubishi Materials and Toshiba put most of their efforts on developing recycling processes.

Table 5 - Patent applications made by the leading applicants in the post-consumption of EEE per link in the production chain.

Applicant	Link in Production Chain – post-consumption	
	Process	Equipment
Sharp	100%	-
GEM CO	10%	90%
Panasonic	100%	-
Shenwu Technology	33%	66%
Pan Pacific Copper	100%	-
Dowa	100%	-
Beijing University of Technology	33%	67%
Mitsubishi Materials	100%	-
Toshiba	100%	-

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3.5 Improvements proposed in the patent applications filed by the leading applicants

3.5.1 Improvements proposed in the patent applications geared to development of EEE

The technical solutions or improvements that documents geared to the development of EEE present are efficiency, energy consumption, assembly and disassembly, durability, manufacturing processes, usability and combinations thereof, as shown in **Error! Reference source not found.**.

The efficiency improvements are designed to make equipment quicker or improve its processing capacity. There were also efficiency gains cited in relation to smarter energy consumption or a longer battery life. Equipment design improvements are geared to making it more attractive or easier to assemble and disassemble both in industrial processes (inventions for machines) and in the structure of equipment, so it can be assembled and disassembled more quickly, more easily, or more cheaply, which is also helpful for repairing devices that would normally be discarded.

Inventions related to durability are designed to increase the useful life of the equipment or its battery. Inventions related to reducing the manufacturing costs or improvements in production processes (time, cost, complexity) were observed. Inventions related to usability are designed to improve user-device interaction by means of components, materials, or interfaces that make the equipment more intuitive, easier to use, more attractive or ergonomic, and thereby improve the user's experience. Other improvements cited, albeit in smaller numbers, are ease of repair, use of fewer parts (e.g., no screws), less polluting processes and components, miniaturization and modularization of electronic equipment.

3.5.2. Improvements proposed in the patent applications geared to post-consumption of *EEE*

The technical solutions or improvements that documents geared to the post-consumption of EEE present are efficiency, less polluting and energy consumption in the recycling process and other improvements applied in combination with less polluting processes, with less toxicity, easier-to-operate equipment, non-destructive processes, processes focused on valuing WEEE. These improvements can come from process improvements or from equipment that result in better processes, as shown in **Error! Reference source not found.**. Improvements in efficiency in the recycling process aim at faster processes, with higher yields, lower costs, recovery of noble metals, less polluting and/or toxic processes, obtaining materials with high purity content, energy efficiency and non-destructive processes. Also, the development of equipment for recycling EEE was retrieved. These machines can present constructive improvements, lower costs, ease of operation or provide process improvements.

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Table 6 - Improvements proposed in the patent applications filed by the leading applicants to the development of EEE.

Improvements proposed / No. of documents	Samsung	Hon Hai	SEL	IBM	Apple	Sony	Cadence	Intel	Microsoft	Lenovo	Sharp	Toshiba
Efficiency	20	6	8	23	7		10	3		4	2	
Efficiency + Energy Consumption	8	2	12	5	7	6		7	2	2		
Energy Consumption	6	4	4	4	2			12				
Efficiency + Other	14		13					3	4	2		
Durability + Other	10		4		4				3			
Assembly + Disassembly		19										
Disassembly + Other	5	8			3							
Production cost	17											
Manufacturing Process + Other	10	2	5									
Usability + Other	5					3		3	4			
Energy Consumption + Other	8	1						3	3			
Usability				3	2		2	3	4			
Efficiency + Energy Consumption + Usability					9	2			2			
Assembly + Other		4			4	3						
Efficiency + Usability	2				3		3	3				
Usability + Energy Consumption	3				6			2				
Design + Other	8		4			3						
Weight/Size + Other	8											
Less effluent in the process												1

Table 7 - Improvements proposed in the patent applications filed by the leading applicants to the post-consumption of EEE.

Improvements proposed / No. of documents	Sharp	GEM CO	Panasonic	Shenwu Technology Group Corp	Pan Pacific Copper	Dowa	Beijing University of Technology	Mitsubishi Materials	Toshiba
Efficiency in the Recycling Process	3	2	1	2	2				
Efficiency in the Recycling Process + Other	3							2	
Efficiency in the Recycling Process + Less polluting process + Ease of equipment operation							2		
Less polluting recycling process + Less toxicity + Non-destructive process + Ease of operate equipment							2		
Less polluting recycling process + Less waste	2								
Less polluting recycling process + Other	3	3							
Energy consumption in the Recycling Process		2							
Energy consumption in the Recycling Process + Valorization of WEEE		1							
Efficiency in the Separation Process					1				
Noble Metal Recycling Process						1			
High purity products + Other						1			
Energy Consumption + Noble Metal Recycling Process									1

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4. Conclusions

This study presented an analysis of the development of technologies for electronic equipment and their recycling process, based on the concepts of the circular economy. The technological developments proposed by the leading patent applicants related to this topic between 2010 and 2017 were studied in more detail. The companies with most patenting activity between 2010 and 2017 are in Asia (Taiwan, Japan, and South Korea) and the USA. The inventions geared to development of EEE are mainly for the raw materials, production processes, product design, and the development of new components. The inventions geared to post-consumption of WEEE are mainly for efficiency in the recycling process, less polluting recycling processes and energy consumption. The priority countries are also the countries responsible for most production and exports of EEE and with some policy geared to resource conservation and the recycling of waste products. Despite the existence of some specific legislation, electronic equipment development is not yet conceived with a circular economy mindset, which would make post-consumption stages more efficient and would foster a continuous cycle. Along with government support through lawmaking and law enforcement, many challenges still need to be overcome, such as the lack of logistical support for WEEE, the inadequate disposal of waste, informal recycling processes, and a shortage of recycled raw materials. Stimuli from external actors, such as consumer groups, governments, and companies working in the collection and recycling of materials, could influence the pace at which manufacturers create new inventions and build the cyclical use of resources into their product design.

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