BIBLIOMETRIC ANALYSIS OF ELECTRICAL AND ELECTRONIC EQUIPMENT PRODUCTION AND CONSUMPTION IN THE CONTEXT OF THE CIRCULAR ECONOMY

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Abstract
The paper aims to highlight the most relevant elements that appear at the intersection of two concepts: the circular economy and electrical and electronic equipment (EEE), as they are reflected in the mainstream of scientific publications to date. This approach is possible through the use of a bibliometric study, following which current trends and new possible perspectives and research directions could be identified to contribute to the promotion of circularity in the production and consumption of EEE. The bibliometric study also involves the temporal and geographical analysis of scientific production, the semantic analysis of keywords with their graphical representation, and the relationship among them, based on the use of specialised software (VOSViewer and Citespace). The main results refer to the existence of four clusters, grouped according to keywords with a frequency of occurrence greater than 10, which refer to EEE waste management, circular economy, material recycling, and environmental management. Regarding the intensity of keyword use, the top three places are *China*, *product*, and *urban mining*. In the end, the conclusions of the study are highlighted, including the grouping of keywords into thematic clusters, the identification of three periods that have been able to stand out so far in scientific research in the domain. As for the limits of the research, they take into account the database that was subjected to the analysis (in the present paper, Web of Science), the software used, the writing language of the scientific production, and the analysis interval. The article concludes with future research directions.

Keywords: Circular economy (CE), consumption of electrical and electronic equipment, waste of electrical and electronic equipment (WEEE), electrical and electronic equipment (EEE), production of electrical and electronic equipment, bibliometric analysis.

JEL Classification: Q53

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Introduction

Social and economic development is an internationally recognized aspiration. In addition to their positive effects, negative consequences on the natural environment can also be observed, determined by a sharp increase in the consumption of raw materials and the generation of waste. This trend has become even more evident in recent decades.

The technological revolution, urbanization, and increase in population living standards have inevitably led to the continuous increase in the demand for more sophisticated electrical and electronic equipment (EEE), as well as to the decrease in their lifespan (Zhang et al., 2019). Electrical and electronic equipment waste (WEEE) is currently the fastest growing waste stream (Singh et al., 2021). On the one hand, WEEE have an economic value and, on the other hand, could represent a threat to the environment and public health (Zhang et al., 2019). Unfortunately, despite substantial efforts in this regard, only about a fifth of the amount of WEEE is collected and recycled (Forti et al., 2020).

The current situation is serious enough to justify the identification of solutions for the sustainable management of WEEE (Popa and Albu, 2019; Wang et al., 2022a), to which also solutions applicable in the design and production stages of EEE should be added. In this context, the circular economy (CE) can represent a potential solution, allowing further economic development, together with reducing the pressure on the natural environment (Velenturf and Purnell, 2021).

From both a theoretical point of view and its concrete application methods, CE enjoys a growing interest from the general public, business, and nongovernmental organisations concerned with the protection of the environment, as well as from supranational structures (Velenturf and Purnell, 2021). Responding to this growing interest, an impressive number of scientific papers have been published in recent decades. It is relevant to mention in this regard that a simple query of the Web of Science Core Collection database (Clarivate, 2022) returned more than 14,500 results, of which more than 2,700 were published in 2022.

Following this interest, several bibliometric analyses have been published to date that have tried to illustrate the state of knowledge regarding CE (Homrich et al., 2018), the application of its principles in different fields, such as retail (Uribe–Toril et al., 2022) and waste management (Tsai et al., 2020; Negrete-Cardoso et al., 2022), as well as elements of convergence with other topical concepts such as sustainability (Geissdoerfer et al., 2017) and digitalisation (Liu, Liu and Osmani, 2021). A series of similar studies considered only the bibliometric analysis of published works on topics dealing with WEEE (Zhang et al., 2019), WEEE management (Andrade, Romanelli and Pereira-Filho, 2019), food, agricultural, textile, plastics and electrical and electronic waste management (Wang et al., 2022a) or the effects of WEEE generation and recovery on soil, health and the environment (Maphosa and Maphosa, 2022).

Furthermore, bibliometric analyzes considered only the link between CE and WEEE (Singh et al., 2021), sustainable product design (Mesa, Esparragoza and Maury, 2019), and sustainable production (Gundu et al., 2022). As can be seen, despite the growing interest in the WEEE literature and CE, the research published to date rarely addressed the issue of the production and consumption of EEE in an integrated manner, from the perspective of CE. Therefore, the purpose of this paper is to present a systematic map of the state of knowledge regarding the intersection of CE and EEE concepts, as reflected in academic publications to date. For this reason, it will be possible to identify current trends, as well as new possible

perspectives and research directions that contribute to the promotion of circularity in the production and consumption of EEE.

The main concepts used in this research refer to the circular economy (also known as circularity) that can be defined as the economy based on the principle of circularity, which refers to reuse, reproduction, and recycling (Mihai et al., 2018); production, consumption, and waste of electrical and electronic equipment; scientific production (all articles, books, book chapters, and works presented at conferences on a certain scientific topic), semantic clusters (which represent the association of some words in groups, based on their semantic meanings), and the intensity of phrase use, which represent an accelerated (sudden) increase in the frequency of occurrence of certain phrases within a specific topic (Kleinberg, 2002).

In the following, the research will focus on the analysis of the theoretical framework regarding electrical and electronic equipment waste from the perspective of the circular economy; the detailed presentation of the main research stages (identification of the optimal database for the analysis, establishment, and analysis of scientific production); analysis of the results obtained through the use of specialized software (VOSViewer and CiteSpace), as well as the presentation of conclusions, research limits, and future directions of analysis.

1. Theoretical framework

1.1. WEEE - A Global Challenge

Global economic growth is inextricably linked to the production and consumption of EEE. Currently, EEE have become indispensable for economic activities, education, health care, and even for the daily life of the population (Forti et al., 2020). Among the factors enabling EEE production and consumption growth can be mentioned: the digital transformation of society, the increase in the purchasing power of the population, urbanization, etc. For example, it is estimated that in 2020 alone, online commerce increased by 16% (CEP, 2021). In addition to the positive effects on society and the economy, the production of EEE can also be associated with a high consumption of nonrenewable raw materials, electricity consumption, but also with negative effects of WEEE, resulting at the end of the life cycle of EEE (de Freitas Juchneski and de Souza Antunes, 2022).

A recent report (Forti et al., 2020) estimates that in 2019, globally 53.6 Mt of WEEE were generated, which represents 7.3 kg per capita. Until 2030, it is estimated that this amount will increase annually by approximately two Mt, reaching 74 Mt in 2030 and 120 Mt in 2050 (CEP, 2021). These estimates become even more alarming if we compare them with data on WEEE collection and recycling. Therefore, in 2019, 9.3 Mt were collected and recycled, which represents only 17.4% of the total generated WEEE. Although efforts have been made in this regard in previous years, between 2014 and 2019 the amount of WEEE increased by almost two Mt annually, while the amounts collected and recycled only increased by almost 0.4 Mt (Forti et al., 2020).

The effects of the COVID-19 pandemic on socio-economic activity at the global level are also expected to manifest themselves in the production of WEEE. Although some data show that EEE consumption has decreased in the first three quarters of 2020, which will also be reflected in a reduction in WEEE, this reduction will not manifest itself uniformly, but by 30% for underdeveloped and developing countries and only by 5% in developed countries (Baldé and Kuehr, 2021). Moreover, other authors (de Freitas Juchneski and de Souza

Antunes, 2022) even estimate an increase in EEE consumption during the pandemic period, due to the increase in the share of organisations that have adopted (and still maintain to some extent) the telework regime, online educational activities, online commerce, etc. Therefore, it can be seen that after the decrease in the first months of the pandemic, the consumption of EEE and the waste it generates began to increase in the medium and long term, which is expected to deepen the gap between production, collection, and WEEE recycling.

1.2 CE solutions for the production and consumption of EEE

In the current context of increasingly limited resources and the continuous plurality and diversification of needs, the issue of CE takes on particular importance (Skvarciany, Lapinskaitė and Volskytė, 2021). The term CE was used for the first time at the beginning of the millennium and denotes the type of economy whose purpose is to "maintain the value of products, materials and resources for as long as possible by returning them into the product cycle at the end of their use, while minimizing waste generation" (Eurostat, n.d.). From this point of view, it should be specified that within CE, products are designed in such a way (from the design phase) that, on the one hand, their production generates the economy of raw materials and, on the other hand, offers the possibility of reducing the quantity of waste (at the time of their removal from use).

Another definition of CE is given by EU Monitor (n.d.): "The circular economy is a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible". According to this definition, it can be observed that in the CE the products offered on the market have a longer life cycle than in the traditional economy. The definition also refers to recycling, which has experienced rapid growth especially with technological innovations and the development of new applications of EEE (Marinescu, Ciocoiu and Cicea, 2016). The latter, and more specifically the waste resulting from their use, present a major risk to the environment considering the enormous amount in which they are found (Marinescu, Ciocoiu and Cicea, 2015). Some countries are believed to use recycling in order to protect themselves from external dependence and price fluctuations of natural resources (Önder, 2018).

Since 2012, the Ellen MacArthur Foundation has identified three ways that can contribute to the transition to a CE, as well as contextual factors that can accelerate these changes (Ellen MacArthur Foundation, 2015): (1) the circular design and manufacturing of products, so that the recovery and reuse of materials is not considered only at the end of their useful life, but from the stage of their design and manufacture; (2) new business models based on providing the functions of products designed to be reused or shared by users rather than actually selling them to consumers; (3) collection and recycling of products after they have reached the end of their useful life, in order to preserve and capitalize on their economic value.

Moreover, contextual factors such as: (1) education for the training of specialists who possess the necessary skills in the new economic paradigm, (2) access to financing, which favors capital investments and those in RD&I, (3) the development of collaborative platforms between business and other stakeholders, and (4) changes in the tax system, can favour the transition to the CE (Ellen MacArthur Foundation, 2015).

These ways of accelerating the transition to CE have inspired further research, some of which have also focused on the field of EEE. For example, adopting a qualitative approach, Pollard

et al. (2021) propose an innovative framework regarding the development and implementation process of a business model in the context of CE (CEBMI), adapted to the specifics of EEE producing companies. The proposed framework includes five interrelated stages and the activities that each of them entails. The starting point of CEBMI is the organization's strategy by transforming the current objectives into objectives adapted to the principles of CE, so that they can then be transposed into the organisation's internal processes. Opportunities, threats, and the legal framework that could influence the circularity of the business model are also considered, so that finally a series of circularity indicators specific to the EEE field are proposed to help measure and evaluate the results obtained.

In a more holistic approach, based on the systematic review of the literature published on this topic, Bressanelli et al. (2021) analyse the relationships between the enabling factors (among which digitisation, the active role of users and government interventions stand out), the levels of action (respectively, the circular design of products, life cycle management, and innovative business models) and the potential economic, social and environmental benefits of the transition to the CE in the field of EEE. However, the adoption of CE principles in the field of EEE may encounter numerous obstacles/challenges. Bressanelli, Perona and Saccani (2019), analysing multiple case studies, synthesized these challenges as being associated with:

- the economic and financial viability of companies that adopt business models based on keeping ownership of EEE and offering them only for use, which can be threatened by the difference in time between costs and revenues, but also by the financial risk that they have to assume;
- the market and competition, the main challenge in this category being the possibility of cannibalising a company's existing products by those designed according to CE principles, more durable and with more attractive features for consumers;
- the characteristics of the product, which over time may no longer be in line with fashion trends and consumer preferences;
- some legal or fiscal provisions that may not favour the production and consumption of EEE in accordance with principles of CE;
- uncertainties regarding the logistics of WEEE collection and reuse;
- the difficulty with which EC-compliant EEE can keep pace with other products in terms of technological progress;
- users' behaviour.

Therefore, it can be seen that WEEE tends to become a problem with significant global implications and that the solutions offered by the circular economy can represent a viable answer to its reduction and efficient recovery. Although this issue is widely reflected in the specialised literature, Bressanelli et al. (2020) note that the research published to date is mainly exploratory, impact assessment, and mostly based on a qualitative approach. Also, strategies for the reduction and recycling of WEEE are addressed in particular, and to a much lesser extent those aimed at the design, production and reuse of EEE according to the principles of the circular economy.

2. Research methodology

As we stated previously, the paper aims to analyse the way in which the connection between the circular economy (in all its forms of manifestation) and the production and consumption of electrical and electronic equipment is reflected in the scientific literature. In this sense, we will use a bibliometric approach in such a way that certain patterns and connections between the two basic analysed concepts can be discovered. In this sense, the research involves the inventory of scientific production in close connection with the topic analysed and the identification of relevant aspects related to keywords, the themes of the journals that analysed the topic, the affiliation of the authors, the spatial and temporal distribution, etc., and an analysis of the temporal and geographical distribution of works in the concerned field. Particular attention will be paid to the identification of future trends in the EEE field in the circular economy context, based on the use of the present bibliometric information. These trends are very important because they can capture how the production and consumption of these specific equipment will evolve in the coming period. The research methodology involves going through some well-established stages, considering previous research carried out in the field (Gora, 2020; Cicea and Marinescu, 2021; Wang et al., 2022b; Dima et al., 2022):

a. Identifying the source of information for the collection of scientific production.

In the field of scientific production (articles, conferences, book chapters, etc.) there are four worldwide known data bases, as follows: Google Scholar (owned by Google), Scopus (owned by Elsevier), Web of Science (owned by Clarivate) and PubMed (owned by the National Institute of Health and United States Library of Medicine). Among them, the last database profiles scientific production in the medical field, therefore, with few connections to the analysed topic. Although the largest database (with the highest number of articles / conferences indexed), the Google Scholar database does not provide significant information to carry out a quality research (it indexes both articles published in reference journals in the field and also articles in journals with less international visibility). Given these considerations, we excluded the two databases from the analysis, choosing between Web of Science and Scopus. A brief comparison between the two databases is shown in the table below.

Table no. 1. Comparison between Web of Science and Scopus

Nr. crt.	Characteristics	Web of Science	Scopus
1.	Owner / country	Clarivate / Great Britain & USA	Elsevier / The Netherlands
2.	Release year	1960	2004
3.	Coverage area	The vast majority of domains from 1975	The vast majority of domains from 1996
4.	Number of indexed journals	< 21,000	< 25,000
5.	Number of registrations	< 79,000,000 (core collection) < 171,000,000 (platform)	< 83,000,000
6.	Scientific areas	Multidisciplinary	Multidisciplinary

Source: the authors' conception based on (Gasparyan et al., 2013), Clarivate.com, Scopus.com

When analyzing the information from the previous table, it is obvious that there is a strong similarity between the two databases, making it rather difficult to choose between them. Moreover, both databases cannot be included simultaneously in the research because a large part of the journals are indexed in both Web of Science and Scopus, which would generate a redundancy of records. Taking into account the above, it is obvious that the choice of database does not significantly influence the research results (regardless of the chosen database, in the context where reference journals are indexed in both databases, the results obtained are similar). Taking these into account, the Web of Science database was chosen due to the higher total number of indexed documents compared to the Scopus database.

b. Finding the scientific production that will be the subject of this analysis.

Following the selection of the Web of Science database, it was queried to identify the scientific output to be analysed. The syntaxes used for the concept of circular economy were: *circular economy* and *circularity*; for EEE production and consumption of EEE, the following syntaxes were used: *electrical equipment*, *electrical device*, *electronic equipment*, and *electronic device* and *e-waste*. Following the query, 503 documents were identified that satisfy the query syntaxes. Later, through successive refinements, the final number of analysed documents became 498. The refinements considered:

- limiting the time horizon to the interval 2003-2022 (practically, before 2003, the term *circular economy* is not found in any indexed work, neither in Web of Science nor in Scopus);

- choosing documents written in English (extremely few documents were written in other languages of international circulation, respectively: Spanish two documents, Japanese, Dutch, and Chinese one document each). In the end, the number of selected documents was 498 (in almost all scientific areas covered by the Web of Science database).

c. Analysing scientific production.

For this, the research methodology involves the use of tools specific to the Web of Science database, but also of specialised programs for bibliometric analysis, namely VOSViewer (van Eck and Waltman, 2010; van Eck and Waltman, 2011) and CiteSpace (Chen, 2006; Chen, 2019). Starting from these stages, the bibliometric analysis will focus on the temporal and geographical distribution of scientific production. Afterward, a semantic analysis will be carried out based on the use of specialized software (VOSViewer and Citespace). At the end of the paper, patterns recorded in the scientific field analysed so far and possible future trends will be identified.

3. Results and discussion

The 498 selected documents cover a wide range of types, starting with articles (75.5%), *review* articles (14.65%), conference proceedings papers (10.04%), *early access* articles (3.61%), and book chapters (1.6%). Ranked last, with very low values, there are two types of documents, editorial and abstract material (with 0.2% each). Regarding the temporal distribution of scientific production, it is shown in figure no. 1.

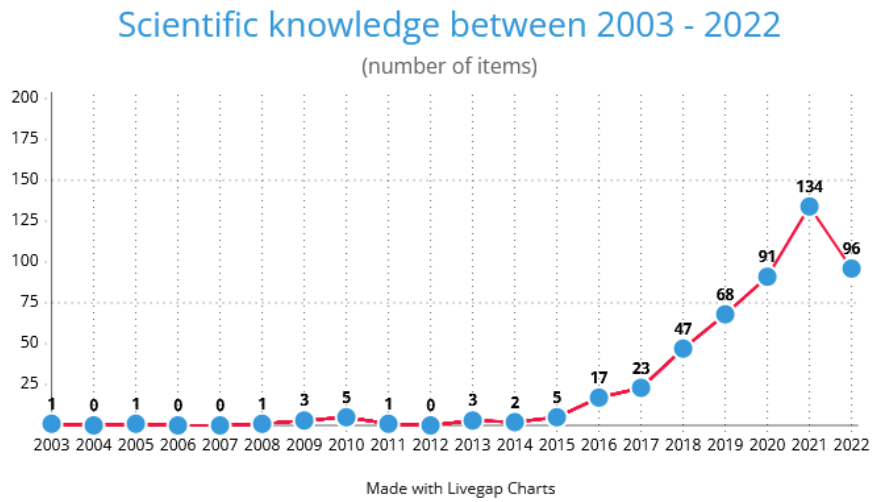
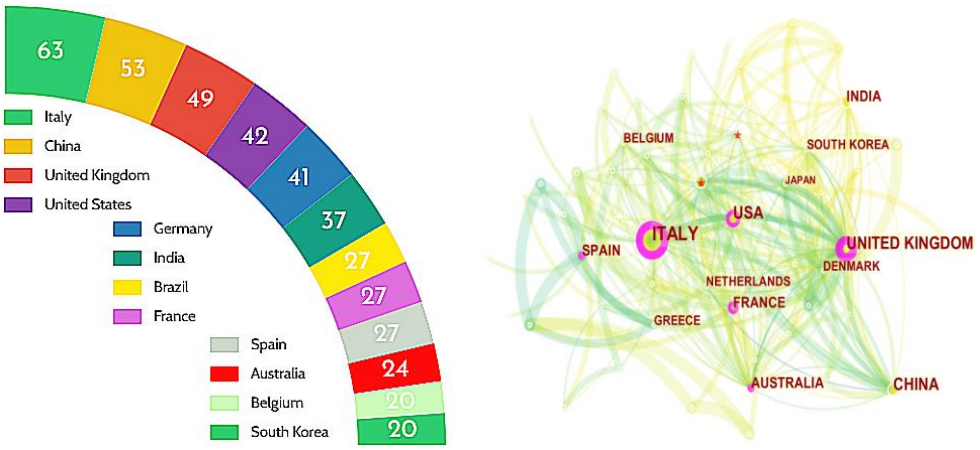


Figure no. 1. The temporal distribution of scientific production
Source: Web of Science and Livegap Charts

When analyzing the information, it can be seen that until 2016, values between 0-3 were recorded annually (with two exceptions, represented by 2010 and 2015 when five documents were recorded each year). Starting from 2016, there is a sharp and constant increase, which demonstrates an awareness of the society regarding the benefits generated by the circular economy on the production and consumption of EEE (we should not be misled by the lower value corresponding to the year 2022, having considered that only the first seven months of this year are considered in the analysis). From a geographical distribution point of view, according to the affiliation of the authors, the scientific production situation is clearly presented in Figure no. 2.



2a. Publication frequency by country *2b. Countries' contribution to the analysed topic*

Figure no. 2. Geographical distribution of scientific production
Source: Web of Science, Livegap Charts, and Citespace

In the previous figure in point 2a, only countries with more than 20 published documents were considered. Based on the presented data, it can be seen that the European Union (represented by Italy, Germany, France, Spain, and Belgium) holds the first place in scientific production, with a total number of 178 documents, far from the second place, represented by China (with 53 documents).

The situation presented in point 2b analyzes the contribution of the countries to the development of the field. From this point of view, one can observe that the United Kingdom, although it has a smaller number of publications in absolute size as compared to Italy (49 compared to 63), they have a greater influence on the analysed field (the United Kingdom has a centrality of 0.34 as compared to Italy which registers a centrality of 0.2). Other high values for centrality were recorded by Australia (0.2), France (0.19), the United States (0.12), and Spain (0.11). Also, in Figure 2b only the countries with a centrality higher than 0.05 were represented.

Also, based on Figure 2b, it should be pointed out that the vast majority of countries have a relatively constant involvement in the research of the analysed topic, over the period 2015 - 2022 (practically, from the moment when scientific production in the field exploded). The exception is India (frequency 37, centrality 0.05), which recorded these values only in the last three years (2019-2022), which illustrates a special interest in this topic among researchers from this country (explainable, in the context in which India is preparing to become the most popular country in the world and where the need to reuse EEE in the context of the circular economy is becoming increasingly important). Finally, also in the same figure 2b, two countries (Brazil and Germany) were presented with a red star, which, although they recorded a high frequency of publications (41 and 27 respectively), did not have an equally relevant contribution to the development of the analysed topic (centrality values below 0.05).

Finally, it should be stated that all the countries presented in Figure 1 (both points a and b) are developed countries, with a high per capita income (which also carries out a research activity supported by numerous specialised research institutes or the university environment), to which are added two booming economies (China and India), also aware of the importance of the production and consumption of EEE in the context of circular economy.

Regarding the semantic analysis of the keywords with the highest number of occurrences in the collection's documents, we present below, in Table no. 2 a selection of the top 20 keywords, based on the strength of the links (given by the number of co-occurrences) they have created with other keywords. We have also included in the table both the number of links created and the number of occurrences (frequency of appearance).

Table no. 2. Keywords included in collection documents

No. crt.	Keywords	Frequency	Links	Total link strength
1	Circular economy	303	72	1282
2	E-waste	147	71	710
3	Management	88	68	499
4	WEEE	94	71	463
5	Recovery	86	66	456
6	Electronic waste	78	68	374
7	Recycling	85	66	369
8	Sustainability	59	67	310
9	Electronic equipment	54	64	306

No. crt.	Keywords	Frequency	Links	Total link strength
10	Reuse	43	58	238
11	Waste management	40	60	224
12	Printed-circuit boards	32	54	204
13	Metals	37	50	192
14	Reverse logistics	32	50	190
15	Life-cycle assessment	30	54	163
16	Extended producer responsibility	25	52	156
17	Collection	23	56	150
18	China	28	51	149
19	Waste electrical and electronic equipment	23	49	142
20	Urban mining	20	44	128

Source: authors with VOSViewer

Figure no. 3 manages to highlight the connections between the keywords, graphically symbolised by the branches that connect various keywords (represented by larger or smaller frames, depending on the number of occurrences in the documents of the analysed collection). The branches are either thinner or thicker depending on the strength of the respective links. For example, a strong link, given by a number of 102 co-occurrences, appears between *circular economy* and *e-waste*, while a weaker link given by a number of 13 co-occurrences appears between *circular economy* and *strategies*.

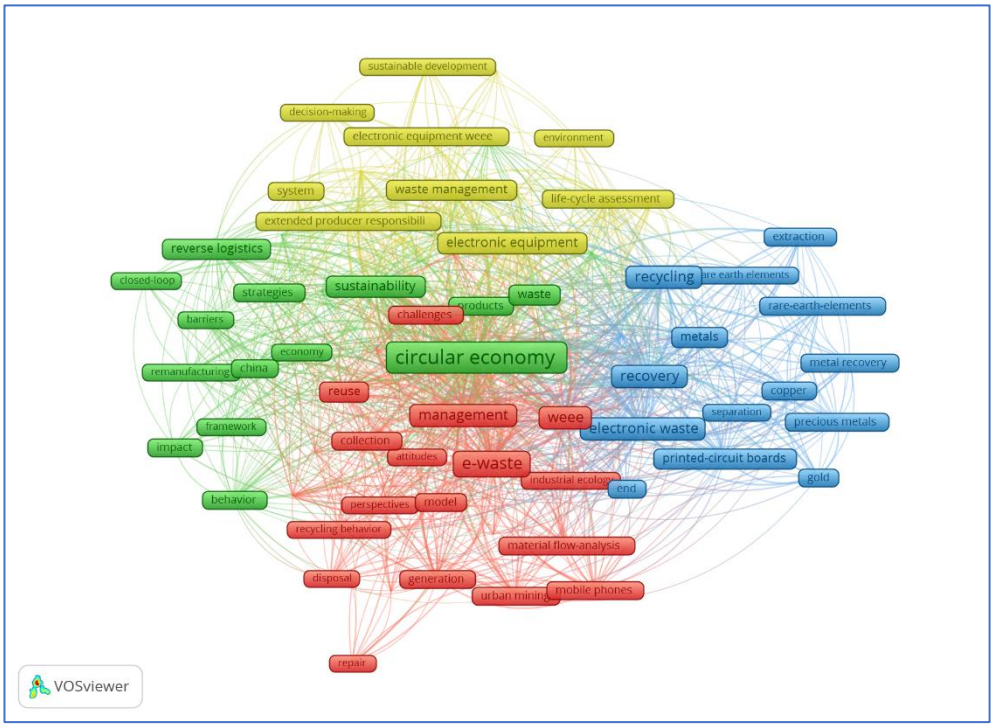


Figure no. 3. Map of links among keywords
Source: authors with VOSViewer

It is necessary to specify the fact that Figure no. 3 contains 73 keywords, each of which has a minimum of ten occurrences in the collection's documents. They were grouped into four clusters according to the distance between them (by positioning them in a two-dimensional plane). The largest cluster includes 26 keywords and is shown in red; it appears to refer to elements of EEE waste management, describing the steps towards a circular economy: *disposal*, *collection*, *repair*, *reuse*, *resource recovery*, *and recycling behaviour*. The second largest cluster is the one represented in green, with 18 keywords. It includes the *circular economy* as the central element with the highest frequency of appearance on the keyword map. It appears to have clustered keywords that this element influences: *impact*, *industry*, *sustainability*, *performance*, *economy*, *behavior*, *waste*, and also elements that it automatically implies, such as: *reverse logistics*, *life cycle assessment*, *strategies*, *remanufacturing*, *closed-loop*. The third cluster, represented by the blue colour, includes 15 keywords that are oriented around the idea of recycling specific EEE components such as certain metals: *copper*, *gold*, *metals*, *metals recovery*, *rare earth elements*, *precious metals*, *extraction*, *separation*, *recovery*, *recycling*. The last cluster according to the number of keywords it contains (14 elements), is shown in yellow and refers to environmental management, with a focus on waste management, product life cycle assessment, as an environmental management technique, to extended producer responsibility as a type of strategy in this area, as well as to the decisions taken for the purpose of sustainable development regarding WEEE.

Regarding the evolution of trends in the field of EEE production and consumption in the context of the circular economy, it is shown in the figure below.

Figure no. 4. Research trends of the analyzed topic.
Source: Citespace

In figure no. 4 the top 20 words, which register high values of intensity (above 1.5), during the analysed time interval. On the basis of the information presented, some suggestive aspects regarding the future prospects of this field can be deduced.

First, the keywords that register the highest intensity (values above 3.0) are *China*, *product*, and *urban mining*. So, it can be said that they have a citation burst. Regarding China, it should be noted that this keyword has the longest period of citation burst (10 years, between 2009 and 2018). Going further with the analysis, we can appreciate that *China* has strong links with other keywords that register high frequencies of appearance (*circular economy, sustainability, recycling*, etc.); worth noting is the identified connection between *China* and *printed circuit boards*, in the context of an economic war between the United States of America and China in the field of microchips and semiconductors. The second keyword that saw a significant increase in citation burst is *product* (including *products*), which also has connections with *circular economy*, *e-waste*, *waste management*, *recycle*, and *recovery*. Finally, in recent years (2020-2022), a new concept has gained particular importance, which is also reflected in the explosion of citations; it is about *urban mining*. The term *urban mine* represents the stock of rare metals abandoned in electrical and electronic products found in a society (Kouichi and Mitsuyoshi, 2011). Consequently, *urban mining* is defined as the process by which raw materials are recovered from various products, buildings, or waste (Kvithyld, n.d.). In other words, in the context in which more and more products of any nature (especially EEE containing rare metals) end up as waste, human communities (cities) have become real mines that must be exploited for the recovery of those materials. From this point of view, the migration trend from the classic mine to the urban mine for a sustainable future is obvious. We are of the opinion that the term *urban mine* will become more and more important (compared to the classic mine) in the context where, based on its exploitation, rational use of resources is achieved, and, very often, it is easier to recover and process raw materials from existing products than the option of extracting from ore.

Secondly, if we look carefully at figure no. 4, we can distinguish three distinct periods that are reflected in the specialised literature, each of them with certain trends and characteristics. The first period (between 2015 and 2017) refers to general aspects of the analysed topic (keywords such as *resource efficiency, environmental impact, recycling*, etc. appear). The second period between 2018 and 2020 already refers to concrete aspects of the production and consumption of EEE in the context of the circular economy (*aluminium*, *precious metal*, *solid waste*, *reverse logistic*). Finally, in the last period (2020-2022), the focus is on the behavioural side of the production and consumption of electrical and electronic products (new terms appear such as *consumer behaviour*, *recycling behaviour*, *barrier*, etc.).

Although, until now, bibliometric analyses have been carried out and addressed the concept of circular economy (Geissdoerfer et al., 2017; Homrich et al., 2018; Liu, Liu and Osmani, 2021) and the application of its principles in different industries (Uribe-Toril et al., 2022), with reference to the stages of design (Mesa, Esparragoza and Maury, 2019), production (Gundu et al., 2022) or management (Andrade, Romanelli and Pereira-Filho, 2019; Tsai et al., 2020; Negrete-Cardoso et al., 2022; Maphosa and Maphosa, 2022; Wang et al., 2022a) of different categories of waste, this research contributes to filling this gap by providing a holistic picture of the application of circularity principles in all stages of design and consumption of an important category of waste generating products – EEE.

Conclusions

Considering the existence of an increased interest in WEEE and the circular economy, but also the need for an integrated approach to the production and consumption of EEE, from the perspective of the circular economy, the purpose of this paper was to highlight the links between the two concepts, through the research carried out in the field, respectively, by analysing the specialized literature with a bibliometric approach, in such a way that certain patterns and connections between the two basic concepts analysed can be discovered.

Following the carried out analyses, the following can be highlighted: (1) although concerns in the field have been reported in the specialised literature since two decades ago, the year 2016 represented a point of awareness of the role that the circular economy has on the production and consumption of EEE; (2) scientific production in this field seems to come mainly from member countries of the European Union, countries with relatively constant involvement in the research of the analysed topic; (3) the map of links between keywords manages to highlight in one of the clusters, very clearly, the steps towards a circular economy; (4) following the analysis of the trends for the concerned topic, three research periods were clearly distinguished: one with an emphasis on general aspects, the second with an emphasis on detailed aspects regarding the production and consumption of EEE in the context of the circular economy, and the third with emphasis on the behavioural side of production and consumption.

As for the limits of the carried out research, they primarily refer to the database used in the analysis (in the present case, Web of Science); taking into account the similarity of the most important databases that register scientific production globally (Web of Science and Scopus), we consider that this limitation does not have a significant influence in relation to the research conclusions. The second limitation concerns the software used in the analysis, namely VOSViewer and CiteSpace. Finally, the last two limitations take into account the writing language of the scientific production (English), as well as the time period under analysis (2003 - 2022). However, as we stated in the paper, all these limitations do not prevent one from obtaining valid conclusions after the research.

Overall, we believe that in the following period of time, the emphasis will be placed more and more on the awareness among the population of the need for a behavior to decrease the amount of waste resulting from EEE. This behaviour will take into account, on the one hand, the reduction of waste (especially by using an EEE as long as possible), and, on the other hand, it will focus on specific ways to recover the materials included in these products.

In perspective, the authors propose as a future research direction to carry out an analysis of how the current global economic situation, characterised by regional military conflicts and the accelerated increase in the price of energy of all types (a situation that is not yet reflected in scientific production) will determine a change or amplification of the trajectory for the production and consumption of electrical and electronic equipment in the context of the circular economy. From this perspective, it could be of real interest to analyse the attitude of consumers towards the solutions offered by the circular economy to reduce electricity consumption, with reference to all stages of the life cycle of EEE. A systematic review of the most relevant works identified through this research can also provide new insights into the production and consumption of EEE.

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