

Dinu, Vasile; Gradinaru, Giani Ionel; Maricut, Alin Cristian; Matei, Bogdan Florin

Article

The Role of Innovation and New Technologies in Closing the Economic Circuit of Electrical and Electronic Equipment

Amfiteatru Economic

Provided in Cooperation with:

The Bucharest University of Economic Studies

Suggested Citation: Dinu, Vasile; Gradinaru, Giani Ionel; Maricut, Alin Cristian; Matei, Bogdan Florin (2023) : The Role of Innovation and New Technologies in Closing the Economic Circuit of Electrical and Electronic Equipment, Amfiteatru Economic, ISSN 2247-9104, The Bucharest University of Economic Studies, Bucharest, Vol. 25, Iss. 62, pp. 12-27, <https://doi.org/10.24818/EA/2023/62/12>

This Version is available at:

<https://hdl.handle.net/10419/281688>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



<https://creativecommons.org/licenses/by/4.0/>

THE ROLE OF INNOVATION AND NEW TECHNOLOGIES IN CLOSING THE ECONOMIC CIRCUIT OF ELECTRICAL AND ELECTRONIC EQUIPMENT

Vasile Dinu¹, Giani Ionel Grădinaru^{2*}, Alin Cristian Maricuț³
and Bogdan Florin Matei⁴

¹⁾³⁾⁴⁾ Bucharest University of Economic Studies, Bucharest, Romania

²⁾ Bucharest University of Economic Studies, Bucharest, Romania and Institute
of National Economy, Romanian Academy, Bucharest, Romania

Please cite this article as:

Dinu, V., Grădinaru, G.I., Maricuț, A.C. and Matei, B.F., 2023. The Role of Innovation and New Technologies in Closing the Economic Circuit of Electrical and Electronic Equipment. *Amfiteatru Economic*, 25(62), pp. 12-27.

DOI: [10.24818/EA/2023/62/12](https://doi.org/10.24818/EA/2023/62/12)

Article History

Received: 25 September 2022

Revised: 6 November 2022

Accepted: 10 December 2022

Abstract

Digitisation and the circular economy open the possibility to ensure efficient products and services development, while promoting the sustainable development of social well-being. Despite being an area with high potential for adopting business models that integrate the perspective of the two concepts, the electrical and electronic sector depends on the opportunity cost that falls under the constraints on rethinking existing industrial processes to reduce non-reusable waste. Therefore, the present study will show the benefits of moving towards a circular model through innovation and new technologies, in accordance with the connection between digitisation and the circular economy at a territorial level. The results will highlight the particularities of the electrical and electronic equipment and the patterns regarding the approach to integrating the two concepts in the same sector, at the level of the EU bloc states.

Keywords: electrical and electronic equipment, circular economy, innovation, new technologies

JEL Classification : C38, L63, O11, O13

* Corresponding author, Giani Ionel Grădinaru – e-mail: giani.gradinaru@csie.ase.ro



This is an Open Access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. © 2022 The Author(s).

Introduction

Whether we refer to a computer or a refrigerator, they all have in common an important aspect to be considered: the major environmental impact of their components that could cause health problems if not reused or recycled. The European Commission has taken the challenge derived from the use of electrical and electronic equipment as a priority, to develop efficient processes throughout the production and logistic chains, while ensuring recovery, reuse, and recycling of the components (Guzzo et al., 2021). This approach can contribute to integrating circular economy and digitalisation concepts, which can lead to reaching the desired objectives. The circular economy policies are yet to be implemented around Europe to support efficient use of resources, recycling, and product lifespan increase. The integration of new technologies represents a great challenge for the existing industrial circuit and the consequences of it for the environmental and social actors.

Through our research, we aim to discover how innovation influences the transition towards a circular economy, with the electrical and electronic devices sector as our focus. The choice of this area is not a coincidence. It is by far the industry with the greatest potential to implement effective circular regulations, as pointed out by several researchers, including Pollard et al. (2021). Here we mention as main challenges the amount of waste generated, the low rate of recycling and reuse, but also the lack of components sold separately on the market to increase the lifespan of an electrical product. In addition, the European Commission (2020) forecasts show increases of over 2% in waste generated annually. On the other hand, electrical and electronic equipment has the greatest potential for sustainable growth through improved reuse and recovery rates (Bovea and Perez-Belis, 2018), reduced use of fossil fuels, extended lifetime, and high adaptability to digitisation (Deviatkin et al., 2022).

Despite the fact that many studies on the relationship between digitisation and circularity have been published recently, there are still open questions on how innovation can support closing the economic circuit. Thus, our research will cover the objectives of determining the relationship between innovation, new technologies, and closing the economic circuit and of identifying structural differences at the regional level in terms of the interdependence between the circular economy and the targeted sector, respectively that of electrical and electronic equipment.

From a structure perspective, the article continues with the review of the specialized literature that outlines the current state of knowledge in the analysed field, the research methodology that describes the elements of quantitative analysis necessary to achieve the set objectives, the results obtained, and the conclusions section.

1. Review of the scientific literature

The challenges associated with climate change and sustainability efforts that could impact waste generation and resource consumption have attracted the attention of policymakers within relevant international institutions, thus supporting the development of a circular economy (EC). They have struggled many times to find a suitable definition of the concept of circularity and to link it to the other terms that address the sustainable development of economic processes. Since 1979 and continuing to the time being, many researchers have studied the solutions offered by the circular economy to environmental problems. Therefore,

Georgescu-Roegen (1979) established the existence of a link with the physical and biological sciences as bioeconomy and presented its implications for economics. Through the assumption that everything is a source for something else, Segerson (1991) coordinated the development of a circular model of the economy and its correlation with the environment through several factors: resource supply, waste management, and utility. Subsequently, numerous definitions and studies have emerged and have led to the creation of a complex framework that embeds all sectors of activity, including the recovery of waste and its use in other processes (Preston, 2012), recycling, limitation and reuse of physical materials in the economy (European Environment Agency, 2014), replacing the concept of “decommissioning” by switching to reusable energy and disposing of toxic chemicals that would prevent waste recycling (Ellen MacArthur Foundation, 2015), and closed-loop production and consumption of goods that to limit waste generation (Sauve et al., 2016). The most recent definition was developed by the European Commission (2022) and refers to a type of economy in which the lifespan of a product, material, or resource is maintained at the highest possible level to reduce waste production.

By emphasising the idea that a concept is not fully independent, the area covered by the circular economy includes interconnected entities, ranked at the same level of importance, but also sectors and economic processes that fall under its influence. Recent studies have identified other domains related to the circular economy by exploring digital solutions that can add value to economic activity. Torfgard et al. (2021) recalled the digitisation process that involves the use of new technologies to adapt traditional sectors to environmental requirements. In addition, digitisation facilitates knowledge of the value chain through effective monitoring (Berg et al., 2020). As stated by D’Amato et al. (2017) and reiterated by Birner (2018) and Kardung et al. (2019), the green economy is presented as an umbrella concept, which includes the bioeconomy, the circular economy, the digital transformation in these areas, but also sustainable and knowledge-based development. This demonstrates the need to optimise resource consumption to reduce waste (Țârțiu et al., 2019).

All the correlations between different concepts presented in this paper guide us to finding common points, but also differences that can outline the major areas of action in the circular economy. Many of them are often interconnected, while, sometimes, companies may adopt a strategy that involves several circular processes. In addition, an important advantage of using circular economy concepts is the increase in social welfare, ensuring the harmonious development of society (Vuta et al., 2018). This was one of the valid points that guided the European institutions toward an integrated policy that could face the new challenges associated with the lack of circularity in the economy. Consequently, the circular economy was added as a key module of the sustainable development agenda to the European Green Pact. In this way, it widens the role of the existing action plans to assess the major changes in the production and consumption behaviour of businesses and consumers, respectively, by extending the life of products and making people responsible for how products are used and recycled (European Commission, 2022). Finally, we are talking about circularity in production processes by promoting the use of digital technologies along the supply chain, by designing processes and verifying them through the environmental technology verification scheme, but also by amending regulations and directives such as the Industrial Strategy, Industrial Emissions Directive or Bioeconomy Action Plan (European Commission, 2018). All these measures will eventually lead to a reduction in waste accumulation, limiting the use

of toxic substances, and a fully functioning European market for secondary raw materials. It is also important to mention the impetus created by the Recovery and Resilience Plan, through which the circular economy directives can be implemented faster in the EU Member States (Dobre-Baron et al., 2022).

The circular economy implementation strategy was expected to face various challenges from the European Union member states (Botezat et al., 2018). Specifically, in addition to the development of research projects that provide a source of truth for this concept, there is a need for openness from the member states, through national, regional, and local authorities and citizens, as they have the responsibility to adapt to the new requirements.

To prevent the challenges related to the redundancy of strategies for the transition to the circular economy, EU member states have had the opportunity to adapt their framework policies to the internal market specificity (Parajuly et al., 2020). Thus, there were differences in strategies between countries, but also between economic sectors. In Finland alone, there have been more than 50 different practices on the circular economy in the electrical and electronic sector, starting from a general view on the product, business model, and ecosystem, to specific situations (Deviatkin et al., 2022). It should be noted that there may be variations between sectors because of the innovation level, the quantity of waste generated, or the variety of necessary components (Bovea and Perez-Belis, 2018). The geographical, financial, and social perspectives have a significant impact on each of the circular processes, as they depend on consumer behaviour (Parajuly et al., 2020). In the same industry, as stated above, we can think of the recycling habits across Europe, the facilities and governmental involvement, and the management systems. Those variations have led to several issues, such as the lack of international consensus on imposing a standardised approach, high costs, or even inconsistency in implementing the EU directives.

Society advanced towards the strong digitisation process of the production sector, but at the same time considering the ecological footprint that appears as an important consequence. Several authors have analysed the relationship between Industry 4.0, which includes sustainable technological progress, and the circular economy, which can be seen as sustainable by definition. This relationship is thus characterised by a constant dynamism, but it also has challenges caused by the high costs and complexity of the two parties (Tavera Romero et al., 2021). On the other hand, the adoption of techniques and processes under the umbrella of digitalization and circular economy concepts brings a significant competitive advantage over the competition (Ranta et al., 2021), but also additional funds from public institutions (Awan et al., 2021), as it contributes substantially to the achievement of sustainable development goals, especially 7 – green and affordable energy, 8 – economic growth and adequate working conditions, 9 – innovation and infrastructure, 11 – sustainable communities, 12 – responsible production and consumption, 13 – combating climate change (Dantas et al., 2021). It should be noted when characterising the link between digitalisation and CE is how recent it is. Regarding this aspect of the novelty, Piscitelli et al. (2019) have highlighted that the research topic is still in its early stage, with more papers being published in the last decade. At the same time, most of the conclusions focus on the traceability of circular economy processes by including industry 4.0 approaches to the business models, technologies, and human resources.

In the case of electrical and electronic industry, the existing studies follow two different paths by presenting, in one case, the benefits of using circular models in its management, as well as the link between digitisation and innovation in the field. The first vision brings to the fore the constraints that a firm may have in the scenario of adopting a circular model, especially due to high costs, human resource training, or logistics chain complexity (Aminoff and Sundqvist-Andberg, 2021), but also the benefits arising from the implementation of related services such as product restoration, maintenance, and recycling (Kim et al., 2022). Bressanelli et al. (2021) integrate the perspective of digitisation into the relationship between circular economy and EEE, presenting a series of facilitators such as the Internet of Things, cloud platforms, or big data, which can lead to the development of new services such as pay-per-use that can solve some of the problems associated with the inability of the economic chain to completely transform an obsolete product. Thus, a product offered as an online service does not need restoration or recycling, as it has periodic updates without user intervention. This new approach considered by economic actors can be translated into electrical and electronic sector by optimising programmes or functions that can be enabled or disabled to increase the products lifespan, but also by transferring these programmes to mobile applications, which reduces the number of physical parts used.

Taking as starting points the studies published by Sauve et al. (2016), Bressanelli et al. (2021) and Tofgard et al. (2022), this paper aims to identify the structural differences from a territorial perspective on the relationship between the circular model applied to the electrical and electronic equipment industry and the digitisation of the same sector.

2. Research methodology

A starting point for the research methodology was represented by the scope of investigating the role that innovation and new technologies play in closing the economic circuit of electrical and electronic equipment in the European Union, but also the particularities between these concepts from a territorial perspective. The elements of the two objectives – studying the link between innovation and circular economy, as well as identifying structural differences from a territorial profile – were transposed quantitatively through 14 indicators detailed in Table no. 1. Their choice depended both on the relevance, availability and accuracy of the data, and on the performance proven in other studies highlighted previously (Piscitelli et al., 2019; Bressanelli et al., 2021). Therefore, the circular economy was measured from an economic (circular use rate, taxes and investments, energy use, raw material consumption, trade with recyclable raw materials) and social (waste generation, recycling rate, number of employed people in the sector) perspectives, with a focus on the electrical and electronic equipment. In parallel, innovation was included through specific indicators on research and development (budgetary allocation for the research and development sector) and scientific and technological progress (patents in the field of recycling and secondary raw materials).

To achieve all the objectives considered in this study, relevant data from the official European statistics were taken into account. They were collected through Eurostat's online database. We have selected values for the last year available (2020) for all 27 member states of the European Union. Where there were missing data, based on the k-means clustering algorithm, an imputation was made with the cluster average value of which the respective country was part.

Table no. 1. Description of variables included in the model

Name of variable	Acronym	Unit of measure
Circular use rate	Circular_UsE	Percentage
Total environmental taxes	Env_tax	Percentage of GDP
Generation of municipal waste per capita	Gen_waste	Kilograms per capita
Gross investment in tangible goods	Tan_goods	Percentage of GDP
Net domestic energy use for energy purposes	Energy_purp	Terajoule
Net domestic energy use for non-energy purposes	Non-Energy_purp	Terajoule
Patents related to recycling and secondary raw materials	Patents_recy	Per million inhabitants
Persons employed to circular economy sectors	Employ_RD	Percentage of total employment
Raw material consumption	Raw_cons	Tonnes per capita
Recycling rate of e-waste	Recy_e-waste	Percentage
Share of Government Budget Allocations for R&D (GBARD) in total general government expenditure	GBARD	Percentage of government expenditure
Trade in recyclable raw materials	Trade_recy	Thousand euro
Use of waste for energetic purposes	Waste_Energy_Purp	Terajoule
Value added at factor cost	Value_added	Percentage of gross domestic product (GDP)

To meet the research objectives using the selected variables, appropriate techniques were used, such as K-means clustering algorithm and Principal Component Analysis (PCA). Principal Component Analysis (PCA) was used to identify the relationship between the circular economy perspective, innovation, and closing the economic circuit of electrical and electronic equipment. The main reason for choosing the principal component analysis method to study the first objective was its ability to split the data set into smaller dimensions that can provide detailed information with a high degree of specificity, thus helping us to observe with high accuracy where the connection between innovation and the circular economy is formed. For the second objective, classification analysis proved to be effective through its property of concentrating a large number of variables without significant loss of information. Principal Component Analysis involves grouping variables into a space of k principal components, thus reducing the massive amount of data. The purpose of these components is to explain at least 70% of the entire variation of the data set, and the variables in the structure of a component must be correlated with each other (James et al., 2013). Another advantage of using this method is the possibility of characterising the individuals in the research study through the visual analysis of the k principal components (Bro and Smilde, 2014). However, Principal Component Analysis has the disadvantage of increasing the difficulty of explaining and understanding the main components, because of the complexity of the variables that make up these main components (Jolliffe and Cadima, 2016).

To answer the second objective of the article, the identification of discrepancies in the territorial profile through the eyes of the circular economy purpose, innovation and new technologies on closing the circuit of electrical and electronic equipment, another unsupervised learning method was used. The K-means clustering algorithm groups statistical units in a way that the statistical population is as homogeneous as possible (minimization of variation) within the cluster and the distances between clusters are as large as possible

(maximization of variation between clusters) (Celebi et al., 2013). The method underlying the use of this algorithm is the Euclidean distance. Therefore, one starts from an initial number of clusters, after which the nearest neighbours are iteratively added to each cluster. The iterations are repeated until the clusters remain identical from one iteration to the next one. However, the optimal number of clusters is given by the dendrogram, at the point where the distance between the clusters is maximum (James et al., 2013).

All processing was done in the RStudio interface, using the R packages: readxl, factoextra, corplot, dplyr.

3. Results and discussion

The first step in achieving the goal of statistical research is to identify the number of principal components. The Elbow method was used to identify the optimal number (Figure no. 1).

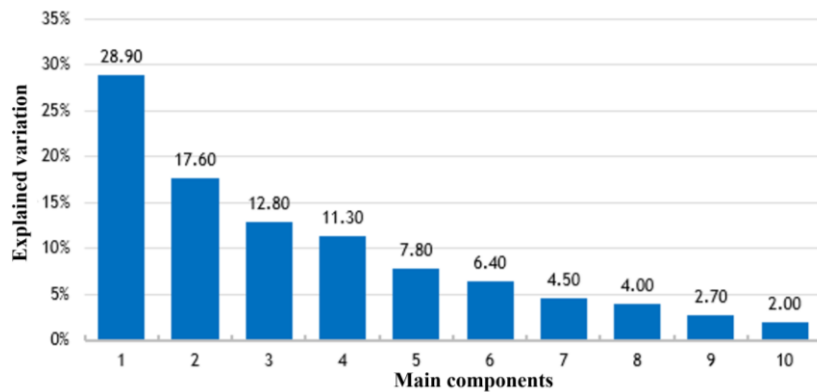


Figure no. 1. Variation explained by each principal components using Elbow method

Figure no. 1 shows the variation explained by each dimension of the data set. To ensure the consistency of the analysis, 4 principal components were considered, explaining approximately 71% of the variation.

Furthermore, perhaps the most important thing in the case of this analysis, is represented by the representation of the variables on each principal component, as well as their contribution to each component (figure no. 2).

The correlogram from figure no. 2 indicates the association between the variables and each principal component. All 14 dimensions are presented, associated with the 14 analysed variables. Therefore, to reduce the volume of the database, the information brought by the 14 dimensions can be synthesised into four main dimensions that explain more than 70% of all the variation of the data set, the last 4 of its (dimensions 11, 12, 13 and 14), being excluded from the start because of the null correlation coefficients.

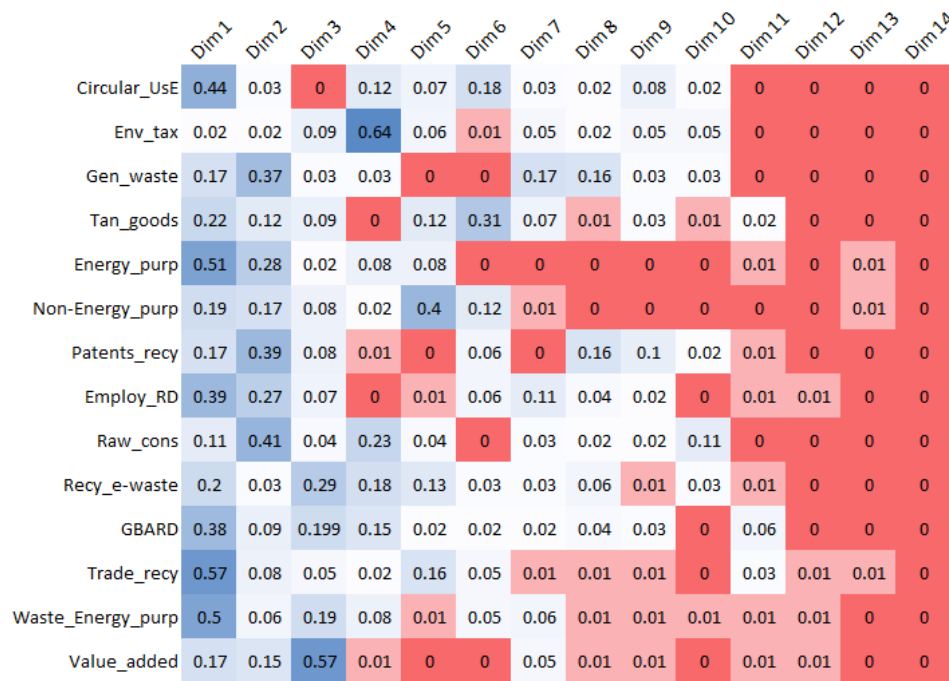


Figure no. 2. Factor contribution to each dimension

Using the information retrieved from the correlogram in Figure no. 2, we have considered the following components of the principal components (Table no. 2):

Table no. 2. Structure of each dimension

Name of Dimension	Variables
1. Circularity through innovation in the energy sector	Circular_UsE, Tan_goods, Energy_purp, Non-Energy_purp, Employ_RD, GBARD, Trade_Recy, Waste_Energy_Purp
2. Circularity through R&D	Gen_waste, Patents_recy, Raw_cons
3. Value added of circular economy	Recy_e-waste, Value_added
4. Government of circular economy	Env_tax

At first glance, there is a degree of association between the circular economy and innovation, as well as between waste management, environmental impact, and added value in the economy. However, to be able to identify the causal relationship between the variables that build each component, an exhaustive analysis of each will be carried out.

The first dimension, called “Circularity through innovation in the energy sector”, includes several areas: circular economy (Circular_UsE, Trade_Recy), innovation (GBARD, Employ_RD) or the energetic sector (Energy_purp, Non-Energy_purp, Waste_Energy_Purp). The most important contribution comes from the trade in recyclable materials (about 15%), followed by the use of energy for production purposes, the reuse of recycled materials, as well as the elements of innovation (the number of employees and the

share of investments in research and development). Therefore, although the first component consists of 7 variables, in reality only 6 of them have a significant contribution to its variation.

The second dimension, called “Circularity through R&D”, consists of only three variables that include the consumption pattern of raw materials, waste production and the number of patents for waste recycling. However, there may be other variables that can make a significant contribution to this component. Component 2 brings to the fore the causal relationship between the consumption of raw materials, waste management, and innovation (research-development), these variables being the only ones that have a significant contribution to it.

The third dimension, called “Value added of circular economy”, brings in foreground the relationship between the circular economy and the added value that the use of this concept can bring to society. In addition, the economical value shows an interdependent relationship with the recycling rate of electronic products, the rebound effect of using products for energy purposes, but also investments in the research and development sector. In other words, the added value in the economy depends on the reuse of electronic products, the efficiency of energy consumption and production, as well as the result of increased investment in the research and development sector.

The fourth dimension, called “Government of circular economy”, measures the interest given by the governments of the member states of the European Union in the impact of economic activities on the environment. However, even if this component provides information on the tax framework with environmental impact, with the variable “Env_Tax” explaining about 40% of the variation in the main component, environmental taxes are closely related to key aspects of the circular economy (recycling of electronic products, consumption of raw materials, the use of recycled products), but also with the level of investments in the research and development sector.

Starting from the contribution of the variables to the four main components, it can be stated that there is an association relationship between innovation and closing the circuit of electrical and electronic equipment.

3.1 Differences in the territorial profile

When the first two main components are analysed, structural differences between the member states of the European Union are identified from the start. Several outliers can be distinguished, such as France, Germany, Croatia, Austria, Denmark, or Finland. France is very well represented in the first component, particularly the management of electrical and electronic resources being the most important factor. A similar pattern is shown by Italy and Spain. Germany and The Netherlands are defined by the concepts of the circular economy (waste reuse rate, trade-in recyclable products, etc.). On the other hand, Croatia, which is a very well represented country in the first component, shows a different behaviour, characterised by the proportion of employees in the research and development sector. Austria, Denmark, Luxembourg, and Finland are very well represented on the second component and, implicitly, are characterised by the variables that make up this dimension (waste management, recycling patents). However, there are a few states that are not significantly influenced by the first two components, such as Romania, Hungary, Estonia, Portugal, or Malta.

Apart from the countries very well defined through the first main component, there is also another outlier, in the third component, namely Greece. The state presents a different economic behaviour from that of the circular economy, especially regarding the reuse of electrical and electronic products, being inversely correlated with the variable “Recy_e-waste”. However, some states are very well represented both on the first main component and on the third, an example of this being Germany, defined by the causality relationship between the circular economy (recyclable materials trade, recycling patents) and Government Budget Allocations for R&D (GBARD).

When the first and the fourth components are compared, things change mainly for countries that are not significantly characterised by the three components analysed earlier, such as Romania, Lithuania, and Ireland. These three countries are very well represented in the fourth component, the type of consumption of raw materials. Despite the strong representation in the fourth component, the three countries are not characterised by a fiscal system that emphasizes environmental protection, being inversely correlated with the “Env-tax” variable. In addition, these countries show low values for the other variables that have a significant influence on this component, the recycling rate of electronic products, the reuse rate of waste and the value of investments in the innovation sector (research and development).

Starting from the analysis of the four main components, it can be observed that there are some states with a multi-sectoral development, being very well represented in all of them, even if they, after all, show somewhat different behaviour. For example, France and Germany are concerned with the efficiency of the energy sector, being less oriented toward the use of new technologies (innovation) and the increase of circular economy concepts usage. On the other hand, the Netherlands, Belgium, and Denmark are oriented towards an innovative approach, which integrates the concepts of the circular economy at the level of the economic behaviour of consumers. There is another model, promoted by Croatia, which is based on environmental taxes, on the implementation of coercive measures for economic agents to increase the recycling rate of electrical and electronic products, thus generating added value in the economy through a significant reduction in the consumption of raw materials.

3.2 European states classification

For a clearer picture of the differences in economic and social behaviour between the member states of the European Union, the clusters resulting from the application of the k-means clustering method were analysed. Based on the contribution of the variables to the four components, the variables that do not significantly influence the variation of one of them, such as the variable “investment in tangible goods” (“Tan_goods”), were eliminated during the clustering process. The first step in clustering involves identifying the optimal number of clusters. To ensure the consistency of the analysis, all values were standardised, respecting the distribution of mean 0 and variance 1.

Using the Euclidean distance algorithm, the optimal number of clusters is $k=3$. Based on it, the clustering of the member states is carried out, based on all the values recorded by them for the analysed variables (Figure no.3).

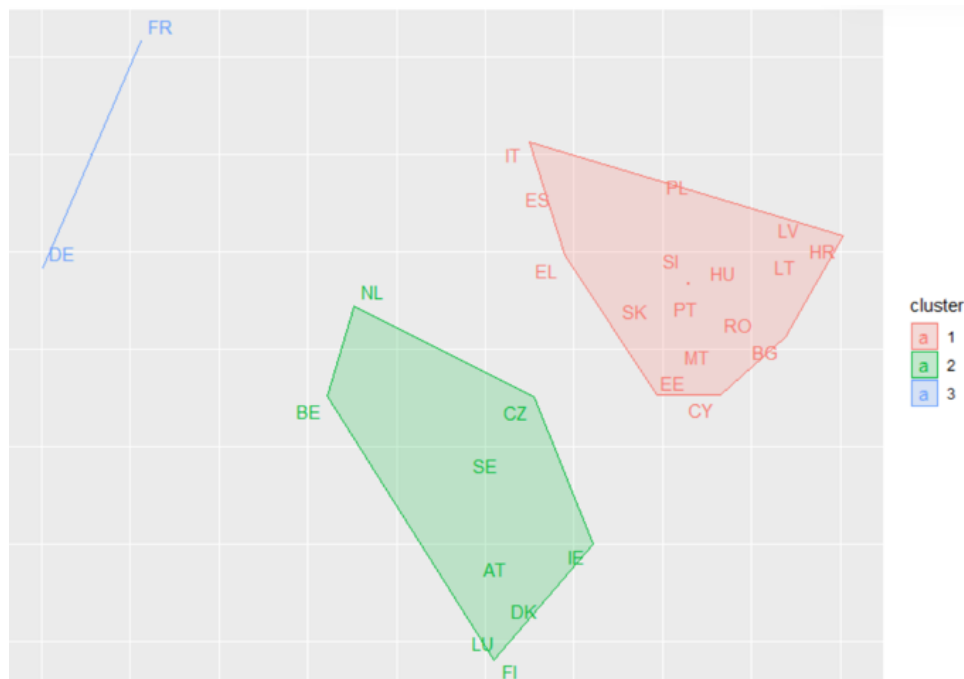


Figure no. 3. Distribution of countries into clusters

As highlighted in figure no. 3, we can determine three groups. The first cluster consists of ex-communist countries from Eastern Europe (Latvia, Lithuania, Poland, Croatia, Slovakia, Romania, Bulgaria, Hungary), island countries (Malta, and Cyprus), and countries from South-West Europe, such as Portugal, Spain, or Italy. Even though all these countries are part of the same cluster, they follow a different pattern. For example, island countries show similar behaviour to eastern countries (Romania, Bulgaria, or Estonia). Cluster 2 consists mainly of Central and Northern European countries (the Netherlands, Belgium, Denmark, Finland, Luxembourg, Sweden). However, this cluster also includes states such as Austria or the Czech Republic, which show different behaviour compared to the two countries (Netherlands, Belgium) that mark similarities with the countries in the first cluster. France and Germany are the only countries that build the third cluster, showing similar patterns regarding the role of the circular economy and innovation in closing the circuit of electrical and electronic equipment.

The first cluster shows moderate asymmetry in terms of waste generation and the percentage of investment in the R&D sector as a share of GDP. For all other variables, there is a positive asymmetry, which leads to the idea that small values predominate in the series. In other words, this cluster is characterised by low values of the circular economy and innovation components. For example, the recycling rate of electrical and electronic products positions itself between 25% (Romania) and 83.4% (Croatia). Another important indicator in the relationship between innovation and closing the circuit of electrical and electronic equipment is the added value brought by using the circular economy as a share of GDP, with values ranging from 0.4% (Greece) to 1.74% (Croatia). Surprisingly, it can be observed that the leaders of this cluster are Croatia and Bulgaria. However, if we refer to the whole concept of

the circular economy, countries such as Italy, Estonia, Spain, or Slovenia constitute the group of member states in this cluster that predominantly use recycled resources in the economic process.

The second cluster shows that Denmark has the highest recycling rate of electrical and electronic products (67.5%), at the opposite pole is Belgium (approx. 39%). It is worth mentioning the amplitude value of the series for the recycling of electronic products, which is much lower than in the case of the first cluster, the states forming this cluster being homogeneous from the point of view of the recycling of electrical and electronic products. Although it has the highest value in this cluster for the recycling of electronic products, Denmark uses only 7.7% of recycled products, the leader in this chapter being the Netherlands (30.9%). However, both Denmark and the Netherlands are two countries that promote the impact of the economy on the environment, recording the highest values for the share of environmental taxes in GDP (3.17% and 3.16%, respectively). Even if these countries allocate an important share of GDP to the research and development sector, they hold a significant number of circular economy patents, plus the value brought by the circular economy sector as a share of GDP remains below 1%, a sign that there is still potential in the development of the circular economy at the level of the entire economic sector.

The third cluster is characterised by two economically and industrially strong countries. Being two predominantly industrial countries, they are characterised by the energy-hungry nature of their economic activities. These countries rely mainly on the research and development (innovation) sector, integrating very little circular economy aspects into overall economic activity. Recycling rates for electrical and electronic products are around 35%, with Germany using around 13% of recycled waste and France 22%.

Conclusions

Based on the results of this research, it can be stated that there is a causal relationship between innovation, new technologies that promote the digitization and utilization of resources and the circular economy, especially from the perspective of electrical and electronic equipment, thus confirming the theories developed by Sauve et al. (2016), Bressanelli et al. (2021), and Tofgard et al. (2022).

However, although this causal relationship exists, and the European Commission is strongly promoting the approach to economic activity from a circular perspective, there are major differences at the level of the member states of the European Union regarding the transition to a circular economy, with minimal impact on the environment. These structural differences can be translated by a lack of consensus at the level of the member states regarding the implementation of European directives, an idea also supported by Rizos and Bryhn (2022). Therefore, as stated by Botezat et al. (2018), openness is needed from member states to increase the use of the circular economy. Of course, respecting David Riccardo's principle, according to which each state will specialise in the production of that good for which it has abundant resources, the member states of the European Union can implement the European directives in relation to the geographical specificity, the availability of resources, the capacity to increase investments in the research and development sector, the available human resources, etc. Even if there is great diversity at the level of the member states, they can sometimes implement common measures to increase the sustainability of the economic and social system. A starting point in this regard can be the three clusters resulting from the analysis of this study, in close correlation with the four main components resulting from the

Principal Component Analysis. For example, the countries that make up the first cluster should, in the first phase, develop the awareness of all participants in the economic activity (commercial agents and consumers) on the advantages and benefits that the circular use of resources offers to the environment, especially from the perspective of electrical and electronic products, which have a special status, being generally products that result from complex manufacturing processes, with a high impact on the environment. The countries that make up cluster 3 (France and Germany) must develop a system that encourages the circularity of resources, because these two countries are highly industrialised (energy-intensive) and invest significant amounts in research and development. On the other hand, the countries in cluster 2, predominantly from the north and centre of Europe, are countries that have passed the first level in the implementation of the circular economy at the level of the entire economy. The main objective of these countries is to increase investments in new and emerging technologies so that they can achieve a higher level of reuse of resources in the economy, thus producing added value in the market economy.

In conclusion, disregarding the particularities of the EU member states, all countries should focus on the development of public policies (at the central and local level), following objective 12 of the National Strategy for Sustainable Development 2030 (Consumption and production responsible), which should focus on two main objectives: encouraging economic agents to recycle and use economic resources resulting from the waste recovery process and changing the consumption model of consumers by encouraging recycling and reducing, as much as possible, waste generation. Increasing the number of employees in the circular economy sector, increasing the allocations from the state budget for innovation (the research and development sector), and proposing fiscal/economic facilities for economic agents to increase the recovery of waste and the reuse of economic resources are just some of the measures that can be considered for the development of public policies.

In accordance with the scientific literature presented, countries with high performance in adopting the circular economy principles also achieve very good results in innovation through digitisation and offer, at the same time, open financing opportunities for private actors to increase the attractiveness of a transition to a green economy.

In addition to this, our analysis demonstrated a greater affinity of electrical and electronic equipment firms for moving to a business model based on circular processes following industrial process re-technologization, a fact evidenced by the patterns present in the first two groupings of states.

The limitations of the study were caused by the missing composite factors that could have better encapsulated the information for each of the concepts included in the analysis and which would have given a more accurate picture of the relationship among the used concepts.

References

- Aminoff, A. and Sundqvist-Andberg, H., 2021. Constraints leading to system-level lock-ins – the case of electronic waste management in the circular economy. *Journal of Cleaner Production*, [e-journal] Vol. 322, no.129029. <https://doi.org/10.1016/j.jclepro.2021.129029>.
- Awan, U., Sroufe, R. and Shahbaz, M., 2021. Industry 4.0 and the circular economy: A literature review and recommendations for future research. *Business Strategy and the Environment*, [e-journal] 30(4), pp.2038-2060. <https://doi.org/10.1002/bse.2731>.

- Berg, H., Le Blévenec, K., Kristoffersen, E., Strée, B., Witomski, A., Stein, N., Bastein, T., Ramesohl, S. and Vrancken, K., 2020. *Digital Circular economy as a cornerstone of a sustainable European industry transformation*. [pdf] Available at: <https://www.era-min.eu/sites/default/files/publications/201023_ecera_white_paper_on_digital_circular_economy.pdf> [Accessed 2 September 2022].
- Birner, R., 2018. Bioeconomy concepts. *Bioeconomy: Shaping the Transition to a Sustainable, Biobased Economy*, [e-journal] pp.17-38. https://doi.org/10.1007/978-3-319-68152-8_3.
- Botezat, E., Dodescu, A., Văduva, S. and Fotea, S., 2018. An Exploration of Circular Economy Practices and Performance Among Romanian Producers. *Sustainability*, [e-journal] 10(9), p.3191. <https://doi.org/10.3390/su10093191>.
- Bovea, M. and Pérez-Belis, V., 2018. Identifying design guidelines to meet the circular economy principles: A case study on electric and electronic equipment. *Journal of Environmental Management*, [e-journal] 228, pp.483-494. <https://doi.org/10.1016/j.jenvman.2018.08.014>.
- Brad, S., Mocan, B., Brad, E. and Fulea, M., 2016. Environmentally Sustainable Economic Growth. *Amfiteatru Economic*, 18(42), pp.446-460.
- Bressanelli, G., Pigosso, D.C.A., Sacconi, N. and Perona, M., 2021. Enablers, levers and benefits of Circular Economy in the Electrical and Electronic Equipment supply chain: a literature review. *Journal of Cleaner Production*, [e-journal] 298, no.126819. <https://doi.org/10.1016/j.jclepro.2021.126819>.
- Bro, R. and Smilde, A., 2014. *Principal Component Analysis. Analytical Methods*, [e-journal] 6(9), pp.2812-2831. <http://dx.doi.org/10.1039/C3AY41907J>.
- Celebi, E., Kingravi, H. and Vela, P., 2013. A Comparative Study of Efficient Initialization Methods For The K-Means Clustering Algorithm. *Expert Systems With Applications*, [e-journal] 40(1), pp.200-210. <https://doi.org/10.1016/j.eswa.2012.07.021>.
- D'Amato, D., Droste, N., Allen, B., Kettunen, M., Lähtinen, K., Korhonen, J., Leskinen, P., Matthies, B. and Toppinen, A., 2017. Green, circular, bio economy: A comparative analysis of sustainability avenues. *Journal of Cleaner Production*, [e-journal] 168, pp.716-734, <https://doi.org/10.1016/j.jclepro.2017.09.053>.
- Dantas, T., de-Souza, E., Destro, I., Hammes, G., Rodriguez, C. and Soares, S., 2021. How the combination of Circular Economy and Industry 4.0 can contribute towards achieving the Sustainable Development Goals. *Sustainable Production and Consumption*, [e-journal] 26, no.213-227, <https://doi.org/10.1016/j.spc.2020.10.005>.
- Deviatkin, I., Rousu, S., Ghoreishi, M., Naji Nassajfar, M., Horttanainen, M. and Leminen, V., 2022. Implementation of Circular Economy Strategies within the Electronics Sector: Insights from Finnish Companies. *Sustainability*, [e-journal] 14(6), p.3268, <https://doi.org/10.3390/su14063268>.
- Dobre-Baron, O., Nițescu, A., Niță, D. and Mitran, C., 2022. Romania's Perspectives on the Transition to the Circular Economy in an EU Context. *Sustainability*, [e-journal] 14(9), p.5324, <https://doi.org/10.3390/su14095324>.
- Ellen MacArthur Foundation, 2015. *Towards a Circular Economy: Business Rationale for an Accelerated Transition*. [pdf] Available at: <<https://ellenmacarthurfoundation.org/towards-a-circular-economy-business-rationale-for-an-accelerated-transition>> [Accessed 3 September 2022].

- European Commission, 2018. *A sustainable bioeconomy for Europe: strengthening the connection between economy, society and the environment: updated bioeconomy strategy*. [pdf] Available at: <<https://data.europa.eu/doi/10.2777/792130>> [Accessed 3 September 2022].
- European Commission, 2022. *Circular Economy Action Plan. For a Cleaner and More Competitive Europe*. [pdf] Available at: <<https://ec.europa.eu/jrc/communities/en/community/city-science-initiative/document/circular-economy-action-plan-cleaner-and-more-competitive>> [Accessed 2 September 2022].
- European Environment Agency, 2014. *Resource-efficient Green Economy and EU policies*. [pdf] Available at: <<https://www.eea.europa.eu/publications/resourceefficient-green-economy-and-eu>> [Accessed 2 September 2022].
- Georgescu-Roegen, N., 1979. Methods in Economic Science. *Journal of Economic Issues*, 13(2), pp.317-328.
- Guzzo, D., Rodrigues, V. and Mascarenhas, J., 2021. A systems representation of the Circular Economy: Transition scenarios in the electrical and electronic equipment (EEE) industry. *Technological Forecasting and Social Change*, [e-journal] 163, no.120414, <https://doi.org/10.1016/j.techfore.2020.120414>.
- James, G., Witten, D., Hastie, T. and Tibshirani, R., 2013. *An Introduction to Statistical Learning with Applications in R*. 1st ed. S.l.: Springer.
- Joliffe, I. and Cadima, J., 2016. Principal component analysis: a review and recent developments. *Philosophical transactions of the royal society a-mathematical physical and engineering sciences*, [e-journal] 374(2065), p.20150202. <https://doi.org/10.1098/rsta.2015.0202>.
- Kardung, M., Costenoble, O., Dammer, L., Delahaye, R., Lovric, M., van Leeuwen, M.G.A., M'Barek, R., van Meijl, H., Piotrowski, S., Ronzon, T.B., Verhoog, A.D., Verkerk, H., Vracholi, M., Wesseler, J.H.H. and Zhu, B.X., 2019. *D1.1: Framework for measuring the size and development of the bioeconomy*. [pdf] Available at: <<http://biomonitor.eu/wp-content/uploads/2020/04/Deliverable-1.1.pdf>> [Accessed 2 September 2022].
- Kim, C.H., Kuah, A.T.H. and Thirumaran, K., 2022. Morphology for circular economy business models in the electrical and electronic equipment sector of Singapore and South Korea: Findings, implications, and future agenda. *Sustainable Production and Consumption*, [e-journal] 30, pp.829-850. <https://doi.org/10.1016/j.spc.2022.01.006>.
- Lewandowski, M., 2016. Designing the Business Models for Circular Economy – Towards the Conceptual Framework. *Sustainability*, [e-journal] 8(1), p.43. <https://doi.org/10.3390/su8010043>.
- Lovins, A., Hawken, P. and Lovins, H., 2008. *Natural Capitalism: Creating the Next Industrial Revolution*. 1st ed. New York: s.n.
- Parajuly, K., Fitzpatrick, C., Muldoon, O. and Kuehr, R., 2020. Behavioral change for the circular economy: A review with focus on electronic waste management in the EU. *Resources, Conservation & Recycling: X*, [e-journal] 6, no.100035. <https://doi.org/10.1016/j.rcrx.2020.100035>.
- Piscitelli, G., Ferazzoli, A., Petrillo, A., Cioffi, R., Parmentola, A. and Travagliani, M., 2020. Circular economy models in the industry 4.0 era: a review of the last decade. *Procedia Manufacturing*, [e-journal] 42, pp.227-234. <https://doi.org/10.1016/j.promfg.2020.02.074>.

- Pollard, J., Osmani, M., Cole, C., Grubnic, S. and Colwill, J., 2021. A circular economy business model innovation process for the electrical and electronic equipment sector. *Journal of Cleaner Production*, [e-journal] 305, no.127211. <https://doi.org/10.1016/j.jclepro.2021.127211>.
- Preston, F., 2012. *A Global Redesign? Shaping the Circular Economy. Briefing Paper*. London: Chatham House.
- Ranta, V., Aarikka-Stenroos, L. and Väisänen, J., 2021. Digital technologies catalyzing business model innovation for circular economy – Multiple case study. *Resources, Conservation and Recycling*, [e-journal] 164, no.105155. <https://doi.org/10.1016/j.resconrec.2020.105155>.
- Rizos, V. and Bryhn, J., 2022. Implementation of circular economy approaches in the electrical and electronic equipment (EEE) sector: Barriers, enablers and policy insights. *Journal of Cleaner Production*, [e-journal] 338, no.130617. <https://doi.org/10.1016/j.jclepro.2022.130617>.
- Sauvé, S., Bernard, S. and Sloan, P., 2016. Environmental sciences, sustainable development and circular economy: Alternative concepts for trans-disciplinary research. *Environmental Development*, [e-journal] 17, pp.48-56. <https://doi.org/10.1016/j.envdev.2015.09.002>.
- Segerson, K., 1991. Review: Economics of Natural Resources and the Environment. *Land Economics*, [e-journal] 67(2), pp.272-276. <https://doi.org/10.2307/3146419>.
- Tavera Romero, C., Castro, D., Ortiz, J., Khalaf, O. and Vargas, M., 2021. Synergy between Circular Economy and Industry 4.0: A Literature Review. *Sustainability*, [e-journal] 13(8), pp.4331. <https://doi.org/10.3390/su13084331>.
- Târțiu, V., Ștefănescu, M., Petrache, A. and Gurău, C., 2019. *Tranziția către o economie circulară*. Bucharest: European Institute of Romania.
- Torfgård, L., Bhatia, R., Blomquist, M., Tunberg, M., Ekegren, K., Roos, A., Korsvik, T. R., Gustafsson, I. and Nordström, I., 2021. *Redefining Digital Bioeconomy reviewing how the digital transformation affects gender inequalities in the Nordic bioeconomy*. [pdf] Available at: <<https://nordicforestresearch.org/wp-content/uploads/2021/01/BioEquality-report-2.pdf>> [Accessed 3 September 2022].
- Vuță, M., Vuță, M., Enciu, A. and Cioacă S.I., 2018. Assessment of the circular economy's impact in the EU economic growth. *Amfiteatru Economic*, [e-journal] 20(48), pp.248-261. <https://doi.org/10.24818/EA/2018/48/248>.