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Article

Level of Competitiveness and Innovation in the Circular Economy of the European Union

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Abstract Sustainable development, as a cornerstone of contemporary political frameworks, is closely linked to the concept of the circular economy (CE). In the context of the European Union (EU), the transition towards a circular economy is considered a key element in achieving a sustainable, low-carbon, resource-efficient, and competitive economic model. The aim of this article is to partially fill the research gap regarding the connections between recycling, the use of secondary raw materials, and the innovation and competitiveness of EU member states' economies. Based on a critical literature review, it was identified that there is a lack of comprehensive studies analyzing these relationships in the context of EU countries, which serves as the starting point for this research. The study applies CE indicators proposed by the European Commission, which, after conducting a literature review, were deemed the most appropriate for analysis. Descriptive statistics were used to analyze data on recycling rates and the use of secondary raw materials in EU countries. Additionally, the study was enhanced by an analysis of the impact of recycling and circular economy practices on innovation and competitiveness in various countries, conducted through a multidimensional comparative analysis using the Hellwig's method. The analysis results indicate a significant positive correlation between recycling rates, the use of secondary raw materials, and economic innovation and competitiveness. Specifically, Germany, with a municipal waste recycling rate of 69.3% in 2021, ranks at the top among countries in terms of the number of patents and investments in technologies related to the circular economy. The findings suggest that national policies should focus on supporting innovation and increasing recycling efficiency, which could benefit both environmental protection and economic growth. The results also indicate that countries with lower recycling rates may face limitations in terms of innovation and competitiveness. In the case of these countries, policies focusing on investments in recycling technologies and the promotion of innovation could help improve performance in both areas.

Keywords sustainable development goals; circular economy sectors; competitiveness and innovation; waste management; secondary raw materials

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1. Introduction

Modern global civilization faces many challenges, such as environmental degradation, the threat of energy depletion, poverty, and significant disparities in the standard of living of people in different countries. These problems have prompted the search for alternative concepts that can minimize risks to socio-economic development. One of the widely adopted and accepted concepts is sustainable development [1].

"Sustainable development means striving to ensure all current living people and future generations high ecological, economic and socio-cultural standards within the limits of tolerance of nature by introducing intragenerational and intergenerational justice" [2]. This concept is based on the concept of "needs" and "restrictions". The concept of "needs" refers to human needs, both basic and those that can be reconciled with other values that should be legally protected. Whereas "restrictions" concern the ability to meet the needs of present and future generations, mainly through technology and social organization [3]. The aim of this concept is to stop the degradation of the natural environment and ensure the fair use of its resources while striving for social well-being. It is therefore the concept of conscious and active formation of human relations, as well as relations of people with the natural environment, which does not contradict the desire for economic growth. Fair use of natural resources means that the consumption of renewable resources must not lead to their complete exhaustion. In the case of non-renewable resources, the need to reduce their consumption and rational use of human products is emphasized. This applies to both the international and intergenerational dimensions [4]. Economic development should include environmentally friendly techniques and technologies, the elimination of poverty and hunger, and the provision of health protection, education, and social security [5].

The main cause of extreme climate change is global warming, which increases the frequency and intensity of extreme weather events such as heat waves, droughts, forest fires, floods, hurricanes, and typhoons [6]. Global warming caused by human activity is already 1 ºC above pre-industrial levels and continues to grow by about 0.2 ºC per decade. At this rate of warming, 99% of coral reefs will disappear in 40 years and sea levels will rise by 7 m, which will have a drastic impact on coastal areas around the world, including islands and lowland areas in Europe [7]. This has disastrous effects on the efficiency of the European economy, public health, food production capacity, and political stability.

Air pollution poses a serious threat to human health and the environment. Along with extreme temperature and noise values, it negatively affects the weakest social groups, mainly in the eastern and southern regions of Europe [8]. Air pollution is the main cause of premature deaths related to the state of the environment. The greatest threat is particulate matter (PM), which penetrates the respiratory system, causing or intensifying lung and respiratory diseases, and even cancer; nitrogen dioxide (NO_2), causing inflammation of the respiratory tract and lung failure; and ground-level ozone (O_3), which causes numerous diseases and negatively affects vegetation. In addition to health ailments, these pollutions have serious economic consequences, related to, among others, the cost of treatment and a decrease in the productivity of the economy due to the poor health of employees. They also damage soil, water, crops, and forests, damage buildings, steel structures, and infrastructure [9].

Sustainable development refers primarily to human decisions about the way of life. The increase in consumerism violates the ecological balance, which threatens economic stability. The effects of current decisions affect almost eight billion people around the world and will be borne by billions of people living in the future [10].

The concept of sustainable development is interdisciplinary, because social sciences (economics, sociology, politics, ethics), legal sciences, and natural sciences contribute to its development [11]. It is also anthropocentric—it is supposed to serve people. The main assumption of the concept is to meet the needs of current people taking into account the needs of future generations [12].

An integral element of sustainable development is the circular economy, which responds to the challenges of limited natural resources, climate change, and the need to protect the environment. Its basic assumption is to maximize the use of raw materials, products, and materials throughout their life cycle, minimizing waste and emissions [13–15].

In the socio-economic context, the circular economy (CE) promotes the creation of new jobs and stimulates innovation. Companies that introduce circular economy solutions often develop new technologies and business models, which in turn drive economic growth and improve competitiveness. Examples include companies involved in recycled production, servicing and repair of products, as well as companies offering rental services instead of sales.

The implementation of the principles of the circular economy is also crucial to achieving the sustainable development goals set by the UN. These goals, such as responsible production and consumption, protection of terrestrial and aquatic ecosystems, as well as climate action, can be effectively implemented by adapting the principles of the circular economy. For example, designing products with longevity and ease of repair in mind not only reduces waste but also saves resources and energy.

The European Union (EU) has implemented many initiatives to improve waste management, promoting a management model based on sharing, borrowing, reusing, repairing, renewing, and recycling existing materials and products. Thanks to this, the life cycle of products is extended to the maximum [16]. The concept of circular economy assumes that already at the stage of product design the use of natural resources and energy will be optimized, and at the end of the product life cycle, it will be restored to use. The key aspect is to maintain the added value and usability of the product and eliminate waste. The model, in which the products introduced to the market are of high quality, allows to significantly reduce the amount of waste shown in Figure 1.

Figure 1. The circular economy model: less raw material, less waste, fewer emissions. Source: https://www.europarl.europa.eu/topics/en/article/20151201STO05603/circular-economy-definition-importance-and-benefits (accessed 3 July 2024).

In light of the above, this article attempts to address the question of the relationship between recycling levels, the use of secondary raw materials, and the innovation and competitiveness of the economies of the European Union member states. The aim of the paper is to assess changes within the framework of the circular economy in the European Union, with a particular focus on the progress made between 2012 and 2021. This issue has been the subject of numerous studies; however, there is a lack of comprehensive analyses that examine the relationships between recycling, the use of secondary raw materials, and innovation and competitiveness in the context of EU countries, representing a significant research gap. The article aims to partially fill this gap by identifying key CE indicators and examining their impact on economic development, innovation, and competitiveness in EU member states.

To achieve the main goal of the paper, the following specific objectives have been set:

1) Assessing changes in production and consumption in EU countries within the context of the circular economy.
2) Assessing changes in waste management practices across member states.
3) Evaluating the level of secondary raw materials usage.
4) Evaluating the competitiveness and innovation in the context of CE in EU countries.

Based on a review of the literature and the CE indicators proposed by the European Commission, the paper presents findings on the relationships between recycling levels, the use of secondary raw materials, and innovation and economic competitiveness. The study applies descriptive statistics and a multidimensional comparative analysis using the Hellwig method, which allows for an evaluation of the progress towards a circular economy in EU member states.

The article is structured as follows. Following the introduction, which outlines the context of the study and its main objectives, a literature review (Section 2) is provided, enabling the identification of a research gap in the area of competitiveness, innovation, and recycling within the framework of the circular economy. The methodology section (Section 3) then describes in detail the indicators and data analysis methods applied in the study, which form the basis for the research. Section 3 presents the results of the analysis of the relationships between recycling levels, innovation, and competitiveness, highlighting significant correlations and differences among EU countries. Section 4 draws conclusions from the analysis, summarizing the main findings and explaining their implications for the development of the circular economy within the European Union. Section 5 focuses on political recommendations derived from the study, aimed at supporting EU member states in shaping policies that promote innovation and competitiveness within a sustainable economy. The article concludes with a summary that not only highlights the study's limitations but also suggests directions for future research, focusing on the further transformation of EU economies toward a more innovative and competitive circular economy.

2. Literature Review

The development of the concept of a circular economy falls in the 21st century, and its theoretical basis can be found as early as the 1970s. It was also then that Stahel & Reday [17] presented a vision of a circular economy based on a product life cycle model. In their view, this economy has had a significant impact on job creation, economic competitiveness, resource-saving, and waste prevention. Further research by Stahela & Börlin [18] resulted in the 1987 report “Economic Strategies of Durability - longer product-life of goods as waste prevention strategy”. In this document, the authors emphasized that companies implementing the principles of the circular economy may achieve higher profitability than their competitors using a traditional, linear approach to the economy. The success of the circular economy, however, requires a fundamental change in the assumptions of the traditional economy. Critics of this theory argue that waste prevention is only possible in a linear economic model in which products become waste from the cradle to the grave [19]. This approach was not agreed with Pearce & Turner [20], and Stahel [21]. McDonough & Braungart [22] in their publication promoted the “Cradle to Cradle”—C2C approach. They emphasized the sequence: obtaining raw materials, production, use, and use of waste in the next production cycle. They pointed to the specific economic and ecological benefits of this approach.

As the years passed and the progress of innovative technologies, this concept gained more and more popularity. The circular economy system enables long-term preservation of the added value of products and the complete elimination of waste, which leads to savings in raw materials. It is based on the closure of the product life cycle, in which after the end of use, the product does not end up in a landfill, but is reused through recovery and recycling. This concept also includes in-house recycling and so-called waste exchanges [23–25]. An important element of this approach is effective product design, assuming minimization of negative impact on the environment throughout the product life cycle and less effect after the period of use. Design in this context focuses on increasing the efficiency and productivity of products through maintenance, reuse and repeated use, renewal, rework, and recycling.

One of the main advantages of the circular economy is its positive impact on the environment. Processes such as reuse and recycling of products significantly reduce the exploitation of natural resources. This, in turn, reduces the degradation of the landscape and habitats and helps to preserve biodiversity. Reducing greenhouse gas emissions is another key advantage of the circular economy. The European Environment Agency indicates that industry and product use account for 9.1% of greenhouse gas emissions in the EU, and waste management for 3.3%. By creating more efficient and sustainable products from the very beginning, the consumption of energy and raw materials can be significantly reduced, as it is estimated that more than 80% of the environmental impact of the product is determined at the design stage [26].

In addition, switching to more durable products that can be reused, improved, and repaired would significantly reduce the amount of waste. The problem of packaging, of which each European generates an average of almost 180 kg per year, could be solved by improving their design, which would support their reuse and recycling.

Also, the growing world population increases the demand for raw materials, while their supply is limited. This leads to a situation in which many EU countries are dependent on the import of raw materials. Eurostat indicates that the EU imports about half of the raw materials consumed, and the total value of trade in raw materials between the EU and the rest of the world has almost tripled since 2002, with exports growing faster than imports. Despite this, in 2021, the EU recorded a trade deficit of 35.5 billion euros [27]. Recycling raw materials reduces supply risks such as price variability, availability issues, and dependence on imports. This applies especially to key raw materials necessary for the production of technologies critical to achieving climate goals, such as batteries and electric motors.

Finally, the transition to a more closed-loop economy can help increase competitiveness, stimulate innovation and economic growth, and create new jobs. It is estimated that by 2030, 700,000 new jobs could be created in the EU alone thanks to the circular economy [28]. Redesigning materials and products for circular use would also stimulate innovation in various sectors of the economy.

CE has gained popularity on the international stage and has been partially or fully adopted by countries and organizations, including the European Union [29]. The basis of the concept of a circular economy in the EU has already appeared in the 6th Environmental Action Programme, adopted by the EU in Decision 1600/2002/EC of 22 July 2002. This program emphasized the importance of promoting rational management of natural resources and effective waste management. The program also pointed out the need to dematerialize the economy, increase resource efficiency, and reduce the amount of waste generated [30]. Subsequent documents drew attention to the need to manage the entire life cycle of products and take into account flows in the value chain, with an emphasis on the use of the life cycle assessment (LCA) metod [31].

In 2015, the European Commission introduced the first circular economy action plan, which aimed to increase global competitiveness, support sustainable economic growth, and create new jobs [32]. This plan included specific actions necessary to take throughout the product life cycle. In 2019, the European Commission published a comprehensive report on the implementation of this plan [33], presenting the main achievements and plans for the transition to a climate-neutral circular economy. In 2020, a new action plan under the European Green Deal [34] was presented, which aimed to adapt the economy to the "green future", strengthen the competitiveness of the EU, protect the environment, and provide consumers with new rights.

The new action plan, based on the work initiated in 2015, focuses on design and production in accordance with the principles of the circular economy to maximize the use of resources in the EU economy [35]. The key here is to ensure the right to remedy and empower citizens [36]. Particular attention was paid to sectors requiring a large amount of resources, such as electronics, information and communication technology (ICT), plastics, textiles, and construction.

In February 2021, the European Parliament voted on a resolution on a new circular economy action plan [37]. Parliamentarians demanded additional measures to achieve a carbon-neutral, environmentally sustainable, and toxin-free fully closed-loop economy by 2050. They also requested stricter regulations on recycling and setting targets for the use and consumption of materials by 2030. The strong synergy between the circular economy and the EU's climate and energy objectives and the Commission's "Clean Energy for All Europeans" package were highlighted.

The first package of proposals under the European Green Deal was presented in March 2022. It included:

- A program to support sustainable products that will be more environmentally friendly, and energy-efficient throughout the life cycle—from design to daily use, disposal, and reuse.
- Strengthening the position of consumers in the field of ecological transformation by informing about the environmental sustainability of products and increasing protection against false ecological marketing.
- Review of construction products regulations so that the regulatory framework enables the implementation of the sustainable development and climate goals in this sector.
- A strategy for sustainable textiles, aimed at making textiles more durable, repairable, reusable, and recycling, and ensuring that textile production is carried out with full respect for workers' rights.

The European Union consistently develops the strategy of the circular economy, focusing on sustainable development, innovation, and environmental protection. The action plan and its subsequent updates are aimed at transforming the economy, increasing competitiveness, and empowering consumers while striving to achieve climate neutrality by 2050.

In November 2022, the European Commission proposed new EU packaging regulations to reduce the amount of packaging waste and improve their design. The proposed regulations include clear labeling to support reuse and recycling and encourage the transition to biodegradable, biodegradable, and compostable plastics.

From the perspective of the evolution of the circular economy and the transformation of economic systems in this direction, monitoring the achievement of its goals is crucial. These actions are undertaken at all levels, namely micro, meso, and macro, and their significance is fundamental. However, the monitoring process presents a challenging task due to the lack of a uniform, widely accepted set of indicators, which may stem from the substantial diversity of these indicators and the varying interpretations of the CE concept by different stakeholders [38]. Currently, many international organizations dealing with issues related to the circular economy have proposed their own solutions for monitoring progress in the implementation of CE [39–41]. Some EU member states have developed their own indicator systems [42–45], which consequently complicates the comparison of the effects of CE-related actions between different countries. Researchers have also carried out measurements and monitoring of CE by developing indicators based on literature reviews and analyses [46–48]. The selection of appropriate indicators for assessing CE has become the subject of intensive discussion. Specifically, these discussions focus on measuring progress towards the transformation into a circular economy and the effectiveness of achieving CE goals, as well as identifying differences between CE assessment indicators and traditional economic indicators [20,49]. Establishing a benchmark for tracking progress in CE implementation is also key [50].

While there is extensive research on the concept of a circular economy and numerous case studies analyzing its implementation in various contexts, there remains a significant lack of specific tools and criteria for assessing the level of product, company, or regional circulation [51]. In response to the need for assessing progress towards a circular economy and the effectiveness of actions at both the EU and national levels, the European Commission has been monitoring the transition of the economy towards a circular model since 2018, evaluating it according to the following criteria: production and consumption, waste management, secondary materials, competitiveness, and innovation [52].

Although the literature provides numerous studies on the CE, there is a noticeable lack of macro-level analyses [53], including comparative studies. This article aims to fill this research. It addresses the research problem formulated as a question: What factors influence the differences in the level of circularity among EU countries, and how do these differences translate into the development of their economies?

In connection with the attempt to answer the above question, the objective of this paper has been defined. The main goal of the article is to assess the changes in the circular economy within the European Union.

The research problem concerning the circular economy has been addressed by many scholars, reflecting the growing interest in this topic in the literature [29,38,46,47,54,55]. However, the authors of this publication aim to conduct a comprehensive analysis that will identify countries with the lowest levels of circularity. Additionally, they intend to highlight areas requiring special attention and action, which may contribute to more effective implementation of sustainable development strategies in these countries. Such a holistic perspective on the issue will not only enhance understanding of the current situation but also help develop recommendations for policymakers and practitioners aimed at improving the efficiency of the circular economy.

3. Methodology

Based on the literature analysis, the authors concluded that the indicators that best reflect the circular economy are the waste management index and the material recycling rate.

Waste recycling is one of the key elements in the waste management strategy and sustainable development. It is the process by which waste materials are processed and returned to economic circulation, thus creating both economic and ecological value. Recycling allows to reduce the amount of waste going to landfills and the demand for primary raw materials, which translates into a lower burden on the environment. In this section, recycling rates for specific waste streams are analyzed. Understanding and monitoring these indicators is essential to assess the effectiveness of the transition to a circular economy in which resources are used in a more efficient and sustainable way. The overall level of recycling is an important indicator of progress in waste management and sustainability.

Increasing the amount of recycled waste is not only a step towards reducing the amount of waste but also a key element in the implementation of the objectives of the circular economy. In this economic concept, materials and products are kept in use for as long as possible, which in turn reduces the need to extract new raw materials and minimizes the negative impact on the environment.

Detailed recycling rates for individual waste streams provide valuable information on how different types of waste are processed and what challenges are associated with them. Among the analyzed streams, special attention is paid to packaging waste, including plastics, as well as electrical and electronic waste. Packaging waste, especially plastic waste, is a significant challenge due to its prevalence and long-term decomposition. Effective management and recycling of this waste are crucial to reducing environmental pollution and saving raw materials. Electrical and electronic waste (WEEE) is another category that requires special attention. Due to the content of hazardous substances and valuable metals, recycling of this waste is not only beneficial to the environment but also economically viable. Effective processing of WEEE allows to recover valuable materials that can be reused in the production of new devices.

Secondary raw materials play a key role in the creation of new products. Through processes such as recycling, regeneration, or renewal, materials and products gain a "second life", which leads to a reduction in the demand for primary raw materials. The use of secondary raw materials not only reduces the negative impact on the environment but also contributes to increased economic efficiency by reducing production costs and reducing dependence on primary raw materials.

To effectively close the circulation of the economy, it is crucial to introduce appropriate mechanisms enabling the reintroduction of materials and products into the economy. In this context, the indicator of the use of closed-loop materials becomes an important measuring tool. This indicator determines the proportion of recycled and re-entered materials, which allows to reduce the demand for the extraction of primary raw materials, in the overall consumption of materials. Material consumption in a circular economy, also called a closed-loop ratio, is expressed as the ratio of the amount of recycled materials to the total consumption of materials. Total material consumption is calculated as the sum of aggregated domestic material consumption (DMC) and the amount of materials entered into the closed circuit. DMC is defined within material flow accounts covering the entire economy. Circulating use of materials is estimated by the amount of waste processed in domestic recovery plants, less imported waste for recovery, and increased by waste exported for recovery abroad. A higher closed-loop coefficient indicates that a larger amount of secondary materials replaces primary raw materials, which in effect reduces the impact of primary raw materials extraction on the environment.

Both of the above indicators were subjected to a detailed analysis of descriptive statistics aimed at presenting changes in the data in the form of a line chart. This method allows for the observation of long-term trends over time for the entire European Union. For individual member states, the data is presented in bar charts that only include the extreme years. By using bar charts, it is possible not only to identify the values of the indicators at key moments but also to compare the dynamics of circularity among different countries. This method of visualization provides valuable insights into the effectiveness of implementing circular economy principles in various contexts and enables a better understanding of the changes occurring in these countries during the analyzed period.

The second stage of the research was conducted based on the acquired knowledge that the transition to a circular economy presents a unique opportunity to enhance the competitiveness and innovation of the economy. Such an economic model extends the life of products, which is achieved by improving their design, which takes into account the principles of the closed circuit, increasing the possibility of their reuse, repair, durability, and modernization. In addition, the circular economy promotes innovative industrial processes, such as industrial symbiosis, and supports modern forms of consumption, such as the sharing economy.

In the context of the analysis of innovation and competitiveness of the circular economy, three statistical indicators are key: private investment and gross added value related to the sectors of the circular economy, people employed in sectors of the circular economy, patents related to recycling, and secondary raw materials. The first two aspects play a fundamental role in the transition to a circular economy. Such an economic model can significantly contribute to the creation of new jobs and economic growth while reducing social inequalities and increasing collective resilience. The number of patents related to recycling and secondary raw materials is an indicator of the level of innovative technologies in the circular economy, which contributes to increasing the global competitiveness of the European Union.

In order to assess the level of competitiveness and innovation achieved by individual member countries, it is necessary to use multidimensional analysis [56]. This analysis allows to assess complex phenomena, i.e., those whose condition is affected at the same time by many features and factors [57].

In recent years, researchers studying the subject matter have primarily employed various analytical methods, such as cluster analysis, the Technique for Order Preferences by Similarity to Ideal Solutions (TOPSIS), and Data Envelopment Analysis (DEA). These methods, which facilitate complex evaluation and classification of objects based on their characteristics, are widely used in the context of multidimensional analysis. Examples of the application of these techniques are presented in Table 1, showing their diversity and relevance in studies concerning efficiency and competitiveness across different fields. The use of these analytical tools enables more precise results and a better understanding of the complex phenomena occurring within the investigated area.

Table 1. Overview of research methods used to study the diversity of the circular economy.

Research Method	Authors
Cluster Analysis	Castillo-Díaz et al. (2024) [29] Mazur-Wierzbicka (2021) [38] Vargas et al. (2024) [55]
Technique for Order Preferences by Similarity to Ideal Solutions (TOPSIS)	Garcia-Bernabeu et al. (2020) [46]
Data Envelopment Analysis (DEA)	Giannakitsidou et al. (2020) [47] Lacko et al. (2024) [54]

In the study of spatial diversity of competitiveness and innovation of the circular economy in the European Union, the method of linear ordering was used, within the multidimensional comparative analysis [57]. The primary purpose of this analysis is to construct a synthetic measure, allowing to replace a large set of features of the studied object with one aggregated variable [56], which is a synthetic representative of these features. This will allow to assess the object (EU-27 countries) using one variable and assign the analyzed objects in terms of the considered (multi-criteria) phenomenon (competitiveness and innovation of the circular economy in the EU). The construction of these measures is distinguished primarily by the way of taking into account features, stimulant and destimulant, and bringing these features to a common comparative system, as well as determining the value of the characteristics of the object, determining the pattern and the structure of the measure (determining the analytical form of the aggregating function) and its properties [58–60].

1) The first stage of the study involved identifying factors determining the advantage of a country over another EU country in terms of competitiveness and innovation of the circular economy or the distance separating these countries. These factors were classified:

- $\boldsymbol{X_1}$—Private investment and gross added value related to circular economy sectors,
- $\boldsymbol{X_2}$—Persons employed in circular economy sectors, and
- $\boldsymbol{X_3}$—Patents related to recycling and secondary raw materials.

The next stage was to build synthetic closed-circuit level meters. All variables accepted for analysis, from an economic point of view, were considered stimulants. The use of the Hellwig method required the construction of an observation matrix $\boldsymbol{X}$ consisting of n rows (EU countries) and m columns (diagnostic features):

$$\boldsymbol{X} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix}. \quad (1)$$

In order to obtain comparability of variables, the observation matrix was transformed into a matrix of variables standardized according to the formula:

$$Z_{ij} = -\frac{x_{ij} - \bar{x}_j}{s_j}, \quad (2)$$

where

Z_{ij}—standardizing the value of a variable in an EU country,
j—variable number,
i—EU country number,
x_{ij}—the value of the variable in the EU country,
$\bar{x}_j$—arithmetic mean of the variable determined according to the formula:

$$\bar{x}_j = n^{-1}\sum_{i=1}^{n} x_{ij}, \quad (3)$$

s_j—the standard deviation of the variable was determined according to the formula:

$$S_j = \sqrt{n^{-1}\sum_{i=1}^{n}(x_{ij} - \bar{x}_j)^2}. \quad (4)$$

In order to determine the diversity of the group of observations, and thus to check whether the given feature is statistically significant, the coefficient of variation was calculated according to the formula:

$$V_j = \frac{S_j}{\bar{x}_j}, \tag{5}$$

where

V_j—coefficient of variation of the variable,

S_j—standard deviation of the variable,

$\bar{x}_j$—arithmetic mean of the variable.

Based on the variables after standardization, a pattern was established, which is an "idealized" state with the best possible coordinates: $(Z_{01}, Z_{02}, \dots, Z_{0k})$, where $Z_{0j} = \max Z_{ij}$.

2) After transforming the variables, the reference method assuming the existence of a model object—a reference one—was used, in relation to which the taxonomic distances of the studied objects are determined using the Euclidean metric. The synthetic measure of the level of competitiveness and innovation of the circular economy was calculated as a synthetic indicator of the taxonomic <distance> of a given country from the theoretical pattern. A distance is specified for each site (EU country) from the pattern (value of the synthetic measure, the so-called measure of development), according to the following formulas:

$$M_i = 1 - \frac{d_{i0}}{d_0}, \ (i = 1, 2, \dots, n), \tag{6}$$

$$d_{i0} = \sqrt{\sum_{j=1}^{m} (z_{ij} - z_{0j})^2}, \ (i = 1, 2, \dots, n; j = 1, 2, \dots m), \tag{7}$$

$$d_0 = \bar{d}_0 + 2S_0, \quad \bar{d}_0 = n^{-1} \sum_{i=1}^{n} d_{i0}, \quad S_0 = \sqrt{n^{-1} \sum_{i=1}^{n} (d_{ij} - d_0)^2}, \tag{8}$$

where

M_i—synthetic meter,

d_{i0}—Euclidean distance of each pattern to build,

m—number of variables,

n—number of countries,

z_{ij}—standardized value of output features (variable for regions),

z_{0j}—the normalized value of the pattern for the variable,

$\bar{d}_0$—arithmetic mean of the taxometric distances,

S_0—standard deviations of the taxonomic distances.

3) In the final stage, a ranking of countries was made and grouped using the k means method, dividing the set into two subsets, i.e., according to objects larger and smaller than the mean, and in subsequent stages—according to intermediate means for each group. Such a division made it possible to distinguish the following groups:

- group I—very high level of circularity if $z_i \geq \bar{Z}_{1l}$,
- group II—moderate level of circularity if $\bar{Z}_1 < z_i \leq \bar{Z}_{1l}$,
- group III—low level of circularity if $\bar{Z}_{2l} < z_i \leq \bar{Z}_l$,
- group IV—very low level of circularity if $z_i \leq \bar{Z}_{2l}$,

where $\bar{Z}_l$—the average of the meter, and $\bar{Z}_{1l}$, $\bar{Z}_{2l}$—intermediate means of the meter values.

The study utilizing multidimensional comparative analysis allowed for a comprehensive examination of objects influenced simultaneously by various characteristics and factors, providing a broad and objective perspective on the phenomenon under investigation.

4. Results

In the first part of the study, the focus was on analyzing changes in the recycling of packaging waste, including plastics, as well as electrical and electronic waste, which are crucial for effective resource management and environmental protection. These changes significantly impact policies related to the circular economy and the actions taken by individual member states of the European Union. To illustrate these trends, the results of the analysis are presented in Figure 2, which depicts changes in recycling levels for the entire EU. This figure facilitates a better understanding of the dynamics of waste processing and helps identify areas that require further attention and action.

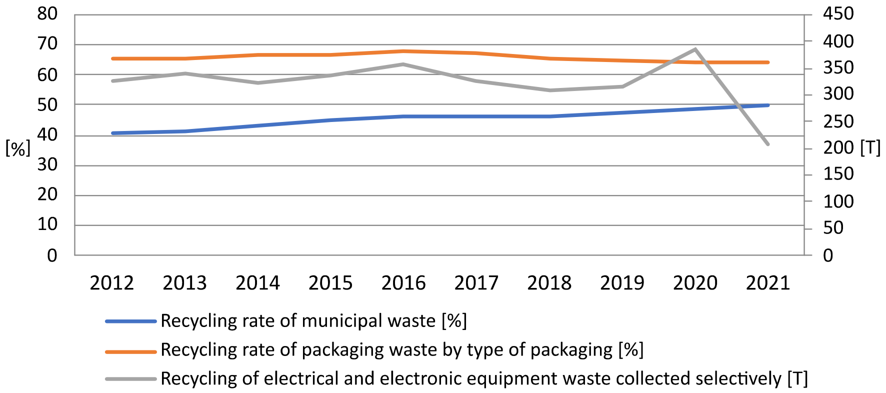

Figure 2. Change in the level of recycling for specific waste streams in the EU between 2012 and 2021. Source: Own study based on https://ec.europa.eu/eurostat/web/circular-economy/database (accessed 10 July 2024).

The first analyzed indicator measures the share of recycled municipal waste in the total amount of municipal waste generated. Recycling includes not only the processing of materials such as plastic, paper, glass, or metal but also the composting of organic waste and anaerobic fermentation. This indicator is expressed as a percentage (%), because both the amount of recycled waste and the total amount of municipal waste are measured in the same unit, i.e., in tons. A high percentage of this indicator indicates effective waste management and effective implementation of recycling practices in a given community. The analysis of this indicator allows to monitor the progress of recycling and identify areas for improvement, which is crucial for the transition to a circular economy. Changes in this indicator in individual EU member states are shown in Figure 3.

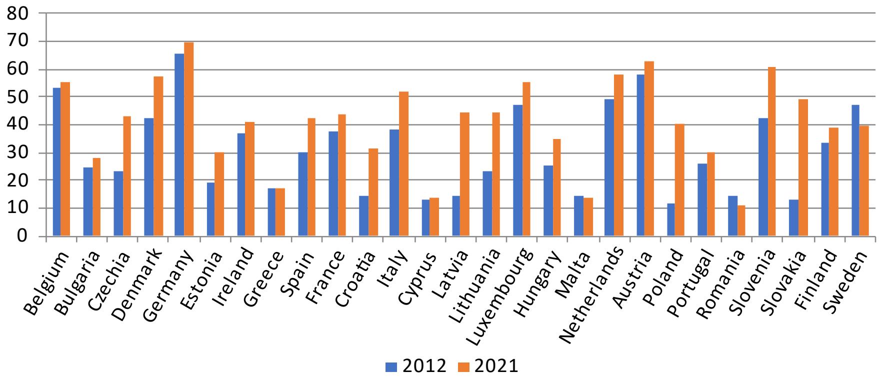

Figure 3. Change in the level of municipal waste recycling in EU countries in 2012 and 2021. Source: Own study based on https://ec.europa.eu/eurostat/web/circular-economy/database (accessed 10 July 2024).

On the basis of the data presented above, it can be noted that in almost all EU member states there has been an increase in the level of recycling of municipal waste. The largest increase was recorded in Slovakia (35.5 percentage points), Latvia (29.5 percentage points), and Poland (28.3 percent points). The decline in the analyzed indicator was recorded only in Sweden (7.4 percentage points), Romania (3.5 percentage points), and Malta (1.2 percentage points). The highest level of municipal waste recycling rate in the entire analyzed period can be observed in Germany, where in 2021 this level was 69.3%.

Another analyzed indicator is defined as the share of packaging waste from plastics recycled in all produced packaging waste from plastics. Packaging waste includes waste generated in the process of storage, protection, handling, delivery, and presentation of goods—from raw materials to finished products, from the manufacturer to the end-user or consumer, excluding production residues. This indicator is expressed in percentages (%), because both the amount of recycled waste and the total amount of plastic packaging waste are measured in the same unit, i.e., in tons.

The recycling rate of plastic packaging waste only takes into account the material that is reprocessed into new plastics, i.e., material recycling. This is a key aspect in assessing the effectiveness of packaging waste management because plastic is a significant part of municipal waste and has a large impact on the environment. The high rate of recycling of plastic packaging waste proves effective systems of segregation, collection, and treatment of this waste. Changes to this indicator are presented in Figure 4.

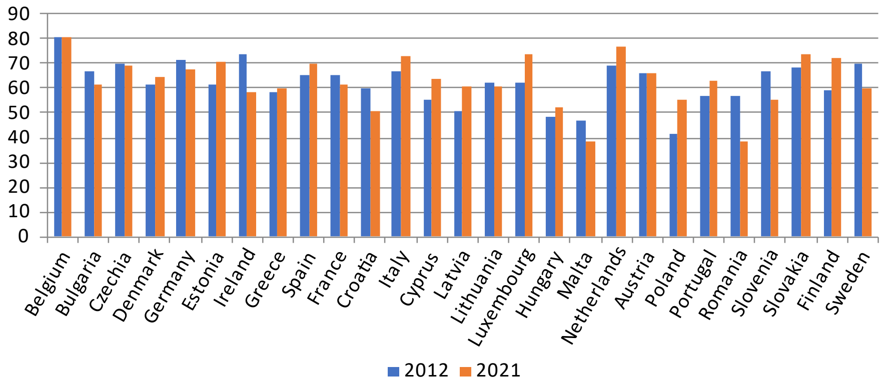

Figure 4. Change in the level of recycling of packaging waste in EU countries in 2012 and 2021. Source: Own study based on https://ec.europa.eu/eurostat/web/circular-economy/database (accessed 10 July 2024).

The data presented above are no longer as clear as the previous ones. As many as 12 countries saw a decrease in the level of recycling of packaging waste, including the largest in: Romania (18.5 percentage points), Ireland (15.9 percentage points), and Slovenia (11.8 percentage points). In 2021, the highest level of the analyzed index was recorded in Belgium—80.4%, while the smallest was in Romania—38.3% and in Malta—38.3%.

The last indicator analyzed in this category is the level of recycling of electrical and electronic equipment waste collected selectively. This indicator is calculated by dividing the mass of used electrical and electronic equipment going to the recycling plant or preparation for reuse by the mass completely selectively collected. Both values are expressed in mass units. In the last analyzed year, a noticeable decrease in this indicator was observed; however, it should be assumed that this decline does not result from entrenched changes but is the effect of a temporary disruption caused by the COVID-19 pandemic. The impact of the pandemic on the economies of EU member states led to disruptions in supply chains and a decrease in economic activity, which consequently affected recycling capabilities. Changes in the level of recycling of electrical and electronic equipment waste in various EU member states are shown in Figure 5.

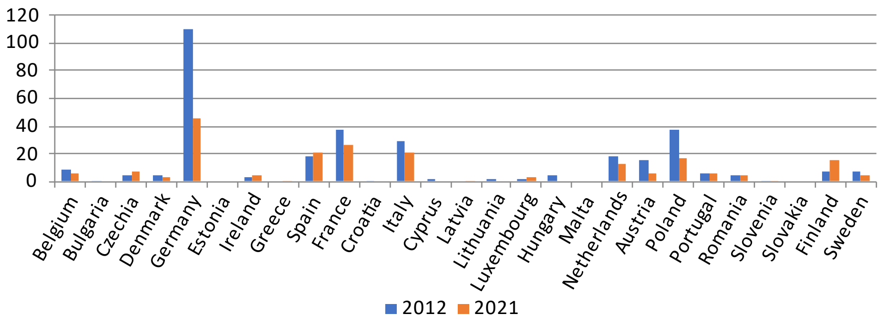

Figure 5. Change in the level of recycling of electrical and electronic equipment waste collected selectively in EU countries in 2012 and 2021. Source: Own study based on https://ec.europa.eu/eurostat/web/circular-economy/database (accessed 10 July 2024).

The above data shows that the highest level of recycling of electrical and electronic equipment waste is in Germany, at the same time it is the country where the largest decrease in the analyzed indicator from 110.25 tons in 2022 to 45.67 tons in 2021. In addition, it is necessary to emphasize that in 2021, the zero level of recycling of electrical equipment waste in electronic equipment was recorded in Bulgaria, Estonia, Croatia, Cypsze, Latwia, Hungary, Malta, and Slovakia.

As part of the second phase of the study, the focus was placed on the use of secondary materials, which play a crucial role in implementing the principles of the circular economy. Changes in the indicator of material utilization in the circular economy at the level of the European Union as a whole are detailed in Figure 6. This visualization illustrates the overall trends and dynamics shaping the approach to the circular economy in the region. Additionally, to better understand the differences among individual countries, these changes are also presented in Figure 7. This chart highlights the variability of indicators among the member states, allowing for the identification of both leaders and areas requiring further action and support in the context of sustainable material use. Such comparisons enable a better understanding of regional differences in the implementation of circular economy principles and indicate potential directions for future policies and development strategies.

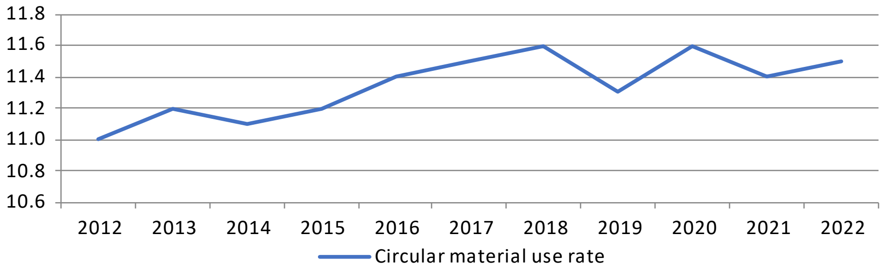

Figure 6. Change in the level of use of circular materials in the EU between 2012 and 2021. Source: Own study based on https://ec.europa.eu/eurostat/web/circular-economy/database (accessed 10 July 2024).

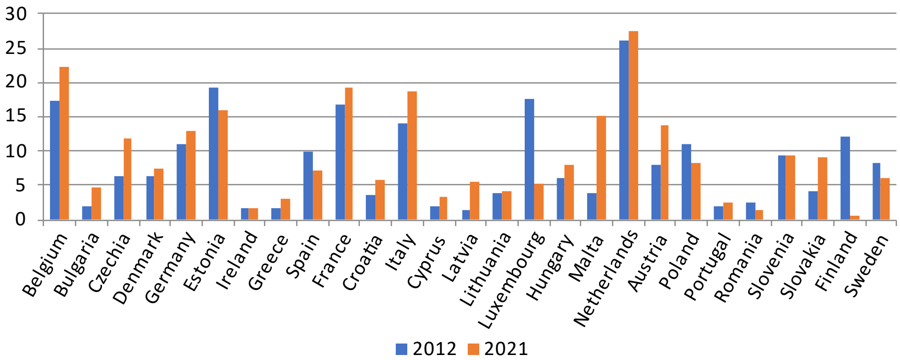

Figure 7. Change in the level of use of circular materials in EU countries in 2012 and 2021. Source: Own study based on https://ec.europa.eu/eurostat/web/circular-economy/database (accessed 10 July 2024).

In addition to the circular economy monitoring framework, the European Commission also calculates the circular use of materials in the EU, which can be tracked on the interactive Sankey diagram (see Figure 8).

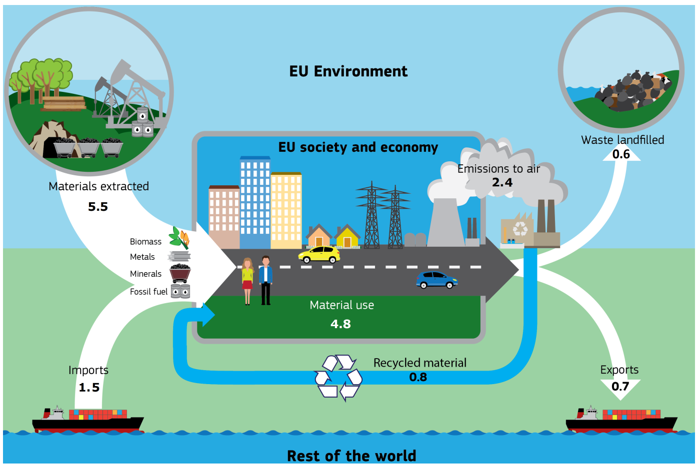

Figure 8. Material flows, EU, 2022 (billion tonnes = Gt). Source: https://ec.europa.eu/eurostat/statistics-explained/index.php?oldid=516747 (accessed 3 July 2024).

The above graphs and diagram determine the level of materials recovered and returned to the economy. Based on the data presented in Figure 6, it can be seen that the circularity index gradually increased from 2014 to 2018, after which in 2019, there will be a sharp decline. It is currently 11.9% [61]. Its trend is growing—it is 3.3 percentage points more than in 2004 [37]. In turn, on the basis of Figure 7, it can be noted that the highest level of the circularity index in 2021 was in the Netherlands (27.5%) and in Belgium (22.2%), the lowest in Finland (0.6%), Romania (1.4%) and Ireland (1.8%). In seven countries, there was a decrease in the circularity index, including in Luxembourg by as much as 11.5 percentage points and in Finland by 11.6 percentage points.

In the final part of the empirical research, the focus was on analyzing indicators related to the competitiveness and innovation of the circular economy in EU countries. Specifically, three key indicators were examined: private investment and gross added value in sectors related to the circular economy, the number of people employed in these sectors, and patents related to recycling and secondary raw materials. The developed diagnostic features provided the basis for creating an observation matrix, in which the arithmetic mean, standard deviations, coefficient of variation, and maximum and minimum values were calculated. Through the standardization of the obtained data, it became possible to compare the variables, and the calculated coefficient of variation indicated that all features were sufficiently diverse, making them statistically significant.

Statistical characteristics of the diagnostic variables and the statistical measures of the development of competitiveness and innovation in the circular economy in EU countries for the years 2012 and 2021 are presented in Tables A1 and A2, respectively. The analysis of individual diagnostic variables allows for the identification of countries with the highest and lowest levels of competitiveness and innovation in the context of the circular economy. Based on the calculated values of synthetic measures in the respective countries, a ranking was developed to illustrate the diversity of development in the examined area (see Table 2). The results of the analysis have also been visualized in Figures 9 and 10, further facilitating their interpretation.

Table 2. The ranking of EU countries in terms of the level of development, competitiveness, and innovation of the CE in 2012 and 2021.

2012			2021		
Country	Synthetic meter M	Level of development competitiveness and innovation	Country	Synthetic meter M	Level of development competitiveness and innovation
Germany	0.8423	very high level	Germany	1.0000	very high level
France	0.6420		France	0.7189	
Italy	0.4934		Italy	0.6170	moderate level
Poland	0.4273	moderate level	Spain	0.5189	
Spain	0.3846		Poland	0.4698	
Netherlands	0.3519		Netherlands	0.4181	
Austria	0.3323		Belgium	0.3490	low level
Belgium	0.3177		Austria	0.3354	
Sweden	0.2686	low level	Finland	0.3311	
Denmark	0.2573		Czechia	0.3159	
Portugal	0.2515		Sweden	0.3055	
Czechia	0.2507		Portugal	0.3054	
Hungary	0.2499		Romania	0.2974	
Romania	0.2471		Ireland	0.2907	
Finland	0.2463		Denmark	0.2890	
Ireland	0.2241	very low level	Hungary	0.2723	very low level
Bulgaria	0.2188		Luxembourg	0.2563	
Greece	0.2186		Greece	0.2545	
Slovakia	0.2153		Slovakia	0.2528	
Croatia	0.2151		Croatia	0.2519	
Lithuania	0.2140		Bulgaria	0.2519	
Luxembourg	0.2092		Lithuania	0.2490	
Cyprus	0.2080		Latvia	0.2461	
Latvia	0.2071		Slovenia	0.2457	
Slovenia	0.2052		Estonia	0.2403	
Estonia	0.2047		Malta	0.2375	
Malta	0.2011		Cyprus	0.2375	

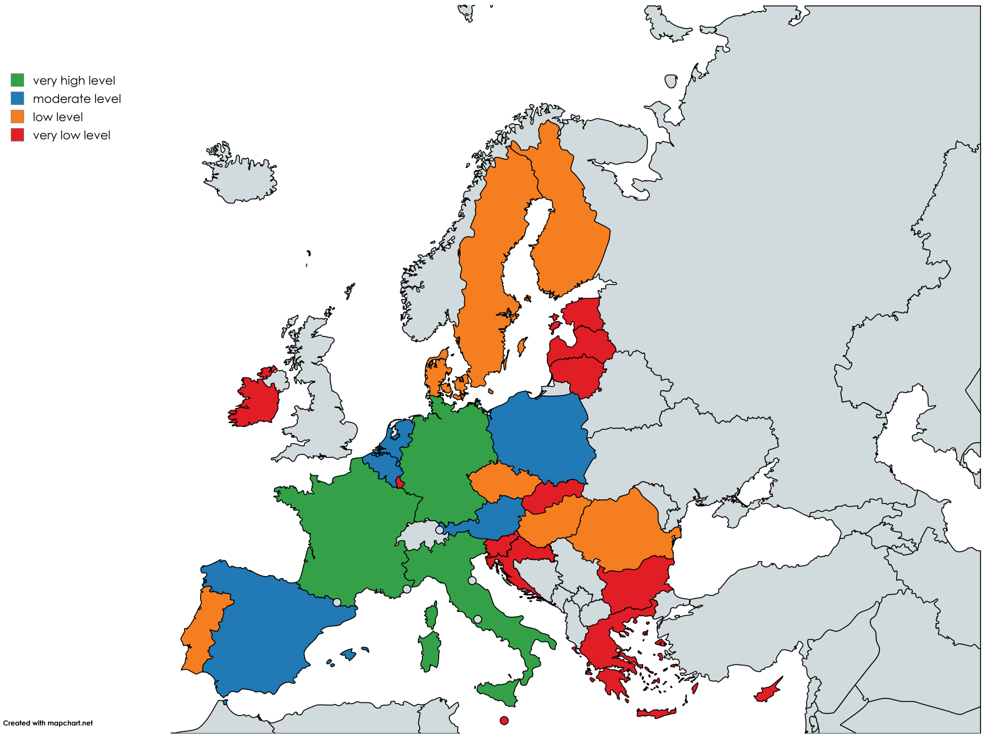

Figure 9. Spatial diversification of competitiveness and innovation of the circular economy in EU countries in 2012.

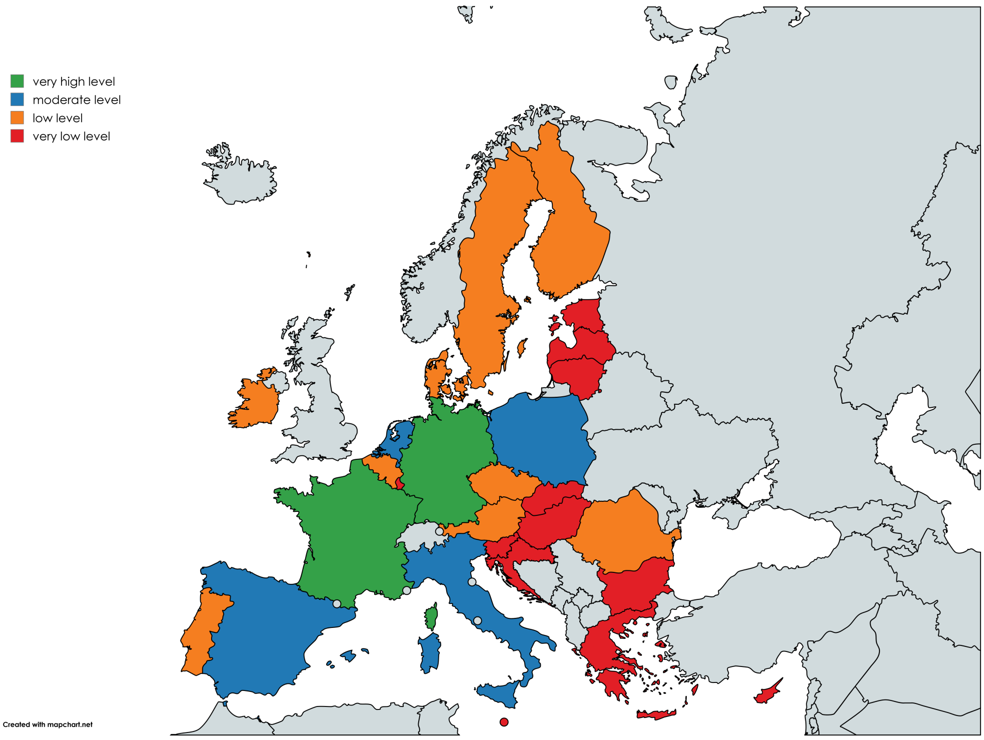

Figure 10. Spatial diversification of competitiveness and innovation of the circular economy in EU countries in 2021.

The highest level of competitiveness and innovation of the circular economy in 2012 was characterized by Germany, France, and Italy. In 2021, only Germany and France remained in this group, while Italy fell to a group with a high level of competitiveness and innovation, although they remained in third place in the ranking. Both in 2012 and 2021, the most, because as many as 12 countries were qualified for the category with a very low level of competitiveness and innovation of the circular economy. At the end of the ranking in both analyzed years were:

Luxembourg, Greece, Slovakia, Croatia, Bulgaria, Lithuania, Latvia, Slovenia, Estonia, Malta, and Cyprus. In 2012, Ireland also joined this group, which in 2021 was promoted to the "low" group, its place was replaced by Hungary, which fell in the ranking by three points.

On the basis of spatial diversity, a ranking of competitiveness and innovation of the circular economy and their changes was developed, the data obtained are presented in Table A3 and also presented graphically (Figure 11).

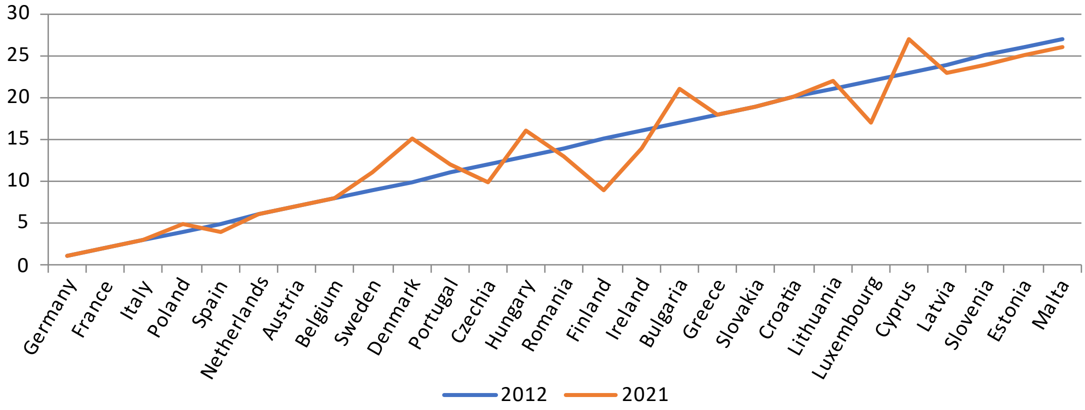

Figure 11. Position in the ranking of EU countries in terms of competitiveness and innovation of the circular economy in 2012 and 2021.

Presented in Table A3 and Figure 11, the changes in Denmark, Bulgaria, Cyprus, Hungary, and Sweden show a lower level of competitiveness and innovation of the circular economy than in other European Union countries. This means that in 2021 there was a decrease in private investment and gross added value related to circular economy sectors, a decrease in people employed in circular economy sectors, a decrease in patents related to recycling and secondary or raw materials from these categories, which is an undesirable phenomenon from the point of view of sustainable development.

5. Conclusions

The circular economy is a fundamental element of the modern sustainable development strategy, aimed at minimizing the waste of resources and maximizing the efficiency of their use. This concept promotes the longevity of products through their reuse, repair, recycling, and other forms of recovery. The transition to the circular economy model is not only necessary from the point of view of environmental protection but also creates unique opportunities for increasing the competitiveness and innovation of economies.

Studies on the level of competitiveness and innovation in the circular economy in the European Union have shown that despite significant progress in waste management and secondary use of raw materials, there are clear disparities between individual member states. The research results indicate that the highest level of competitiveness and innovation in the circular economy is observed in countries with developed economies. These countries are characterized by more advanced technologies, better recycling infrastructures, and greater support for innovative enterprises operating in the circular economy sector.

The identified inequalities are the result of various factors, such as the level of private investment and gross value added related to the sectors of the circular economy, people employed in the circular economy sector, or patents related to recycling and secondary raw materials. Economically developed countries, such as Germany and France, show higher rates in terms of the number of patents related to recycling and secondary raw materials, which indicates their innovative advantage. Investments in the recycling and repair and reuse sectors are also more intensive in these countries, contributing to higher gross value added and job creation.

This article examines the relationships between the levels of recycling and the use of secondary raw materials and the levels of innovation and competitiveness in the economies of EU member states. Based on the available data on waste recycling, it is evident that countries such as Germany, Belgium, Slovakia, and Poland have made significant progress in recycling municipal waste, with Germany and Belgium presenting the highest rates. Conversely, these same countries, particularly Germany, also stand out in terms of innovation and competitiveness, as confirmed by the results regarding the number of patents and investments in sectors related to the CE.

Germany, which achieved the highest level of municipal waste recycling in 2021 (69.3%), also demonstrates strong innovation indicators, suggesting that its circular economy strategy combines effective waste management with the development of innovative technologies. Similarly, Belgium, with a packaging waste recycling rate of 80.4%, ranks among the leaders in innovation within the CE sector.

On the other hand, in countries with lower recycling rates, such as Romania and Bulgaria, there are also observed limitations in innovation and competitiveness. For example, Romania, despite its efforts to improve, recorded a significant drop in the recycling rate of packaging waste (18.5 percentage points), which may be related to insufficient investments in recycling technologies and a limited number of innovations in this area.

The article fills the research gap by providing a detailed analysis of the relationships between circularity levels and the development and competitiveness of the economies of EU member states. Previous studies have not sufficiently addressed the complex interactions between these elements. This analysis provides new insights, showing how the implementation of circular economy principles can foster economic efficiency while simultaneously enhancing the competitiveness of EU member states. It also allows for the identification of differences in circularity levels and their impact on the competitiveness and innovation of the economies of EU countries, providing valuable information on key areas that require support in national policies for a more effective transition towards a circular model.

In summary, the analysis indicates a positive relationship between recycling levels and the use of secondary raw materials and economic innovation and competitiveness. National policies should therefore focus on supporting innovation and increasing recycling efficiency, which can bring benefits not only for environmental protection but also for economic development. Additionally, investing in education and raising social awareness is essential to support CE processes at both local and national levels. Further research may help to better understand how specific economic strategies can contribute to the better integration of innovation and competitiveness with the circular economy in various EU countries.

However, like any analysis, this one also has its limitations. It is primarily constrained by the absence of certain indicators that are part of the CE monitoring framework, which prevented their inclusion in the research. Nevertheless, the results presented in the article can serve as a starting point for further studies, including extending the analyzed period (according to data availability), incorporating new indicators, applying different statistical methods, or constructing econometric models. Thus, the analysis presented in the article may serve as a basis for further research on actions aimed at transforming the linear economy into a circular economy in EU countries, as well as studying the impact of this transformation on economic growth and social and economic development in individual countries.

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Data Availability

Data supporting this study are openly available from Eurostat at https://ec.europa.eu/eurostat/web/circular-economy/database.

Author Contributions

Conceptualization: B.Ś., & M.K.; Data curation: B.Ś., M.K., & Z.K.; Investigation: B.Ś., M.K., & Z.K.; Methodology: B.Ś., & M.K.; Resources: M.K., & Z.K.; Supervision: B.Ś., & M.K.; Visualization: M.K., & Z.K.; Writing – original draft: B.Ś., M.K., & Z.K.; Writing – review & editing: B.Ś., & M.K.

Conflicts of Interest

The authors have no conflict of interest to declare.

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Appendix A

Table A1. Statistical characteristics of diagnostic variables and statistical measures the level of competitiveness and innovation of the circular economy in EU countries in 2012.

Country	X1	X2	X3	Standardization			EulcideanDistance	Synthetic meter M
Belgium	5612.00	63,376.00	8.37	0.66	−0.36	−0.16	6.32	0.3177
Bulgaria	211.00	50,643.00	1.00	−0.53	−0.43	−0.49	7.23	0.2188
Czechia	460.00	119,217.00	4.46	−0.47	−0.05	−0.34	6.94	0.2507
Denmark	2413.00	33,009.00	4.99	−0.04	−0.53	−0.31	6.88	0.2573
Germany	13,299.00	617,452.00	110.25	2.35	2.71	4.37	1.46	0.8423
Estonia	196.00	10,687.00	0.00	−0.53	−0.66	−0.54	7.37	0.2047
Ireland	478.00	23,458.00	3.75	−0.47	−0.58	−0.37	7.19	0.2241
Greece	241.00	60,948.00	0.00	−0.52	−0.38	−0.54	7.24	0.2186
Spain	3423.00	343,199.00	17.66	0.18	1.19	0.25	5.70	0.3846
France	19,945.00	487,496.00	37.54	3.81	1.99	1.14	3.32	0.6420
Croatia	183,00	42,218.00	0.67	−0.53	−0.48	−0.51	7.27	0.2151
Italy	6283.00	573,325,00	29.45	0.81	2.47	0.78	4.69	0.4934
Cyprus	121.00	5582.00	1.80	−0.55	−0.68	−0.45	7.33	0.2080
Latvia	180.00	20,476.00	0.00	−0.53	−0.60	−0.54	7.34	0.2071
Lithuania	138,00	30,335.00	1.50	−0.54	−0.55	−0.47	7.28	0.2140
Luxembourg	312.00	1722.00	1.67	−0.50	−0.71	−0.46	7.32	0.2092
Hungary	480.00	112,989.00	4.57	−0.47	−0.09	−0.33	6.95	0.2499
Malta	64.00	4361.00	0.00	−0.56	−0.69	−0.54	7.40	0.2011
Netherlands	4774.00	99,896.00	18.52	0.48	−0.16	0.29	6.00	0.3519
Austria	5100.00	47,954.00	15.95	0.55	−0.45	0.17	6.18	0.3323
Poland	1833.00	387,443.00	36.90	−0.17	1.43	1.11	5.30	0.4273
Portugal	961.00	82,546.00	5.25	−0.36	−0.26	−0.30	6.93	0.2515
Romania	676.00	84,408.00	5.00	−0.42	−0.25	−0.31	6.97	0.2471
Slovenia	109.00	14,648.00	0.20	−0.55	−0.63	−0.53	7.36	0.2052
Slovakia	319.00	43,835.00	0.00	−0.50	−0.47	−0.54	7.27	0.2153
Finland	750.00	43,654.00	7.79	−0.41	−0.47	−0.19	6.98	0.2463
Sweden	1842.00	74,598.00	7.33	−0.17	−0.30	−0.21	6.77	0.2686
Arithmetic average	2607.5	128,869.4	12.0	0.0	0.0	0.0	6.5	0.300
Standard deviation	4550	180,291	22	1	1	1	1	0
Volatility coefficient	174%	140%	187%					50%
Max	19,945.00	617,452.00	110.25	3.81	2.71	4.37	7.40	0.8423
Min	64.00	1722.00	0.00	−0.56	−0.71	−0.54	1.46	0.2011

Table A2. Statistical characteristics of diagnostic variables and statistical measures the level of competitiveness and innovation of the circular economy in EU countries in 2021.

Country	X1	X2	X3	Standardization			Euclidean Distance	Synthetic meter M
Belgium	7251.00	63,868.00	5.49	0.43	−0.39	−0.20	6.05	0.3490
Bulgaria	395.00	52,323.00	0.00	−0.53	−0.45	−0.70	6.96	0.2519
Czechia	905.00	124,592.00	7.16	−0.46	−0.11	−0.04	6.36	0.3159
Denmark	3063.00	36,207.00	2.83	−0.16	−0.52	−0.44	6.61	0.2890
Germany	31,507.00	785,297.00	45.67	3.82	3.01	3.49	0.00	1.0000
Estonia	200.00	14,152.00	0.00	−0.56	−0.63	−0.70	7.06	0.2403
Ireland	2699.00	33,541.00	3.83	−0.21	−0.53	−0.35	6.59	0.2907

Table A2. (*Continued*)

Greece	171.00	59,634.00	0.50	−0.56	−0.41	−0.66	6.93	0.2545
Spain	6108.00	454,085.00	21.34	0.27	1.45	1.26	4.47	0.5189
France	20,405.00	523,904.00	27.09	2.27	1.78	1.78	2.61	0.7189
Croatia	404.00	52,113.00	0.00	−0.53	−0.45	−0.70	6.95	0.2519
Italy	12,423.00	613,339.00	21.51	1.15	2.20	1.27	3.56	0.6170
Cyprus	51.00	8827.00	0.00	−0.58	−0.65	−0.70	7.09	0.2375
Latvia	233.00	24,105.00	0.50	−0.55	−0.58	−0.66	7.01	0.2461
Lithuania	447.00	39,115.00	0.00	−0.52	−0.51	−0.70	6.98	0.2490
Luxembourg	722.00	2158.00	2.50	−0.48	−0.68	−0.47	6.91	0.2563
Hungary	1081.00	109,215.00	0.00	−0.43	−0.18	−0.70	6.77	0.2723
Malta	166.00	4970.00	0.00	−0.56	−0.67	−0.70	7.09	0.2375
Netherlands	8700.00	105,173.00	13.25	0.63	−0.20	0.51	5.41	0.4181
Austria	5474.00	49,173.00	6.49	0.18	−0.46	−0.11	6.18	0.3354
Poland	3890.00	441,671.00	17.25	−0.04	1.39	0.88	4.93	0.4698
Portugal	1771.00	87,525.00	5.42	−0.34	−0.28	−0.20	6.46	0.3054
Romania	1091.00	91,467.00	5.00	−0.43	−0.26	−0.24	6.53	0.2974
Slovenia	108.00	15,816.00	1.00	−0.57	−0.62	−0.61	7.01	0.2457
Slovakia	502.00	52,248.00	0.00	−0.51	−0.45	−0.70	6.95	0.2528
Finland	733.00	41,744.00	15.00	−0.48	−0.50	0.67	6.22	0.3311
Sweden	2265.00	85,100.00	4.72	−0.27	−0.29	−0.27	6.46	0.3055
Arithmetic average	4176.5	147,087.5	7.7	0.0	0.0	0.0	6.0	0.354
Standard deviation	7161	212,254	11	1	1	1	2	0
Volatility coefficient	171%	144%	142%					50%
Max	31,507.00	785,297.00	45.67	3.82	3.01	3.49	7.09	1.0000
Min	51.00	2158.00	0.00	−0.58	−0.68	−0.70	0.00	0.2375

Table A3. Ranking of EU countries in terms of competitiveness and innovation of the circular economy in 2012 and 2021.

Country	Synthetic meter M		Place in the ranking		Change
	2012	2021			
Germany	0.8423	1.0000	1	1	0
France	0.6420	0.7189	2	2	0
Italy	0.4934	0.6170	3	3	0
Poland	0.4273	0.4698	4	5	−1
Spain	0.3846	0.5189	5	4	1
Netherlands	0.3519	0.4181	6	6	0
Austria	0.3323	0.3490	7	7	0
Belgium	0.3177	0.3354	8	8	0
Sweden	0.2686	0.3055	9	11	−2
Denmark	0.2573	0.2890	10	15	−5
Portugal	0.2515	0.3054	11	12	−1
Czechia	0.2507	0.3159	12	10	2
Hungary	0.2499	0.2723	13	16	−3
Romania	0.2471	0.2974	14	13	1
Finland	0.2463	0.3311	15	9	6
Ireland	0.2241	0.2907	16	14	2
Bulgaria	0.2188	0.2519	17	21	−4

Table A3. (*Continued*)

Greece	0.2186	0.2545	18	18	0
Slovakia	0.2153	0.2528	19	19	0
Croatia	0.2151	0.2519	20	20	0
Lithuania	0.2140	0.2490	21	22	−1
Luxembourg	0.2092	0.2563	22	17	5
Cyprus	0.2080	0.2375	23	27	−4
Latvia	0.2071	0.2461	24	23	1
Slovenia	0.2052	0.2457	25	24	1
Estonia	0.2047	0.2403	26	25	1
Malta	0.2011	0.2375	27	26	1