SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2025
ORGANIZATION AND MANAGEMENT SERIES NO. 226

CONTEMPORARY CHALLENGES OF THE CIRCULAR ECONOMY

Agnieszka KOMOR

Department of Management and Marketing, University of Life Sciences in Lublin;
agnieszka.komor@up.lublin.pl, ORCID: 0000-0002-7532-3141

Purpose: The purpose of this study was to identify the current challenges and conditions for circular economy (CE) development, overcoming which would enable the transformation of the linear economy into CE. The empirical part assesses the level of CE development in EU countries using a synthetic index.
Design/methodology/approach: The study used statistical data from EUROSTAT. A synthetic taxonomic index was proposed to assess the level of development of CE in EU countries using the taxonomic linear ordering method, taxonomic classification.
Findings: The study identifies economic, social, technological, and political challenges that condition the transformation of the modern economy towards CE. The results showed that Luxembourg had the highest level of the examined index, followed by Belgium, Italy, Austria, and the Netherlands. Relatively low levels of CE development were observed in Greece, Romania, Bulgaria, and Cyprus. This indicates a significant spatial disparity in the level of CE development across EU countries.
Research limitations/implications: The research identified challenges related to the availability of statistical data on CE at the EU country level in public statistics, which posed a limitation for this study. Future research directions could include the analysis and evaluation of spatial disparities in CE development within individual countries.
Practical implications: The study indicates desirable actions to support the adoption of the CE, providing recommendations for public policy initiatives.
Social implications: This research contributes to expanding knowledge about CE. It can serve as a source of information for businesses and society regarding the conditions for transforming the linear economy into a circular one.
Originality/value: The study found that financial support for circular enterprises, changes in the way products are produced and consumed, shaping demand for circular enterprises' products and services, efforts to develop an explicit legal framework for circular enterprises, and access to modern digital technologies are key to transforming the economy towards increasing circularity. The study also proposes a synthetic index for assessing the level of CE development in EU countries.
Keywords: circular economy, development conditions, European Union countries.
Category of the paper: Research paper.

1. Introduction

The concept of the circular economy (CE) is a response to environmental issues related to inefficient resource management within the traditional linear economy. The circular economy originates from ecological economics, environmental economics, and industrial ecology and represents an alternative model to neoclassical economics. The literature provides numerous definitions of CE. Research indicates that the circular economy is most commonly presented as a concept emphasizing reduction, reuse, and recycling, with its primary goal being economic well-being and improved environmental quality (Kirchherr et al., 2017). It is important to recognize that the circular economy should be understood as a fundamental systemic change. Its ultimate goal is to achieve economic growth without environmental pressure. CE requires the adoption of new production models in enterprises, increased responsibility and awareness among producers and consumers, the use of modern technologies and materials, as well as the implementation of appropriate policies and tools (Ghisellini et al., 2016).

The goal of the circular economy is to enhance efficiency and maximize resource utilization, which implies reducing environmental impact and, in the long term, achieving zero emissions and zero waste (by-products, damaged, or unnecessary materials should serve as raw materials in a new production cycle) (Liao, 2022). The circular economy aims to maintain resources in circulation for as long as possible, reducing raw material and energy consumption, emissions into the environment, and waste generation (Milhem et al., 2024). Consequently, the waste and recycling industry plays a crucial role in the circular economy (Karstensen et al., 2020).

Beyond environmental benefits, CE practices contribute to significant economic advantages, such as reducing demand for new raw materials (Koech, Munene, 2020). Implementing circular economy principles also generates other positive economic effects, such as financial and operational benefits for companies and increased firm value for their customers (Silva et al., 2024). These practices encourage job creation, stimulate market growth, and strengthen competitiveness (Milhem et al., 2024).

The purpose of this study was to identify the current challenges and conditions for circular economy development, overcoming which would enable the transformation of the linear economy into a circular economy. Additionally, the empirical part assesses the level of circular economy development in EU countries using a synthetic index.

2. Conditions for circular economy development

The transition to CE requires significant changes in technology, business models, and consumer behavior. Overcoming these challenges and transforming economic processes toward a circular economy necessitates increased awareness, engagement, and cooperation among various stakeholders through continuous learning, the implementation of appropriate monitoring systems, regulatory changes, and the adoption of Industry 4.0 technologies (Dennison et al., 2024).

The transition to a circular economy involves multiple challenges across different dimensions, including economic, social, technological, and political aspects.

Among the economic determinants of CE development, financial factors are of key importance. The lack of access to adequate financing and high initial investment costs in implementing circular economy practices constitute significant barriers (Badjeena et al., 2024; Rizos et al., 2016). These can be mitigated by reducing bureaucratic barriers to financing access. Furthermore, the economic benefits of implementing circular economy practices are often not immediately apparent, making it difficult for firms to justify transitioning from a linear to a circular model. This challenge is compounded by the need to use advanced infrastructure and technologies, which are often costly (Reuter et al., 2019). It is worth noting that the cost analysis system in the linear economy does not account for long-term social and environmental benefits, which are considered within the circular economy framework (including full life-cycle analysis, a product's contribution to sustainable development, and health benefits) (Singh et al., 2024). The transformation toward a circular economy requires changes in production methods—products should be designed to ensure greater durability, upgradability, and/or repairability, as well as reusability and circular consumption (Pavliashvili, Prasek, 2020). Consequently, transitioning to CE necessitates significant changes in business models. Circular economy business models include (Lacy et al., 2014):

– circular supplies – providing materials based on bio-products and/or renewable energy that can be fully recycled, enabling multiple uses of the same resources,
– resource recovery – using innovative technological solutions to recover useful resources or energy from disposed products,
– product life extension – maintaining products in economic usability for as long as possible through maintenance, repair, refurbishment, or remarketing,
– sharing platforms – increasing the efficiency of rarely used goods by enabling consumers and businesses to share and exchange them via online platforms,
– product as a service – offering access to a product instead of ownership, allowing customers to pay only for its effective use while ensuring durability and servicing.

An important group of CE development determinants consists of social and integrative factors. Some authors emphasize that social issues (e.g., social inclusion, well-being, and equality) are not sufficiently highlighted in the circular economy. Therefore, there is a need to address sustainable social development alongside environmental and economic goals, including integrating CE with human development approaches (Schröder et al., 2020) and ensuring inclusivity and fairness in CE practices (Clube, Tennant, 2022). A key challenge is increasing consumer awareness and promoting eco-friendly behaviours in society through educational and informational campaigns, showcasing best practices, engaging governmental and local authorities in encouraging circular behaviours, and implementing responsible procurement policies in the public sector. These measures will help increase demand for circular products and services, which is essential for the CE transition (Badjeena et al., 2024).

A crucial determinant of circular economy development is technological and technical factors related to the advancement of modern digital technologies. Transitioning to a more circular economy involves innovations across various domains (including technology, organization, society, financing methods, and policies) (COM (2014) 398) and the utilization of modern digital technologies (COM (2020) 67). Achieving sustainable development goals and transitioning toward minimal or zero net waste requires digitalization (Govindan, 2023). Waste management can be optimized through innovations, leading to higher resource recovery rates. This is possible by creating decentralized waste management systems closer to their source, in line with CE principles (Peters, Samarasinghe, 2021). The transformation from a linear to a circular model requires modern technologies for measuring sustainability impacts and ensuring responsible resource utilization (Hsieh, Wang, 2023). Digital technologies are a key determinant of circular economy development, providing tools for digitalizing numerous operations and processes. The significance of the relationship between CE and the smart economy is reflected in the emerging concept of the smart circular economy (Truant et al., 2024; Bressanelli et al., 2022). Research indicates that digital technologies, including ICT, are essential for enabling circular economy development and its transformation into a smart circular economy (Komor, 2024). The use of digital technologies will accelerate the circular transition and reduce reliance on primary raw materials, following the principle: waste + data = resources. Examples of digital technologies contributing to CE development and its transformation into a smart circular economy are presented in Figure 1. The role of digital technologies in transitioning from a circular economy to a smart circular economy is illustrated in Figure 2.

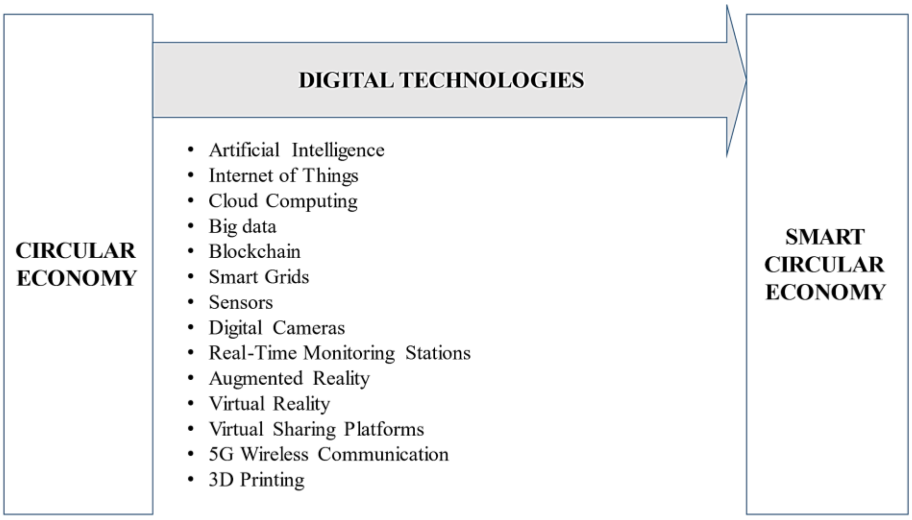

Figure 1. Selected digital technologies used in the transition from circular economy to smart circular economy.

Source: own study.

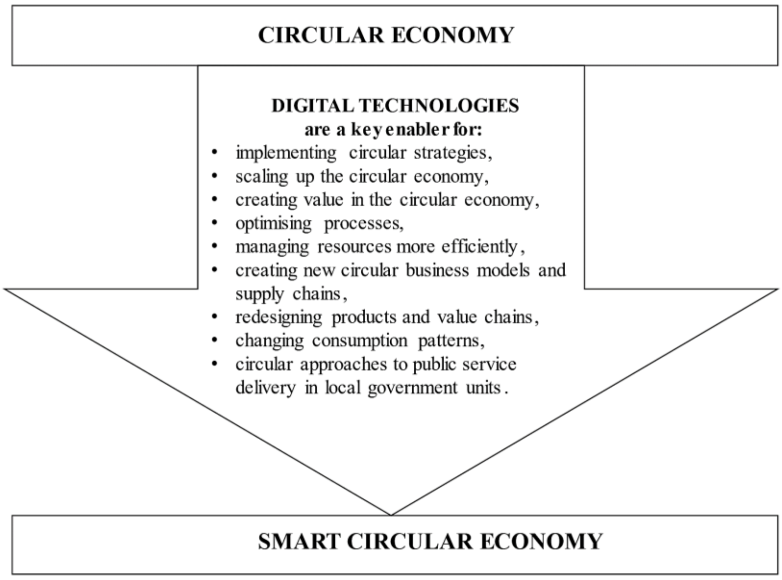

Figure 2. The role of digital technologies in the transition from a circular economy to a smart circular economy.

Source: Komor, 2024.

The next group of determinants for the transition to a circular economy are political and regulatory challenges. Political support and clear legal frameworks are crucial for CE implementation. European and national policies play an important role in encouraging eco-friendly consumer preferences, supporting businesses adopting circular business models (Rizos et al., 2016), and implementing responsible procurement policies in the public sector. Effective policy coordination across various levels - European Union, national, and local governments (Kaewunruen et al., 2024) - is essential to provide tailored support for circular entrepreneurs. Policies promoting circular entrepreneurship, economic incentives (e.g., tax relief and subsidies), and streamlined administrative procedures for financing can facilitate CE transition.

3. Materials and Methods

To conduct the study, statistical data from EUROSTAT were used. The research area covered 27 EU countries. The study period primarily included the years 2020-2023, utilizing the most recent available data for each indicator. The selection of indicators was guided by the research objective - assessing the level of circular economy development in EU countries - and data availability. A key limitation of this study was the lack of comprehensive statistical data on CE at the national level within the EU.

A synthetic taxonomic index of circular economy development (CE_INDEX) was constructed to evaluate CE development levels across EU countries. It comprised six diagnostic variables:

- X1 – circular material use rate (%),
- X2 – recycling rate of all waste excluding major mineral waste (%),
- X3 – share of private investments in CE-related sectors in GDP (%),
- X4 – share of gross value added from CE sectors in GDP (%),
- X5 – share of employment in CE sectors in total employment (%),
- X6 – number of patents related to recycling and secondary raw materials per million inhabitants (-).

The variables were assessed for formal criteria: measurability, completeness, and comparability. The correlation strength among diagnostic indicators was analysed, confirming that all variables were suitable for further research.

Table 1 presents the statistical characteristics of the diagnostic variables. Disparities among countries were identified, focusing on minimum and maximum values and the coefficient of variation. The relative measure of dispersion - the classical coefficient of variation (V_j) - was used to assess variability:

$$V_j = \frac{AV_j}{S_j} \tag{1}$$

where:

AV_j – arithmetic mean of indicator x_j.

S_j – standard deviation of indicator x_j.

Indicators with $|V_j| < 0.1$ were excluded. All indicators exhibited sufficient variability, with coefficient values ranging from approximately 0,32 (for the share of gross value added from CE sectors in GDP) to 1,54 (for the number of patents related to recycling and secondary raw materials per million inhabitants).

Table 1.
Descriptive statistics of diagnostic variables

Descriptive statistics	Diagnostic variables					
	X1	**X2**	**X3**	**X4**	**X5**	**X6**
Arithmetic mean	10,28	52,70	0,69	1,69	2,50	0,55
Standard deviation	6,97	18,38	0,32	0,53	1,37	0,85
Maximum	30,6 (Netherlands)	87 (Belgium)	1,4 (Belgium)	2,9 (Malta)	7,9 (Estonia)	3,97 (Luxembourg)
Minimum	1,3 (Romania)	10,0 (Estonia)	0,1 (Greece)	0,5 (Greece)	1,1 (Netherlands)	0,0 (Malta, Estonia, Croatia, Cyprus)
Coefficient of variation	0,68	0,35	0,46	0,32	0,55	1,54

Source: own elaboration based on EUROSTAT data. Retrieved from: https://ec.europa.eu/eurostat/data/database, 02.01.2025.

All features are stimulants, where low values are undesirable from the perspective of the analysed phenomenon. To achieve the research objective, the taxonomic linear ordering method was used, taxonomic classification (Hellwig, 1968). Diagnostic variables X1-X6 constituted the classification space, representing a set of characteristics defining the elements of the studied objects (i.e., EU countries). Based on these, a synthetic taxonomic indicator aggregating all diagnostic variables was constructed.

The first step involved normalizing the variables using the zero-unitarization method (Kijek, 2013; Kukuła, 2000):

For stimulants:

$$z_{ik}^{t} = \frac{x_{ik}^{t} - \min_{t} \min_{i} \{x_{ik}^{t}\}}{\max_{t} \max_{i} \{x_{ik}^{t}\} - \min_{t} \min_{i} \{x_{ik}^{t}\}} \tag{2}$$

For destimulants:

$$z_{ik}^{t} = \frac{\max_{t} \max_{i} \{x_{ik}^{t}\} - x_{ik}^{t}}{\max_{t} \max_{i} \{x_{ik}^{t}\} - \min_{t} \min_{i} \{x_{ik}^{t}\}} \tag{3}$$

where:

z_{ik}^{t} - normalized value of the k-th feature in the i-th object at time t (t = 1, 2, ..., T),

x_{ik}^{t} - original value of the k-th feature in the i-th object at time t.

It is worth noting that the indicator values range from <0;1>, with values closer to one indicating higher levels of the analyzed feature.

Next, a non-referential method with a fixed weighting system was selected for constructing synthetic metrics, influenced by the previously applied normalization method. Synthetic taxonomic indices were constructed as follows:

$$z_{i}^{t} = \frac{1}{k} \sum_{k=1}^{m} z_{ik}^{t} \tag{4}$$

Based on the synthetic index values, the analysed countries were classified into four groups based on their level of circular economy development. Group I included countries with the highest levels, while Group IV had the lowest. The class ranges were determined using left-closed intervals: Group I: Av + S(x), Group II: Av, Group III: Av-S(x), Group IV: 0 (where Av is the arithmetic mean, S(x) is the standard deviation).

4. Research Results

The highest synthetic index of circular economy development (CE_INDEX) was recorded in Luxembourg (Tab. 2). This was influenced by the highest number of patents related to recycling and secondary raw materials per million inhabitants in the EU, as well as relatively high values for the recycling rate of waste (excluding major mineral waste) and the share of private investments in CE sectors in GDP. Belgium ranked second, characterized by the highest recycling rate and the highest share of private investments in circular economy sectors in GDP. Italy ranked third in the CE development ranking, with relatively high indicators for the share of gross value added from CE sectors in GDP and waste recycling. The lowest synthetic index value was recorded in Greece, followed by Romania and Bulgaria. Greece had the lowest levels of private investments in CE-related sectors in GDP and the share of gross value added from CE sectors in GDP among the analysed countries. Romania had the lowest circular material use rate.

Table 2.
Circular economy development levels in EU countries

European Union countries	Diagnostic variables						Synthetic index of circular economy development (CE_INDEX)	Country ranking position
	X1	X2	X3	X4	X5	X6		
Luxembourg	0,304	0,792	0,692	0,250	0,456	1,000	0,582	1
Belgium	0,628	1,000	1,000	0,500	0,015	0,121	0,544	2
Italy	0,666	0,805	0,462	0,833	0,132	0,091	0,498	3
Austria	0,444	0,688	1,000	0,625	0,044	0,184	0,497	4
Netherlands	1,000	0,831	0,692	0,208	0,000	0,191	0,487	5
Malta	0,631	0,195	0,769	1,000	0,235	0,000	0,472	6
Estonia	0,573	0,000	0,462	0,583	1,000	0,000	0,436	7
Lithuania	0,089	0,805	0,538	0,542	0,456	0,136	0,428	8
Germany	0,430	0,584	0,615	0,708	0,088	0,139	0,427	9
Croatia	0,167	0,649	0,462	0,708	0,412	0,000	0,400	10
Denmark	0,266	0,688	0,615	0,542	0,029	0,123	0,377	11
France	0,556	0,481	0,538	0,458	0,103	0,101	0,373	12
Latvia	0,126	0,779	0,462	0,417	0,368	0,065	0,369	13
Poland	0,212	0,545	0,462	0,542	0,176	0,116	0,342	14
Ireland	0,034	0,403	0,385	1,000	0,029	0,194	0,341	15
Czechia	0,392	0,636	0,231	0,375	0,221	0,169	0,337	16
Slovenia	0,256	0,909	0,077	0,417	0,235	0,121	0,336	17
Slovakia	0,317	0,649	0,308	0,292	0,235	0,169	0,328	18

Cont. table 2.

Hungary	0,157	0,571	0,462	0,500	0,176	0,078	0,324	19
Spain	0,246	0,494	0,308	0,583	0,132	0,113	0,313	20
Finland	0,038	0,390	0,154	0,375	0,059	0,683	0,283	21
Portugal	0,051	0,377	0,538	0,417	0,176	0,134	0,282	22
Sweden	0,294	0,519	0,231	0,375	0,059	0,116	0,266	23
Cyprus	0,140	0,442	0,077	0,458	0,250	0,000	0,228	24
Bulgaria	0,123	0,169	0,385	0,417	0,235	0,018	0,224	25
Romania	0,000	0,351	0,308	0,208	0,176	0,065	0,185	26
Greece	0,133	0,221	0,000	0,000	0,059	0,013	0,071	27

Source: own elaboration based on EUROSTAT data. Retrieved from: https://ec.europa.eu/eurostat/data/database, 02.01.2025.

In the next step, the countries under study were classified into one of four groups based on their level of circular economy development, with Group I consisting of countries with the highest level of the synthetic index of circular economy development (CE_INDEX), and Group IV consisting of countries with the lowest level. A total of five countries were classified into the first group, which had the highest level of circular economy development: Luxembourg, Belgium, Italy, Austria, and the Netherlands (Tab. 3). The second group included: Malta, Estonia, Germany, Lithuania, Croatia, Denmark, France, and Latvia. The third group comprised: Poland, Ireland, Czechia, Slovenia, Slovakia, Hungary, Spain, Finland, Portugal, and Sweden. The lowest values of the studied indicator were recorded in Cyprus, Bulgaria, Romania, and Greece. Therefore, it can be concluded that these countries exhibited a relatively low level of circular economy development.

Table 3.
Classification of EU countries based on the value of the synthetic index of circular economy development (CE_INDEX)

Group	Number of countries in the group	Level of measurement	Countries
I	5	equal to and greater than 0.474	Luxembourg, Belgium, Italy, Austria, Netherlands
II	8	from 0.361 to 0.473	Malta, Estonia, Lithuania, Germany, Croatia, Denmark, France, Latvia
III	10	from 0,248 to 0,360	Poland, Ireland, Czechia, Slovenia, Slovakia, Hungary, Spain, Finland, Portugal, Sweden
IV	4	less than 0.248	Cyprus, Bulgaria, Romania, Greece

Source: own elaboration based on EUROSTAT data. Retrieved from: https://ec.europa.eu/eurostat/data/database, 02.01.2025.

5. Discussion

Circular economy offers a solution to overcome the current production and consumption model based on continuous resource use growth. Circular economy systems allow for the longest possible retention of the value of products, materials, and resources in the economy, enabling the repeated use of products to preserve their added value and eliminate waste, contributing to the achievement of the Sustainable Development Goals (Roleders et al., 2022). Some authors argue that circular economy is one of the elements of the concept of sustainable development (Grzymala, 2023). Others emphasize that the terms circular economy and sustainable development are not identical, but there are various relationships between them (Geissdoerfer et al., 2017). According to other authors, CE goes beyond sustainable development by preventing resource extraction, production, and disposal, making products durable, reusable, repairable, and renewable, as well as utilizing recyclable materials (Raja Kamal, Singha, 2023). In another approach, circular economy is seen as a management model in the paradigm of sustainable development (Skawińska, Zalewski, 2018).

Given the importance of circular economy in the context of sustainable development, many authors have undertaken the study of CE, including the challenges for its development. Literature identifies studies on drivers and barriers to the adoption of circular economy based on a systematic literature review (Pasqualotto et al., 2023). The study identified ten categories of driving factors and barriers: environmental, supply chain, economic, informational, legal, market, organizational, public, social, and technological. These categories largely align with those identified in this study, with some of them being part of broader categories mentioned here (e.g., legal and public conditions are part of political conditions, while supply chain and organizational factors are part of economic conditions). The environmental aspect - mentioned in the aforementioned study as related to sustainable development, resource shortage, waste management, and recycling - is difficult to classify as drivers or barriers to implementing CE. It seems to be more of a characteristic of CE and the reasons and goals for its implementation.

A study on the conditions for the transition to circular economy in the pharmaceutical industry identified obstacles to CE implementation, such as technology, finance, return on investment, regulations, stakeholder management, and corporate strategy (Kharat et al., 2025). In this industry, challenges related to reverse logistics were particularly significant due to the toxicity of the products. In another study, interviews with managers of small and medium-sized Swiss enterprises identified four external barriers to implementing CE: technology, market, legislation, and society and consumers (Takacs et al., 2022), which correspond to the conditions identified in this study. Similar results were obtained by Grafström (2025), who identified four main barriers to the implementation of circular economy: economic, technological, social, and institutional/regulatory.

In the context of transforming economies toward a circular economy, monitoring and measuring the achievement of its goals is of great importance. The literature does not agree on a single, universally accepted set of indicators for conducting this measurement. A review of various approaches to monitoring and assessing the level of CE development was presented by Mazur-Wierzbicka (2021). Some authors suggest that the transition to CE is slower in Central and Eastern European countries and Southern Europe than in Western European countries (D'Adamo et al., 2024; Mazur-Wierzbicka, 2021).

This article proposes a synthetic index to assess the level of circular economy development in EU countries. The obtained research results are difficult to directly compare with the findings of other authors due to the diversity of methodological approaches. One study showed that the choice of research method - even with the same set of indicators to assess CE development - significantly influences the diversity of results (D'Adamo et al., 2024). The study analysed two scenarios using the same set of variables. In the baseline scenario, each indicator was assigned a weight, while in the alternative scenario, all indicators were given equal importance. In both scenarios, Belgium was the leader (the country ranked second in this study in the ranking of EU countries in terms of CE development level). In the baseline scenario, Italy, France, and Latvia followed, while in the alternative scenario, the Netherlands ranked second, ahead of Italy. It is worth noting that only two of the 27 countries held the same position in both scenarios, and at the bottom of the ranking in the baseline scenario were Cyprus, Malta, and Luxembourg. In another study, the five best countries in terms of CE efficiency were: the Netherlands, Luxembourg, Belgium, France, and Germany (Candan et al., 2022). Another study divided EU countries into three groups based on CE development level. The highest level was represented by Germany, the Netherlands, France, and Italy, while Belgium, Denmark, Poland, Spain, Luxembourg, and Austria were at the medium level (Gedvilaitė et al., 2024).

6. Conclusions

This study identified, based on literature reviews, the current challenges and conditions for the development of circular economy, whose overcoming will enable the transformation of the linear economy into a circular economy. These challenges are of an economic, social, technological, and political nature. Among the economic conditions, important roles are played by access to financing sources, high initial investment costs, the cost of acquiring and implementing modern technologies, as well as the need for changes in business models. The transition to CE requires a radical change in the way products are produced and consumed, focusing on durability, modernization potential, repairability, and reuse. Social conditions are significant, including promoting pro-environmental behaviors in society and shaping consumer awareness regarding circular products, which will contribute to increased demand for such products. Among technological conditions, digital technologies are a key factor enabling the development of the circular economy, providing tools for the digitalization of many operations and processes. This study identified the main digital technologies used in the transition from circular economy to smart circular economy and discussed their role in this process. Among political conditions, collaboration between European, national, regional, and local policies aimed at promoting consumer eco-preferences and supporting circular entrepreneurs is crucial. Effective implementation of CE principles often requires political support, appropriate and clear regulatory frameworks, and economic incentives for companies adopting business models characteristic of the circular economy (e.g., tax breaks, subsidies, or streamlining administrative procedures for financing). It is important to emphasize that these conditions are universal; however, certain specific features may exist regarding particular sectors or countries.

In the empirical part of the study, a synthetic index for assessing the level of circular economy development in EU countries was proposed. It was shown that Luxembourg had the highest level of the studied indicator, followed by Belgium, Italy, Austria, and the Netherlands. A relatively low level of circular economy development was observed in Greece, as well as in Romania, Bulgaria, and Cyprus. This indicates significant spatial differentiation in the level of circular economy development in EU countries. The transformation of the EU economy towards greater circularity will only be possible after overcoming the challenges and conditions identified in this study.

In light of the research results, several key actions can be identified to further develop the circular economy:

- Support for circular enterprises, including easing bureaucratic barriers to access to financing, financial incentives for circular businesses, projects and programs supporting digitization processes in enterprises, developing clear legal frameworks for circular businesses, and providing expert support for circular processes.
- Stimulating demand for products and services from circular enterprises, including building consumer trust in businesses adopting circular practices, raising consumer awareness through education and training, promoting pro-environmental behaviours, and promoting green public procurement.
- Expanding ICT infrastructure to enable widespread use of digital technologies in business activities and public services related to circular economy. Investments in broadband internet, sharing platforms, and data management systems are crucial for supporting innovative solutions in CE.
- Strengthening communication and coordination between ICT entrepreneurship and other key sectors for implementing circular processes (e.g., waste management and resource recovery). This will enhance the effectiveness of circular economy initiatives and accelerate their implementation.
- Supporting local initiatives through financing and advisory services to help develop innovative circular projects, such as circular supplies.
- Encouraging cross-sector collaboration by creating platforms for knowledge and experience exchange between local governments, NGOs, the business sector, and local communities. This approach enables sharing best practices and implementing proven circular economy solutions.

During the research, problems with the availability of statistical data in public statistics on circular economy at the country level in the EU were identified, which was a limitation in this study. Future research directions may include the analysis and assessment of the spatial differentiation of circular economy development levels within individual countries.

References

1. Badjeena, B.P., Ali, E., Wonyra, K.O., Tamou, K. (2024). Green entrepreneurship: Opportunities and challenges for the transition to a circular economy in Togo, West Africa. *World Development Sustainability, 100181,* https://doi.org/10.1016/j.wds.2024.100181.
2. Bressanelli, G., Adrodegari, F., Pigosso, D.C.A., Parida, V. (2022). Towards the Smart Circular Economy Paradigm: A Definition, Conceptualization, and Research Agenda. *Sustainability, 14(9),* 4960, https://doi.org/10.3390/su14094960.
3. Candan, G., Cengiz Toklu, M. (2022). A comparative analysis of the circular economy performances for European Union countries. *International Journal of Sustainable Development & World Ecology, 29(7),* pp. 653-664, https://doi.org/10.1080/13504509.2022.2084794.
4. Clube, R.K., Tennant, M. (2022). Social inclusion and the circular economy: The case of a fashion textiles manufacturer in Vietnam. *Business Strategy & Development, Vol. 5(1),* 4-16, https://doi.org/10.1002/bsd2.179.
5. COM (2014) 398, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Towards a circular economy: A zero waste programme for Europe. Brussels, 25.9.2014.
6. COM (2020) 67, Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions, Shaping Europe's digital future. Brussels 19.2.2020.
7. D’Adamo, I., Favari, D., Gastaldi, M., Kirchherr, J. (2024). Towards circular economy indicators: Evidence from the European Union. *Waste Management & Research, 42(8),* pp. 670-680, https://doi.org/10.1177/0734242X241237171.
8. Dennison, M.S., Kumar, M.B., Jebabalan, S.K. (2024). Realization of circular economy principles in manufacturing: obstacles, advancements, and routes to achieve a sustainable industry transformation. *Discover Sustainability, Vol. 5(1),* 438, https://doi.org/10.1007/s43621-024-00689-2.
9. *EUROSTAT.* Retrieved from: https://ec.europa.eu/eurostat/data/database, 02.01.2025.
10. Gedvilaitė, D., Lapinskienė, G., Szarucki, M. (2024). Assessment of the Development of the Circular Economy in the EU Countries: Comparative Analysis by Multiple Criteria Methods. *Emerging Science Journal, 8(2),* pp. 574-591.

11. Geissdoerfer, M., Savaget, P., Bocken, N.M., Hultink, E.J. (2017). The Circular Economy– A new sustainability paradigm? *Journal of Cleaner Production, Vol. 143,* pp. 757-768, https://doi.org/10.1016/j.jclepro.2016.12.048.
12. Ghisellini, P., Cialani, C., Ulgiati, S. (2016). A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production, Vol. 114,* pp. 11-32, https://doi.org/10.1016/j.jclepro.2015.09.007.
13. Govindan, K. (2023). How digitalization transforms the traditional circular economy to a smart circular economy for achieving SDGs and net zero. *Transportation Research Part E: Logistics and Transportation Review, Vol. 177,* 103147, https://doi.org/10.1016/ j.tre.2023.103147.
14. Grafström, J. (2025). Decoding the barriers for a circular plastics industry: An equation framework. *Sustainable Production and Consumption, Vol. 54,* pp. 375-388, https://doi.org/10.1016/j.spc.2025.01.010.
15. Grzymala, Z. (2023). Circular Economy as a Sustainable Development Marketing Tool. In: I. Gigauri, M. Palazzo, M. Ferri (Eds.), *Handbook of Research on Achieving Sustainable Development Goals With Sustainable Marketing* (pp. 288-302). Hershey, PA, USA: IGI Global Scientific Publishing, https://doi.org/10.4018/978-1-6684-8681-8.ch015.
16. Hellwig, Z. (1968). Zastosowanie metody taksonomicznej do typologicznego podziału krajów ze względu na poziom ich rozwoju oraz zasoby i strukturę wykwalifikowanych kadr. *Przegląd Statystyczny, nr 4,* pp. 307-327.
17. Hsieh, T.-S., Wang, Z. (2023). Adopting modern technology to evaluate circular economy investments. *Cutter Business Technology Journal, Vol. 36(10),* pp. 36-41. Retrieved from: https://www.cutter.com/article/adopting-modern-technology-evaluate-circular-economy-investments, 20.12.2024.
18. Kaewunruen, S., Teuffel, P., Donmez Cavdar, A., Valta, O., Tambovceva, T., Bajare, D. (2024). Comparisons of stakeholders' influences, inter-relationships, and obstacles for circular economy implementation on existing building sectors. *Scientific Reports, 14(1),* 11046, https://doi.org/10.1038/s41598-024-61863-0.
19. Karstensen, K.H., Engelsen, C.J., Saha, P.K. (2020). Circular economy initiatives in Norway. In: S. Ghosh (Eds.), *Circular Economy: Global Perspective* (pp. 299-316). Singapore: Springer, https://doi.org/10.1007/978-981-15-1052-6_16.
20. Kharat, M.G., Kapoor, S., Parhi, S., Kharat, M.G., Pandey, S. (2025). Operationalizing sustainability in pharmaceuticals: Green supply chain metrics for circular economy. *Sustainable Futures, 9,* 100413, https://doi.org/10.1016/j.sftr.2024.100413.
21. Kijek, A. (2013). *Ryzyko sektorowe przemysłu przetwórczego. Modelowanie i ocena*. Lublin: Wydawnictwo UMCS.
22. Kirchherr, J., Reike, D., Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling, Vol. 127*, pp. 221-232, https://doi.org/10.1016/j.resconrec.2017.09.005.

23. Koech, M.K., Munene, K.J. (2020). Circular economy in Kenya. In: S. Ghosh (Eds.), *Circular Economy: Global Perspective* (pp. 223-239). Singapore: Springer, https://doi.org/10.1007/978-981-15-1052-6_12.
24. Komor, A. (2024). Smart city and the circular economy: The case of selected cities in the European Union. In: A. Visvizi, O. Troisi, M. Grimaldi (Eds.), *ICT, the Business Sector and Smart Cities* (pp. 117-137). England, UK: Routledge, Taylor & Francis Group.
25. Kukuła, K. (2000). *Metoda unitaryzacji zerowanej*. Warszawa: PWN.
26. Lacy, P., Keeble, J., McNamara, R., Rutqvist, J., Eckerle, K., Haglund, T., Buddemeier, P., Cui, M., Sharma, A., Cooper, A., Senior, T., Pettersson, P. (2014). *Circular Advantage: Innovative Business Models and Technologies to Create Value in a World without Limits to Growth*. Chicago: Accenture.
27. Liao, A. (2022). Circular Economy. In: A. Liao, *Warranty Chain Management: Digitalization and Sustainability* (pp. 375-399), Singapore: Springer Nature Singapore, https://doi.org/10.1007/978-981-19-2104-9_15.
28. Mazur-Wierzbicka, E. (2021). Circular economy: advancement of European Union countries. *Environmental Sciences Europe, 33,* pp. 1-15, https://doi.org/10.1186/s12302-021-00549-0.
29. Milhem, M., Ateeq, A., Al Astal, A., Alzoraiki, M., Ateeq, R.A., Shafie, D.I., Santhanamery, T. (2024). Advancing Sustainability: Embracing the Circular Economy for Environmental and Economic Resilience. In: E. AlDhaen, A. Braganza, A. Hamdan, W. Chen (Eds.), *Business Sustainability with Artificial Intelligence (AI): Challenges and Opportunities. Vol. 2* (pp. 57-68). Switzerland: Springer Cham., https://doi.org/10.1007/978-3-031-71318-7_6.
30. Pasqualotto, C., Callegaro-De-Menezes, D., Schutte, C.S.L. (2023). An Overview and Categorization of the Drivers and Barriers to the Adoption of the Circular Economy: A Systematic Literature Review. *Sustainability, 15(13),* 10532. https://doi.org/10.3390/su151310532.
31. Pavliashvili, S., Prasek, D.E. (2020). Accelerating transition to the circular economy in Georgia. *Bulletin of the Georgian National Academy of Sciences, Vol. 14(3),* pp. 7-13. Retrieved from: http://science.org.ge/bnas/t14-n3/01_Pavliashvili_Inaugural%20 Article.pdf, 02.01.2025.
32. Peters, S., Samarasinghe, K. (2021). Waste management practices: innovation, waste to energy and e-EPR. In: L. Liu, S. Ramakrishna (Eds.), *An Introduction to Circular Economy* (pp. 287-301). Singapore: Springer, https://doi.org/10.1007/978-981-15-8510-4_15, 287-301.
33. Raja Kamal, C.H., Singha, S. (2023). Green Economy Mechanisms in the Age of Technology and the Circular Economy. In: A. Hamdan, E.S. Aldhaen (Eds.), *Artificial Intelligence and Transforming Digital Marketing* (pp. 73-79). Switzerland: Springer, Cham., https://doi.org/10.1007/978-3-031-35828-9_7.

34. Reuter, M.A., van Schaik, A., Gutzmer, J., Bartie, N., Abadías-Llamas, A. (2019). Challenges of the circular economy: a material, metallurgical, and product design perspective. *Annual Review of Materials Research, Vol. 49(1),* pp. 253-274, https://doi.org/10.1146/annurev-matsci-070218-010057.
35. Rizos, V., Behrens, A., Van der Gaast, W., Hofman, E., Ioannou, A., Kafyeke, T., Flamos, A., Rinaldi, R., Papadelis, S., Hirschnitz-Garbers, M., Topi, C. (2016). Implementation of Circular Economy Business Models by Small and Medium-Sized Enterprises (SMEs): Barriers and Enablers. *Sustainability, 8(11),* 1212, https://doi.org/10.3390/su8111212.
36. Roleders, V., Oriekhova, T., Zaharieva, G. (2022). Circular economy as a model of achieving sustainable development. *Problemy Ekorozwoju, 17(2),* pp. 178-185, https://doi.org/10.35784/pe.2022.2.19.
37. Schröder, P., Lemille, A., Desmond, P. (2020). Making the circular economy work for human development. *Resources, Conservation and Recycling, Vol. 156,* 104686, https://doi.org/10.1016/j.resconrec.2020.104686.
38. Silva, P.M., Santos, J.F., Torres, A.F. (2024). Does the adoption of circular economy principles impact the value proposition and performance of companies? Effects on the origin and sector of activity of the companies. *International Journal of Innovation and Sustainable Development, Vol. 18(3),* pp. 276-292, https://doi.org/10.1504/IJISD. 2024.138180.
39. Singh, S., Bansal, H., Sharma, S.K., Sundaramurthy, S., Kansal, S.K. (2024). The Future Perspectives of Global Circular Economy Transition and Comprehensive Cost Analysis. In: S. Singh, S. Sundaramurthy, A. Ibhadon, F. Khan, S. Kumar Kansal, S.K. Mehta (Eds.), *Energy Materials. A Circular Economy Approach* (pp. 347-363). Boca Raton, USA: CRC Press, Taylor&Francis Group, https://doi.org/10.1201/9781003269779.
40. Skawińska, E., Zalewski, R.I. (2018). Circular Economy as a Management Model in the Paradigm of Sustainable Development. *Management, Vol. 18(2),* pp. 217-233, https://doi.org/ 10.2478/manment-2018-0034
41. Takacs, F., Brunner, D., Frankenberger, K. (2022). Barriers to a circular economy in small- and medium-sized enterprises and their integration in a sustainable strategic management framework. *Journal of Cleaner Production, 362,* 132227, https://doi.org/10.1016/j.jclepro. 2022.132227.
42. Truant, E., Giordino, D., Borlatto, E., Bhatia, M. (2024). Drivers and barriers of smart technologies for circular economy: Leveraging smart circular economy implementation to nurture companies' performance. *Technological Forecasting and Social Change, Vol. 198,* 122954, https://doi.org/10.1016/j.techfore.2023.122954.