

Analysis of the implementation of the circular economy model in the area of production and use of secondary raw materials in neighbouring countries – Poland and Slovakia

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Abstract

The aim of the study was to conduct a comparative analysis of progress in implementing the circular economy in the production and use of secondary raw materials in neighbouring countries – Poland and Slovakia. Research in the field of production and consumption includes analyses of the material footprint, resource productivity, and waste production. The analysis of the level of secondary raw material use concerns the use of circular economy materials and trade in recyclable raw materials. As a result of comparative research between Poland and Slovakia and the EU, it was found that between 2014 and 2024 there was a noticeable improvement in production and consumption, as well as in the use of secondary raw materials. Countries are gradually implementing measures related to the transition to a circular economy. The recommendations resulting from the comparative analysis the value chain. Raising consumer awareness and developing a waste the circular economy.

Keywords

Circular economy, product life cycle, sustainable development, sustainable production, production and quality, resource management



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Introduction

The current economic system is characterised by a linear flow of raw materials and resources. The foundation for the development of this system was access to relatively cheap energy, raw materials and low-interest loans. As a result, mass-produced goods were inexpensive, which allowed consumers to increase their consumption steadily. Mass consumption corresponds to an increase in production volume, which in turn leads to a constant demand for raw materials, intermediate products, and semi-finished products (Agyapong et al., 2024; Korzynski et al., 2009; Pacana et al., 2018). However, the consumption of significant amounts of natural resources, coupled with the production of large amounts of waste, degrades the environment beyond its capacity for renewal and regeneration (Czerwińska et al., 2024).

Unlike the currently prevailing linear model of economic development, the concept of a circular economy (CE), also known as the circular economy, aims to ensure the value of products, materials and resources within a closed economic cycle, as a result of which demand for them can be met by resources recovered from the previous economic cycle (Council, 2023; Valentine, 2024). The very notion of the CE stems from several theories and schools of thought that challenge the widespread linear economic systems that assume resources are inexhaustible. The key assumptions of the CE concept are defined by the 3R principle, i.e. reduce, reuse, recycle (Kirchherr et al., 2017). This type of economy is a regenerative economic system based on minimising the consumption of raw materials, waste, emissions and energy loss by creating closed loops in which waste from one process is used as input for another (D'Urzo and Campagnaro, 2023; Pacana et al., 2015). The concepts of the circular economy and sustainable development share a common message, but the CE has much more radical implications. The messages conveyed by the idea of sustainable development have not yet had a binding impact on changing the priorities of economic activity, i.e., to produce as cheaply and quickly as possible and sell as much as possible, without reflecting on the environmental consequences ('use and throw away') (Rosario et al., 2024; Pacana et al., 2014). The prospect of transitioning from a linear to a circular model of production and consumption is the subject of research in various sectors of the economy, but most often concerns material production (Neves and Marques, 2022; Cruz et al., 2024).

The circular economy is an important component in building a competitive, innovative economy based on resource efficiency and low carbon emissions. The continuous depletion of raw materials, rising prices, and increasing dependence on suppliers and distributors, often from other countries, pose a threat to both the environment and stable economic growth and development (Clifton et al., 2024). For this reason, it is essential to take appropriate measures that will have a comprehensive impact on the production of goods and the provision of services in the economy, from the supply of raw materials, through design, production and consumption, to rational waste management (Pohrebniak et al., 2024; Czerwińska et al., 2025). Waste should be reduced, but if its generation is unavoidable, it should be viewed as a secondary raw material. This should be achieved through activities preceding waste generation in the early stages of a product or service's life cycle (product design, product launch) (Bentkowska, 2024).

The circular economy is also linked to extending product life cycles. This means both designing products appropriately and sharing them, thus involving activities on the part of both the manufacturer and the consumer. This type of systemic approach is consistent with the principles of the new sharing economy, a component of the rapidly developing collaborative economy (Rugine and Ziliene, 2024; Ulewicz et al., 2023). The essence of this socio-economic phenomenon is dispersed networks of interconnected individuals and communities, i.e. cooperation (in the form of direct service provision, such as co-creation, co-use and co-purchasing, based on trust) stimulated and supported by information and communication technologies (ICT) (Souza et al., 2024; Czerwińska and Pacana, 2022). The collaborative economy has enabled the effective and innovative use of previously underutilised resources. The development of ICT has contributed to this growth. ICT is changing the way products are manufactured and consumed, blurring the boundaries between producers and consumers (Korzynski and Pacana, 2010; Carlos et al., 2024).

Given the importance of the circular economy and the process of economic transformation towards it, it is essential to monitor the implementation of stages and objectives. This is a difficult undertaking due to the lack of a single, commonly accepted indicator or set of indicators to measure progress in CE implementation at the enterprise, economic sector, city, region, or country level (Croitoru et al., 2024). It is impossible to identify the numerous dimensions and complexities of the comprehensive changes transforming the economy and economic systems into a circular economy using a single measure or indicator. The literature on the subject indicates that researchers, institutions and individual countries have presented a number of assumptions for the construction of indicators, as well as models that form the basis for the assessment of selected activities within the implementation of the circular economy concept at various systemic levels. A significant number of indicators relate to the creation of new business models (Gomes, 2024; Skare et al., 2023). Meanwhile, it is worth noting that at the heart of the CE are industrial activity (mainly raw material processing) and consumers who use various types of products and services available on the market, and whose choices may be more or less consistent with the idea of the CE (Dagilene and Varaniute, 2023; Pacana and Czerwińska, 2020).

The aim of the study was to conduct a comparative analysis of progress in implementing the circular economy in the area of production and use of secondary raw materials. Research in the field of production and consumption includes analyses of the material footprint, resource productivity, and waste production. The analysis of the level of secondary raw material use concerns the use of circular economy materials and trade in recyclable raw materials. The research focused on a comparative analysis of neighbouring countries – Poland and Slovakia. The reference point for the analysis was the average level achieved by the EU over a specific period of time.

Method

A comparative analysis of progress in implementing the circular economy in the production and use of secondary raw materials in Poland and Slovakia was conducted systematically. The approach adopted comprised six main steps, the implementation of which enabled the research objective set out in the study to be achieved. Table 1 presents a summary of the key stages of the research process.

Tab. 1. Description of the key stages of the adopted research procedure

No.	Stage	Details of the proceedings
1.	Specifying the subject and purpose of the research	This stage involves precisely defining what will be studied (the research subject) and what we want to achieve through the research (the research objective). The subject of the research should relate to a specific aspect of reality, phenomenon, issue or problem that will be better understood through the research. The research objective is the researcher's general intention, which defines what relationships to explore, what knowledge to acquire or what problems we want to solve in order to expand and enrich the existing state of scientific knowledge. This stage also includes the identification of elements and areas for comparison. In each of the countries selected for analysis, it is important to define the research issues precisely and ensure their equivalence.
2.	Identifying reliable data sources	This stage involved locating, analysing, and evaluating data from various sources to understand their location, significance, and reliability. As part of the analysis, this process should include the analysis of external data (public data, internet data, research results). Data sources are verified for accuracy, reliability, timeliness, and objectivity. Due to the subject matter of the research, the following were considered useful and reliable sources of data: statistical datasets (from state institutions and statistical offices at national and regional levels), official documents (reports, censuses, minutes), scientific studies, and expert opinions.
3.	Identification of appropriate indicators in relation to the adopted research objective	This stage involves selecting and defining appropriate indicators for the thematic areas covered by the study. Due to the complexity of the main issues, i.e. production and consumption as well as secondary raw materials, a broad set of indicators should be used to analyse: material footprint, resource productivity and waste production, use of closed-loop materials, and trade in recyclable raw materials.
4.	Collection and assessment of the usefulness of the data obtained	The collection and assessment of the usefulness of the data obtained is a stage that involves verifying whether the data is reliable, complete, fit for purpose, and lawful. The assessment of the usefulness of the data involves determining whether the data is adequate, correct and actually serves the intended purpose. If necessary, this stage also includes activities such as supplementing, correcting or deleting incorrect data. An important aspect is the comparability of data, meaning using domestic and foreign data on monitored issues in a consistent manner.
5.	Comparative analysis and interpretation of results	Comparative analysis is the stage of identifying and comparing similarities and differences between the countries under study, at a specific point in time, using a specific point of reference. The interpretation of the results involves explaining the significance of the similarities and differences identified as particularly important. On this basis, it will be possible to predict the likelihood of certain events occurring in the future.
6.	Conclusions and recommendations	Clarification of conclusions and reflections arising from identified differences and similarities, and identification of priority areas for development.

Consistent implementation of the methodological recommendations listed in Table 1 ensures the proper quality of cross-country studies and enables them to be carried out more accurately. The temporal aspect of comparability was also maintained in the study. Studies carried out in neighbouring countries covered the years 2014-2024.

Method verification and results

In accordance with the presented model of conduct, Poland and Slovakia, neighbouring countries, were analysed to diagnose the level of CE implementation in the industrial sector. The circular economy in the sphere of production is a model in which products and materials are designed, manufactured and used in a way that ensures they remain in circulation for as long as possible, while waste is treated as secondary raw materials and an input for subsequent production processes. The circular economy maximises the value and lifespan of products through reuse, repair, refurbishment and recycling. This approach reduces the demand for primary raw materials and decreases waste generation.

Stage 1. Specifying the subject and purpose of the research

The research focused on two neighbouring countries, Poland and Slovakia, regarding the implementation of the circular economy. The purpose of the research was to conduct a comparative analysis of Poland and Slovakia

in the context of the implementation of the circular economy, with particular emphasis on this economic model in the production and use of secondary resources. The starting point for interpreting the results of the cross-country comparative research was the results achieved by the European Union. The analysis covered the years 2014-2024.

Stage 2. Identification of reliable data sources

The data sources were verified for accuracy, reliability, timeliness, and objectivity. This stage involved the collection, processing, and analysis of secondary data from various publicly available sources – the identification of existing data. At this stage, desk research was used, in particular, secondary statistical analysis and content analysis. Based on the analysis of data sources, the following were considered useful: statistics and compilations from statistical offices (the European Statistical Office, the Central Statistical Office and the Statistical Office of the Slovak Republic), results of social research (project reports), as well as information available online (scientific studies, expert opinions).

Stage 3. Identification of appropriate indicators for the research objective

In connection with the established research objective and the specified area of analysis, adequate indicators were identified, i.e. those that accurately and appropriately reflect the measured value (avoiding excessive optimism) and are related to the objective. Table 2 summarises the selected indicators.

Tab. 2. Synthetic description of the indicators used in the study

No.	Thematic area	Indicator	Synthetic description of the indicator
1.	Production and consumption	Material footprint	The indicator quantifies global demand for raw materials (biomass, metal ores, non-metallic minerals and fossil fuels/energy carriers) resulting from consumption and investment by households, governments and businesses in the EU. It represents the amount of material in raw material equivalent (RME) needed (or the amount of domestic and foreign extraction required directly and indirectly) to produce the products consumed in the geofigural reference area. It is calculated as raw material input (RMI) minus exports in RME (calculated at the aggregate product level, by material).
2.		Resource productivity	This indicator is defined as gross domestic product (GDP) divided by domestic material consumption (DMC). DMC measures the total amount of materials directly used by the economy. It is defined as the annual amount of raw materials extracted from the territory of the local economy, plus all physical imports, minus all physical exports.
3.		Waste generation per capita	This indicator is defined as the total amount of waste generated in a given country, including main mineral waste (all NACE activities plus households), divided by the country's average population. This indicator covers the main mineral waste for all NACE activities and households.
4.	Recyclable materials	Circular material use rate	Total material consumption is measured by adding together total domestic material consumption (TDM) and closed-loop material circulation. TDM is defined in the national material flow accounts. Closed-loop material circulation is estimated based on the amount of waste recycled in domestic recovery facilities, minus imported waste intended for recovery and plus exported waste intended for recovery abroad.
5.		Trade in recyclable raw materials	This indicator measures the volume of recyclable waste and scrap, as well as other secondary raw materials (by-products), transported within the EU (between EU Member States) and across EU borders (outside the EU). This indicator covers the following selected types of materials: plastics (including rubber), paper and cardboard, ferrous metals, and precious metals (copper, aluminium, and nickel).

Source: own study based on: <https://ec.europa.eu/>

In the context of the inter-country research undertaken, indicators were selected that could be applied in the countries analysed.

Stage 4. Collection and assessment of the usefulness of the data obtained

Based on identified reliable data sources, a set of actual data and information on achievements in implementing the GOZ in the countries studied (Poland and Slovakia in relation to the EU) was compiled. A key step was to assess the value of the collected data and information in terms of their quality, completeness, and comparability over time and space, as well as to check whether their quantity was sufficient to achieve the objectives.

Stage 5. Comparative analysis and interpretation of results

In the circular economy, the material footprint refers to the total amount of primary raw materials and materials used throughout the product life cycle. The circular economy aims to minimise the material footprint through reuse, repair, refurbishment, and recycling, thereby keeping materials in the economy for as long as possible to avoid waste and minimise dependence on the extraction of new raw materials (D'Urzo and Campagnaro, 2023). The material footprint is very important in the current political context. The European Union's circular economy action plan clearly promotes the use of material footprint indicators. This is due to the specific nature of EU production, which has a greater share in global consumption than in global production, as a significant amount of consumer goods production in Europe is located in Asia. The material footprint indicator draws attention to the responsibility of the EU and its individual countries for environmental pressure in other parts of the world as a consequence of goods exported to the EU (Mesa et al., 2020). Figure 1 shows the achievements in minimising the material footprint of Poland and Slovakia compared to the EU.

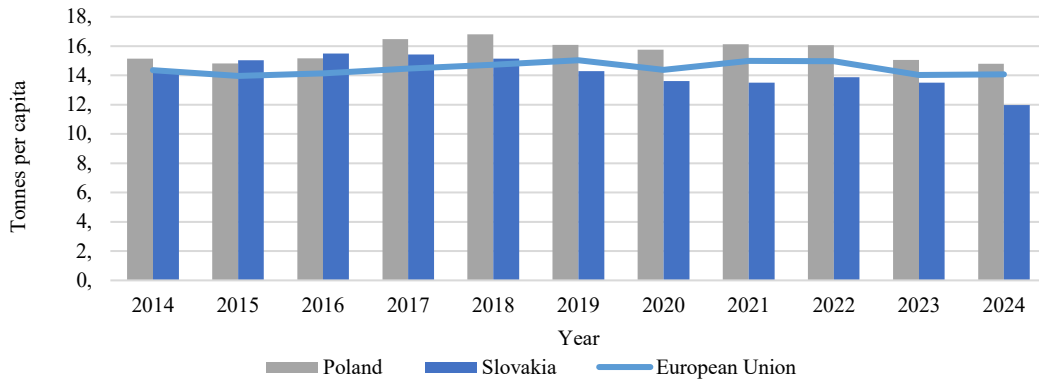


Fig. 1. The material footprint of Poland and Slovakia compared to the EU
 Source: own study based on: <https://ec.europa.eu/>

According to Figure 1, the material footprint index fluctuates between 14.78 and 16.79 tonnes per capita in the analysed period. Since 2021, there has been a decrease in the value of the indicator by 2.016 tonnes per capita. In the years analysed, Slovakia recorded lower values of the indicator than Poland (except in 2015 and 2016). The material footprint for Slovakia ranged from 15.488 to 11.976 tonnes per capita. In recent years, Slovakia has also reduced its material footprint and has been achieving values below the EU average since 2019. A low material footprint may indicate a more efficient use of raw materials and production processes in the Slovak economy. The higher indicator values for Poland may result from the specific nature of its economy, which is based on intensive extraction of raw materials.

An important issue related to the circular economy is the improvement of material productivity – the efficiency of material use, which contributes to reducing pressure and impact on the environment, but its growth is much slower than the growth of labour and energy productivity (Blomsma and Brennan, 2017). Figure 2 shows the level of resource productivity in Poland and Slovakia compared to the EU.

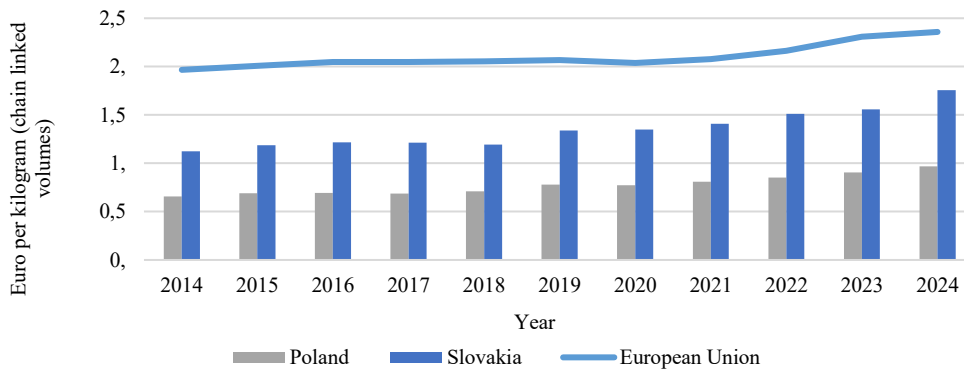


Fig. 2. Resource productivity in Poland and Slovakia compared to the EU
 Source: own study based on: <https://ec.europa.eu/>

An increase in resource productivity was observed in both countries studied. In Slovakia, the increase amounted to 0.63 euros per kilogram over 2014–2024, reaching 1.75 euros per kilogram in 2024, while in Poland it was 0.31 euros per kilogram. In 2024, Poland achieved a resource productivity of EUR 0.97 per kilogram. The EU also shows an upward trend in resource productivity, with a clear positive change since 2020, indicating improvements in resource condition and efficiency. Resource productivity should increase, as it is associated with higher production with less labour input, which is important for economic growth, per capita income growth and the overall improvement of the standard of living of a country's inhabitants.

The circular economy reduces waste by extending the life cycles of products, reusing, repairing, refurbishing, and recycling existing materials. The aim is therefore to transform waste into secondary raw materials, rather than viewing it as a problem. In this context, per capita waste production is the most important indicator of efficiency. Figure 3 illustrates per capita waste production levels in the countries analysed.

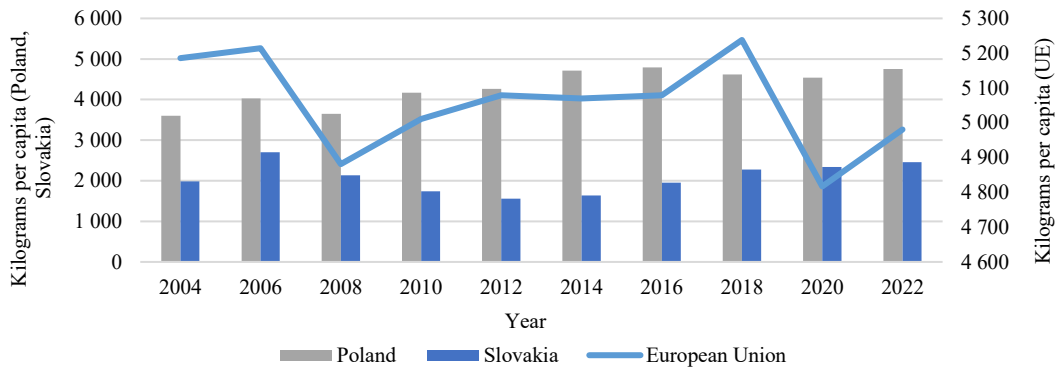


Fig. 3. Waste production per capita in Poland and Slovakia compared to the EU
Source: own study based on: <https://ec.europa.eu/>

The indicator for waste generation per capita is examined every two years. For this reason, the time horizon for this indicator has been extended.

The EU's waste management policy aims to minimise the environmental impact of waste and increase the efficiency of resource use. In EU countries implementing the circular economy, there are significant differences in waste production per capita (Lehmann et al., 2023; Lacko et al., 2024). The situation in the two countries studied differs significantly. Waste production in Slovakia was among the lowest in the Central and Eastern European region, except in 2022, when the difference between the EU and Slovakia was 2,523 kilograms per capita. In Slovakia, there is a need to further reduce the amount of waste generated, especially in the context of municipal waste, which often ends up in landfills instead of being recycled. Poland has achieved values above the EU average in almost every year surveyed, indicating potential for improvement but also the need to raise environmental awareness and improve the inefficient waste monitoring system.

As part of the analysis of the implementation of the circular economy, the circularity index (the indicator of the use of circular materials) was also examined. This indicator determines the share of recycled materials that were subsequently reintroduced into the economy (thus saving primary raw materials) in the total consumption of materials. Figure 4 shows the level of circular material utilisation in Poland and Slovakia.

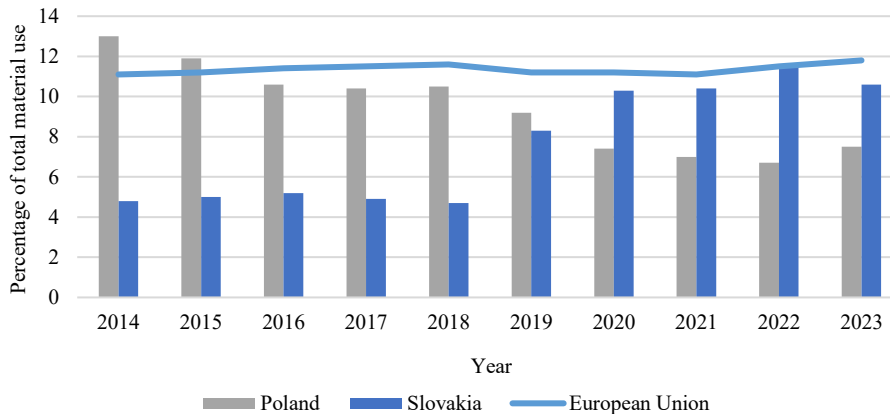


Fig. 4. Level of closed-loop material utilisation in Poland and Slovakia compared to the EU
Source: own study based on: <https://ec.europa.eu/>

2023 is the latest year for which circularity index values are available.

During the period under review, the circularity index for the EU as a whole ranged between 11.1% and 11.8%. It reached its highest value in 2023. In 2022, Poland recorded a decline in this index to 6.7%, and in 2023, an increase to 7.5%, which resulted in a drop from 10th to 16th place in the EU. The decline in the indicator was the result, among other things, of the accumulation of materials in infrastructure and long-term products, as well as the relatively high share of fossil fuels. In the case of Slovakia, there has been a significant increase in the indicator since 2019. In 2022, Slovakia reached the EU average, but in 2023, there was a decline to 10.6%. The high value of the indicator shows that a significant proportion of materials are recovered and reintroduced into circulation.

The trade index for recyclable raw materials was also analysed. Trade in recovered raw materials is a practical application of the circular economy principle, whereby waste and post-consumer materials are processed into secondary raw materials (Lingaitiene and Burinskiene, 2024). The level of trade in recyclable raw materials in Poland and Slovakia is shown in Figure 5.

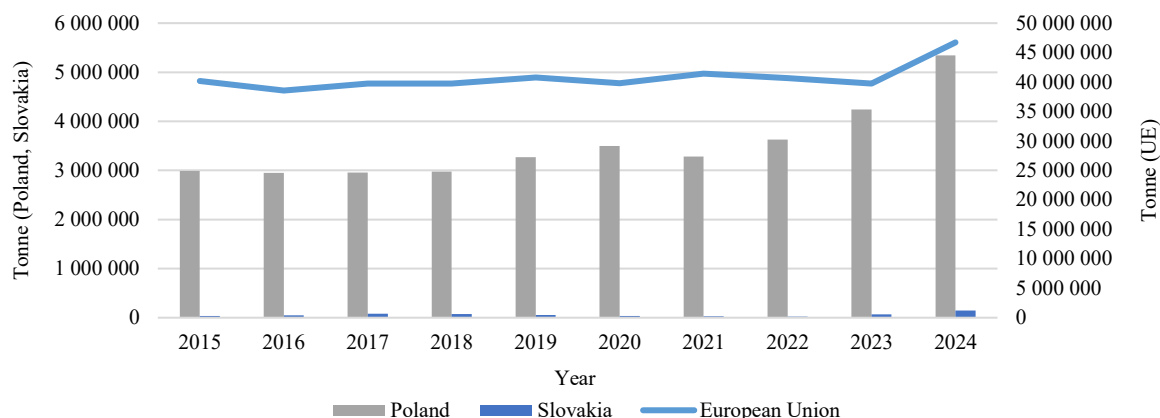


Fig. 5. Level of trade in recyclable raw materials in Poland and Slovakia compared to the EU
Source: own study based on: <https://ec.europa.eu/>

Based on Figure 4, it can be seen that trade in recyclable raw materials in Poland is at a much higher level than in Slovakia. Between 2015 and 2024, Slovakia achieved relatively low values for this indicator compared to the EU. Slovakia ranked 22nd among EU countries in terms of trade in recyclable raw materials. The situation is different in Poland. Since 2021, the index has grown from 3,282,768 tons to 5,341,494 tons in 2024. In 2024, Poland ranked third among EU countries.

Stage 6. Conclusions and recommendations

A thorough analysis of the research objective of comparing the progress of implementing the circular economy in the area of production and use of secondary raw materials in Poland and Slovakia against the European Union required the use of the following indicators:

- with regard to production and consumption:
 - material footprint,
 - resource productivity,
 - waste generation per capita,
- with regard to secondary raw materials:
 - circular material use rate,
 - trade in recyclable raw materials

The identified obstacles to conducting cross-national comparative studies were problems related to secondary data sources. These included: limited availability or lack of certain types of information; limitations in the comparability of sources; limitations in data accuracy; limitations in the relevance of information; limited timeliness; and limitations in the reliability of information. These difficulties contribute to a reduction in the number of indicators that can be used in comparative analysis. Due to data availability constraints, not all indicators could be analysed in the period 2014–2024.

In cross-country comparative studies, the limitations of aggregate indicators have been noted. The lack of a precise reflection of the economic situation of the countries studied stems from the complexity of the factors that differentiate and stimulate individual countries' economies. However, this type of analysis is more effective over a longer period of study to identify the direction of economic change.

The analysis, using indicators related to production, consumption, and secondary raw materials, enabled the drawing of conclusions, the development of recommendations, and the identification of best practices for the countries studied.

When developing recommendations and guidelines, it is important to remember that the circular economy should not be seen as an idea focused solely on reducing waste and its proper management. The circular economy is a development strategy that allows for economic growth while optimising resource consumption. In addition, it profoundly reshapes typical production and consumption chains and stimulates the design of new industrial systems. Given the multifaceted nature of the circular economy and the results of the indicator analysis, the development priorities for Poland and Slovakia should be:

- increasing the efficiency of production processes and the use of raw materials in the economy,
- reducing dependence on primary raw materials and increasing the resource efficiency of the economy,
- investing in renewable energy sources and technologies that reduce raw material consumption,
- promoting and developing information and communication technologies and innovations in processing technologies, materials, and business models that support the circular economy concept.
- protecting the environment by reducing the amount of waste going to landfills and reducing pollution,

- increasing environmental awareness and developing a waste monitoring system,
- extending the impact of the circular economy beyond national borders through international cooperation and support for global action.

Due to significant differences in the indicators used, in addition to the recommendations for both countries, the recommendations for Poland in the area of circular economy include:

- implementation of European Union regulations concerning the Single Use Plastics Directive, which aims to reduce waste from single-use plastic products. The directive also addresses minimising the adverse impact of plastics on the environment.
- financial support for businesses for investments in smart manufacturing, biodegradable materials, and reusable systems.

The recommendations for Slovakia in the area of circular economy focus on:

- using economic instruments that promote the transition to a circular economy model, reducing waste generation and raw material consumption.

The transition to a circular economy would not only increase competitiveness but, above all, would stimulate innovative solutions and economic growth. Future research directions will focus on expanding the analyses to include further areas related to the circular economy, i.e., waste management, competitiveness and innovation, global sustainability, and resilience. The research will also be extended to other neighbouring countries. Future research will support the diagnosis of the current state of affairs and the development of multifaceted recommendations for economic development.

Conclusions

The idea of a circular economy has gained considerable popularity, as evidenced by EU policy. The benefits of the circular economy mean that EU member states will undergo an effective transformation, expecting to achieve measurable economic (development of innovation, increased competitiveness) and environmental (reduction of waste, reduction of greenhouse gas emissions) benefits. However, this comes with a number of challenges, as implementing CE solutions requires long-term, profound changes across key areas of state functioning.

The aim of the study was to conduct a comparative analysis of progress in implementing the circular economy in the area of production and use of secondary raw materials. Research in the field of production and consumption includes an analysis of the material footprint, resource productivity, and waste production. The analysis of the level of secondary raw material use concerns the use of circular economy materials and trade in recyclable raw materials. The research focused on a comparative analysis of neighbouring countries – Poland and Slovakia. The reference point for the analysis was the average level achieved by the EU over a specific period of time.

As a result of comparative studies of Poland and Slovakia with the EU, it was found that between 2014 and 2024 there was a noticeable improvement in production and consumption, as well as in the use of secondary raw materials. Countries are gradually implementing measures related to the transition to a circular economy. Poland does not exceed the EU average in any of the indicators analysed. The higher values achieved by Poland may result from the specific nature of its economy, which is based on intensive raw material extraction. Slovakia is developing a circular economy. The country is gradually moving towards greater efficiency in the use of raw materials, reduced waste, and achieving the European Union's environmental goals, particularly those related to sustainable consumption. The level of development in the areas studied (production and consumption, and the use of secondary raw materials) compared to the EU average was assessed as moderately satisfactory.

The recommendations resulting from the comparative analysis mainly concern the promotion and development of innovation in processing technologies, the implications of a systemic approach throughout the entire product life cycle, and cooperation across the entire value chain. Raising consumer awareness and developing a waste-monitoring system also play key roles in advancing the circular economy.

A comparative analysis of neighbouring countries—Poland and Slovakia—in terms of progress in implementing the circular economy has enabled an understanding of and determination of the current state of affairs. Examining key areas such as production, consumption, and the use of secondary resources has enabled the development of recommendations and the identification of best practices for the countries studied.

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