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From Concept to Assessment: Evaluating the Circular Economy in the EU and Romania using Eurostat Circularity Indicators

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Abstract:
The circular economy has become a central pillar of the European Union's sustainable development policies; however, the transition from an extensive conceptual framework to rigorous empirical assessment remains uneven across Member States.
This study represents a preliminary and diagnostic analysis of Romania's circular economy performance within the EU, using the Eurostat Circular Economy Monitoring Framework updated in 2023. Rather than providing a definitive ranking, the research examines the capacity and limitations of exhaustive indicator-based assessments in comparative contexts.
The research combines a literature review with descriptive and comparative analysis of official statistical data across the five dimensions of the European framework.
Findings reveal methodological challenges, including indicator heterogeneity, unequal analytical relevance, and sensitivity to structural differences between Romania and other EU member states. Romania consistently ranks among the lower-performing Member States (Eurostat, 2025), reflecting high resource consumption, low material productivity, limited recycling, and modest integration into secondary raw material markets. However, these results are intended as a diagnostic assessment rather than a definitive evaluation.
The study contributes to the literature by providing a systematic assessment of Romania's circular economy performance within a European comparative context and by highlighting the limitations of approaches based exclusively on exhaustive indicators.
The research highlights the need for a selective set of indicators structured according to an input–process–output logic, forming a foundation for constructing composite indicators, cluster-based comparisons, and more coherent, policy-relevant monitoring of circular economy transition.

Keywords: *circular economy, circularity indicators, Eurostat, Romania*

JEL: Q56, Q53, C81, C82

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INTRODUCTION

Circular economy has consolidated over recent decades as a key concept in sustainable development policies (Kirchherr et al., 2017; European Commission, 2020), being promoted at the European Union level as a strategic alternative to the linear economic model. The specialized literature reflects a rapid and deeply interdisciplinary expansion of research dedicated to the circular economy, covering areas such as resource efficiency, waste management, eco-innovation, and bioeconomy. However, although the conceptual framework of the circular economy is well developed, its operationalization

through standardized measurement tools remains incomplete. The measurement of the circular economy has become a central concern in European policy and academic research, particularly following the adoption of the EU Circular Economy Action Plan and the establishment of a standardized monitoring framework based on Eurostat indicators.

Although these indicators provide an unprecedented empirical basis for tracking progress toward circularity goals, existing research shows that approaches to measuring circularity vary widely across contexts and scales. Recent systematic reviews reveal that current measurement frameworks often emphasize different aspects of circularity (such as material flows, resource efficiency, and life cycle outcomes) without offering a unified or universally applicable methodology (Calzolari et al., 2021; Lee et al., 2024). Furthermore, critical assessments specifically focused on EU key indicators highlight limitations in capturing essential circular practices such as waste prevention and material reuse, underscoring the need for more targeted and context-sensitive indicator selection (Păcurariu et al., 2021b; Martinho, 2021).

In the case of Romania, research on the circular economy is relatively recent and dominated by descriptive studies, while critical syntheses integrating theoretical, methodological, and empirical perspectives are limited. This situation justifies the need for a systematic and critical review of the specialized literature, analyzing both the conceptual evolution of the circular economy and the tools used to assess circularity, while situating Romania's performance within a comparative European context.

Within this context, the present study is explicitly framed as a preliminary and diagnostic analysis, forming the first analytical stage of a broader research framework. Its purpose is not to deliver a definitive measurement of Romania's level of circularity, but to critically assess the analytical capacity of the Eurostat indicator framework when used exhaustively in comparative evaluations. By examining the extent to which individual and aggregated indicators are able to capture meaningful differences between Romania and the EU average, the study identifies the methodological limitations of direct indicator-based assessments and justifies the need for a more selective and structured evaluation approach. The findings of this analysis provide the conceptual and empirical foundation for subsequent research stages focused on indicator selection, composite index construction, and cluster-based comparative analysis at EU level.

Accordingly, the objective of this study is to evaluate the extent to which the exhaustive use of Eurostat circularity indicators can support meaningful comparative assessments of national circular economy performance, using Romania as a case study.

MOTIVATION

The motivation for this study stems from the need to clarify and systematize the specialized literature on the circular economy, in a context characterized by a rapid increase in publication volume and a diversification of conceptual and methodological approaches. Although the circular economy is extensively discussed at the theoretical level, the literature highlights an imbalance between the breadth of conceptual development and the advancement of tools used to measure circular performance, particularly at the macroeconomic level.

Specifically, literature dedicated to circularity indicators represents a much narrower segment but essential for underpinning public policies and monitoring the progress of member states. In this context, Eurostat indicators are frequently used in comparative studies; however, few analyses critically assess their adequacy, coherence, and limitations, especially with respect to emerging economies or countries with different structural profiles, such as Romania.

Furthermore, Romanian research on the circular economy is fragmented and predominantly oriented toward the analysis of existing data, without systematically integrating theoretical and methodological contributions from the international literature. This gap justifies the need for a review that provides a synthetic perspective on the state of research, identifies prevailing trends, and highlights underexplored directions.

This study is explicitly designed as a preliminary and diagnostic investigation, aiming to bridge the gap between conceptual discussions and empirical measurement. By focusing on Romania as a representative emerging economy with specific structural characteristics, the research highlights both the potential and limitations of using existing Eurostat circularity indicators in comparative analyses.

Accordingly, the study responds to a dual need: first, to synthesize critically the literature on the circular economy and circularity indicators, providing a structured perspective on trends, gaps, and methodological challenges; second, to contextualize Romania's performance within the European framework, using official data as illustrative support. This approach contributes to clarifying the limitations of current comparative assessments and establishes a conceptual and methodological foundation for subsequent research stages, including the development of selective indicator frameworks, composite indices, and cluster-based comparative analyses.

METHODOLOGY

This study is designed as a literature review, combining bibliometric analysis with a narrative and critical synthesis of the main theoretical and methodological contributions in the field of circular economy and circularity indicators. The research does not aim to empirically test hypotheses, but rather to systematize, critically evaluate, and integrate existing knowledge.

In the first stage, an analysis of international and national literature on the circular economy was conducted, using publications indexed in the Web of Science Core Collection (Clarivate, 2025) and associated databases. The literature selection aimed to identify works that are conceptually and methodologically relevant, with an emphasis on studies explicitly addressing the measurement of circularity and the use of indicators at the macroeconomic level.

This stage allowed the identification of key conceptual and methodological trends and gaps, providing the basis for a subsequent, more structured indicator selection and comparative analysis.

In the second stage, the study examined literature dedicated to circularity indicators, with particular focus on the Eurostat circular economy monitoring framework (2023 version). This analysis aimed to evaluate the structural coherence of the indicators, their relevance for comparative analyses, and the limitations identified in the specialized literature.

This step highlighted both the potential and the constraints of using the full set of Eurostat indicators in comparative studies, especially for structurally distinct economies such as Romania.

In the third stage, Eurostat statistical data were used as illustrative analytical support to contextualize Romania's positioning relative to the EU average and other member states. The analysis is descriptive and comparative in nature, intended to support the critical synthesis of the literature rather than constitute an independent empirical investigation.

It is important to note that the statistical analysis is purely illustrative and diagnostic, serving to demonstrate the interpretative limits of existing indicators rather than to provide definitive rankings or policy prescriptions.

The methodological approach is integrative, combining bibliometric analysis, narrative review, and descriptive comparison. This structure allows for highlighting the relationship between the conceptual evolution of the circular economy, the available measurement tools, and reported performances,

thereby contributing to clarifying the limitations of current assessments and suggesting directions for future research.

Overall, this integrative methodology establishes a foundation for future research stages, including the development of selective indicator frameworks, composite indices, and cluster-based comparative analyses at the EU level.

1. A BIBLIOMETRIC ANALYSIS OF THE SPECIALIZED LITERATURE

This bibliometric analysis constitutes the preliminary diagnostic stage of the present research and aims to map the evolution, structure, and methodological orientation of circular economy scholarship, with particular emphasis on the emerging subfield of circularity indicators.

The literature corpus was constructed using the Web of Science Core Collection (Clarivate, 2025) and its associated databases. A topic-based search strategy was applied to titles, abstracts, and author keywords using combinations of “circular economy”, “circularity”, “circularity indicators”, “material circularity”, and “resource efficiency”. No disciplinary filters were imposed in order to capture the inherently interdisciplinary nature of circular economy research, spanning environmental sciences, economics, engineering, management, and public policy. Records were subsequently screened for relevance, duplicates were removed, and only documents with complete bibliographic metadata were retained for analysis, ensuring the robustness of citation and temporal mapping.

This procedure yielded approximately 51,500 publications addressing circular economy topics. However, only 3,502 studies (around 6.8%) explicitly engage with circularity indicators in a systematic manner, confirming that while circular economy is extensively discussed conceptually, its operationalization through measurable frameworks remains comparatively underdeveloped (see Figure 1).

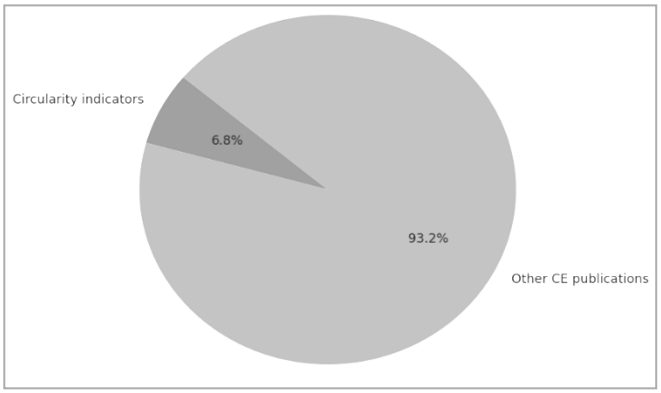

Figure 1. Proportion of Circular Economy Publications Explicitly Addressing Circularity Indicators

Source: Authors based on data from Clarivate, 2025

Temporal analysis reveals a pronounced acceleration in publication output after 2018, with the period 2019–2025 accounting for the majority of studies. This trend reflects both growing academic interest and institutional pressure linked to the circular transition promoted within the European Union. The literature is primarily concentrated in environmental science, industrial engineering, and sustainability-oriented journals, whereas public administration and policy-focused outlets remain underrepresented.

Recent studies highlight substantial methodological fragmentation in circularity measurement frameworks. For example, Saidani et al. (2019) identify a proliferation of heterogeneous indicator typologies with limited analytical convergence, while Haas et al. (2015) and Mayer et al. (2019) demonstrate that most existing metrics remain focused on material flows and fail to capture systemic

circular performance. Institutional assessments by the European Environment Agency and the OECD further emphasize that current monitoring frameworks insufficiently address life-cycle extension, waste prevention, and socio-economic impacts, limiting their relevance for policy evaluation.

Taken together, these findings reveal a persistent gap between normative discourse on circular economy principles and rigorous assessment of circular performance. Although bibliometric clustering identifies active journals, authors, and geographical concentrations, much of the literature remains descriptive or context-specific, with limited attention devoted to standardized and analytically robust measurement frameworks.

At the national level, research associated with România follows similar temporal dynamics, albeit with a noticeable delay. While publication output has increased sharply since 2019, Romanian studies remain predominantly descriptive and largely dependent on existing Eurostat indicators, with relatively few contributions engaging in methodological innovation or selective indicator design. Only a small subset directly addresses circularity measurement, reinforcing the gap between conceptual engagement and empirical operationalization.

Overall, the bibliometric evidence points to rapid quantitative growth of circular economy research globally and nationally, accompanied by persistent qualitative limitations in indicator comparability, methodological coherence, and cross-sector integration. These structural shortcomings provide the foundation for the present study, which departs from exhaustive indicator inventories and instead adopts a selective, functionally structured input–process–output framework. Building on insights from a diverse range of academic and institutional sources, including Saltelli et al., (2020), Urbinati et al. (2017), Kirchherr et al. (2017), Linder & Williander (2017), European Environment Agency (2021), OECD (2020), and Circle Economy (2023), this approach aims to enhance analytical clarity and support more policy-relevant comparative assessments, particularly for structurally heterogeneous or emerging economies.

The selected literature highlights that while the conceptual discussion of circular economy is extensive, the operationalization through measurable indicators remains fragmented and inconsistent across sectors and geographies (Urbinati et al., 2017; Kirchherr et al., 2017). Institutional analyses confirm that existing monitoring frameworks, including those used by EU member states, often fail to capture life-cycle extension, material reuse, and socio-economic dimensions, limiting their utility for policy evaluation (European Environment Agency, 2021; OECD, 2020). Practical reports also emphasize the need for indicators that are adaptable to diverse economic structures and comparable across contexts (Circle Economy, 2023; Saltelli et al., 2020). Taken together, these observations justify the adoption of a selective, structured framework in the present study, enabling both analytical rigor and alignment with sustainability dimensions recognized in the broader literature.

2. THE EUROPEAN MONITORING FRAMEWORK FOR THE CIRCULAR ECONOMY (2023 VERSION)

The present section provides a structured description of the EUROSTAT circular economy monitoring framework (2023 version), as part of a preliminary and diagnostic analysis. In European policy circles, the circular economy is often presented as a key instrument for enhancing resource efficiency and reducing environmental pressures while simultaneously improving Europe's competitiveness (European Commission, 2020).

At present, the circular economy must move from concept to reality and demonstrate tangible impacts on the environment, economy, and society. To achieve this, it is essential to establish reliable monitoring frameworks capable of providing empirical evidence of the circular economy's impact at macro, meso-, and micro levels.

The 2023 revision of the monitoring framework reorganizes the indicator system into five analytical dimensions, introducing a distinct global sustainability and resilience component (European Commission, 2023).

To track the progress of member states in transitioning toward a circular economy, the European Union, through EUROSTAT, has developed a harmonized monitoring framework based on a set of statistically relevant and comparable indicators at the European level. It is important to note that the indicators are used here as illustrative and diagnostic tools, rather than to deliver a definitive assessment of Romania's circular economy performance.

The importance of this system lies in its ability not only to measure the individual progress of each member state but also to enable cross-country comparisons, identify best practices, and highlight existing gaps. Furthermore, EUROSTAT indicators provide an essential tool for public policy formulation and for adjusting national strategies in line with objectives set at the European level.

The analysis presented focuses on describing the indicators and their relevance for comparative assessment, while highlighting methodological limitations that justify the subsequent development of selective indicator frameworks, composite indices, and cluster-based comparative analyses. The study examines Romania's evolution relative to the EU average over the reporting period.

Three representative time points are selected: the initial reporting year, an intermediate year, and the most recent year for which data are available. For the latest time point, the analysis will include Romania's ranking among the 27 member states, providing an integrated and diagnostic perspective on national performance relative to European dynamics.

The first dimension of the EUROSTAT circular economy framework (as shown in Table 1) focuses on production and consumption, in other words the stage where resources are introduced into the economy and managed throughout the product life cycle. The indicators in this dimension measure not only recycling performance but also provide an overview of how production and consumption contribute to reducing pressures on natural resources and extending material life cycles (Eurostat, 2025).

Material Footprint (RMC) – This indicator quantifies the demand for material extraction (biomass, metal ores, non-metallic minerals, and fossil energy carriers) triggered by household, government, and business consumption and investment in EU member states. It is measured in tons per capita. In 2023, the EU average was 14 t/cap, while Romania recorded 31 t/cap. While the EU reduced its material footprint by approximately 25% between 2008 and 2024, Romania's footprint increased by around 40%, placing it 25th out of 27 countries, i.e., the third-highest per capita consumer in the EU, indicative of a material-intensive economy.

Green Public Procurement – This indicator measures the share of public procurement procedures above EU thresholds (in number and value) that include environmental criteria. ("To What Extent Are the Green Public Procurement Criteria in National ...") Public procurement accounts for approximately 14% of EU GDP. Eurostat has not reported values for this indicator.

Resource Productivity (DMC) – This indicator measures the total materials directly used by an economy, defined as the annual domestic extraction plus total physical imports minus total physical exports. Measured in euro/kg, the EU average increased from 1.5496 €/kg in 2000 to 2.3584 €/kg in 2024, while Romania decreased from 0.542 €/kg in 2000 to 0.3719 €/kg in 2024. Resource productivity reflects GDP generated per kilogram of material consumed. The EU improved steadily (52% increase from 2000 to 2024), while Romania's productivity fell to the lowest level in the EU (27th), indicating a resource-intensive and inefficient economic model.

Total Waste Generation per Capita – Defined as all waste generated within a country, including major mineral waste (from all economic activities and households), divided by the average population.

Expressed in kg/cap, the EU average decreased slightly from 5,186 kg/cap in 2004 to 4,984 kg/cap in 2022. In Romania, the value decreased from an extreme 17,215 kg/cap in 2004 to 8,140 kg/cap in 2022, ranking 22nd among 27 monitored EU countries.

Waste Generation Excluding Major Mineral Waste per Unit of GDP – Defined as all waste generated (excluding major mineral waste) per unit of GDP (in euros), expressed in kg/1,000 €. The EU average decreased from 76 kg/1,000 € in 2004 to 60 kg/1,000 € in 2022. Romania decreased from 379 kg/1,000 € in 2004 to 110 kg/1,000 € in 2022, ranking 23rd of 27 EU countries.

Municipal Waste Generation per Capita – Measures waste collected by or on behalf of municipal authorities and managed via municipal waste systems, expressed in kg/cap. The EU average remained stable from 513 kg/cap in 2000 to 515 kg/cap in 2022. Romania decreased from 355 kg/cap in 2000 to 303 kg/cap in 2022, ranking 25th out of 25 reporting EU countries.

Food Waste – Defined as annual food waste generated divided by the average population. Expressed in kg/cap, the EU average was 129 kg/cap in 2022, while Romania reported 181 kg/cap, ranking 24th of 27 monitored EU countries.

Packaging Waste per Capita – Includes all packaging covered by the EU Waste Framework Directive 2008/98/EC (excluding production residues), expressed in kg/cap. The EU average increased from 158.27 kg/cap in 2005 to 186.85 kg/cap in 2022. Romania increased from 53.51 kg/cap in 2005 to 130.13 kg/cap in 2022, ranking 6th among 27 EU countries.

Plastic Packaging Waste per Capita – Includes plastic packaging waste, expressed in kg/cap. The EU average increased from 28.18 kg/cap in 2005 to 36.17 kg/cap in 2022. Romania increased from 15.56 kg/cap in 2005 to 26.78 kg/cap in 2022, ranking 8th of 27 EU countries.

Table 1. Production and Consumption Dimension

Circular Economy Dimension	Monitoring directions	Monitoring indicators	Unit of measurement	EUROPEAN UNION			România			
				Initial values	Intermediate values	Latest monitoring	Initial values	Intermediate values	Latest monitoring	Ranking at the latest monitoring
Production and Consumption	Material Consumption	Material Footprint	*tones per capita*	18,755 / 2008	14,136 / 2016	14,076 / 2024	23,029 / 2008	23,212 / 2016	31,346 / 2024	25 / 27
		Resource Productivity	*euro/kg*	1,5496 / 2000	1,9037 / 2012	2,3584 / 2024	0,542 / 2000	0,4143 / 2012	0,3719 / 2024	27 / 27
		Green Public Procurement	*Number and value*	NA	NA	NA	NA	NA	NA	NA
	Waste generation	Total Waste Generation per Capita	*kg per capita*	5186 / 2004	5079 / 2014	4984 / 2022	17215 / 2004	8871 / 2014	8410 / 2022	22 / 27
		Waste Generation Excluding Major Mineral Waste per Unit of GDP	*kg / 1000 euro*	76 / 2004	68 / 2014	60 / 2022	379 / 2004	147 / 2014	110 / 2022	23 / 27
		Municipal Waste Generation per Capita	*kg per capita*	513 / 2000	488 / 2012	515 / 2022	355 / 2000	251 / 2012	303 / 2022	25 / 25
		Food Waste	*kg per capita*	128 / 2020	129 / 2021	129 / 2022	166 / 2020	177 / 2021	181 / 2022	24 / 27
		Packaging Waste per Capita	*kg per capita*	158,27 / 2005	161,42 / 2014	186,85 / 2022	53,51 / 2005	62,52 / 2014	130,13 / 2022	6 / 27
		Plastic Packaging Waste per Capita	*kg per capita*	28,18 / 2005	29,80 / 2014	36,17 / 2022	15,56 / 2005	16,92 / 2014	26,78 / 2022	8 / 27

Source: Adapted from Eurostat, 2025

The second fundamental dimension of the EUROSTAT circular economy monitoring framework is waste management (as shown in Table 2). This dimension reflects how member states succeed in reducing the environmental impact of waste flows and in harnessing the potential for reintegrating materials into the economic cycle.

Table 2. Waste Management Dimension

Circular Economy Dimension	Monitoring directions	Monitoring indicators	Unit of measurement	EUROPEAN UNION			România			
				Initial values	Intermediate values	Latest monitoring	Initial values	Intermediate values	Latest monitoring	Ranking at the latest monitoring
Waste Management	General recycling rates	Municipal Waste Recycling Rate	(%)	27,3 / 2000	41,5/ 2013	49,1 / 2022	0 / 2000	13,2/ 2013	12,3 / 2022	25/25
		Recycling Rate of All Waste Except Major Mineral Waste	(%)	53 / 2010	56/ 2016	58 / 2020	26 / 2010	29 / 2016	37 / 2020	20/21
		Total Packaging Recycling Rate	(%)	58,8/2006	66,50/2014	64 / 2022	28,60/2006	54,8/2014	37,3/2022	26/27
	Recycling rate for specific waste streams	Plastic Packaging Recycling Rate	(%)	29,8/2014	34,18/2019	36,17/2022	16,92/2014	24,87/2019	26,78/2022	20/27
		Separate Collection Recycling Rate for Waste Electrical and Electronic Equipment (WEEE)	(%)	81,90/2014	81,7 / 2018	81,6 / 2021	87,30/2014	83,1 / 2018	79,0 / 2021	22/27

Source: Adapted from Eurostat, 2025

The indicators associated with this dimension are designed to capture both the efficiency of collection and treatment systems, as well as the level of material and energy recovery from waste. Through these indicators, it is possible to assess whether member states are approaching the ambitious European targets for reducing landfill disposal and increasing recycling rates (Eurostat, 2025).

Municipal Waste Recycling Rate – This indicator measures the share of municipal waste recycled from the total municipal waste generated. Municipal waste primarily reflects waste generated by end consumers, as it includes household waste and waste from other sources similar in nature and composition to household waste.

The municipal waste recycling rate provides a good indication of the overall quality of the waste management system. In 2022, the EU average for this indicator was 49.1%, while Romania reported 12.3%, ranking 25th out of 25 EU countries reporting this indicator.

Recycling Rate of All Waste Except Major Mineral Waste – This indicator is calculated as the quantity of recycled waste (RCV_R) divided by the total treated waste excluding major mineral waste (TRT), multiplied by 100. It is expressed as a percentage (%) since both terms are measured in the same unit, namely tonnes. In 2020, the EU average was 58%, while Romania reported 37%, ranking 20th out of 21 reporting countries.

Total Packaging Recycling Rate – This indicator is defined as the share of recycled packaging waste out of all packaging waste generated. It is expressed as a percentage (%) because both terms are measured in tonnes. For two types of waste (plastic and wood), an adjusted recycling rate is included. In 2022, the EU average was 64%, while Romania reported 37.3%, ranking 26th out of 27 reporting EU countries.

Plastic Packaging Recycling Rate – This indicator measures the share of recycled plastic packaging waste out of all plastic packaging waste generated. Expressed as a percentage (%), it includes only material that is recycled back into plastic (material recycling/production). In 2022, the EU average was 36.17%, while Romania reported 26.78%, ranking 20th out of 27 reporting countries.

Separate Collection Recycling Rate for Waste Electrical and Electronic Equipment (WEEE) – This indicator is calculated by dividing the weight of WEEE entering recycling or preparation for reuse by the total weight of separately collected WEEE (both in mass units). It is expressed as a percentage (%) because both terms are measured in tonnes. In 2021, the EU average for this indicator was 81.6%.

The third dimension of the EUROSTAT circular economy monitoring framework is dedicated to secondary raw materials, a central element in the transition from a linear to a circular model (as shown in Table 3). This dimension assesses the extent to which materials resulting from recycling processes can replace primary resources in the economy, thereby reducing environmental pressure and dependence on raw material imports (Eurostat, 2025).

Table 3. Secondary Raw Materials Dimension

Circular Economy Dimension	Monitoring directions	Monitoring indicators	Unit of measurement	EUROPEAN UNION			România			
				Initial values	Intermediate values	Latest monitoring	Initial values	Intermediate values	Latest monitoring	Ranking at the latest monitoring
Secondary Raw Materials	Contribution of recycled materials to raw material demande	Circular Material Use Rate (DMC)	*(%)*	10,07 / 2010	11,4 / 2016	11,8 / 2023	3,5 / 2010	1,8/ 2016	1,3/ 2023	27/27
		End-of-Life Recycling Rate (EOL-RIR)	*(%)*	Aluminiu (35); Paladiu (35); Platină (35); Nichel (32); Oțel (22) / 2013	Plumb (75); Oțel (31,5); Ytriul (31,4); Zinc (31): Molibden (30) / 2019	Plumb (83); Cupru (55); Zinc (34): Aluminiu(32); Oțel (31) / 2022	NA	NA	NA	NA
	Trade in recyclable raw materials	Imports from Non-EU Countries	*tones*	40.186.332/ 2015	39.778.635/ 2020	46.731.102/ 2024	501.411/ 2015	638.189/ 2020	1.448.802/ 2024	11/27
		Exports to Non-EU Countries	*tones*	30.635.166/ 2015	36.738.496/ 2020	35.705.419/ 2024	1.070.910/ 2015	1.872.834/ 2020	1.750.853/ 2024	8/27
		Intra-EU Trade	*tones*	80.350.704/ 2015	83.055.931/ 2020	84.380.021/ 2024	549.314/ 2015	776.484/ 2020	792.665/ 2024	19/27

Source: Adapted from Eurostat, 2025

Circular Material Use Rate (DMC) – This indicator measures the share of recycled material reintroduced into the economy, thereby saving primary raw material extraction in total material use. A higher circularity rate indicates that more secondary materials replace primary raw materials, reducing the environmental impact of raw material extraction. It is expressed as a percentage (%) because both terms are measured in tonnes. In 2023, the EU average was 11.8%, while Romania reported 1.3%, ranking 27th out of 27 reporting countries.

End-of-Life Recycling Rate (EOL-RIR), Aluminum – This indicator measures, for a specific raw material, the proportion of its input into the production system derived from the recycling of "old waste," i.e., waste from products that have reached the end of their life, excluding waste from manufacturing processes ("new scrap"). It is expressed as a percentage (%) because both terms are measured in tonnes. Eurostat does not provide a European average for this indicator. The first monitoring in the EU occurred in 2010. In the latest monitoring (2022), the main raw materials re-entering production through waste recycling were: Lead (83%); Copper (55%); Zinc (34%); Aluminum (32%); Steel (31%).

Imports from Non-EU Countries – This indicator measures the quantities of selected waste categories and secondary products imported by EU member states from third countries. Expressed in tonnes,

the EU average in 2023 was 46,731,102 tonnes, while Romania reported 1,448,802 tonnes, ranking 11th out of 27 reporting countries.

Exports to Non-EU Countries – This indicator measures the quantities of selected waste categories and secondary products exported by EU member states to third countries. Expressed in tonnes, the EU average in 2024 was 35,705,419 tonnes, while Romania reported 1,750,853 tonnes, ranking 8th out of 27 reporting countries.

Intra-EU Trade – This indicator measures the quantities of selected waste categories and secondary products imported by an EU member state from another member state. Expressed in tonnes, the EU average in 2024 was 80,380,021 tonnes, while Romania reported 792,665 tonnes, ranking 19th out of 27 reporting countries.

The fourth dimension of the EUROSTAT circular economy monitoring framework focuses on competitiveness and innovation, highlighting how the adoption of circular principles stimulates sustainable economic growth and technological development (as shown in Table 4). This dimension examines the impact of the circular economy on productivity, industrial process efficiency, value creation, and employment generation in sustainable sectors (Eurostat, 2025).

Table 4. Competitiveness and Innovation Dimension

Circular Economy Dimension	Monitoring directions	Monitoring indicators	Unit of measurement	EUROPEAN UNION			România			
				Initial values	Intermediate values	Latest monitoring	Initial values	Intermediate values	Latest monitoring	Ranking at the latest monitoring
Competitiveness and innovation	Private investments, jobs, and gross value added related	Private Investments	*(% din GDP)*	0,6 /2014	0,9/2019	0,8/2023	0,9/2014	0,5/2019	0,4/2023	22/27
		Employment	*(%)*	2/ 2014	2,1/ 2019	2/ 2023	2,3/ 2014	2,4/ 2019	2,3/ 2023	15/27
		Gross Value Added	*(%)*	1,9/2014	2 /2019	1,8/2023	1/2014	1.1/2019	0,8/2023	26/27
	Innovation	Patents Related to Waste Management and Recycling	*Number*	324,62/2011	325,76/2016	206,55/2020	5/2011	5,71/2016	5/2020	12 / 27

Source: Adapted from Eurostat, 2025

Private Investments – This indicator measures gross investments in tangible goods within the recycling, repair, and reuse sectors. Gross investment in tangible goods is defined as investment during the reference year in all tangible assets. ("Glossary:Gross investment in tangible goods - SBS") It is expressed as a percentage (%) of GDP at current prices. In 2023, the EU average was 1.8%, while Romania reported 0.8%, ranking 26th out of 27 reporting countries.

Employment – This indicator measures the number of people employed in three sectors: recycling, repair and reuse, and rental and leasing. Employment is expressed both as the number of employees and as a percentage (%) of total employment. In 2023, the EU average was 2%, while Romania reported 2.3%, ranking 15th out of 27 reporting countries.

Gross Value Added – This indicator measures value added at factor cost in the recycling, repair and reuse, and rental and leasing sectors. Value added at factor cost represents gross operating income adjusted for operating subsidies and indirect taxes. It is expressed as a percentage (%) of GDP at current prices. In 2023, the EU average was 1.8%, while Romania reported 0.8%, ranking 26th out of 27 reporting countries.

Patents Related to Waste Management and Recycling – This indicator measures the number of patents related to recycling and secondary raw materials. ("Patents related to waste management and recycling") It is expressed in numerical units. In 2023, the EU reported an average of 206.5 patents

related to waste management and recycling, ranking 4th globally. In the same year, Romania reported 5 patents, ranking 12th out of 27 reporting EU countries.

The fifth dimension of the EUROSTAT circular economy monitoring framework focuses on global sustainability and resilience (as shown in Table 5). It assesses how member states not only reduce pressure on domestic natural resources but also contribute to international sustainable development goals, the reduction of global greenhouse gas (GHG) emissions, and the responsible management of material flows in international trade (Eurostat, 2025).

Table 5. Global Sustainability and Resilience Dimension

Circular Economy Dimension	Monitoring directions	Monitoring indicators	Unit of measurement	EUROPEAN UNION			România			
				Initial values	Intermediate values	Latest monitoring	Initial values	Intermediate values	Latest monitoring	Ranking at the latest monitoring
Global sustainability and resilience	Global sustainability from the circular economy	Consumption Footprint	*index 2010 = 100 (%)*	101/2014	108/2019	106/2023	101/2014	106/2019	112/2023	11 / 27
		GHG Emissions from Production Activities	*kilograms of CO_2 equivalent per capitar*	8.642,67/ 2008	7.267.44/ 2016	5.965.44/ 2023	6.792,16 / 2008	5.050.15/ 2016	4.660.57/ 2023	22/27
	Resilience from the circular economy	Material Import Dependency	*(%)*	21/2000	22,7/2012	22,4/2024	13,4/2000	9,8/2012	9/2024	27/27
		EU Self-Sufficiency for Raw Materials, Aluminum (SS)	*(%)*	Calcar (89,9); Cupru (57,4); Fier (25,5); Fluorit - CaF2 (23; Aluminiu (16,8) / 2011	Calcar (93,7); Cupru (62,1); Fluorit (29,7); Fier (28); Cobalt (15,3) / 2016	Calcar (100); Vanadium (100); Cupru (52); Fluorit (40); Fier (23) / 2022	NA	NA	NA	NA

Source: Adapted from Eurostat, 2025

Consumption Footprint – The consumption footprint indicator estimates the environmental impact of consumption in the EU and its member states by combining data on consumption intensity and the environmental impact of representative products. The indicator covers five consumption domains: food, mobility, housing, appliances, and household goods. It is expressed as a percentage relative to a base index (2010 = 100), with values converted into US dollars. In 2023, the EU average was 106, while Romania reported 112, ranking 11th out of 27 reporting countries.

GHG Emissions from Production Activities – This indicator presents greenhouse gas emissions from all production activities within the EU economy, including emissions from international aviation carried out by EU-resident airlines. It is measured in kilograms of CO_2 equivalent per capita. In 2023, the EU average was 5,965.44 kg/capita, while Romania reported 4,660.57 kg/capita, ranking 22nd out of 27 reporting countries.

Material Import Dependency – This indicator measures the ratio of imports (IMP) to domestic material input (DMI) in percentage terms, indicating the extent to which an economy relies on imports to meet its material needs. Material import dependency cannot be negative or exceed 100%; values of 100% indicate no domestic extraction in the reference year. In 2024, the EU average was 22.4%, while Romania reported 9%, ranking 27th out of 27 reporting countries.

EU Self-Sufficiency for Raw Materials, Aluminum (SS) – The self-sufficiency indicator measures the EU's independence from the rest of the world for various raw materials. It is expressed as a percentage. First monitored in 2011, the latest monitoring in 2022 shows the main raw materials re-entering production through waste recycling were: Limestone (100%); Vanadium (100%); Copper (52%); Fluorite (32%); Iron (23%). Eurostat calculates this indicator only at the EU level. This new dimension reflects closer alignment with the European Green Deal, as well as EU strategic autonomy and resource security objectives.

By including these indicators, the monitoring framework extends beyond domestic material flows and resource efficiency, providing an integrated perspective on the global impact of the circular economy. It facilitates the evaluation of how member states contribute to sustainability objectives and enhances economic and ecological resilience at both European and international levels.

The analysis of EUROSTAT indicators provides valuable descriptive insights into Romania's performance relative to the EU average. However, it also reveals important methodological limitations. While certain trends, such as resource productivity improvements or waste management gaps, are clearly visible, the exhaustive use of all indicators simultaneously can produce ambiguous or partially misleading interpretations.

These findings highlight the heterogeneity of the indicator framework and the challenges of capturing structural differences across member states, particularly for emerging economies with distinct economic and industrial profiles.

Importantly, the diagnostic insights gained here lay the groundwork for the subsequent research stage, which will focus on selecting a reduced and analytically coherent set of indicators, on constructing a composite circularity index, and identifying clusters of EU member states for meaningful comparative analysis.

In this context, the current section bridges the descriptive evaluation of available indicators and the analytic, policy-relevant conclusions presented in the following section.

CONCLUSIONS

The analysis of the scientific literature confirms that the circular economy has rapidly evolved from an emerging field into a consolidated domain characterized by intense and interdisciplinary research output (Clarivate, 2025). However, the conceptual maturation of the circular economy has not been proportionally accompanied by the development of measurement tools, as the literature on circularity indicators represents a relatively narrow yet essential segment for underpinning comparative assessments and public policy (Urbinati et al., 2017; Kirchherr et al., 2017; Saltelli et al., 2020; Calzolari et al., 2021).

The accelerated interest in circularity indicators in recent years reflects both institutional pressures generated by European policies and an international research shift toward measurability, comparability, and performance monitoring (European Commission, 2020; OECD, 2020; European Commission, 2023). In this context, the EU circular economy monitoring framework, operationalized by Eurostat, provides a coherent set of indicators structured around thematic dimensions and comparable across member states (European Environment Agency, 2021; Eurostat, 2025; Păcurariu et al., 2021b).

Nevertheless, both the literature and empirical evidence highlight the limitations of using this indicator set exhaustively, particularly in comparative analyses involving structurally heterogeneous economies. Numerous studies emphasize the need for a functional organization of indicators based on an input–process–output logic, which better captures causal relationships, facilitates cross-country comparisons, and reveals gaps in critical areas such as waste prevention, material reuse, and resource efficiency (Linder & Williander, 2017; Moraga et al., 2019; Martinho, 2021; European Environment Agency, 2021). Certain indicators, such as resource productivity, may reflect process characteristics rather than simple production or consumption outcomes (D'Adamo, 2024; Urbinati et al., 2017).

Regarding Romania, both literature and data indicate a consistently lower positioning compared to the EU average across most circularity indicators, reflecting high material intensity, low resource-use

efficiency, and limited capacity to reintegrate secondary raw materials (Păcurariu et al., 2021a; Eurostat, 2025). The direct use of EU indicators without functional adaptation is therefore insufficient to provide a robust assessment, as heterogeneity and unequal analytical relevance limit their explanatory power in comparative evaluations.

Methodologically, this study underscores that meaningful comparative assessments require selective indicator frameworks, based on transparent multi-criteria screening (relevance, discriminative capacity, and coherence within an input–process–output structure). Drawing on diverse academic and institutional critiques (Saltelli et al., 2020; Urbinati et al., 2017; Kirchherr et al., 2017; Linder & Williander, 2017; European Environment Agency, 2021; OECD, 2020; Circle Economy, 2023; Calzolari et al., 2021; Păcurariu et al., 2021b; Lee et al., 2024; Martinho, 2021), this study emphasizes the importance of selecting a targeted set of indicators and structuring them functionally, ensuring that comparative analyses are both coherent and policy-relevant.

From a policy perspective, the findings indicate that Romania's transition to a circular economy cannot be adequately monitored without improving both the quality of data and the analytical structure of evaluation tools. Priority should be given to indicators capturing waste prevention, material reuse, and resource efficiency, alongside strengthening administrative capacity for data collection and integration into strategic planning.

This study contributes to the literature by providing a systematic diagnostic assessment of Romania's circular economy performance within a European comparative framework, critically examining the limitations of exhaustive indicator-based approaches. By emphasizing the need for a selective input–process–output framework, the research advances methodological debates on circularity measurement and offers a foundation for developing composite indices and cluster-based comparative models, particularly for structurally heterogeneous or emerging economies.

Finally, these insights provide the analytical basis for a subsequent stage of research focused on constructing a composite circularity indicator and identifying clusters of EU member states with comparable structural characteristics. Only within such a framework can circular economy indicators fully serve their intended role as instruments for comparative evaluation and policy guidance (European Environment Agency, 2021; Circle Economy, 2023; Saltelli et al., 2020; Calzolari et al., 2021; Păcurariu et al., 2021b).

AUTHORS CONTRIBUTIONS

Within this conceptual and methodological context, the present study makes a significant contribution by highlighting the inherent limitations of circularity assessments based on the totality of available indicators. Given the profound heterogeneity of European countries in terms of economic structure, material intensity, industrial profile, degree of urbanization, and level of environmental policy implementation, the exhaustive use of indicator sets inevitably produces results that are difficult to interpret and poorly comparable. The literature review confirms that while comprehensive measurement, including all circularity indicators, may be theoretically desirable, it becomes practically unfeasible for rigorous comparative assessment and the formulation of coherent policy directions.

Building on these limitations, the study proposes an alternative approach centered on the selection of a subset of representative indicators tailored to the analytical objectives and the specific national or regional context. The core contribution lies in the methodological justification for applying such a selective approach, which should not be arbitrary or based solely on data availability, but grounded in systematic and transparent procedures. Specifically, the study recommends multi-criteria screening methods capable of identifying indicators with the highest analytical relevance, discriminative capacity across countries, and internal consistency in line with an input–process–output framework.

By integrating these criteria, the research demonstrates that a robust assessment of circularity depends not on the sheer number of indicators, but on their relevance and functionality, particularly their ability to capture the relationships between initial material pressures, management and efficiency mechanisms, and final environmental and economic impacts. Consequently, the study offers both a critical interpretation of the current indicator framework and a practical methodological approach to enhance the comparative analysis of circularity at European and national levels.

PhD Student Maria Daniela Petruse (married name: Zanca), conducted the primary research and led the development of the article. Responsibilities included conceptualization, study design, data collection, data analysis, interpretation of results, and drafting the original manuscript.

Professor PhD Bogdana Neamțu, provided academic supervision as PhD coordinator. Responsibilities included methodological guidance, critical review of the analysis and manuscript, and oversight of the research process. Associate Professor PhD Bogdana Neamțu did not participate in data collection.

Both authors reviewed and approved the final version of the manuscript and agree to be accountable for its content.

CONFLICT OF INTEREST STATEMENT

The authors declare that this research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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