

Article

Progress Toward a Circular Economy: A Comparative Analysis of EU Member States

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Abstract

Moving toward a circular economy is vital for sustainable development in the European Union. However, it is challenging to assess how well each member state is performing because there are many different factors, and the choices can be subjective. This study develops an assessment framework that integrates CRITIC-TOPSIS for objective analysis and Picture Fuzzy SWARA for subjective evaluation. The present study also used 20 circular economy factors from Eurostat for 2018 and 2023. The findings reveal shifts in factor importance over time, highlighting the impact of subjective judgments on policy evaluations and showing differences in country rankings depending on the weighting method. The study concludes that integrating both objective and subjective approaches provides a more comprehensive assessment of CE performance and supports more balanced policy development to provide insight for EU policy harmonization. Also, results indicated that Germany, France, and Italy were consistent leaders, while Estonia and Bulgaria lagged in both years. In addition, the analysis directly contributes to Sustainable Development Goals (SDGs), particularly SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action), as the circular economy models enhance resource efficiency and reduce environmental impacts.

Keywords: circular economy; picture fuzzy; MCDM; sustainability; green economy

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1. Introduction

The Circular Economy (CE) is a progressive economic model that shifts away from the conventional linear so-called ‘take-make-dispose’ toward a regenerative system, emphasizing the reduction, reuse, and recycling of materials. The idea of the CE was first introduced in 1990, and it highlights the connection between economic activity and environmental sustainability. This shift changes the usual benefit–cost framework to include the concept of intergenerational equity [1]. Its main goals are promoting sustainable economic growth, improving environmental quality, and creating social value for both current and future generations [2]. The CE encourages a fundamental change in societal mindset, promoting the adoption of sustainable business practices. Moreover, it aims to achieve economic growth goals while also reducing environmental impact [3].

The CE has gained increasing international attention and has been partially or fully adopted by various countries and organizations, including the European Union. The need for sustainable economic, social, and environmental development promotes CE. Within the European Union, there is a notably stronger focus on the CE compared to other regions [4].

The European Commission works to harmonize industry, environmental, and climate policies while maintaining its current energy strategies. Additionally, it aims to create a favorable business environment that supports sustainable growth, employment, and innovation. In line with these goals, the Commission launched the EU Action Plan on Circular Economy in 2015 [5]. The action plan is a strategy to shift the EU economy toward a circular model. This plan focuses on extending the life of products and materials to maximize their value as well as generating significant economic benefits along with social and environmental improvements.

Furthermore, the CE also gained attention among academics. Some analyses highlighted the implementation challenges of circular economy practices in the apparel accessories sector. They concluded that the complexity of product design, supply chain coordination, and stakeholder engagement can impede the transition from linear to circular models [6]. Other studies studied the shift toward sustainability through the CE. They highlighted that true circularity hinges not only on resource efficiency and waste reduction, but also on rethinking value creation, digital tools such as IoT, and blockchain [7]. On top of that, some studies proposed a holistic indicator framework for evaluating CE strategies called the 9R hierarchy. The proposed framework enhanced the assessment of different recovery strategies from refuse to remanufacture [8]. Other analyses evaluated the European countries' circular economy policies. Their results emphasized again that the goal of the circular economy is to extend product lifespans via reuse, refurbishment, repair, and recycling [9].

Furthermore, the circular economy is also closely aligned with the United Nations Sustainable Development Goals (SDGs). It supports SDG 12 (Responsible Consumption and Production) by promoting resource efficiency, waste reduction, and recycling, and SDG 13 (Climate Action) by reducing greenhouse gas emissions and fostering low-carbon transitions. Our study contributes to this agenda by providing a comparative evaluation framework that highlights gaps and progress across EU countries, thus informing policies aimed at achieving these global goals.

However, evaluating the circular economy remains a significant challenge in the academic field. This challenge arises not only from the variety of criteria and factors involved, often measured in different units, but also from the lack of adequate and standardized indicators to capture key strategies such as product life cycle prolongation and product usage intensity. These limitations make it difficult to conduct a clear, comprehensive assessment and confidently identify the most suitable processes or materials. Furthermore, action plans should be localized for any country according to its national goals, which might cause subjectivity. On top of that, several decision-making methods have been applied so far in this field; however, most of these approaches relied exclusively on either objective data-driven weighting or expert-based judgments, and many used reduced sets of indicators. This creates a gap for studies that integrate both perspectives while employing the complete Eurostat framework.

Therefore, the present study aims to develop an evaluation framework for assessing the EU countries' performance toward the circular economy, as well as investigating the subjectivity and its role in decision-making. To this end, the present study aims to apply the Criteria Importance Through InterCriteria Correlation (CRITIC) [10]—Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) [11] method for evaluating the EU countries' performance and then apply the Step-wise Weight Assessment Ratio Analysis (SWARA) [12] method under a Picture Fuzzy (PF) [13] environment to determine the subjective weight of CE factors. Specifically, it asks: (i) Which CE indicators gained or lost importance between 2018 and 2023? (ii) Which countries lead or lag under different

weighting schemes? (iii) What are the implications for EU policy and national strategies? All in all, the main contributions of the present research are:

- The study creates a framework to assess EU member states' progress toward a circular economy.
- It applies CRITIC-TOPSIS for objective evaluation and SWARA with picture fuzzy logic for subjective factor weighting.
- The research examines how local priorities and interpretations influence circular economy policy.

The structure of the article is as follows: Section 2 presents the circular economy overview in the EU. Section 3 presents the research method. The results are presented in Section 4. Sensitivity analyses and the PF-SWARA are given in Section 5. Section 6 discusses the results. A broad conclusion is explained in Section 7.

2. Circular Economy in the EU

In 2020, the European Commission introduced the CE Action Plan, aligning it with the Renewed Industrial Strategy for Europe and building on the 2015 Action Plan. This updated plan proposes measures to establish a strategic framework focusing on the value chain, waste minimization, and secondary raw materials efficiency in the EU's internal market. Its goal is to generate substantial economic, environmental, and social advantages [14]. On top of that, the plan highlights sustainable products and aims to empower consumers and public buyers, and focuses on sectors with high resource consumption, such as ICT and electronics, batteries and vehicles, packaging, plastics, textiles, construction, water, and nutrients, as well as food and waste reduction [15].

Furthermore, recent studies have emphasized the growing relevance of circular economy practices in advancing the Sustainable Development Goals. Some conducted a conceptual matching of CE practices to SDG targets and found strong alignments with SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), SDG 12 (Responsible Consumption and Production), and SDG 15 (Life on Land). Also, they studied the trade-offs, especially in areas such as human health and safe working conditions, associated with waste-related practices [16]. Others evaluated 27 circular strategies against the full spectrum of 17 SDGs and their 169 targets. They identified the strongest contributions to SDG 8, SDG 12, and SDG 13 (Climate Action). Results highlighted three high-impact transition pathways that accounted for two-thirds of CE's potential SDG impact [17]. Also, Fauzi et al. [18] offered a bibliometric review of the literature linking CE and SDGs. The study showed that both concepts are increasingly prominent and interconnected.

In this context, all EU countries have introduced a series of policies to support CE. Subsequently, academic research on CE performance in the EU has presented several findings regarding its implementation across various economic sectors and EU countries [19]. Furthermore, the EC has recently established the guidelines for Industry 5.0, which, in contrast to the Industry 4.0 paradigm. It focuses on human well-being and progress, promoting a shift in production and consumption toward a sustainable and circular economy, as outlined by the Green Deal [20]. Therefore, the transition to CE is now inevitable, though there are barriers to adopting CE.

One of the main barriers to adopting a CE in the EU is cultural resistance, both on the consumer and company sides. The most mentioned cultural barrier is a lack of consumer interest and awareness, as they tend to buy short-lived products, not in line with CE values [21,22]. Also, consumers might have a limited awareness of sustainability issues, influencing the demand for circular products [23]. On the other hand, hesitation in integrating the CE initiatives into core decision-making processes. Consequently, it might

decrease companies' readiness for CE adoption [24]. Additionally, market barriers also hinder CE development in the EU. Low raw material prices and high initial investment costs make recycled options less appealing and stop business innovation. This cost gap, along with financial uncertainty, causes many companies to postpone or skip adopting circular economy models, even when funding is available [25,26].

Furthermore, illegal waste management is an obstacle to effective CE practices in some EU member states. It is emphasized that improper waste management and disposal practices can significantly impact resource recovery processes, pose environmental risks, and compromise the quality of recyclable materials [27]. Subsequently, CE systems could be affected, and their overall efficiency would be decreased. Additionally, the lack of technical expertise and insufficient investment in circular technologies could weaken the foundation of CE in the EU. Many local authorities remain uncertain about the criteria that differentiate waste from secondary raw materials [28]. Also, the unjust distribution of the CE benefits might hinder the adoption of the CE in the EU. Policymakers should focus on initiatives that improve skills development, offer clear guidelines for waste management, and ensure justice in the sharing of CE benefits [27].

These barriers can be directly related to the indicators employed in our analysis. Cultural resistance and low consumer awareness manifest in higher waste generation per capita (C11), food waste (C12), and packaging waste (C13–C14). Market barriers such as high costs of recycled materials or low raw material prices are reflected in a lower circular material use rate (C16) and reduced private investment in CE sectors (C2). Weak enforcement of waste regulations and illegal waste flows undermine the recycling rates of municipal waste (C18), packaging waste (C19), and WEEE (C20). Finally, institutional and innovation barriers, such as limited technical expertise and uneven benefit distribution, correspond to lower performance in recycling-related patents (C3) and employment in CE sectors (C1). This mapping highlights how structural barriers directly translate into gaps across the Eurostat framework used in this study.

In this context, recent research applied Multicriteria Decision-Making (MCDM) methods to assess the performance of the EU in dealing with CE adoption and its challenges. Also, beyond MCDM approaches, other methods have also been employed to determine CE progress. Cluster analysis has been used to group EU countries according to their CE performance [29,30]. DEA models have been applied to measure the relative efficiency of resource use and waste management [31,32]. Moreover, econometric and statistical frameworks have been utilized to explore the relationship between CE indicators and broader sustainability outcomes [33].

However, regarding MCDM methods, Ūsas et al. [34] applied an integrated MCDM method to evaluate CE development based on criteria such as input use (circularity), trade flows, and recycling processes. In their research, they applied CRITIC to determine the objective weights of criteria, and they applied three ranking methods, including TOPSIS, ELimination Et Choix Traduisant la REalité (ELECTRE), and Preference Ranking Organization METHod for Enrichment Evaluation (PROMETHEE). The results indicated strong disparities between Western and Eastern EU countries, with Germany, Sweden, and the Netherlands performing best. Also, D'Adamo, Favari, Gastaldi and Kirchherr [27] applied the Analytic Hierarchy Process (AHP) to evaluate the CE performance of EU27 using 15 indicators shown in Eurostat, including production and consumption, waste management, secondary raw materials, competitiveness and innovation, and global sustainability. The results indicated the dominance of innovation and competitiveness indicators in driving circularity. They also highlighted challenges such as illegal waste flows, limited investment in CE technologies, and unequal distribution of CE benefits.

Furthermore, Candan and Cengiz Toklu [35] applied an integrated fuzzy Simple Multi-Attribute Rating Technique (SMART) and COmbinative DIstance-based ASsessment (CODAS) framework to assess CE in the EU. They used 15 indicators shown in Eurostat for multiple years, including 2014, 2016, and 2018. The results indicated that the Netherlands, Luxembourg, and Belgium are leading in CE efficiency. They also emphasized the need for robust, dynamic indicator systems and newer decision-making tools to support more effective policy intervention. Also, Kaya et al. [36] applied a k-means clustering method and integrated the CRITIC–Method based on the Removal Effects of Criteria (MEREC)–Measurement of Alternatives and Ranking according to COmpromise Solution (MARCOS) approach to study the social aspects of CE in the EU. The indicators were assessed as employment, corruption, and income distribution. The results indicated that there are significant differences in social performance among EU countries, with the Netherlands, Croatia, and Lithuania identified as cluster leaders.

Additionally, Grybaitė and Burinskienė [37] applied the Simple Additive Weighting (SAW) method to evaluate CE development in EU countries. The results indicated that Italy, Germany, and the Netherlands have achieved success. However, it is also highlighted that there are limitations in indicators and data that hinder cross-country comparisons. On top of that, the need for a framework is emphasized to monitor CE progress and address disparities in social, technological, and environmental capacities across Europe.

3. Materials and Methods

The present study evaluates the EU countries according to the CE criteria provided by Eurostat for 2018 and 2023. We selected these two years since 2018 was a baseline after the EU CE Action Plan, and 2023 is the most recent available. The indicators are taken from Eurostat’s official Circular Economy Monitoring Framework. Eurostat’s circular economy monitoring framework is structured around five main dimensions, each with specific sub-indicators. Production and consumption focus on reducing material use and waste, with indicators such as municipal waste per capita, packaging and plastic waste per capita, food waste, and waste generation per GDP. Waste management assesses recycling efficiency through indicators like recycling rates of municipal waste, all waste, packaging waste, and e-waste. Secondary raw materials evaluate the reuse of materials, including the circular material use rate and trade in recyclable raw materials. Competitiveness and innovation capture economic and innovation dynamics via private investments, value added, employment in CE sectors, and recycling-related patents. Finally, global sustainability and resilience examine broader environmental and resource impacts through resource productivity, material footprint, material import dependency, greenhouse gas emissions, and the consumption footprint.

Furthermore, this study used the CRITIC-TOPSIS approach to assess EU countries based on circular economy indicators. CRITIC provided objective indicator weights, which TOPSIS then used to rank the countries. The CRITIC assigns higher weight to indicators that vary strongly across countries (contrast) and are less correlated with others, ensuring unique information contributes more.

We selected the CRITIC–TOPSIS method because it objectively determines the importance of indicators by considering both their variability across countries and their correlation structure, ensuring that unique and contrasting information is given more weight. This reduces subjectivity and improves comparability across EU member states. To complement this, we applied PF–SWARA, which allows experts to provide judgments under uncertainty and incorporates hesitation degrees, thereby capturing national policy priorities and expert knowledge that are not fully reflected in statistical data. The integration of both approaches provides a more balanced assessment of CE performance.

Regarding data preprocessing, missing values were addressed in two ways. If data for a given indicator were unavailable for both years for a country, that country was excluded from the analysis. If data were missing for only one of the two years, we substituted values from the closest available year, following Eurostat's official data guidelines. This ensured that all 20 Eurostat indicators were included in the analysis while maintaining cross-country comparability. The method's steps are outlined below.

3.1. CRITIC-TOPSIS

3.1.1. Decision Matrix

Let $\{c_1, c_2, \dots, c_m\}$ a set of EU members, and $\{I_1, I_2, \dots, I_n\}$ a set of factors; thus, $\mathbb{Z} = (x_{ij})_{m \times n}$, where $x_{ij} \forall i = 1, \dots, m; j = 1, \dots, n$, is the value assigned to i th country according to j th factor.

3.1.2. Normalization

Let $\mathbb{N} = (\bar{x}_{ij})_{m \times n}$ The normalized matrix. Equation (1) normalizes the decision matrix, where $x_j^- = \min_i x_{ij}$ and $x_j^+ = \max_i x_{ij}$. Normalization is needed to ensure comparability across indicators measured in different units, e.g., tons, euros, percentages.

$$\bar{x}_{ij} = \begin{cases} \frac{x_{ij} - x_j^-}{x_j^+ - x_j^-}, & j \in N_b \\ \frac{x_j^+ - x_{ij}}{x_j^+ - x_j^-}, & j \in N_n \end{cases} \quad (1)$$

3.1.3. Standard Deviation

Equation (2) calculates the standard deviation (σ_j), where $\bar{x}_j = \sum_{i=1}^m \frac{\bar{x}_{ij}}{m}$.

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^m (\bar{x}_{ij} - \bar{x}_j)^2}{m}} \quad (2)$$

3.1.4. Correlation

Equation (3) calculates the correlation (r_{jt}).

$$r_{jt} = \frac{\sum_{i=1}^m (\bar{x}_{ij} - \bar{x}_j)(\bar{x}_{it} - \bar{x}_t)}{\sqrt{\sum_{i=1}^m (\bar{x}_{ij} - \bar{x}_j)^2 \sum_{i=1}^m (\bar{x}_{it} - \bar{x}_t)^2}} \quad (3)$$

3.1.5. Information Quantity

Equation (4) calculates information quantity (v_j).

$$v_j = \sigma_j \left(\sum_{t=1}^n (1 - r_{jt}) \right) \quad (4)$$

3.1.6. Objective Weights

Equation (5) calculates weights (ω_j).

$$\omega_j = \frac{v_j}{\sum_{i=1}^m v_j} \quad (5)$$

3.1.7. Normalizing for TOPSIS

Equation (6) is applied for normalizing for TOPSIS.

$$\tilde{x}_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} \quad \text{for } (j = 1, \dots, n) \quad (6)$$

3.1.8. Weighted Matrix

Equation (7) is used for creating a weighted matrix, subject to $\sum_{i=1}^n \omega_j = 1$.

$$\hat{x}_{ij} = \bar{x}_{ij} * \omega_j \quad (i = 1, \dots, m; j = 1, \dots, n) \quad (7)$$

3.1.9. Ideal Solutions

Equations (8) and (9) calculate ideal solutions.

$$A^+ = \left\{ \left(\max_i \hat{x}_{ij} | j \in J \right), \left(\min_i \hat{x}_{ij} | j \in \bar{J} \right) | i = 1, \dots, m \right\} = \{x_1^+, x_2^+, \dots, x_n^+\} \quad (8)$$

$$A^- = \left\{ \left(\min_i \hat{x}_{ij} | j \in J \right), \left(\max_i \hat{x}_{ij} | j \in \bar{J} \right) | i = 1, \dots, m \right\} = \{x_1^-, x_2^-, \dots, x_n^-\} \quad (9)$$

where $J = \{j = 1, 2, \dots, n | j \text{ associated with the benefit criteria}\}$, and $\bar{J} = \{j = 1, 2, \dots, n | j \text{ associated with the cost criteria}\}$.

3.1.10. Ideal Separations

Equations (10) and (11) calculate ideal separations.

$$S_i^+ = \sqrt{\sum_{j=1}^n (\hat{x}_{ij} - x_j^+)^2} \quad (i = 1, \dots, m) \quad (10)$$

$$S_i^- = \sqrt{\sum_{j=1}^n (\hat{x}_{ij} - x_j^-)^2} \quad (i = 1, \dots, m) \quad (11)$$

3.1.11. Closeness

Equation (12) calculates the relative closeness.

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^+}, \quad 0 < C_i^* < 1, \quad i = 1, \dots, m \quad (12)$$

where $C_i^* = 1$ if $A_i = A^+$, and $C_i^* = 0$ if $A_i = A^-$. members are ranked in the descending order of C_i^* .

4. Results

Tables 1 and 2 show CE data for the EU countries for 2018 and 2023, respectively. The Eurostat circular economy monitoring framework includes 20 key indicators across five thematic areas. Patent data often involve reporting delays and may not capture recent innovation trends; certain recycling indicators are based on estimates; and trade in secondary raw materials may reflect international flows rather than domestic progress. Despite these limitations, all 20 indicators were included in our analysis to ensure comparability across EU member states.

Table 1. Data for 2018.

Factors	Competitiveness and Innovation			Global Sustainability and Resilience				Production and Consumption							Secondary Raw Materials		Waste Management				
Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	
BE	64,180.00	6551.00	16.08	108.00	7897.42	72.70	14.92	3.04	409.00	100.00	5967.00	146.00	157.51	30.40	1,504,426.00	20.60	81.00	54.40	85.30	72.50	
BG	102,997.00	409.00	0.50	113.00	7944.98	15.70	18.35	0.35	426.00	490.00	18,470.00	114.00	74.13	19.57	160,701.00	2.40	27.00	31.50	60.40	81.00	
CZ	134,088.00	1557.00	4.67	105.00	10,018.36	32.80	17.83	1.11	494.00	86.00	3560.00	91.00	122.00	25.16	83,630.00	10.50	61.00	32.20	69.60	84.70	
DK	44,698.00	2762.00	5.63	114.00	15,143.96	38.10	23.18	2.11	814.00	37.00	3702.00	221.00	173.10	42.88	1,965,787.00	8.10	59.00	49.90	70.10	80.70	
DE	757,319.00	34,605.00	84.57	101.00	8613.63	40.00	16.21	2.59	606.00	51.00	4891.00	131.00	227.49	39.03	4,307,106.00	12.00	53.00	67.10	68.50	85.60	
EE	24,783.00	240.00	1.00	112.00	14,529.23	23.40	30.58	0.55	405.00	646.00	17,539.00	125.00	158.15	41.90	32,953.00	13.80	19.00	28.00	60.40	85.70	
IE	39,154.00	568.00	1.87	109.00	13,548.05	30.70	16.64	2.62	595.00	28.00	2874.00	152.00	206.76	53.90	2,280,016.00	1.90	45.00	37.70	63.90	82.90	
GR	83,534.00	220.00	2.25	100.00	8811.13	35.50	12.18	1.38	515.00	83.00	4215.00	191.00	75.91	18.83	1,142,067.00	3.00	27.00	20.10	63.60	80.70	
ES	433,421.00	5427.00	18.45	107.00	5756.71	42.80	11.02	2.63	475.00	61.00	2945.00	69.00	161.27	35.38	5,183,097.00	8.90	47.00	34.80	68.80	86.20	
FR	533,783.00	19,016.00	37.16	108.00	5303.94	38.60	14.30	2.96	557.00	46.00	5112.00	129.00	195.49	35.09	3,747,237.00	19.50	52.00	40.70	63.50	74.20	
HR	65,707.00	388.00	2.16	114.00	4679.73	31.40	13.71	1.18	443.00	75.00	1355.00	73.00	69.44	16.13	298,764.00	5.00	56.00	25.30	58.40	91.20	
IT	518,324.00	11,572.00	23.39	102.00	5476.95	50.60	10.30	3.53	502.00	69.00	2855.00	136.00	212.16	38.11	3,748,682.00	18.80	67.00	49.80	68.30	84.30	
CY	12,715.00	94.00	1.00	111.00	8283.57	34.00	19.37	1.36	662.00	38.00	2646.00	273.00	86.73	19.97	129,647.00	2.80	32.00	16.80	70.20	90.60	
LV	37,238.00	241.00	1.00	100.00	5656.76	32.90	17.18	0.96	407.00	58.00	920.00	145.00	133.54	22.63	193,775.00	4.70	50.00	25.20	55.80	81.40	
LT	57,748.00	345.00	1.00	105.00	7232.60	41.40	20.07	0.84	461.00	102.00	2527.00	136.00	125.79	26.91	275,006.00	4.30	68.00	52.60	60.70	81.80	
LU	6922.00	425.00	2.33	123.00	13,998.79	91.20	28.34	4.16	803.00	27.00	14,828.00	147.00	224.04	42.61	30,150.00	10.80	70.00	49.00	70.90	88.00	
HU	119,335.00	1020.00	2.00	108.00	5612.03	29.50	15.52	0.82	384.00	86.00	1879.00	94.00	139.33	35.09	91,720.00	6.90	49.00	37.40	46.10	83.50	
MT	7677.00	74.00	1.00	135.00	4247.53	75.10	10.01	1.96	673.00	53.00	5336.00	160.00	146.87	31.84	4053.00	8.30	28.00	10.40	35.70	73.60	
NL	112,626.00	9344.00	33.46	112.00	10,047.97	80.40	9.00	3.92	511.00	62.00	8429.00	161.00	165.05	30.35	6,523,721.00	25.80	66.00	55.90	79.40	75.60	
AT	64,285.00	5613.00	13.01	104.00	6418.27	44.50	23.95	2.36	579.00	50.00	7428.00	136.00	159.90	34.16	374,526.00	11.80	63.00	57.70	65.50	79.80	
PL	412,438.00	4024.00	22.21	116.00	9701.83	19.50	16.80	0.70	329.00	166.00	4621.00	120.00	143.98	25.94	2,973,318.00	10.50	60.00	34.30	58.70	87.60	
PT	123,193.00	2011.00	2.00	113.00	5897.21	31.40	16.98	1.16	504.00	73.00	1546.00	175.00	172.62	40.11	876,319.00	2.20	40.00	29.10	57.90	73.00	
RO	202,654.00	903.00	9.50	108.00	5216.13	10.70	23.42	0.42	272.00	125.00	10,425.00	166.00	80.47	20.10	592,489.00	1.60	29.00	11.10	57.90	83.10	
SI	21,968.00	153.00	1.00	103.00	6613.24	46.80	17.93	1.47	486.00	74.00	3964.00	74.00	114.81	23.81	1,295,358.00	10.10	82.00	58.90	68.00	84.60	
SK	68,927.00	579.00	1.50	110.00	6496.70	43.00	15.14	1.19	414.00	101.00	2277.00	107.00	102.20	24.22	72,347.00	4.70	50.00	36.30	66.60	88.90	
FI	29,797.00	803.00	18.63	101.00	9681.54	19.80	49.35	0.87	551.00	70.00	23,253.00	113.00	127.93	24.52	411,819.00	4.40	37.00	42.30	70.20	89.70	
SE	79,887.00	1887.00	19.17	102.00	4562.36	26.80	25.96	1.92	434.00	49.00	13,628.00	121.00	133.04	24.17	1,471,960.00	6.60	49.00	45.80	65.00	83.30	

Table 2. Data for 2023.

Factors	Competitiveness and Innovation			Global Sustainability and Resilience				Production and Consumption							Secondary Raw Materials		Waste Management				
Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	
BE	61,760.00	7634.00	5.49	107.00	6392.17	75.60	13.82	2.84	689.00	80.00	5363.00	151.00	167.10	31.36	1,363,116.00	19.70	87.00	54.70	80.40	73.20	
BG	95,233.00	422.00	0.50	117.00	6634.92	16.10	21.29	0.39	488.00	500.00	14,603.00	95.00	80.92	22.95	302,390.00	4.90	23.00	24.60	58.30	85.60	
CZ	137,827.00	1780.00	7.16	110.00	8013.37	32.40	18.60	1.22	570.00	81.00	3672.00	101.00	131.68	26.05	51,923.00	12.80	59.00	43.00	70.80	92.80	
DK	41,556.00	3176.00	2.83	115.00	12,481.46	39.80	21.93	2.36	802.00	31.00	3333.00	254.00	187.73	35.83	1,817,183.00	9.10	63.00	45.70	64.90	82.40	
DE	771,814.00	39,500.00	45.67	101.00	6571.09	37.50	14.54	3.04	601.00	48.00	4604.00	129.00	226.94	39.49	3,529,796.00	13.90	55.00	69.20	68.50	85.50	
EE	54,510.00	256.00	0.50	111.00	7669.51	19.20	29.89	0.64	373.00	470.00	16,752.00	134.00	143.21	33.83	23,658.00	18.10	10.00	33.20	73.00	80.80	
IE	36,056.00	956.00	3.83	110.00	11,176.07	33.50	11.79	4.02	637.00	20.00	2971.00	144.00	231.72	66.16	1,843,127.00	2.30	41.00	41.00	61.70	82.20	
GR	76,522.00	174.00	0.50	101.00	6428.94	39.40	11.67	1.71	519.00	70.00	2858.00	196.00	104.95	24.65	1,190,987.00	5.20	27.00	17.30	43.40	74.90	
ES	428,345.00	7604.00	21.34	115.00	4590.57	42.00	8.17	3.13	465.00	58.00	2480.00	65.00	182.80	41.43	4,912,742.00	8.50	48.00	42.90	69.40	69.50	
FR	537,036.00	22,515.00	27.09	107.00	4424.19	35.30	13.53	3.16	530.00	43.00	5076.00	139.00	188.54	35.75	4,048,134.00	17.60	47.00	41.20	67.20	77.20	
HR	66,309.00	347.00	0.50	115.00	4515.01	36.90	15.19	1.23	475.00	86.00	1838.00	72.00	82.17	19.26	910,284.00	6.20	60.00	34.20	52.40	90.10	
IT	507,749.00	10,173.00	21.51	100.00	4990.41	48.00	10.52	3.59	486.00	66.00	3212.00	139.00	232.36	39.45	3,474,989.00	20.80	72.00	53.30	71.90	83.70	
CY	13,849.00	68.00	0.50	116.00	7714.93	32.70	20.71	1.36	674.00	71.00	3294.00	294.00	98.55	23.97	152,817.00	5.40	44.00	14.80	69.50	78.70	
LV	32,971.00	234.00	0.50	103.00	5236.38	28.60	19.56	0.90	464.00	85.00	1330.00	124.00	153.44	26.00	679,362.00	5.00	70.00	50.80	60.80	82.70	
LT	61,452.00	464.00	0.50	111.00	7131.53	34.20	23.03	0.79	446.00	96.00	2003.00	140.00	151.12	37.81	495,055.00	3.90	72.00	48.40	58.30	81.80	
LU	21,482.00	1060.00	2.50	134.00	11,332.23	88.70	32.05	4.53	712.00	31.00	15,169.00	122.00	208.91	34.94	32,526.00	10.20	71.00	55.60	63.70	85.00	
HU	109,363.00	1145.00	3.00	110.00	4806.94	24.10	15.67	0.96	429.00	110.00	2838.00	84.00	166.47	44.64	397,448.00	5.90	54.00	32.80	44.60	79.30	
MT	8145.00	83.00	0.50	146.00	6443.67	70.90	5.84	2.82	606.00	44.00	5004.00	162.00	167.16	29.26	3167.00	19.80	25.00	12.50	31.80	75.90	
NL	110,564.00	11,229.00	13.25	111.00	7631.59	82.70	6.02	5.46	468.00	56.00	6921.00	129.00	168.78	31.14	5,709,245.00	30.60	74.00	57.60	75.20	72.60	
AT	65,849.00	5406.00	6.49	108.00	6097.95	41.50	22.03	2.54	803.00	50.00	8079.00	131.00	163.20	33.17	323,993.00	14.30	63.00	62.60	66.20	84.00	
PL	411,141.00	4283.00	17.25	121.00	8923.10	19.90	15.84	0.86	367.00	138.00	4739.00	123.00	182.10	33.12	4,241,737.00	7.50	52.00	40.90	64.00	86.60	
PT	117,372.00	1781.00	5.42	124.00	4507.01	29.60	16.46	1.27	505.00	72.00	1878.00	184.00	187.46	43.17	847,375.00	2.80	39.00	30.20	61.10	56.60	
RO	198,459.00	1167.00	5.00	112.00	4660.57	8.10	33.16	0.35	303.00	110.00	8410.00	181.00	130.13	26.78	910,125.00	1.30	37.00	12.30	37.30	79.00	
SI	29,463.00	127.00	1.00	101.00	5285.51	41.50	22.79	1.38	517.00	57.00	5397.00	71.00	142.12	26.88	1,275,506.00	8.80	80.00	62.60	62.60	80.90	
SK	64,966.00	555.00	3.67	114.00	5583.14	43.30	13.81	1.53	472.00	95.00	2462.00	106.00	108.38	26.72	70,480.00	10.60	60.00	49.50	72.20	90.90	
FI	41,773.00	984.00	15.00	99.00	6966.69	16.10	46.56	0.98	468.00	49.00	19,950.00	109.00	159.86	28.94	55,395.00	2.40	40.00	43.70	73.50	88.40	
SE	79,323.00	2481.00	4.72	101.00	3833.55	23.60	22.09	2.19	392.00	48.00	15,627.00	117.00	131.46	32.98	1,109,316.00	9.90	50.00	39.70	66.30	76.00	

The selected indicators and their newly assigned indices are as follows: C1—Persons employed in circular-economy sectors (full-time equivalent, FTE); C2—Private investment and gross value added related to circular-economy sectors (million €); C3—Patents related to recycling and secondary raw materials (number); C4—Consumption footprint (index, 2010 = 100); C5—Greenhouse-gas emissions from production activities (kg per capita); C6—Material import dependency (%); C7—Material footprint (tons per capita); C8—Resource productivity (€/kg, chain-linked volumes 2015); C9—Generation of municipal waste (kg per capita); C10—Generation of waste excluding major mineral wastes (kg per thousand € GDP, chain-linked volumes 2010); C11—Waste generation per capita (kg per capita); C12—Food waste (kg per capita); C13—Generation of packaging waste (kg per capita); C14—Generation of plastic packaging waste (kg per capita); C15—Trade in recyclable raw materials (tons); C16—Circular material-use rate (%); C17—Recycling rate of all waste excluding major mineral wastes (%); C18—Recycling rate of municipal waste (%); C19—Recycling rate of packaging waste by type of packaging (rate); and C20—Recycling rate of WEEE separately collected (%). Together, these twenty indicators provide a comprehensive picture of Europe’s progress toward a more circular, sustainable, and resource-efficient economy.

The selected indicators for assessing circular economy performance are divided into beneficial and non-beneficial criteria. Beneficial criteria (where higher values indicate better performance) include: persons employed in circular economy sectors, private investment and gross added value in CE sectors, patents related to recycling and secondary raw materials, resource productivity, trade in recyclable raw materials, circular material use rate, recycling rate of all waste, recycling rate of municipal waste, recycling rate of packaging waste, and recycling rate of WEEE. Non-beneficial criteria (where lower values are preferable) consist of: consumption footprint, greenhouse gas emissions, material import dependency, material footprint, generation of municipal waste, waste generation per capita, food waste, packaging waste, plastic packaging waste, and generation of waste excluding major mineral wastes per GDP unit.

After collecting data from Eurostat for 2018 and 2023, the CRITIC is applied to determine the objective weights. The results of the CRITIC steps are shown in Table 3.

Table 3. CRITIC results.

Years	2018			2023		
	v_j	Weight	Rank	v_j	Weight	Rank
C1	3.50304	0.05174	6	3.42486	0.04988	12
C2	2.6982	0.03985	19	2.78661	0.04058	20
C3	2.7757	0.041	18	3.06092	0.04458	18
C4	3.30386	0.0488	11	3.44655	0.0502	9
C5	4.31914	0.0638	2	3.91783	0.05706	2
C6	3.1585	0.04665	15	3.37074	0.04909	14
C7	2.98296	0.04406	17	3.12317	0.04549	16
C8	3.14123	0.0464	16	3.11628	0.04539	17
C9	3.36248	0.04967	10	3.67099	0.05346	3
C10	3.27932	0.04844	13	3.47959	0.05068	8
C11	4.19511	0.06197	3	4.44337	0.06471	1

Table 3. Cont.

Years	2018			2023		
	v_j	Weight	Rank	v_j	Weight	Rank
C12	3.5263	0.05209	5	3.64528	0.05309	5
C13	3.41876	0.0505	8	3.48433	0.05075	6
C14	3.43396	0.05072	7	2.98603	0.04349	19
C15	3.40815	0.05034	9	3.66611	0.05339	4
C16	3.28835	0.04857	12	3.43416	0.05001	10
C17	3.56236	0.05262	4	3.4329	0.05	11
C18	3.21373	0.04747	14	3.41246	0.0497	13
C19	2.64482	0.03907	20	3.48123	0.0507	7
C20	4.48448	0.06624	1	3.27954	0.04776	15

The most important criterion in 2018 is C20 (Recycling rate of WEEE separately collected) with a weight of 0.06624, followed closely by C5 (Greenhouse-gas emissions) and C11 (Waste generation per capita). In contrast, in 2023, the most important criterion becomes C11 (Waste generation per capita) with an increased weight of 0.06471, while C20 drops to 15th place with 0.04776 weight. In 2023, waste generation per capita received the highest CRITIC weight, reflecting increasing emphasis on waste reduction following the EU Waste Framework Directive and stronger societal concern about overconsumption.

Afterward, the TOPSIS is applied to rank countries according to weighted criteria for both years. Table 4 shows the results of the TOPSIS for both years.

Table 4. TOPSIS results.

Countries	C_i^*	2018 Ranking	C_i^*	2023 Ranking
Belgium	0.49189	7	0.46882	7
Bulgaria	0.30503	26	0.29694	26
Czechia	0.45139	12	0.44954	9
Denmark	0.43932	18	0.43148	17
Germany	0.75134	1	0.74667	1
Estonia	0.24471	27	0.28572	27
Ireland	0.4419	17	0.44302	12
Greece	0.43304	20	0.42457	18
Spain	0.57406	4	0.59433	4
France	0.65768	2	0.6722	2
Croatia	0.46417	8	0.45016	8
Italy	0.6158	3	0.61632	3
Cyprus	0.4228	21	0.39758	23
Latvia	0.44708	13	0.43969	14
Lithuania	0.43629	19	0.421	20
Luxembourg	0.38558	24	0.37687	24
Hungary	0.45312	11	0.43312	16
Malta	0.41724	23	0.42126	19
Netherlands	0.57382	5	0.57509	5

Table 4. Cont.

Countries	C_i^*	2018 Ranking	C_i^*	2023 Ranking
Austria	0.45886	10	0.44172	13
Poland	0.51603	6	0.52003	6
Portugal	0.44375	15	0.43416	15
Romania	0.4193	22	0.39995	22
Slovenia	0.46311	9	0.44421	11
Slovakia	0.44247	16	0.44535	10
Finland	0.36457	25	0.37349	25
Sweden	0.44504	14	0.41749	21

In both 2018 and 2023, Germany ranks first, showing it had the strongest overall performance across all 20 circular economy indicators. France and Italy consistently follow in second and third place, respectively, for both years. Other top performers include Spain and the Netherlands, maintaining their positions in the top five. Meanwhile, Estonia ranks last (27th) in both years, indicating the weakest performance, followed closely by Bulgaria. Countries like Finland, Luxembourg, and Malta also remain in the lower tier of the ranking. Figure 1 shows a comparison of EU countries' rankings in 2018 and 2023 based on their circular economy performance, as measured by the integrated CRITIC-TOPSIS method.

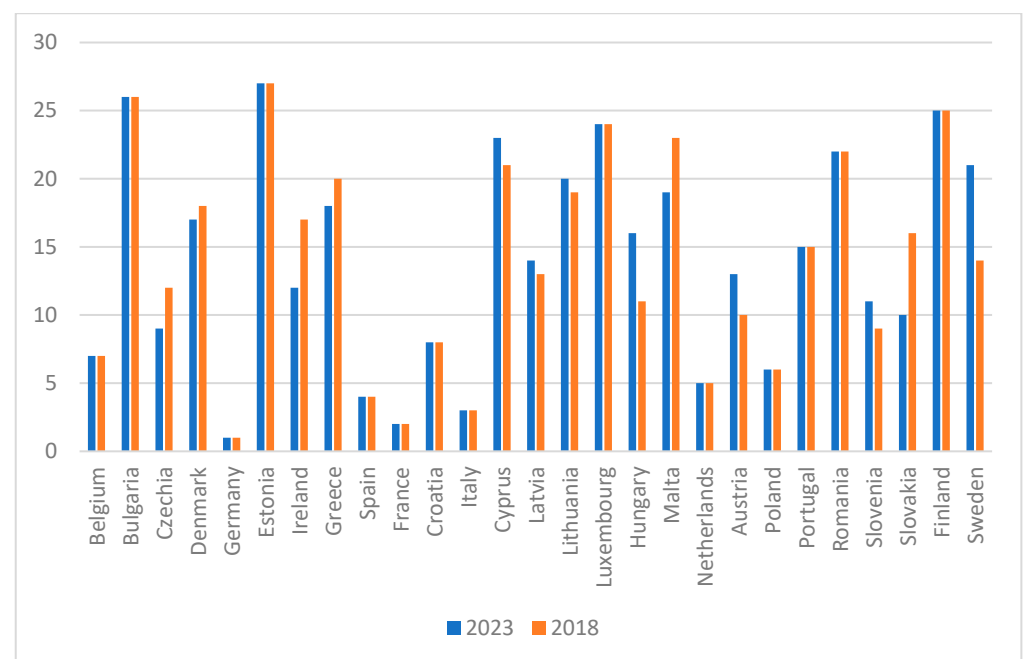


Figure 1. Comparison of progress in 2018 and 2023.

Germany consistently ranked first, supported by strong industrial recycling systems, high CE investments, and policy enforcement. Estonia's last-place ranking reflects structural limitations, including a smaller economy, lower recycling infrastructure, and reliance on landfilling. France and Italy followed Germany, largely due to strong performance in waste management, secondary materials trade, and innovation-related indicators. Eastern European countries such as Bulgaria, Romania, and Latvia ranked in the lower tier, reflecting lagging infrastructure and limited CE policy enforcement.

5. Sensitivity Analysis

In the present research, the SWARA method is used under a picture fuzzy environment to determine the subjective weights of criteria and show how sensitive the results of the present research are to subjectivity. To this end, three academics supported the criteria using linguistic variables shown in Table 5. Three academic experts were from Lithuanian higher education institutions. Each holds a PhD and has over ten years of experience in sustainability research and practice. The linguistic scale used in this study (Very Low to Very High) and its corresponding picture fuzzy numbers were adapted from prior applications in fuzzy MCDM research [38–40]. These terms and membership assignments have been validated in earlier decision-making studies and are considered reliable for capturing uncertainty, hesitation, and expert subjectivity. Thus, the chosen fuzzy sets ensure consistency with established practice while adequately reflecting the nuances of expert judgment in sustainability assessment.

A Picture Fuzzy Set (PFS) on a universe of X is $\{\langle x, \mu_A(x), \eta_A(x), \nu_A(x) \rangle | x \in X\}$ Where the positive membership degree is $\mu_A(x) \in [0, 1]$, the negative membership degree is $\nu_A(x) \in [0, 1]$, and the neutral membership degree is $\eta_A(x) \in [0, 1]$, subject to $0 \leq \mu_A(x) + \eta_A(x) + \nu_A(x) \leq 1, \forall x \in X$.

Table 5. Linguistic variables.

Linguistic Variables	Picture Fuzzy Numbers
Very Low (VL)	{0.05, 0.45, 0.5}
Low (L)	{0.1, 0.4, 0.45}
Medium-Low (ML)	{0.15, 0.35, 0.4}
Medium (M)	{0.3, 0.35, 0.35}
Medium-High (MH)	{0.4, 0.2, 0.15}
High (H)	{0.45, 0.15, 0.1}
Very High (VH)	{0.5, 0.1, 0.05}

PF-SWARA-TOPSIS

Step 1. Creating a decision-making matrix

Let $\{ce_1, ce_2, \dots, ce_q\}$ a set of CE factors, $E = \{e_1, e_2, \dots, e_r\}$ a set of experts. $Z = (a_{ij})_{q \times r}$, where $x_{ij} \forall i = 1, \dots, q; j = 1, \dots, r$, is the linguistic variables assigned to i th CE factor by j th expert. The Experts' support for factors using linguistic variables is shown in Table 6.

Table 6. Experts' support.

	E1	E2	E3
C1	VL	MH	L
C2	MH	H	MH
C3	L	ML	L
C4	M	MH	MH
C5	M	MH	VH
C6	M	ML	M
C7	ML	ML	ML
C8	VL	ML	VL
C9	H	H	MH

Table 6. *Cont.*

	E1	E2	E3
C10	H	H	ML
C11	VH	H	VH
C12	VH	H	H
C13	MH	VH	H
C14	VH	VH	VH
C15	VH	M	H
C16	M	M	H
C17	H	MH	M
C18	ML	VL	L
C19	M	VL	L
C20	ML	M	ML

Step 2. Score function

Firstly, individual matrices should be aggregated using Equation (13). Assume $\alpha_j = (\mu_{\alpha_j}, \eta_{\alpha_j}, \nu_{\alpha_j})$; then the PFWA aggregates matrices [40]:

$$PFWA_{\omega}(\alpha_1, \alpha_2, \alpha_3, \dots, \alpha_n) = \bigoplus_{j=1}^n (\omega_j \alpha_j) \quad (13)$$

$$= \left(1 - \prod_{j=1}^n (1 - \mu_{\alpha_j})^{\omega_j}, \prod_{j=1}^n (\eta_{\alpha_j})^{\omega_j}, \prod_{j=1}^n (\eta_{\alpha_j} + \nu_{\alpha_j})^{\omega_j} - \prod_{j=1}^n (\eta_{\alpha_j})^{\omega_j} \right)$$

Then, Equation (14) calculates the score function [38]:

$$\dot{S} = \frac{\mu_{\alpha} + \eta_{\alpha} - \nu_{\alpha} + 1}{2} \quad (14)$$

Step 3. Sorting factors

Factors should be sorted from the most to the least significant score function.

Step 4. Comparative coefficient (k_j) using Equation (15). k_j for the factor with the highest score function is 1.

$$k_j = \begin{cases} 1 & j = 1 \\ s_j + 1 & j > 1 \end{cases} \quad (15)$$

In which S_j shows the score value's comparative significance.

Step 5. Equation (16) estimates the weights.

$$p_j = \begin{cases} 1 & j = 1 \\ \frac{p_{j-1}}{k_j} & j > 1 \end{cases} \quad (16)$$

Step 6. Normalizing the weights using Equation (17).

$$w_j = \frac{p_j}{\sum_{j=1}^n p_j} \quad (17)$$

The results of PF-SWARA are presented in Table 7.

Table 7. PF-SWARA results.

Factors	w_j	Rank
C1	0.0004	14
C2	0.015075	7

Table 7. Cont.

Factors	w_j	Rank
C3	6.79×10^{-5}	18
C4	0.002984	10
C5	0.008725	8
C6	0.000641	13
C7	0.000104	17
C8	2.93×10^{-5}	20
C9	0.045388	5
C10	0.001755	11
C11	0.243723	2
C12	0.138541	3
C13	0.079074	4
C14	0.430775	1
C15	0.026138	6
C16	0.001037	12
C17	0.005087	9
C18	4.45×10^{-5}	19
C19	0.000161	16
C20	0.000252	15

After this step, the rest of the steps are similar to TOPSIS steps in Section 3.1. The results of PF-SWARA-TOPSIS are presented in Table 8 for both years.

Table 8. Sensitivity analyses.

Countries	C_i^*	2018 Ranking	C_i^*	2023 Ranking
Belgium	0.69016	12	0.73482	10
Bulgaria	0.50669	24	0.594	22
Czechia	0.79882	6	0.82878	4
Denmark	0.57905	21	0.67791	17
Germany	0.62216	19	0.67221	18
Estonia	0.31577	27	0.46727	25
Ireland	0.52119	23	0.46607	26
Greece	0.8023	5	0.81173	5
Spain	0.70195	11	0.69173	15
France	0.66147	15	0.70545	13
Croatia	0.89596	1	0.90552	1
Italy	0.65837	16	0.68664	16
Cyprus	0.76081	9	0.74322	8
Latvia	0.83341	2	0.84787	2
Lithuania	0.78293	7	0.71671	12
Luxembourg	0.35698	26	0.48509	24
Hungary	0.70678	10	0.64602	21

Table 8. Cont.

Countries	C_i^*	2018 Ranking	C_i^*	2023 Ranking
Malta	0.67664	13	0.7515	7
Netherlands	0.63811	18	0.71826	11
Austria	0.61969	20	0.66026	19
Poland	0.7752	8	0.74205	9
Portugal	0.64224	17	0.64957	20
Romania	0.6658	14	0.6945	14
Slovenia	0.81282	4	0.7954	6
Slovakia	0.82399	3	0.84035	3
Finland	0.40208	25	0.46341	27
Sweden	0.57026	22	0.50011	23

This sensitivity analysis was conducted by first determining subjective weights using the SWARA method under a picture fuzzy environment, followed by applying the TOPSIS method to rank EU countries for the years 2018 and 2023. The results show that Croatia, Slovakia, and Czechia consistently rank among the top three performers in both years. In contrast, Estonia, Ireland, and Finland achieved the lowest ranks in both 2018 and 2023. However, it is noticeable that countries' ranks are different from the results of CRITIC-TOPSIS. Unlike CRITIC, which is purely data-driven, PF-SWARA incorporates expert judgment, allowing hesitation in responses. This makes it more reflective of policy priorities, complementing the objectivity of CRITIC-TOPSIS. Figure 2 shows a comparison of the results of the subjective and objective methods for weight determination in 2018.

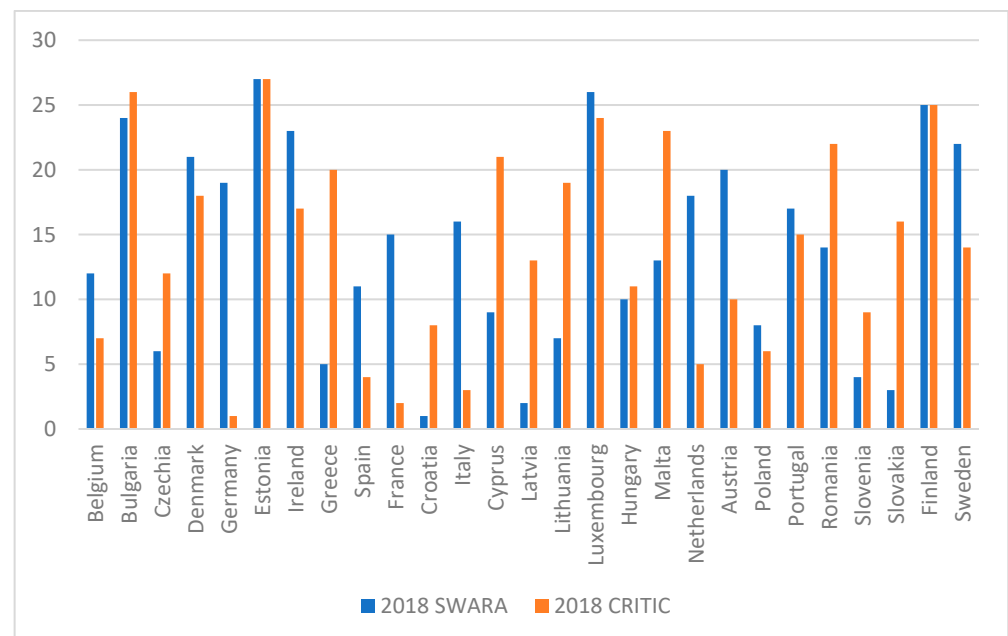


Figure 2. Comparison of the results of the subjective and objective methods for weight determination in 2018.

As shown in Figure 2, the results of PF-SWARA-TOPSIS are different from the results of CRITIC-TOPSIS for 2018. Figure 3 shows a comparison of the results of the subjective and objective methods for weight determination in 2023.

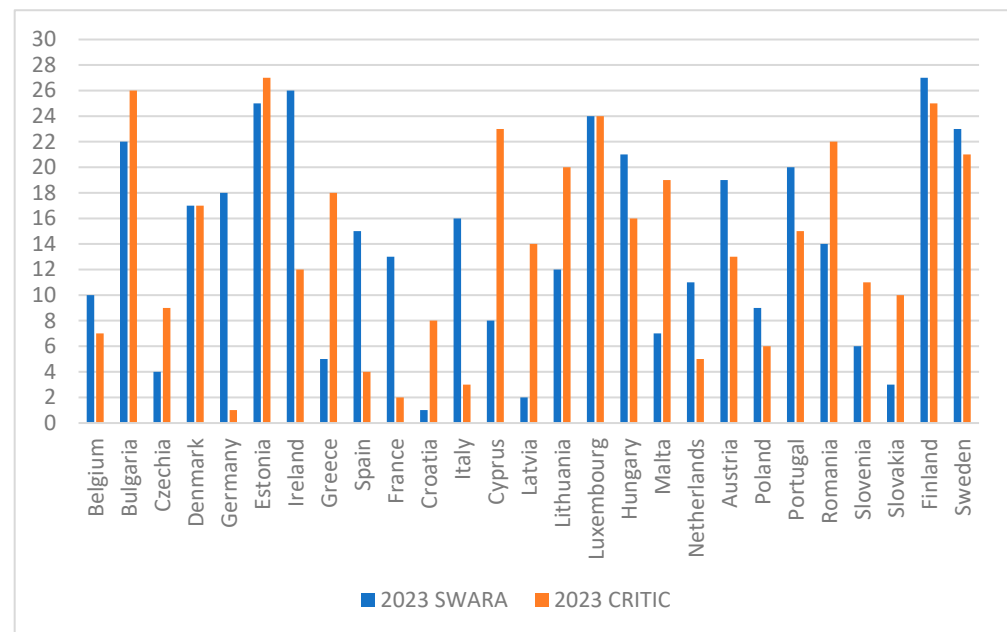


Figure 3. Comparison of the results of the subjective and objective methods for weight determination in 2023.

Croatia's ranking improved under PF-SWARA, suggesting that when expert judgment emphasizes food waste reduction and recycling, Croatia's policy focus is more strongly reflected than under purely statistical weighting. The divergence between PF-SWARA and CRITIC–TOPSIS highlights how objective data-driven variability may undervalue certain policy-prioritized indicators, whereas expert-based weighting captures national strategic priorities. This divergence has implications for designing EU-wide vs. national CE monitoring frameworks. Also, between 2018 and 2023, Slovenia and the Netherlands improved their rankings due to gains in secondary materials use and food waste reduction, while Poland and Hungary declined slightly, largely because of stagnant recycling rates and increased waste generation per capita.

6. Discussion

The present study used CRITIC to determine the objective weights of CE factors by considering their variability and correlating them. Therefore, determined weights for the same set of CE factors are different in 2018 and 2023. For example, C20 (WEEE recycling rate) was the most important criterion in 2018, while C11 (waste generation per capita) became the most influential in 2023. It shows how CE factors interact statistically and how they are driven by changing policies and socioeconomic conditions. In contrast, the PF-SWARA method uses expert judgment within a picture fuzzy environment, resulting in a consistent set of subjective weights for both years.

On the other hand, PF-SWARA determined the same weights for both years, as it works based on experts' support rather than statistical variation. It is noticeable that the experts prioritized visible and urgent environmental pressures, such as C14 (plastic packaging waste), C11 (waste generation per capita), and C12 (food waste), as the most important, while indicators like C8 (resource productivity) and C15 (WEEE recycling) received minimal weight. The contrast between the two methods highlights the value of combining objective and subjective weighting approaches in decision-making. It helps decision-makers to gain a more comprehensive and policy-relevant understanding of circular economy dynamics in the EU.

Furthermore, according to Figure 1, the top performers in both years are Germany, France, Italy, and Spain. Germany, in particular, shows remarkable stability and reflects a sustained national commitment to circular economy practices. On top of that, France and Italy also show steady high performance, confirming their long-standing investment in CE frameworks. Some countries show notable changes between 2018 and 2023. Poland and Malta, for example, display significant positive improvements in ranking, indicating progress in multiple indicators and possibly effective policy implementation. However, Ireland, Estonia, and Finland experience a notable decline. These declines suggest growing performance gaps in certain areas of circular economy implementation.

Moreover, Figure 2 compares the 2018 rankings of EU countries based on two different weighting methods. The chart clearly shows how the choice of weighting method can greatly affect the final rankings. Some countries hold relatively high positions in both methods, including Croatia, France, and Italy; however, some experience significant shifts, including Germany, Luxembourg, and Finland. Additionally, Figure 3 shows the same difference but for 2023. It shows countries like Croatia, Latvia, and Slovakia rank much higher under PF-SWARA, reflecting the focus experts place on indicators like packaging and food waste. Meanwhile, Germany, France, and Spain perform better under CRITIC, due to their strong data-driven consistency across various indicators. However, some countries, such as Estonia, Finland, and Ireland, rank low with both methods, highlighting ongoing structural or policy-related CE challenges. These figures emphasize the need to use multiple weighting strategies for a balanced and comprehensive view of circular economy performance.

Germany, France, and Italy's strong performance aligns with prior studies [27,35], which also identified these countries as CE leaders. Their advanced recycling infrastructure, policy enforcement, and innovation systems contribute to consistent high rankings. However, our results differ from D'Adamo, Favari, Gastaldi and Kirchherr [27] those who found that competitiveness and innovation indicators dominated EU circular economy assessments. In contrast, our CRITIC–TOPSIS analysis emphasized waste-related indicators such as waste generation per capita and WEEE recycling, while PF-SWARA highlighted plastic and food waste as expert priorities.

7. Conclusions

This study evaluated EU member states' circular economy performance from 2018 to 2023 using 20 Eurostat indicators and a hybrid CRITIC–TOPSIS and PF-SWARA framework. The results indicated that some factors, such as waste generation per person, plastic packaging waste, and food waste, consistently ranked among the most important factors in determining CE performance. It can be concluded that CE is not concerned only about environmental issues, but a variety of factors also influence the progress of countries. Therefore, it can be concluded that countries that focus on reducing waste through improved infrastructure or increased consumer awareness might enhance their rankings. In other words, focusing on these key factors should be prioritized in national CE strategies. Also, results revealed a persistent west–east divide in CE performance: Germany, France, and Italy consistently lead, while Estonia, Bulgaria, and Romania lag, reflecting disparities in infrastructure, innovation, and policy maturity.

Furthermore, according to sensitivity analyses, it can be concluded that subjectivity can impact the perceived importance of CE criteria and, consequently, change the ranking of countries. In contrast, it can be concluded that objective methods emphasize statistical differences, making them more useful when there is no local priority in decision-making. In other words, this subjectivity is particularly useful in scenario planning, where expert-based weighting can guide localized CE strategies that align with specific environmental,

social, or economic contexts. Including expert opinions in decision models ensures that policy frameworks are sensitive to regional challenges and societal expectations, making CE implementation more adaptable and inclusive.

Moreover, although the present study showed decision-making tools help evaluate countries' performance according to CE factors, the study also demonstrates that their results are highly sensitive to whether weights are based on objective data or subjective expert judgment. Objective tools offer consistency and reproducibility, but subjective methods provide flexibility and context relevance. Therefore, it can be concluded that combining both approaches improves policy evaluation. In other words, it can be concluded that combining methods can balance analytical precision with real-world priorities and support more effective monitoring and benchmarking.

Additionally, the findings of this study also carry important implications in the context of the UN Sustainable Development Goals. By identifying the most critical factors, such as waste generation, plastic packaging, and food waste, and by benchmarking EU member states' progress, the study directly contributes to SDG 12 (Responsible Consumption and Production).

Moreover, by emphasizing the importance of reducing material footprints and greenhouse gas emissions, the study indirectly supports SDG 13 (Climate Action). Thus, our framework not only evaluates CE progress but also provides actionable insights into how EU countries can accelerate the achievement of global sustainability goals.

7.1. Policy Implications

Based on the findings of this study, the following policy implications are recommended for EU countries aiming to accelerate progress toward a circular economy:

- **Prioritize High-Impact Waste Factors:** Countries should concentrate policy efforts on reducing waste generation per person, especially in the areas of plastic packaging and food waste. This is due to the fact that these factors were identified as the most influential factors across both objective and subjective assessments.
- **Incorporate Expert Judgment in Local Strategy Development:** Countries should include expert consultations in CE planning processes since subjective weighting emphasizes different priorities than objective approaches. Including experts helps ensure that local policies respond to specific environmental pressures, public values, and implementation capabilities.
- **Adopt Hybrid Evaluation Tools for Policy Monitoring:** Hybrid tools offer a more balanced perspective and support evidence-based benchmarking and scenario planning. These tools make sure that both performance metrics and societal priorities guide policy development.

7.2. Research Limitations and Recommendations for Future

Data missing was one of the main limitations in the present research. This limitation impacted the research in two ways: missing data for a specific country in both years, and missing data for a country in one of the years. The present study dealt with the first way by excluding the country and coping with the second one by using the data for the closest year. Another limitation was connected to the limited knowledge of experts regarding the applied methods, as we needed their support. Therefore, the data collection for the sensitivity analyses was a time-consuming task.

It is recommended to apply fuzzy cognitive maps to develop scenarios for EU countries according to their local strategies. Also, it is recommended to apply the proposed method for other groups of countries, such as ASEAN countries, to see how the proposed method works and compare the results with the present research results. Additionally, it is also

recommended to apply the proposed method under different fuzzy environments to see how fuzzy logics can impact the results.

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