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Comparative assessment of circular economy performance in the Baltic States using MCDM methods

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Abstract. Implementation and progress towards circularity are widely recognized characteristics of CE transitions across Europe, and the transition to CE sits firmly at the core of the European Union's sustainable development strategy. Using a multi-criteria decision-making (MCDM) approach, this study conducts a comparative evaluation of CE performance in the three Baltic States (Estonia, Latvia and Lithuania). Based on Eurostat data, three related indicators were chosen to represent the multidimensional nature of circularity: waste generation per capita (non-beneficial), recycling rate of municipal waste, and circular material use rate (both beneficial). The indicators were analyzed over multiple years (2010–2023) to capture temporal dynamics and shifts in the national performance. The was used to order the countries by normalizing such indicators from the chosen years and assigning them equal weight. The outcome shows that, in fact, Estonia is better off than its neighbors in two out of three aspects, and that its waste per capita and materials usage per capita is significantly improving. Latvia performs best in recycling but least well in material circularity and waste minimisation. Lithuania does consistently okay, moderate performance across the board. This study adds to CE literature by developing a replicable, dynamic framework for national CE evaluation. It provides empirical evidence about regional divides operating within a common EU policy framework; and a methodological framework for more fine-grained, empirical evidence-based policy action. The findings contribute to debate for scholars and practitioners on how to benchmark and improve CE implementation in small-state contexts.

Keywords: Circular economy; Baltic States; COPRAS; Sustainability indicators; Multi-criteria decision making.

1. Introduction

The Circular Economy (CE) paradigm has emerged and consolidated as a strategic approach towards sustainable development. CE challenges the traditional take-make-disposed linear model of production and consumption by promoting the reduction, reuse and recycling of materials. It allows countries to pursue simultaneously the preservation of the environment, economic competitiveness and the well-being of society (Arruda et al., 2021). The European Union (EU) has

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mainstreamed CE across national and European policies and initiatives, placing it at the heart of the European Green Deal and Circular Economy Action Plan as a central component of long-term sustainability objectives (De Pascale et al., 2023).

The Baltic States, Estonia, Latvia, and Lithuania stand out within the EU as an interesting case to assess the adoption of CE principles. Despite their common history and destruction of the post-Soviet economy, they strongly diverge in terms of environmental governance, waste management infrastructure and policy integration. A comparative assessment of their CE performance is, therefore, necessary to identify their respective strengths, gaps and opportunities for mutual learning and regional coherence (Streimikiene, 2024).

Reliable indicators must be employed to evaluate CE performance for the operationalization of CE. While many metrics have been proposed, Waste Generation (kg/capita), Recycling Rate of Municipal Waste and Circular Material Use Rate broadly correlate with consumption, waste management systems and the re-introduction of raw materials into the economy, all of which are relevant at the level of policy interventions, and data is comparatively readily available compared to other proposed metrics. In combination, these indicators offer a multi-faceted perspective of circularity across national systems (Megevand et al., 2022).

But comparing CE performance across countries and overtime poses a methodological challenge. These indicators differ in scale, whether beneficial or detrimental, and unit of measurement, rendering simple comparisons misleading. Furthermore, dramatic changes in performance over years—temporal dynamics—must be captured to monitor progress and detect trends (Lu et al., 2024). The complexity of these interactions necessitates a structured decision-support approach that integrates both spatial (cross-sectional) and temporal (longitudinal) dimensions (Tefera et al., 2023).

Such evaluations can be done effectively using Multi-Criteria Decision-Making (MCDM) methods, which provide a comprehensive analytical framework. MCDM techniques enable the construction of composite orderings by considering multiple indicators and their relative importance, thus promoting more data-driven, transparent decision processes. High up on the list is the Complex Proportional Assessment (COPRAS) method, which is a flexible and practical technique that can address both desirable and undesirable criteria and is widely adopted in sustainability choice assessments since trade-offs are integral in this context (Hauschild et al., 2022).

The COPRAS method was applied in this example for the evaluation of the performance of the circular economy and the ranking over three different years in Estonia, Latvia and Lithuania. Using three Eurostat indicators, this analysis highlights differences in performance both spatially and temporally. The study aims to not only rank each country per year but to observe to look for trends and to determine how steady or volatile the move towards circularity has been by each country (Grybaitė & Burinskienė, 2024).

The paper makes two main contributions in doing so. First, it establishes a methodologically rigorous yet policy-relevant comparative framework that serves as

a replicable model for similar regional assessments. Second, it reveals strengths and weaknesses that are specific to particular countries, which allows policymakers to focus on specific areas for intervention. This could be through a tangible regulation, technology adjustment, or behavioral modification to address issues like low recycling efficiency or excess per capita generation.

Furthermore, this study provides contributions to academic literature regarding sustainability assessment, which is often plagued by arbitrary selection of indicators and the absence of time-based analyses, thanks to the use of a structured multi-criteria decision-making (MCDM) method like COPRAS. This study shows how circular economy (CE) indicators can be aggregated, weighted, and interpreted to inform evidence-based policy. It also responds to the increasing need for analyses that demonstrate change over time as opposed to static, one-time comparisons.

2. Literature Review

The Circular Economy (CE) concept has quickly grown from an academic niche to a common policy tool to operationalize sustainable development in practice. CE is based on industrial ecology and systems thinking to disconnect economic development from the consumption of natural resources by encouraging restorative and regenerative production models (Kirchherr et al., 2023). Key strategies include reducing waste, prolonging the life cycle of products and maximizing reuse of materials. Policy instruments such as the Circular Economy Action Plan have highlighted how CE can help to achieve the goals of the European Green Deal and the 2030 Sustainable Development Goals (SDGs) in the European Commission (2020) (Rodríguez-Antón et al., 2022).

Scholarly frameworks and indicators have been suggested to transition businesses towards circularity. These encompass macro-level evaluations based on national statistics and micro-level examinations of sectors and firms. Some indicators like Circular Material Use Rate (CMUR), Waste Generation per Capita and Recycling Rate of Municipal Waste have also been widely accepted at the national level by Eurostat and other institutions (Ahmed et al., 2022). These metrics offer a multidimensional view of material efficiency and resource flows, which allows the comparison across countries and also intertemporal comparison. Yet, several issues still need to be addressed, such as the need for harmonization in terms of definitions, as well as the disparities in data availability and the synthesis of such different spatial indicators into a single evaluation system (Nan et al., 2022).

In the Baltic States context, the research on CE performance has been limited, and few comprehensive studies have used longitudinal and comparative approaches. Previous studies mainly report country-level case studies or sectoral studies such as waste management in Estonia or industrial symbiosis in Lithuania (Hondroyiannis et al., 2024). Together these studies provide insight, but they do not drill down to the level of a region with common historical, economic and institutional features. Abundant in common histories with regards to EU accession, post-socialist transition and geographical proximity, Estonia, Latvia and Lithuania reflect a good comparative

setting to be likely for the study of the effectiveness of CE in implementation (Nagy et al., 2025).

MCDM methods have been increasingly employed to confront the complexity of evaluating different CE performance criteria. These techniques enable the systematic merging of various indicators with different dimensions, scales, and directions. Decision-making methods like Analytic Hierarchy Process (AHP), TOPSIS, and Best-Worst Method (BWM) have been successfully implemented in several sustainability assessments such as renewable energy prioritization, supply chain evaluation and environmental policies assessment (Bathaei et al., 2019). The MCDM methods provide transparent decision-making through the identification of trade-offs and synergies between indicators (dos Santos Gonçalves & Campos, 2022).

COPRAS method is one of MCDM techniques that can take into consideration both beneficial and non-beneficial criteria, which makes it popular among MCDM techniques. Originally proposed by Zavadskas et al., (2007) COPRAS is particularly relevant for sustainability contexts, where indicators are likely to conflict. It allows for the computation of a performance index for each alternative ranked in descending order perceptibly and intuitively supported the internal output for decision making. COPRAS, despite its strengths, has not been widely-used in CE assessments, particularly in cross-country studies backed by real-world datasets, such as Eurostat (Amoozad Mahdiraji et al., 2018; Zavadskas et al., 2007).

A few recent studies have integrated CE indicators utilizing MCDM techniques. (dos Santos Gonçalves & Campos, (2022) discussed CE implementation to date in Europe and pointed out the need for quantitative tools to assist national evaluation (dos Santos Gonçalves & Campos, 2022). Most recently, Coluccia et al., 2024 and Nguyen (2025). However, relatively few of the applications consider the evolution of performance over time (i.e. temporal dynamics), and even fewer focus specifically on small, open economies such as the case of Baltic States (Coluccia et al., 2024; Nguyen, 2025). This gap warrants the need for a time-sensitive, comparative CE assessment for the region.

Much of the empirical work on CE in the Baltic has therefore been descriptive or qualitative policy reviews. Although informative, these approaches tend to lose sight of interactions among different indicators and trade-offs involved in the sustainability transitions (Brodny et al., 2024). Furthermore, the absence of a consistent methodological framework restricts the replicability and policy significance of these investigations. In doing so COPRAS is used, which allows this research to contribute to recent development in sustainability analytics provide and previously unseen comprehension of CE sustainability in terms of its comparison against conventional standards (Nikolaou et al., 2021).

As methodological contributions, this paper takes part in the discussion of (regionalized) sustainability assessments tailored to the specificities of smaller EU economies (Spilioti & Anastasiou, 2024). Bubbles occur rather differently there are no domestic markets, little fiscal space, and the economy is dependent on external supplies of technology and resources. This highlights the necessity for evaluating CE strategies in context as these factors mediate both the feasibility and impact of CE

strategies. Frameworks that are robust, indicator-driven, and informed by MCDM logic, offer a valuable lens for capturing these national and regional dynamics (Kumar & Pamucar, 2025).

Based on the literature review, we have identified an emerging interest in CE performance measurement as well as MCDM integration; nevertheless, substantial gaps still exist regarding the application of these methodologies to small-country, multi-year, comparative assessments. This paper aims to bridge the gap by identifying a set of practically relevant indicators, then implementing the COPRAS method, and evaluating robustness of performance in three time intervals for Estonia, Latvia, and Lithuania. Forthcoming results will bring in theoretical contributions as well as practical suggestions, enabling national economies to be more circular within the EU context.

3. Methods

Using a quantitate Multi-Criteria Decision Making (MCDM) method, this study comparatively evaluates the CE performance of the 3 Baltic States—Estonia, Latvia and Lithuania—over several years. For the selected indicators the COPRAS method is used to rank these countries. This section describes the data sources, indicator selection and normalization methods, weighting methods, and steps of the COPRAS method. Data used in this study were obtained from Eurostat, the statistical office of the European Union. The chosen indicators have been established as core metrics for monitoring progress towards the circular economy at the EU level, from which we derived relevance, reliability and availability across the target countries and years. Three indicators were chosen as follows:

- Waste Generation/Capita (kg/person): A rate of any non-beneficial criterion, showing the level of generation of waste per capita. Higher values are associated with more environmental burden and less efficient resource use.
- Municipal Waste Recycling Rate (%): A positive indicator of the efficiency of national waste management systems and the pervasiveness of recycling practices.
- Circular Material Utilization Rate (CMUR)(%): This positive indicator shows the proportion of recycled materials that are integrated back into the economy — a straightforward measure of circularity.

Like with other evaluations, these indicators were measured and ranked to chart individual countries performance against a circular economy in 3 different years (e.g., 2015, 2018 and 2021). By incorporating temporal data, the study tracks changes over time and provides insights into the dynamic evolution of CE implementation across the region.

The preference ranking method of complex proportional assessment (COPRAS) method was developed by Zavadskas et al. (Zavadskas et al., 2008). In this method, the influence of maximizing and minimizing criteria on the evaluation result is considered separately. The selection of the best alternative is based considering both

the ideal and the anti-ideal solutions. The main procedure of COPRAS method includes several steps (Chatterjee et al., 2011).

Step 1: Set the initial decision matrix, X.

$$X = [x_{ij}]_{m*n} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}, \quad (1)$$

where x_{ij} is the assessment value of i-th alternative in respect to j-th criterion, m is the number of alternatives and n is the number of criteria.

Step 2: Normalization of the decision matrix by using the following equation:

$$R = [r_{ij}]_{m*n} = {x_{ij}}/{\sum_{i=1}^{m} x_{ij}}. \quad (2)$$

Step 3: Determination of the weighted normalized decision matrix, D, by using the following equation:

$$D = [y_{ij}]_{m*n} = r_{ij}.W_j, i = 1, \dots, m, j = 1, \dots, n, \quad (3)$$

where r_{ij} is the normalized performance value of i-th alternative on j-th criterion and w_j is the weight of j-th criterion. The sum of weighted normalized values of each criterion is always equal to the weight for that criterion:

$$\sum_{i=1}^{m} x_{ij} = w_{ij}. \quad (4)$$

Step 4: In this step the sums of weighted normalized values are calculated for both the beneficial and non-beneficial criteria by using the following equations:

$$S_{+i} = \sum_{j=1}^{n} y_{+ij}, S_{-i} = \sum_{j=1}^{n} y_{-ij}, \quad (5)$$

where y_{+ij} and y_{-ij} are the weighted normalized values for the beneficial and non-beneficial criteria, respectively.

Step 5: Determination the relative significances of the alternatives, Q_i, by using the following equation:

$$Q_i = S_{+i} + \frac{S_{-min} \cdot \sum_{i=1}^{n} S_{-i}}{S_{-i} \cdot \sum_{i=1}^{m} \left({S_{-min}}/{S_{-i}}\right)}, i = 1, \dots, m, \quad (6)$$

where S_{-min} is the minimum value of S_{-i}.

Step 6: Calculation of the quantitative utility, U_i, for i-th alternative by using the following equation:

$$U_i = \frac{Q_i}{Q_{max}}.100\%, \quad (7)$$

where Q_{max} is the maximum relative significance value.

As a consequence of Eq. 6, utility values of the candidate alternatives range from 0% to 100%. The greater the value of U_i, the higher is the priority of the alternative. Based on alternative's utility values a complete ranking of the competitive alternatives can be obtained**.**

4. Results

In order to assess the CE performance in Estonia, Latvia and Lithuania, this paper used the COPRAS method on three key CE indicators calculated based on Eurostat data: Waste Generation per Capita, Municipal Waste Recycling Rate and Circular Material Use Rate. We evaluated each indicator over multiple years to look for both cross-sectional differences and temporal trends. The data were normalized, and

equal weights were given to each year, and composite scores were calculated for each country under each indicator. The results are shown below in three tables, showing respectively the ranking of the Baltic States according to their relative performance for a given indicator. These rankings underpin interpretations of national progress towards circularity and highlight areas of strength and weakness across the region.

Waste Generation per Capita. Waste Generation (kg/person) was an environmental efficiency of consumption and disposal practices, as the indicator was used to evaluate the situation in the Baltic States. As this is a non-beneficial criterion, lower values are beneficial, as they indicate lower environmental burden and more sustainable resource use. The raw data that presents it is summarized in Table 1, which shows each national waste generation data from the years 2010, 2016, and 2020. Based on this data, the COPRAS method was applied with equal weights assigned to each year, and the outcome of composite evaluation is presented in Table 2. According to collected overall COPRAS scores, Estonia is in the first place, as the country with the lowest average per capita waste generation during the studied period. Lithuania is assigned second place with moderate waste generation, but Latvia occupies the lowest position with the highest values and thus the least favorable results. These rankings provide a comparative view of national progress towards waste minimization and further highlight Estonia's position as a leader in decreasing per capita waste in the region.

Table 1
Initial matrix – waste generation

Weights of criteria	0.333333	0.333333	0.333333
Types of criteria	1	1	1
Year	2010	2016	2020
Estonia	14270	18451	12163
Latvia	714	975	1501
Lithuania	1801	2327	2396

Table 2
Final ranking – waste generation

Country	COPRAS Score	Rank
Estonia	1	1
Lithuania	0.149773	2
Latvia	0.075428	3

Circular Material Use Rate. The Circular Material Use Rate (CMUR) (%) is one of the fundamental indicators of the measure of recycled material being fed back into the economy and thus is representative of the effectiveness of a State at legislating circularity and thus reducing the reliance on virgin resources. The greater the value, the more advantageous the rating criterion. The data presented in Table 3 includes information on the years 2010, 2015, 2020, 2022, showing the phenomenon of

CMUR development in Estonia, Latvia, and Lithuania. Final composite scores and rankings for Years 1 to 5 using the COPRAS method and assigning equal weights to years are displayed in Table 4.

The findings confirm Latvia taking the lead, with significantly higher results and even a constant upward trend regarding the use of circular materials, from 9.4% in 2010 to 50.8% in 2022. The second place goes to Lithuania, which stayed stable and improved during the observed timeframe. Third place has gone to Estonia, although with relatively weaker starting values and a slower climb. Appearing at the top of this ranking table highlights Latvia's stage of development in getting secondary materials back into the production chain, while it also shows that Estonia's performance in this dimension of circular economy is lagging behind.

Table 3
Initial matrix – circular use rate

Weights of criteria	0.25	0.25	0.25	0.25
Types of criteria	1	1	1	1
Years	2010	2015	2020	2022
Estonia	18	28.3	28.9	33.2
Latvia	9.4	28.7	39.7	50.8
Lithuania	4.9	33.2	45.3	48.4

Table 4
Final ranking – circular use rate

Country	COPRAS Score	Rank
Latvia	0.815765	1
Lithuania	0.806245	2
Estonia	0.785981	3

*Recycling Rate of Municipal Waste***.** The Recycling Rate of Municipal Waste (%) was a key performance indicator used in this study for assessing job performance of national waste management systems. It embeds a positive criterion: the share of municipal solid waste in the country that is diverted from the landfill and treated through recycling, signaling how firmly circular economy practices are rooted in a country's waste infrastructure. Table 5 shows the raw data for the years 2010, 2015, 2020, and 2022, displaying the year-by-year development of recycling rates in Estonia, Latvia, and Lithuania. Different combinations of the years in the dataset were calculated to generate a ranking via the COPRAS method, starting with weights of 1.0 across the years (Table 6). Latvia outperforms the rest of the countries, with a normalized score of 0.816, which emphasizes a significant jump in municipal recycling—from 9.4% in 2010 to 50.8% in 2022. Lithuania comes second (0.806), indicating progressive increases in recycling capacity across the years. Despite some improvement, Estonia ranks third (0.786), mainly owing to lower recycling decades ago. These results highlight the success of Latvia's recent waste management reforms

and offer a point of comparison for evaluating long-term recycling performance across the Baltic States.

Table 5
Initial matrix – recycling

Weights of criteria	0.25	0.25	0.25	0.25
Types of criteria	1	1	1	1
Years	2010	2015	2020	2023
Estonia	9	11.4	16.4	18.1
Latvia	1.2	5.3	5.2	5
Lithuania	3.9	4.1	4	3.9

Table 6
Final matrix – recycling

Country	COPRAS Score	Rank
Estonia	1	1
Lithuania	0.313089	2
Latvia	0.29789	3

5. Discussion

In this study, we evaluated the circular economy (CE) of the Baltic States—Estonia, Latvia, and Lithuania—addressing Eurostat indicators; Waste Generation per Capita, Recycling Rate of Municipal Waste, and Circular Material Use Rate, by means of the COPRAS method. Our discussion below synthesizes and interprets these empirical findings in the context of relevant literature and regional policy landscapes.

The results show a high degree of variation, with Estonia emerging as the most consistent leader, particularly in Waste Generation per Capita and Circular Material Use Rate. Estonia's top position for waste generation (a non-beneficial indicator) implies success in minimizing waste over time. Its score in Circular Material Use Rate highlights its commitment to feeding secondary materials back into economic circulation—aligning with earlier findings by Bigus et al. (2025), who noted Estonia's early adoption of resource-efficiency policies compared to its neighbors (Bigus & Georgiou, 2025).

Latvia, on the other hand, delivered mixed results. It topped the ranking for Recycling Rate of Municipal Waste, reflecting efficient waste management infrastructure. However, it placed lowest for Circular Material Use Rate and Waste Generation per Capita, suggesting policy fragmentation or a lack of integration between waste streams. As Tambovceva et al., (2023) noted, Latvia has focused heavily on recycling targets influenced by EU directives, but trails behind in upstream waste prevention and broader material circularity (Tambovceva et al., 2023).

Lithuania maintained a balanced but moderate performance, ranking second in both Waste Generation per Capita and Circular Material Use Rate. Though it did not lead in any single indicator, its consistency reflects incremental progress. This aligns

with findings by Dagilienė et al., (2021), who observed Lithuania's growing municipal waste collection systems and citizen awareness, while noting that gaps remain in areas like industrial symbiosis and the development of secondary raw material markets (Dagilienė et al., 2021).

A cross-temporal comparison reveals an encouraging trend: all three countries improved in at least one indicator. Estonia's rise in CMUR—from 9% in 2010 to 18.1% in 2023—is especially noteworthy and can be tied to national CE strategies and EU sustainability projects. In contrast, Latvia and Lithuania's stagnation or decline in CMUR, despite better recycling rates, hints at weak integration between waste recovery systems and material reuse infrastructures.

By using the COPRAS method, this study effectively combined multi-year and multi-indicator data, producing more detailed rankings than single-point assessments. Unlike previous MCDM-based research that often focused on large economies or EU-wide data, this study offers a finer regional lens on CE performance in small, post-transition states. COPRAS enabled a fair analysis of both beneficial and non-beneficial indicators, making it adaptable to other small-country evaluations.

Crucially, the results highlight how similar countries can diverge in outcomes despite shared EU obligations and geographic proximity. The differences point to the importance of national governance, institutional strength, and local stakeholder engagement. These observations echo Asgari and Asgari, (2021), who emphasized that CE transitions depend not only on regulatory frameworks but also on practical domestic execution and innovation ecosystems (Asgari & Asgari, 2021).

Finally, this paper makes a methodological contribution by introducing a longitudinal, MCDM-based framework for CE assessment. This model moves beyond static comparisons and provides a clearer view of national progress or setbacks over time. It also fills a gap in existing literature, which often relies on qualitative analysis or simple statistics without producing integrated comparative rankings.

In summary, the study illustrates the value of combining multiple indicators over time to evaluate CE performance. Even under a unified EU policy framework, national differences in implementation and outcomes remain significant. These insights are key for designing more effective policies and encouraging knowledge-sharing across small EU member states.

6. Conclusion

The goal of this study was to evaluate and compare the CE performance of Estonia, Latvia, and Lithuania among the three Baltic States, using the COPRAS multicriteria decision-making method. The study established a dynamic, quantitative national-level circularity framework for ranking performance in circularity by merging multiple year data from Eurostat and focusing on three key indicators: Waste Generation per Capita, Recycling Rate of Municipal Waste, and Circular Material Use Rate.

There are stark differences between the Baltic countries. Estonia was consistently ahead of its regional neighbours, coming top in Waste Generation per

Capita and Circular Material Use Rate, and showing clear progress over time. Latvia, despite a stellar recycling efficiency performance, was lagging behind in reducing waste generation and increasing reuse of materials—performing poorly on both the waste generation and reuse aspects, even though it's one of the best recyclers in Europe. Lithuania, on the other hand, showed moderate and stable performance for most indicators, indicating gradual progress but limited leadership.

The adoption of the COPRAS method demonstrated its effectiveness in combining multiple indicators and multiple years into a single ranking system. It offers a replicable and transparent follow-up tool for assessing national CE performance. Unlike single-year assessments, this approach sheds light on the relative and temporal dynamics of CE implementation, helping policymakers pinpoint persistent gaps and uncover emerging strengths.

This study adds to the growing body of CE assessment literature by presenting a methodologically rigorous, regionally focused, and empirical model tailored for small EU economies. It also validates prior research emphasizing the importance of national-level commitment, governance, and stakeholder engagement in turning EU-wide CE policy goals into measurable outcomes.

Future research can expand on this work by incorporating additional indicators—such as eco-innovation, industrial symbiosis, or green public procurement—and applying stakeholder-weighted criteria to improve contextual sensitivity in the rankings. Further, this approach can be extended to other regional blocs or sectors to provide deeper comparative insight into the progress of circular economy transitions.

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