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# Assessment of Circular Economy Development in the EU Countries Based on SAW Method

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**Abstract:** The transition to a circular economy is important in achieving sustainability, promoting resource efficiency, and reducing environmental impact. This paper aims to assess the development of a CE in EU countries and highlight the use of environmentally friendly practices for its development. Decision-making methods based on various criteria provide a solid basis for evaluating complex and multidimensional circular economy (CE) initiatives. Simple Additive Weighting (SAW), the widely used MCDM method, facilitates sorting and selection according to the generalised results obtained according to weighted criteria. Due to its simplicity and ease of use, this method is particularly useful for assessing CE development in different countries. The evaluation will be based on a comprehensive overview of the available literature and empirical data, allowing for a comprehensive assessment of the CE's development initiatives in the European context using the SAW method. The results show that while significant progress has been made in the EU's transition to a circular economy (CE), disparities among Member States and data limitations hinder a comprehensive assessment. Italy, Germany, France, the Netherlands, and Spain are among the most advanced countries in achieving a circular economy's objectives. The study proposes a novel MCDM-based framework that effectively evaluates CE performance, identifying key strengths and weaknesses across countries. By focusing on competitiveness and innovation indicators and incorporating environmental factors, the framework offers valuable insights for policymakers and stakeholders.

**Keywords:** circular economy; development; multi-criteria evaluation; SAW method; EU countries

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**Citation:** Grybaitė, V.; Burinskienė, A. Assessment of Circular Economy Development in the EU Countries Based on SAW Method. *Sustainability* **2024**, *16*, 9582. https://doi.org/10.3390/su16219582

Academic Editors: Anna Mazzi and Adriana Del Borghi

Received: 21 August 2024
Revised: 20 October 2024
Accepted: 28 October 2024
Published: 4 November 2024



## 1. Introduction

Notwithstanding the implementation of measures aimed at curbing waste generation and mitigating environmental impacts, the quantity of waste is not decreasing [1]. The European Union (EU) is grappling with an annual production of approximately 2.2 billion tons of waste, as reported by the European Parliament, based on Eurostat 2020 data [2]. This waste generation poses significant challenges as a result of the depletion of non-renewable resources and the environmental harm caused by human activities. In a linear economy, resources are used for product manufacturing, but ultimately products are discarded at the end of their useful life. Consequently, this practice contributes to the accumulation of pollutants and waste. The prevailing economic model of "take, make, use, and throw" is heavily based on the production of inexpensive, easily accessible materials and substantial energy consumption, which makes this model unsustainable. The linear model is unsustainable in many ways—non-renewable resources are wasted, and materials and products are discarded and used inappropriately or insufficiently. The extraction and use of raw materials significantly impact the environment and natural assets. These processes lead to increased energy consumption and the release of large amounts of $CO_2$ into the environment.

The idea of a circular economy has become a central strategy for shifting to a more sustainable economic model [3]. The circular economy is a key mechanism to promote sustainable production, and a potential paradigm shift that could facilitate industrial transformation. Implementing circular economy principles is anticipated to engender a profound transformation in economic activity, shifting away from reliance on non-renewable and carbon-intensive resources and towards more sustainable production and consumption [4].

The transition to a circular economy in the European Union (EU) is a fundamental change in economic development that strikes a balance between economic growth and environmental sustainability. In contrast to the traditional linear economy, which is based on the discard model, the CE emphasises the continued use of resources in line with the principles of reuse and redistribution. This approach not only solves environmental problems but also provides significant economic opportunities, reduces dependence on financial resources, and reduces the amount of waste [5]. The EU has played a key role in supporting the CE and recognising its potential to contribute to sustainable development. The CE plays an important role in implementing the EU's strategy to achieve the Sustainable Development Goals, particularly SDG 12 (sustainable consumption and production) and SDG 9 (sustainable industry, innovation, and infrastructure). The promotion of resource efficiency and waste reduction by the CE will reduce pollution and promote a sustainable industry. Several policy initiatives have been launched to facilitate this transition, such as the Circular Economy Action Plan. This policy aims to integrate CE rules into different sectors and promote innovation and sustainable practices. However, the progress and implementation of the CE's actions varies greatly between Member States due to differences in economic structures, policy frameworks, and industrial capacity [6].

As the European Commission documents highlighted, the transition to a circular economy will allow Europe to renew its economy and gain new, sustainable competitive advantages. The circular economy is posited to facilitate the emergence of novel business opportunities and the development of more innovative and efficient production and consumption practices. The implementation of a circular economy would not only result in a reduction in $CO_2$ emissions but would also stimulate economic growth and the creation of new employment opportunities [7]. Furthermore, implementing a circular economy action plan will lead to implementing Sustainable Development Goals by 2030 [1].

The structure of the paper is as follows. Six sections form the paper. The first section is dedicated to the introduction. The second section focuses on the literature review. The third section presents a methodology, and the fourth section presents the empirical results of the research. Finally, the paper ends with discussions and conclusions as two separate sections.

## 2. Understanding the Circular Economy: Definitions and Metrics

Notwithstanding the increasing number of articles devoted to the circular economy, the concept lacks a universally accepted definition.

There is no generally accepted definition of the circular economy, and different researchers interpret it differently. For example, Hahladakis et al. (2019) described the circular economy as a system for processing, storing, and redistributing materials, components, and products [8]. Gladek (2017) defined it as a "new economic model" that aims to meet human needs and distribute resources evenly while respecting planetary limits [9].

Kirchherr et al. (2017), who analysed 114 definitions, found significant differences in interpretation, with many researchers focusing on recycling, while broader concepts of reduction and reuse are often underestimated [10]. We propose to use a more comprehensive definition, defined by the Commission as an economic system aimed at reducing, reusing, recycling, and recycling materials in production, distribution, and consumption processes [1]. Saidani et al. (2019) stressed that sustainable development is an important EU objective that should bring environmental, economic, and social benefits to present and future generations [11].

These definitions underline the Commission's new interpretation, which moves away from a narrow interpretation of recycling towards a more inclusive approach, taking into account resource efficiency and sustainability at different levels (micro, meso, and macro).

The studies on the CE could be grouped into such categories:

- Implementing the circular economy at the regional and national levels in the EU;
- Challenges and differences in the reception of the European Commission by the EU;
- Indicators and methodology for assessing the circular economy.

The authors will provide an overview of the studies in each category in detail.

### 2.1. Implementing the Circular Economy at Regional and National Levels in the EU

The transition to the European Community in the Union has accelerated, but the level of implementation varies between Member States. Marino and Pariso (2020) compared the performance of EU countries regarding resource efficiency, waste management, and business models [12]. The authors found that countries with comprehensive national strategies and significant investment in EU technologies perform better. This comparative study provides valuable information on best practices and provides policymakers with an action plan to improve the functioning of the Commission.

Škrinjarić (2020) empirically assessed Central European countries and used quantitative indicators to measure performance in each EU country [13]. The results show that countries with greater innovation capacity and more robust regulatory frameworks perform better than others, underlining the importance of governance and innovation in the progress of the Commission.

Sverko Grdic et al. (2020) examined the integration of CoE into national economic development strategies [5]. They note that the Commission promotes resource efficiency through recycling, reuse, and waste prevention but that Member States are at different stages of implementation and that sustainable EU practices must be better coordinated.

### 2.2. Challenges and Differences in the Reception of the European Commission by the EU

Despite significant progress, there are still differences between EU Member States regarding admission to the EU. Mazur-Wierzbicka (2021) pointed out significant differences in the adoption and implementation of EU policies in the EU, with countries such as Germany, the Netherlands, and Sweden leading the way in creating robust policy frameworks and public–private partnerships [6]. On the other hand, Eastern European countries are lagging, highlighting the need for targeted political support and mechanisms to promote sustainable development in the region.

Silvestri et al. (2020) adopted a multidimensional approach and analysed EU regional development from an economic, social, and environmental perspective [14]. The report concludes that regions with strong industries and better preventive environmental policies are functioning and stresses the importance of political support, industrial cooperation, and public awareness.

### 2.3. Indicators and Methodology for Assessing the Circular Economy

Appropriate indicators should be selected to measure Community progress at national and regional levels. Different surveys used different indicators, often based on Eurostat databases. For example, Mazur-Wierzbicka (2021) chose 13 indicators, most of which were related to waste management [6]. Škrinjarić (2020) also discussed a broader set of indicators reflecting different aspects of the EU, such as energy consumption, recycling, and innovation (e.g., recycling patents) [13].

Nazarko et al. (2022) used CE indicators on Eurostat data to measure countries' performance in terms of production and consumption, waste management, secondary resources, and competitiveness [15]. Their research highlights the diversity of approaches for evaluating the progress of the circular economy, with different authors classifying each aspect according to the purpose of their research. For example, Candan et al. (2022) focused on indicators in four thematic areas: production and consumption, waste management, secondary raw materials, and competitiveness [16].

However, a general limitation of the studies is that they do not contain comprehensive indicators covering all aspects of the Commission's activities. Due to the availability of data (or lack thereof), researchers often focus on specific issues such as waste management or recycling. This reflects the need to develop more comprehensive evaluation systems that consider different aspects of the EU and additional data sources to assess time series in all EU countries.

The EU literature on the circular economy can be divided into four main categories: conceptualisation and definitions, implementation in EU Member States, challenges and differences, and indicator-based assessment. This structured analysis shows the evolution of the Commission's approach from an initial focus on recycling to a broader framework of resource reduction, reuse, and efficient use. It also reflects significant regional disparities in the implementation of the European Commission's tasks, which are influenced by the policy framework, governance, and innovation capacity. Finally, the use of different Community indicators in surveys reflects the complexity of measuring progress, which requires a more comprehensive and standardised system for effectively measuring EU performance across the EU.

The above-mentioned studies are grouped into categories to explain the relevance of each work to the research topic and provide a more coherent picture of the current state of Community research in the European Union.

## 3. Multiple Criteria Evaluation Methods Used for the Assessment of Circular Economy Development in the EU Countries

The methods for evaluating many criteria provide a solid basis for assessing the circular economy's (CE) development in EU countries and provide a thorough, systematic, and objective analysis of various factors. These approaches can take into account the complex and multifaceted nature of circular economy initiatives, which require the consideration of different criteria.

### *3.1. A Comparative Analysis of MCDA Methods*

Several multi-criteria methods have been used to assess the circular economy's (CE) development in the European Union (EU). These methods provide different decision-making tools, considering different factors and their importance. Each method has specific features and applications, in particular, to evaluate the results of the circular economy using a holistic and multidimensional approach. The methods presented in this article are described in the following with regard to their role in the circular economy.

1. *TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution)*

TOPSIS develops alternatives based on proximity to the ideal solution and distance from the negative ideal solution. This is particularly useful for complex systems that require a combination of a range of indicators, such as circular economy assessments.

Dos Santos Gonçalves et al. (2022) [17], Ozdemir et al. (2024) [18] and Ūsas et al. (2021) [19] highlighted that TOPSIS is excellent for assessing the performance of the circular economy, as it can meet various criteria at the same time (resource productivity, waste generation, and circular economy investments).

Garcia-Bernabeu et al. (2020) [20] used the TOPSIS-ORIENTED PROCESS-ORIENTED method to create a composite CE index that helps classify EU countries in strict compliance with the best practices of the circular economy.

This methodology has also been used in combination with other methods, such as MULTIMOORA Nikanorova et al. (2020) [21] and Stankevičienė et al. (2020) [22], demonstrating its flexibility in the broader framework of comparing environmental and economic performance in regions such as the Baltic Sea.

TOPSIS is based on different indicators, as it is a strong point in the circular economy in different countries. Its ability to rank alternatives according to their proximity to the ideal level of the circular economy makes it helpful in comparing countries.

2. *MULTIMOORA (Multi-Objective Optimization by Ratio Analysis)*

MULTIMOORA is an effective decision-making system based on several criteria: a quota system, a methodology of reference points, and a fully multifunctional form. This method provides a more detailed assessment compared to simple assessment methods.

With the help of Nikanorova et al. (2020) [21] and Stankevičienė et al. (2020) [22], the MULTIMOORA project assessed the development of environmental pillars in the context of the European Commission, particularly in the Baltic Sea region. By comparing the performance of the CE across different dimensions, MULTIMOORA provides a new understanding of the strengths and weaknesses of the European Commission's regional strategies.

MULTIMOORA in-depth TOPSIS assessment methodology considers several (often conflicting) criteria, such as economic and environmental objectives.

3. *PROMETHEE II (Preference Ranking Organization Method for Enrichment Evaluation)*

PROMETHEE II is a great way to classify options by comparing pairs of criteria and determining the strength of the options between them. This is particularly effective in decision-making situations where a balance between criteria must be maintained.

Candan et al. (2022) [16] used PROMETHEE II in collaboration with other methodologies (TOPSIS and ELECTRE I) to assess the circular economy in EU countries. PROMETHEE II adds value by allowing for more accurate comparisons and estimates when the performance of countries is very similar.

The ability of PROMETHEE II to manage trade between CE indicators is essential to assess countries that perform similarly across dimensions for ranking EU countries based on their performance.

4. *ELECTRE I (Elimination and Choice Expressing Reality)*

ELECTRE I is an overestimated methodology that identifies and eliminates less desirable alternatives compared to the dominance of each criterion. It focuses on finding solutions that others cannot easily eliminate, making it suitable for multidimensional problems.

Candan et al. (2022) [16] presented ELECTRE I to evaluate CE performance and highlighted its power, providing more nuanced comparisons when the capabilities were very close to overall performance. This approach is particularly useful when policy recommendations are developed based on different and potentially conflicting criteria.

ELECTRE's ability to identify countries that are improving or weakening in certain aspects of the CE, regarding management or resource productivity, is beneficial.

5. *COPRAS (Complex Proportional Assessment)*

COPRAS is a methodology used to evaluate various criteria and maximise and minimise the characteristics of indicators. It is suitable for decision making when a balance between criteria is needed.

COPRAS was used by Özkay et al. (2024) [23] and Burhan et al. (2024) [24] to compare the development of centres of excellence in EU countries and Turkey. This methodology is particularly effective in balancing a number of indicators relevant to assessing the circular economy, such as resource productivity and waste generation.

COPRAS ensures a balanced classification of countries based on criteria with different units of measurement and values.

6. *AHP (Analytical Hierarchy Process)*

AHP helps break down complex decision-making problems into simpler hierarchies and uses pair comparisons to assess the relative importance of each criterion.

D'Adamo et al. (2024) [25] applied the AHP developed to define and assess circular economy indicators in the EU. The AHF helps to prioritise various indicators (e.g., investments in renewable energy and waste generation) by providing a structured framework for determining their relative importance.

The climate assessment mechanism is used in the paper to support the integration of criteria and ensure that CE indicators are properly highlighted in the final analysis of Member States' circular economy performance.

7. *SWARA (Step-wise Weight Assessment Ratio Analysis) and VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje)*

SWARA is a method used to determine the importance of criteria when comparing pairs, and VIKOR is used to find trade-offs in multi-criteria decision problems when conflicting goals arise.

Burhan et al. (2024) [24] used SWARA and VIKOR to compare circular economy advances across EU countries, while VIKOR focuses on providing solutions that balance competing goals such as growth and environmental sustainability.

SWARA helps to clarify the importance of different CE indicators, while VIKOR helps to identify trade-offs between conflicting criteria, thus ensuring a fair and realistic assessment of the effectiveness of the circular economy in the Member States.

The use of multi-criteria assessment methods such as TOPSIS, MULTIMOORA, PROMETHEE II, ELECTRE I, COPRAS, AHP, SWARA, and VIKOR provides a comprehensive framework for assessing the development of the circular economy in EU countries. Each of the methodologies has unique features that increase the reliability and depth of the analysis and allow for an accurate assessment that describes the complexity of the circular economy outcomes in different dimensions.

### 3.2. The Application of MCDA Methods in Circular Economy Research

A diverse array of multi-criteria methods, predicated on the assumption of complex systems, are extensively employed across scientific, business, and governmental domains. These methodologies have the potential to improve decision quality by fostering efficiency, transparency, and rationality in the decision-making process [26,27].

Table 1 provides an overview of the various studies that have used decision-making methods based on various criteria to assess the progress of the circular economy, particularly in the Member States of the EU and other regions. This study shows a growing interest in the use of MCDM methods to understand and improve the transition to a circular economy, highlighting the importance of a systematic and methodological approach to decision making in this area.

**Table 1.** Multiple criteria evaluation methods were used to assess the development of the circular economy in EU countries.

| Method | Description | Reference |
|---|---|---|
| TOPSIS | A systemic review for measuring circular economy with multi-criteria methods. | [17] |
| TOPSIS | Development and integrated assessment of the circular economy in the European Union: the outranking approach. | [19] |
| TOPSIS | A process-oriented MCDM approach to construct a circular economy composite index. | [20] |
| TOPSIS, MULTIMOORA | Development of environmental pillar in the context of circular economy assessment: Baltic Sea region case. | [21] |
| TOPSIS, MULTIMOORA | Analysis of green economy dimension in the context of circular economy: The case of Baltic sea region. | [22] |
| TOPSIS, PROMETHEE II, ELECTRE I | A comparative analysis of the circular economy performances for European Union countries. | [16] |
| COPRAS | An Analysis of the circular economy in Europe through Comparative Research Employing the CRITIC-Based MAUT and COPRAS Methods. | [23] |
| COPRAS | Determinants of progress in circular economy: A comparative multi-criteria analysis of EU member states and Türkiye. | [24] |
| AHP | Towards circular economy indicators: Evidence from the European Union. | [25] |
| SWARA, VIKOR | Determinants of progress in circular economy: A comparative multi-criteria analysis of EU Member States and Türkiye. | [24] |
| Fuzzy VIKOR | A multi-criteria decision-making framework for sustainable supplier selection in the circular economy and Industry 4.0 era. | [28] |

TOPSIS is a widely used MCDM method that classifies options based on their distance from the ideal solution and thus effectively evaluates CE performance. In the [19] study, TOPSIS was combined with other EU methods for assessing the evolution of ecosystem services, and the authors highlighted its usefulness in a complex environment where different sustainability indicators need to be considered. Garcia-Bernabeu et al. (2020) developed a composite circular economy index using the process-oriented TOPSIS methodology, emphasising the usefulness of the method in synthesising different indicators into one useful indicator [20].

Stankevičienė et al. (2020) used TOPSIS and MULTIMOORE methodologies to analyse aspects of the circular economy and confirm the relevance of these methods in a broader context [22]. In addition to TOPSIS, the authors also used the VIKOR method. For example, the study by Ref. [24] included the VIKOR method for analysing CE progress and Ref. [28] introduced a Fuzzy VIKOR framework using uncertain environments typical of the CE context.

These studies highlight the crucial role of MCDM approaches in promoting the circular economy by providing reliable and systematic tools to assess and compare different aspects of the CE. TOPSIS, COPRAS, AHP, and other approaches provide valuable insights into the development of different regions and countries towards a circular economy, allowing policymakers and stakeholders to make more informed decisions.

### *3.3. SAW Method for Circular Economy Assessment*

The SAW method is popular and widely used by researchers in different research areas [29]. The SAW approach was employed by Ref. [30] in order to address the issue of supplier selection, to assess the progress of circular economy practices [31]. Ref. [32] used the SAW method to develop an environmental quality index and analyse the environmental quality status in selected regions. Wira Trise Putra and Augustian Punggara (2018) highlighted the precision of assessments facilitated by the Simple Additive Weighting (SAW) method [33]. Furthermore, Refs. [34–36] contended that the SAW method is the most suitable multi-criteria decision-making technique, attributed to its straightforward calculation algorithm. The popularity of the SAW method is underpinned by its simplicity and capability [37] to evaluate complex phenomena represented through diverse indicators. Furthermore, according to [38], the SAW method offers several advantages: it allows for compensation among criteria, is intuitive for decision-makers, involves straightforward calculations, does not require complex programming, and aids in visually distinguishing between compared objects through the use of normalised values.

The use of Simple Additive Weighting is justified in assessing the development of the circular economy in EU countries, especially with regard to multi-criteria decision making. Here are the main reasons to use SAW in this study:

The circular economy is multidimensional and covers economic, environmental, and social aspects. Indicators such as resource efficiency, waste management, and recycling rates are often used to assess the progress of the European Commission (Mazur-Wierzbicka, 2021 [6]; Garcia-Bernabeu et al., 2020 [20]). The SAW method is particularly suitable for this, as it allows several criteria of the combined result to be combined, simplifying the overall evaluation of the various CE performance indicators (Zavadskas et al., 2011) [27].

One of the most significant advantages of SAW is its simplicity. The method involves normalising the data, assigning weights to criteria, and summing the weighted values for ease of use and interpretation (Taherdoost, 2023) [38]. Due to the complexity of the data, where different countries may have different units of measurement or levels of data availability, the SAW standardisation phase ensures that all data can be compared at a single scale, making it suitable for packet comparisons (Ciardiello and Genovese, 2023 [37]; Stankevičienė et al., 2020 [22]).

The SAW method is consistent with many European Commission-related indicators used in EU surveys (Saidani et al., 2019 [11]; Marino et al., 2020 [12]). EU reports (European Commission, 2020) [1] and studies (Škrinjarić, 2020) [13] often use quantitative or qualitative indicators that can be easily integrated into a single evaluation system using SAW. This flexibility justifies the European Commission's assessment of the different datasets needed for the evaluation (Ginevičius et al., 2008) [39].

SAW facilitates using different weighting systems, which allows the model to demonstrate the relative importance of different CE dimensions identified by policymakers or researchers (Singh et al., 2021) [40]. For example, some Commission evaluations could place more emphasis on recycling rates, while others could prioritise resource productivity. The adaptability of the method supports the use of different weighting methods, such as expert or data-driven methods, as assessed by the European Commission (Ginevičius et al., 2006) [41] (Korhonen et al., 2018) [4].

Several studies examining the effectiveness of the CE have already used multi-criteria methods such as SAW, making them well-established approaches in the field (Garcia-Bernabeu et al., 2020 [20]; dos Santos Gonçalves and Campos, 2022 [17]). In addition, previous studies have shown that SAW is highly effective in evaluating CE performance in different countries (Candan and Toklu, 2022) [16] because it offers a simple yet comprehensive analytical framework.

The SAW method is stable in terms of the use of both quantitative and qualitative data, which is essential for assessing EU countries where the level of EU implementation and the available data may vary significantly (Nazarko et al., 2020) [15]. This flexibility allows SAW to take into account differences in EU development, allowing for a fair and balanced comparison (Korhonen et al., 2018) [4].

The SAW method provides a simple, transparent, and flexible approach to assessing the development of the circular economy in the Union. An excellent tool for this is the ability to manage multi-criteria assessments and be consistent with existing Community indicators, which supports their successful use in previous sustainability studies and circular economy assessments.

Multi-criteria methods are adept at quantitatively assessing complex phenomena characterised by multiple criteria. These methods have been effectively applied to the comprehensive evaluation of multifaceted quantities. By integrating all the indicators of a given system into a single indicator, multi-criteria approaches make it possible to assess a country's development in a circular economy [17,20]. Calculating such indicators over a period allows for the assessment of a particular country's development trajectory. Additionally, comparing computed integral indicators across different countries offers valuable insight into their unique developmental characteristics.

Overall, the implementation of multi-criteria evaluation methods provides a strong and transparent framework for assessing circular economy developments in EU countries. Taking into account different benchmarks and perspectives, policymakers and stakeholders can identify best practices, compare results, and develop effective strategies to promote the circular economy.

The revision of multi-criteria evaluation methods for the circular economy assessment shows that other authors did not employ the SAW method for the specified topic.

## 4. The Framework Development for the Assessment of Circular Economy in the EU Countries Using the SAW Method

In the context of sustainable development, the transition to a circular economy is one of the key priorities of the European Union (EU). These changes require an evaluation system that can comprehensively assess the progress of Member States. Simple Additive Weighting (SAW), a multi-criteria decision-making tool (MCDM), offers a structured approach to evaluating such complex systems. This chapter presents the evolution of the circular economy assessment system in EU countries for which the SAW method is an important analytical tool.

The SAW method provides a simple calculation process and flexibility in managing a variety of metrics. It is also applied in many areas, including environmental management and supply chain optimisation. Its popularity in MCDM analysis is due to its ability to integrate and normalise deconstructed data types and assign weights to different criteria based on their relative importance. Thus, the methodology sets out the priorities for the solutions (e.g., EU countries) and indicates which Member States are the best performers in selected circular economy indicators.

The process of implementing the SAW method consists of several essential steps: identifying and selecting the appropriate evaluation criteria, identifying opportunities (in this case, EU Member States), assessing these opportunities according to the established criteria, and finally ranking them based on the total number of points. This approach allows policymakers to focus on a balanced view of the performance of the circular economy, allowing for a balance between criteria and ensuring that no indicator disproportionately exhausts the overall assessment.

Six main criteria were selected for this system: recycled patents, employment in the Community industry, and resource productivity based on their usefulness and use in research. The dataset, based on the Eurostat database and used for the analysis in 2010–2020, includes maximisation and minimisation criteria. The framework provides a reliable mechanism for monitoring the EU's progress across the Union and provides policymakers with valuable insights into countries leading the EU's actions that are failing, allowing for targeted improvements in sustainable development practices.

This paper uses the SAW method, which is based on a systematic data-driven assessment framework for the circular economy that facilitates continuous evaluation and policymaking in the European Union.

When establishing a comprehensive framework to measure progress in the circular economy in EU countries, choosing the right indicators and impacts is essential. The six criteria selected for this framework—recycling of secondary raw materials and patents, EU industrial workers, private investment in EU industry, resource productivity, circularity, material consumption, and per capita waste generation—are different elements of the circular economy. Together, they provide a balanced and multifaceted picture of EU countries' progress towards achieving the EU's goals.

The main steps for the application of the multi-criteria evaluation method are these:

- Establishing a system for evaluation criteria;
- Identifying alternatives (such as the selected EU countries);
- Evaluating alternatives in terms of criteria used for assessment;
- Applying the multi-criteria evaluation method, in particular SAW;
- Accepting one alternative with the highest score (preferred);
- If the final solution is not accepted, new information has to be gathered, and the next iteration of multi-criteria evaluation has to be made (Figure 1).

Further, the authors will develop a framework for assessing the circular economy in the EU countries. For the framework development, the authors selected the SAW method.

The SAW approach was employed by [30] in order to address the issue of supplier selection, to assess the progress of circular economy practices [31]; Ref. [32] used the SAW method to develop an environmental quality index and analyse the environmental quality status in selected regions. Wira Trise Putra and Augustian Punggara (2018) highlighted the precision of assessments facilitated by the Simple Additive Weighting (SAW) method [33]. Furthermore, Refs. [34–36] contended that the SAW method is the most suitable multi-criteria decision-making technique, attributed to its straightforward calculation algorithm. The popularity of the SAW method is underpinned by its simplicity and capability, as stated by Ref. [37], to evaluate complex phenomena represented through diverse indicators. Furthermore, according to Ref. [38], the application of SAW method offers several advantages: it allows for compensation among criteria, is intuitive for decision-makers, involves straightforward calculations and does not require complex programming. The application of SAW method aids in visually distinguishing between compared objects through the use of normalised values.

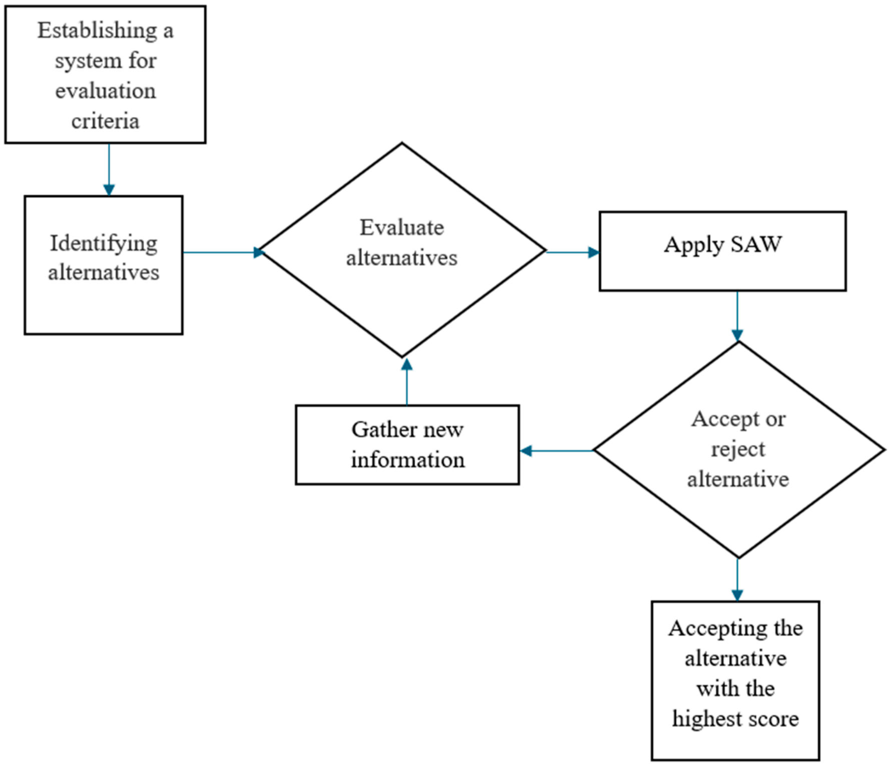


**Figure 1.** The main steps for the application of the SAW method.

The SAW method involves normalising the criteria values and incorporating their importance weights into a single criterion using the following formula [36]:

$$S_j = \sum_{j=1}^{n} w_i r_{ij},\ i = \overline{1,m} \tag{1}$$

where $S_j$ is the cumulative sum; $w_i$ is the weight of criterion; $n$ is the number of all chosen alternatives; $r_{ij}$ is normalised values of criterion; $i$ is the index for criterion; $m$ is the number of all chosen criteria; and $j$ is the index for alternatives.

Before implementing the method, it is necessary to ascertain the nature of the indicators (whether they are to be maximised or minimised). It is important to note that the SAW method exclusively uses maximising criteria and positive values; therefore, any minimising criteria must be converted into maximising criteria [36,39]. The best values of the maximised criteria are the largest, i.e., the situation of the considered phenomenon improves as the value of the indicator increases. On the contrary, the best values of the criteria to be minimised are the smallest, and as the value of the criteria increases, the situation worsens.

For the calculation of SAW, the normalisation of the values of alternatives is based on the following formula:

$$\tilde{r}_{ij} = \frac{r_{ij}}{\sum_{j=1}^{n} r_{ij}} \text{ or } \frac{\bar{r}_{ij}}{\sum_{j=1}^{n} \bar{r}_{ij}},\ i = \overline{1,m} \tag{2}$$

According to [36,39], the minimising variables can be transformed into maximising variables using the formula:

$$\bar{r}_{ij} = \frac{\min\limits_{j} r_{ij}}{r_{ij}},\ j = \overline{1,n},\ i = \overline{1,m} \tag{3}$$

where min $r_{ij}$ is the smallest value of criterion $i$ for all the number of $n$ alternatives considered; $\bar{r}_{ij}$ shows the converted value for the criterion $i$ and alternative $j$. The result depends on the magnitude of the shift of the set of values of criteria $i$ among all alternatives. Such an equation is used when all criteria values are positive.

The transformation formula utilised for the maximisation of criteria is presented below [36]:

$$\tilde{r}_{ij} = \frac{r_{ij}}{\max_{j} r_{ij}}. \tag{4}$$

where max $r_{ij}$ is the largest value of criterion $i$ for all the number of $n$ alternatives.

After establishing the indicator framework, the subsequent step involves determining the significance of the indicator values. Most methods for ascertaining the significance of indicators in a multi-criteria assessment rely on expert evaluation. According to Ref. [27], the expert evaluation method is among the most accurate, straightforward, and widely used methods. Notably, the number of experts contributing to research significantly influences the results' reliability. Furthermore, Ginevičius (2006) claimed that experts can accurately estimate only a limited number of indicators; typically, no more than twelve [41,42].

Consequently, according to Ref. [43], when a greater number of indicators are needed for research, it is advisable to integrate these indicators into subsystems and establish a hierarchical structure. As stated by Ref. [44], a fundamental challenge in multi-criteria analysis models lies in determining appropriate criterion weights. Choosing a suitable method for assigning weights within the multi-criteria decision-making (MCDM) framework is essential. Zavadskas et al. (2016) highlighted the difficulty in selecting a single optimal MCDM method due to the potential for divergent weight estimations between different techniques [45]. The literature presents various approaches to weighting criteria, but there is no consensus on the optimal method for this process. Singh and Pant (2021) distinguished three approaches for determining the criteria weights: subjective, objective, and combinative [40]. Following the findings of Ref. [40], the subjective approach is the most commonly employed. One of the subjective methods, the direct weighting method, is a widely used technique for determining indicator weights. In the direct weighting procedure, the expert assigns a value to each criterion based on their relative importance [40]. Ginevičius et al. (2021) asserted that the direct weighting method can be effectively employed when the total number of indicators is small [46]. However, when there are more indicators, this becomes a more complex problem.

To monitor the development of the circular economy in EU Member State countries, the authors of this paper apply the SAW method, which allows the integration of criteria describing the circular economy. The application of SAW is helping to assess the circular economy development in EU countries. Multi-criteria evaluation methods require that each criterion varies unidirectionally, either maximised or minimised. Maximised criteria have the highest values, while minimised criteria have the lowest. The data were collected from the Eurostat Database and covered ten years from 2010 to 2020 for research purposes.

For the development of the framework, the authors selected six criteria:

1. *Patents related to recycling and secondary raw materials*

This indicator indicates innovation in recycling and the development of technologies for reusing secondary raw materials. The patents serve as a benchmark for circular R&D and demonstrate the country's ability to develop new solutions that improve processes in the EU. The high percentage of patents reflects a focus on technological developments that can improve the efficiency of recycling, recycling, and waste reduction, which is essential for achieving circular economy goals.

2. *Persons employed in the circular economy sectors*

Employment in EU sectors such as waste, recycling, and resource recovery is an important indicator of the economic and social integration of the circular economy principles. The number of people employed in these sectors shows how Community practices are integrated into the economy, and the potential for job creation and labour force development through the development of Community practices. It also reflects the economic transformation needed to transition from a linear to a circular economy, where more jobs are focused on resource recovery and sustainable management.

3. *Private investment related to circular economy sectors*

Private investment is a key driver of innovation, infrastructure development, and the expansion of EU practices. This indicator reflects the financial contribution of the private sector to circular economy activities, such as recycling technologies, sustainable production, and waste management. The increase in private investment reflects the growing economic benefits of the circular economy, as companies are aware of the economic potential to reduce waste, reuse materials, and improve resource efficiency. It also reflects the Commission's commitment to broader economic planning and industrial strategies.

4. *Resource productivity*

Resource productivity measures how efficiently a country uses its natural resources to create economic value. This is an important indicator that economic growth is decoupled from resource use, which is a fundamental principle of the circular economy. Higher resource productivity means that a country can produce more with less effort, reduce its environmental impact, and improve sustainability. This indicator is particularly relevant for assessing progress in reducing resource dependency and improving the long-term viability of economic activities within limited financial resources.

5. *Circular material use rate*

The level of circular material consumption reflects the share of recycled and recycled materials in the economy as a share of total raw materials. A high CMU indicates efficient bending of materials, where residues are returned to production cycles, reducing the need for intact materials and reducing environmental impact. It also shows that national policies and procedures to promote recycling and waste reduction are effective.

6. *Waste generation per capita*

Waste generation per capita is an important indicator of a country's overall resource efficiency and progress in reducing its environmental impact. A lower per capita level of waste shows that the country is better able to reduce waste at its source, promote sustainable consumption, and improve resource efficiency. This indicator is important for understanding the effectiveness of waste prevention strategies and the extent to which the country's population adopts sustainable practices.

Each of these six indicators provides unique insights into how to measure progress in the circular economy across EU Member States. They combine innovation (patents), economic inclusion (employment and investment), resource efficiency (productivity), circular materials, and waste management (waste per capita) to create a comprehensive framework for measuring EU progress. By including these indicators, the framework will enable an in-depth analysis of the environmental and economic aspects of the circular economy and provide valuable information to policymakers and stakeholders to improve sustainable development across the Union.

Other researchers have also widely adopted the criteria selected in this study. The circular material use rate is a well-established indicator cited in previous works, such as that of Refs. [6,13,15,16,19,47,48]. Similarly, patents related to recycling and secondary raw materials are frequently utilised, as evidenced by the studies of Refs. [6,12,13,15,16]. Employment in circular economy sectors is another common metric referenced in the research of Refs. [13,15,16]. Waste generation indicators are employed in the studies by Refs. [14,15]. Additionally, investment related to circular economy sectors is discussed by Refs. [6,16], while resource productivity is highlighted in the study by Ref. [49]. This convergence with other researchers underscores the significance and robustness of these indicators in assessing the circular economy.

Table 2 below delineates which criteria should be maximised and which should be minimised.

**Table 2.** Direction of criteria.

| No | Criteria | Direction |
|---|---|---|
| 1 | Patents related to recycling and secondary raw materials (number) | Max |
| 2 | Persons employed in the circular economy sectors (Percentage of total employment—numerator in full-time equivalent (FTE) | Max |
| 3 | Private investment related to circular economy sectors (Percentage of GDP) | Max |
| 4 | Resource productivity (Purchasing power standard (PPS) per kilogram) | Max |
| 5 | Circular material use rate (percentage) | Max |
| 6 | Waste generation per capita (kilograms per capita) | Min |

After the criteria are defined, we could construct the matrix of alternatives. Under the Table 3, the matrix is presented.

**Table 3.** Matrix.

| Criteria | | | Alternatives | | | | | Sum of Values |
|---|---|---|---|---|---|---|---|---|
| Name | Direction | Weight | A1 | A2 | A3 | ... | An | |
| | | | Values of Alternatives for Each Criteria | | | | | |
| $C_1$ | Max | $w_1$ | $r_{11}$ | $r_{12}$ | $r_{13}$ | ... | $r_{1n}$ | $S_1 = \sum_{j=1}^{n} w_1 r_{1j}$ |
| $C_2$ | Max | $w_2$ | $r_{21}$ | $r_{22}$ | $r_{23}$ | ... | $r_{2n}$ | $S_2 = \sum_{j=1}^{n} w_2 r_{2j}$ |
| $C_3$ | Max | $w_3$ | $r_{31}$ | $r_{32}$ | $r_{33}$ | ... | $r_{3n}$ | $S_3 = \sum_{j=1}^{n} w_3 r_{3j}$ |
| $C_4$ | Max | $w_4$ | $r_{41}$ | $r_{42}$ | $r_{43}$ | ... | $r_{4n}$ | $S_4 = \sum_{j=1}^{n} w_4 r_{4j}$ |
| $C_5$ | Max | $w_5$ | $r_{51}$ | $r_{52}$ | $r_{53}$ | ... | $r_{5n}$ | $S_5 = \sum_{j=1}^{n} w_5 r_{5j}$ |
| $C_6$ | Min | $w_6$ | $r_{61}$ | $r_{62}$ | $r_{63}$ | ... | $r_{6n}$ | $S_6 = \sum_{j=1}^{n} w_6 r_{6j}$ |

The role of weight (wi) is explained below:

For Simple Additive Weighting (SAW), the weight of each criterion (expressed in wi) plays an important role in improving the clarity and stability of the entire method. Wi weight reflects the relative importance of each criterion in the decision-making process and ensures that not all criteria are treated in the same way and that relevant factors have a greater impact on the end result.

The importance of determining the right and correct weights can be understood in several main ways:

1. *Consider the relative importance of the criteria*

The SAW method takes into account various alternatives, which often have different meanings. Some criteria may have a greater impact on the decision-making process than others. The importance of wi allows decision makers to emphasise the importance of certain criteria over others. For example, when assessing the effectiveness of the circular economy, resource productivity, depending on the context, may be considered more important than private investment. Wi weight ensures that these significant differences are accurately taken into account when calculating the other side's final scores.

2. *Improve decision-making accuracy*

When determining the appropriate masses, the SAW method becomes more accurate in the order of the options. If all criteria are treated equally, the results do not correspond to the real priorities of the decision-making process. It ensures that the method corresponds to the nuances of the problem, which allows you to make more informed and accurate decisions. For example, if a criterion disproportionately impacts the outcome, it can lead to misleading conclusions if the best option is not sufficiently considered.

3. *Improve the sensitivity and responsiveness of the model*

Wi weight makes SAW more sensitive to real-world considerations, allowing decision makers to experiment with different scenarios and understand how changes in the relative importance of criteria affect the final decision. This sensitivity analysis helps ensure the stability of the method by showing how different scales can affect the sequence and providing a deeper understanding of the context of the decision-making process.

4. *Provide resistance to subjectivism*

Although determining weight is often a subjective assessment, making the right decision helps reduce the tactile sensation of the process. Expert opinions, statistical analysis, or other objective methods of mass determination can confirm the SAW method. If the scales are precisely defined, the SAW method can produce consistent, reliable, and widely accepted results, increasing the credibility and legitimacy of the decision-making process.

5. *Support the standardisation process*

The balance also plays a role in normalising the criteria values of the SAW method. Because criteria can have different units and scales, standardisation ensures that all criteria are comparable. The complete weighting method used in SAW helps to aggregate these normalised values in a way that maintains the relative importance of each criterion and ensures that the more important criteria have a greater impact on the end result than the small ones.

6. *Criteria for maximising and reducing the balance*

The problems of multi-criteria decision-making aim to maximise some criteria (resource productivity) while reducing others (reducing per capita waste). Weights help balance these different criterion types, ensuring that each criterion's impact is proportional to its importance and avoiding any re-evaluation of the criteria. This increases the overall credibility of the SAW method by ensuring a balanced assessment of the various criteria.

In the SAW method, it is important to ensure that the final sequence of options accurately reflects the priorities of the decision makers and the specific context of the decision-making problem. After careful consideration, the method becomes clearer, more accurate, and more powerful, allowing for a more reliable evaluation of options based on several criteria. This will contribute to the overall effectiveness of the SAW method in different decision-making situations, including in assessing the development of the circular economy in EU countries.

Following Equations (3) and (2), the values presented according to Table 3 are normalised. The results of normalisation could be presented as provided in Table 4.

The smallest value is used during conversion for minimising the 6th criterion. Values are normalised by using vertical normalisation approach.

**Table 4.** Normalised matrix.

| Alternatives (*j*) | Criteria (*i*) | | | | | | The Sum of Normalized Maximising Criteria | The Relative Importance of Comparable Alternatives |
|---|---|---|---|---|---|---|---|---|
| Name | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | | |
| | Normalised Values | | | | | | | |
| $A_1$ | $\tilde{r}_{11}$ | $\tilde{r}_{21}$ | $\tilde{r}_{31}$ | $\tilde{r}_{41}$ | $\tilde{r}_{51}$ | $\tilde{r}_{61}$ | $S_{+1}$ | $Q_1$ |
| $A_2$ | $\tilde{r}_{12}$ | $\tilde{r}_{22}$ | $\tilde{r}_{32}$ | $\tilde{r}_{42}$ | $\tilde{r}_{52}$ | $\tilde{r}_{62}$ | $S_{+2}$ | $Q_2$ |
| $A_3$ | $\tilde{r}_{13}$ | $\tilde{r}_{23}$ | $\tilde{r}_{33}$ | $\tilde{r}_{43}$ | $\tilde{r}_{53}$ | $\tilde{r}_{63}$ | $S_{+3}$ | $Q_3$ |
| ... | ... | ... | ... | ... | ... | ... | ... | ... |
| $A_n$ | $\tilde{r}_{1n}$ | $\tilde{r}_{2n}$ | $\tilde{r}_{3n}$ | $\tilde{r}_{4n}$ | $\tilde{r}_{5n}$ | $\tilde{r}_{6n}$ | $S_{+n}$ | $Q_n$ |

Here in $\tilde{r}_{ij}$, the value could be between 0 and 1.

Where sum $S_{+j}$ of normalised values $\tilde{r}_{ij}$ is calculated following Equation (5):

$$S_{+j} = \sum_{j=1}^{n} \tilde{r}_{ij},\ i = \overline{1,m} \quad (5)$$

Finally, the priority sequence is defined as
$Q_1 > Q_2 > Q_3$. It means the greater the number is for $Q_j$, the higher priority is.

## 5. Results

The authors applied the developed framework for the period 2010–2020 for 27 EU countries. Criteria and explanations of each criterion are presented in Section 4. Applying the SAW method, each country's criteria weights and normalised scores were calculated; the values above the average are marked in green, and those below the average are marked in red (Table 5). This process highlights how multi-criteria methods such as SAW simplify the evaluation of CE performance across various dimensions, integrating data into a single, meaningful output.

According to Table 5, the best results in the CE are evident for Italy in 2020 and the lowest for Romania (2013). A review of the data over the past decade reveals that Ireland has experienced the most significant advancement, with a 72% change between 2010 and 2020. However, it is important to acknowledge that Ireland's performance has remained below the average for the European Union (EU) as a whole. In 2020, Ireland was ranked 18th among the 27 EU countries. Another country that has demonstrated considerable advancement is Spain, with a percentage change of 52% between 2010 and 2020. Indeed, Spain's performance is above the EU average, and in 2020, Spain was ranked sixth among the 27 EU countries.

Notably, the average values for Italy, the Netherlands, France, Belgium, and Germany exhibit minimal variation. For instance, Italy's average value over the period 2010–2020 is 0.5749, representing the highest among the five countries, while Germany's is 0.5141, the lowest among the five countries (Figure 2).

Examining solely the results of the 2016 calculations reveals that the outcomes are comparable to those obtained by Ref. [20]. Ref. [20] used the TOPSIS method to develop a circular economy indicator to evaluate the circular economy performance of EU Member States for 2016. The findings indicate that Germany, France, the Netherlands, Italy, and Belgium are the leading countries in the field. However, it should be noted that the authors of this article only focused on current EU member states countries, excluding the UK. The study's findings are consistent with those of Ref. [6], who determined that Germany, Belgium, France, Spain, Italy, and the Netherlands are the most advanced in achieving the circular economy goals. Furthermore, Ref. [13] identified Italy, Germany, France, and the Netherlands as the field's most advanced countries.

This research results offer insights into European countries' present state and circular economy (CE) performance trends.

**Table 5.** The application of the developed framework.

| | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Austria | 0.40671 | 0.409269 | 0.422407 | 0.432403 | 0.427586 | 0.447653 | 0.413803 | 0.439598 | 0.45165 | 0.429968 | 0.43268 |
| Belgium | 0.426067 | 0.487269 | 0.514304 | 0.491146 | 0.483622 | 0.52408 | 0.52868 | 0.546054 | 0.560594 | 0.551428 | 0.569432 |
| Bulgaria | 0.191432 | 0.182271 | 0.196179 | 0.182353 | 0.202718 | 0.219365 | 0.218383 | 0.232299 | 0.226756 | 0.220439 | 0.238025 |
| Cyprus | 0.256035 | 0.266777 | 0.287082 | 0.308463 | 0.260397 | 0.298278 | 0.279251 | 0.299945 | 0.297526 | 0.290453 | 0.315461 |
| Croatia | 0.419167 | 0.456383 | 0.476242 | 0.488673 | 0.511946 | 0.514452 | 0.461861 | 0.484138 | 0.495994 | 0.494437 | 0.532405 |
| Czechia | 0.307241 | 0.325562 | 0.365725 | 0.362388 | 0.349756 | 0.36856 | 0.354074 | 0.38164 | 0.367588 | 0.374539 | 0.418662 |
| Denmark | 0.33043 | 0.322198 | 0.333376 | 0.333943 | 0.364375 | 0.368816 | 0.334882 | 0.362354 | 0.352405 | 0.335052 | 0.368585 |
| Estonia | 0.274079 | 0.338952 | 0.391388 | 0.332643 | 0.302336 | 0.306467 | 0.291955 | 0.312524 | 0.34468 | 0.324916 | 0.364432 |
| Finland | 0.248571 | 0.266411 | 0.287043 | 0.249886 | 0.246498 | 0.254162 | 0.234775 | 0.263912 | 0.265513 | 0.217489 | 0.249619 |
| France | 0.511622 | 0.509123 | 0.557409 | 0.528034 | 0.574173 | 0.555248 | 0.530644 | 0.569184 | 0.548182 | 0.540368 | 0.591956 |
| Germany | 0.482727 | 0.496181 | 0.510253 | 0.489652 | 0.507814 | 0.528492 | 0.514115 | 0.573003 | 0.602142 | 0.567881 | 0.601099 |
| Greece | 0.224216 | 0.219287 | 0.194033 | 0.190258 | 0.207639 | 0.225317 | 0.225748 | 0.238443 | 0.226285 | 0.255408 | 0.283319 |
| Hungary | 0.43782 | 0.433371 | 0.449266 | 0.403385 | 0.395535 | 0.440628 | 0.442518 | 0.437755 | 0.43078 | 0.409458 | 0.446606 |
| Ireland | 0.21629 | 0.249424 | 0.261432 | 0.25608 | 0.253526 | 0.291218 | 0.26393 | 0.287915 | 0.281723 | 0.318164 | 0.371032 |
| Italy | 0.464371 | 0.461444 | 0.520149 | 0.544371 | 0.525749 | 0.567076 | 0.574856 | 0.610898 | 0.596315 | 0.646802 | 0.658766 |
| Latvia | 0.432737 | 0.411656 | 0.434176 | 0.429308 | 0.447949 | 0.491766 | 0.488077 | 0.501138 | 0.495038 | 0.494509 | 0.501101 |
| Lithuania | 0.28647 | 0.319137 | 0.358462 | 0.360638 | 0.371904 | 0.392462 | 0.402017 | 0.427403 | 0.377788 | 0.375653 | 0.430028 |
| Luxembourg | 0.4192 | 0.409035 | 0.397076 | 0.380571 | 0.363003 | 0.385969 | 0.320313 | 0.377225 | 0.354295 | 0.386037 | 0.376911 |
| Malta | 0.441532 | 0.414944 | 0.415884 | 0.445061 | 0.417777 | 0.409622 | 0.389162 | 0.430338 | 0.427438 | 0.44192 | 0.476149 |
| Netherlands | 0.494294 | 0.530094 | 0.522817 | 0.526751 | 0.527399 | 0.575966 | 0.556995 | 0.561235 | 0.592399 | 0.581065 | 0.590893 |
| Poland | 0.388119 | 0.391198 | 0.455998 | 0.437042 | 0.425325 | 0.526978 | 0.450162 | 0.448817 | 0.447359 | 0.409132 | 0.447721 |
| Portugal | 0.355535 | 0.362748 | 0.360124 | 0.370173 | 0.363269 | 0.411644 | 0.380571 | 0.396488 | 0.412336 | 0.406021 | 0.455372 |
| Romania | 0.19404 | 0.203178 | 0.191425 | 0.17467 | 0.230064 | 0.198973 | 0.182048 | 0.213989 | 0.187087 | 0.181499 | 0.206539 |
| Slovakia | 0.344335 | 0.35004 | 0.367803 | 0.378674 | 0.365241 | 0.397165 | 0.367531 | 0.358986 | 0.355463 | 0.378028 | 0.420332 |
| Slovenia | 0.267007 | 0.294765 | 0.337903 | 0.328797 | 0.31785 | 0.337577 | 0.319289 | 0.33844 | 0.328888 | 0.363195 | 0.327154 |
| Spain | 0.356812 | 0.382089 | 0.430751 | 0.468074 | 0.446012 | 0.456474 | 0.460108 | 0.456537 | 0.447111 | 0.461995 | 0.543668 |
| Sweden | 0.267381 | 0.276412 | 0.282273 | 0.2781 | 0.266141 | 0.28481 | 0.282492 | 0.309581 | 0.294694 | 0.26393 | 0.292154 |

Green colour means that correlation coefficient shows midle or strong correlation, purple colour—corelation is weak.

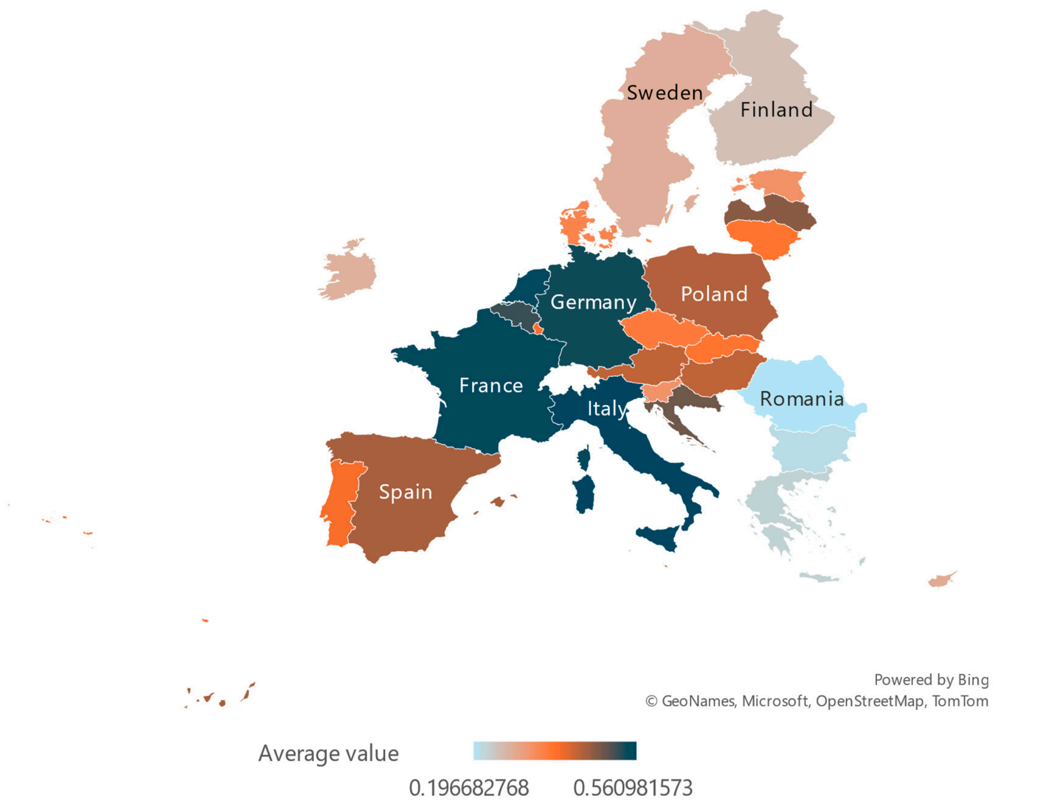


**Figure 2.** The application of the framework for the EU countries in the period 2010–2020 (source: elaborated by the authors).

## 6. Discussion

In recent years, there has been a greater focus on the concept of the circular economy, in particular with regard to sustainability and resource management. However, the widespread lack of a CE definition is a constant problem as scientists interpret the term differently. For example, Hahladakis et al. (2019) described it as a system focused on the processing, storage, and distribution of content, and Gladek (2017) described it as a new economic model focused on the equitable distribution of resources on the planet [8,9]. After an analysis of over 100 definitions, Kirchherr et al. (2017) found that while we tend to focus on recycling, broader aspects such as reduction and reuse are often not taken into account [10]. The European Commission (2020) is proposing a more comprehensive CE definition, going beyond recycling and focusing on the reducing, reusing, and sustainability of production, distribution, and consumption processes [1]. Saidani et al. (2019) stressed that the Commission's interpretation at EU level aims to ensure environmental, economic, and social benefits for current and future generations [11].

*Implementing the circular economy at the regional and national levels in the EU*. EU implementation varies considerably across Member States. Marino and Pariso (2020) showed that countries with current strategies, such as Germany and The Netherlands, outperform other countries in terms of resource efficiency and waste management [12]. Comparative analysis of EU countries shows that investment in CE-supportive technologies, regulatory frameworks, and public–private partnerships are key to successful implementation. Škrinjarić (2020) extended this analysis to the use of quantitative indicators to measure the performance of the CE, strengthened innovation capacity, and the central role of management in achieving national performance [13]. Sverko Grdic (2020) highlighted that while the Union promotes resource efficiency, Member States are at different stages of integration with the CE [5]. The lack of coordination and divergence in sustainable practices across the European Union point to the need for a stronger and more coherent framework.

*Challenges and differences in the reception of the European Commission by the EU*. Despite efforts to establish a coherent policy framework, the level of application of the CE is uneven across the EU. Mazur-Wierzbicka (2021) pointed out significant political contradictions, as countries such as Sweden and Germany are at the forefront, while Eastern European countries struggle to keep up [6]. The need for targeted support is clear, especially in regions where CE absorption is declining. Silvestri et al. (2020) pointed out that regions with good implementation of industrial and preventive environmental policies tend to perform better, stressing the importance of industrial cooperation and policy support [14].

*Indicators and methodology for assessing the circular economy*. One of the main problems in supporting research in the CE is the lack of standardised indicators to effectively measure progress. Various studies, such as the Mazur-Wierzbická study (2021) and the Nazarko et al. study (2022), used different indicators, mainly from Eurostat databases [6,15]. These indicators focus largely on waste management, energy consumption, and recycling, which are important but do not reflect the full scope of CE action. Nazarko et al. (2022) stressed the need for comprehensive assessment systems that go beyond waste management and cover broader parameters such as innovation, energy efficiency, and the use of secondary resources [15]. The inconsistency in the selection of indicators for different surveys shows that there are limitations in the proper assessment of CE progress. Candan et al. (2022) indicated that researchers tend to focus on specific topics related to their research goals, making it difficult to compare [16].

This debate highlights the complexity of defining and implementing a circular economy across the EU. While significant progress has been made, in particular in Western Europe, the impact of policy, performance measurement, and coordination between Member States remains incomplete. Future research should focus on the development of standardised indicators reflecting the multidimensional nature of the CE and targeted policy support to address gaps in CE implementation across the European Union. The widespread acceptance of CE practices depends on a common approach involving all levels of government and industry.

## 7. Conclusions

The transition to a circular economy brings opportunities and challenges for the EU. While significant progress has been made, differences in CE approval and performance across Member States highlight the need for targeted policy interventions and investments. Integrating green practices into emission reduction measures can improve the EU's performance and contribute to economic growth and sustainable environmental management. Future research and policy efforts should focus on developing relevant circular economy indicators, removing obstacles to implementation, and fostering cooperation between stakeholders to support the Union's transition to a circular economy.

The CE's literature on EU countries underlines that these changes are multifaceted and have economic, social, and environmental aspects. While significant progress has been made, challenges such as regional disparities, policy coherence, and stakeholder involvement remain. The most important development evaluation indicators are improving the policy environment and fostering stakeholder cooperation to accelerate the transition to a circular economy in the Union.

Implementing the MCDM technique provides effective tools for evaluating and managing CE practices. By systematically evaluating the various criteria, MCDM methodologies help to make informed decisions and identify the most effective strategies to achieve the EU's objectives. Including environmental aspects and advanced computing technologies further improves its application, making MCDM an integral part of the CE's assessment. To support the ongoing transition to a circular economy, research into innovative forms of MCDMs and their application in different EU contexts should be continued.

The transition to a circular economy offers significant opportunities for sustainable development but also presents challenges, mainly due to regional disparities between EU Member States. The study shows that significant progress has been made, but concrete policy measures are needed for the different levels of use in Central and Eastern Europe. MCDM methods, such as the SAW method, reflect the scientific intensity of CE efficacy evaluation in several dimensions.

The suggested MCDM-based framework is novel and covers the gaps found among developed frameworks in the literature. The suggested framework (1) follows the logic of the SAW method application; (2) allows easy comparison of the CE practices in different EU countries; (3) presents results in an easily understandable visual format, which is selected to show the gaps between EU countries; and (4) the selected criteria comprehensively cover key aspects of the circular economy, including patents related to recycling, employment in circular economy sectors, private investment, resource productivity, circular material use rate, and waste generation per capita.

The process of normalising indicator values and applying weights is important if decisions are made based on a set of criteria. By adding a separate table of interaction calculations (e.g., normalised scores and weights), it is possible to gain a more scientific understanding of how to obtain the final results.

Displaying the final composite score for each country and rankings adds scientific value to the conclusions, making it easier to identify patterns and areas where further action is needed. The decision now includes specific data findings, such as classification areas and diversity, that contribute to the scientific contribution of the study.

Some limitations of the study should be considered. First, it should be noted that no expert evaluation was used to determine the relative importance of the indicators. Instead, the calculations were based on the assumption that all indicators were of equal significance, and thus all were assigned equal weight. Future research should involve expert evaluation to refine these weights. The limited availability of data between 2010 and 2020 restricts the incorporation of a broader range of circular economy indicators in this analysis. Furthermore, the study concentrated more on circular economy indicators in the competitiveness and innovation category.

Future research should focus on developing meaningful indicators, improving the political environment, and fostering cooperation between stakeholders to accelerate the transition to the EU. Further, the EU can achieve sustainable economic growth, reduce its environmental impact, and contribute to achieving the Global Sustainable Development Goals.

**Author Contributions:** Conceptualisation, A.B. and V.G.; methodology, V.G.; validation, A.B. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Data is contained within the article.

**Conflicts of Interest:** The authors declare no conflicts of interest.

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