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A Process Oriented MCDM Approach to Construct a Circular Economy Composite Index

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Abstract: The purpose of this contribution is to develop a Circular Economy Composite indicator to benchmark EU countries performance. Europe is at the forefront of the global transition towards a sustainable and circular economy. To this end, the European Commission has launched in 2015 a Circular Economy Action Plan including a monitoring framework to measure progress and to assess the effectiveness of initiatives towards the circular economy in the European Union (EU) and Member States. Still, this monitoring framework lacks a composite indicator at the national level to aggregate the circular economy dimensions into a single summary indicator. Although there is a wide range of sustainability composite indicators, no aggregate circular economy index exits to this date. We use a multi-criteria approach to construct a circular economy composite index based on TOPSIS (Technique for Order Preferences by Similarity to Ideal Solutions) methodology. In addition, we introduce a novel aggregation methodology for building a composite indicator where different levels of compensability for the distances to the ideal and anti-ideal (or negative-ideal) values of each indicator are considered. In order to illustrate the advantages of this proposal, we have applied it to evaluate the Circular Economy performance of EU Member States for the year 2016. This proposal can be a valuable tool for identifying areas in which the countries need to concentrate their efforts to boost their circular economy performance.

Keywords: circular economy; composite indicators; multi-criteria analysis; sustainability; TOPSIS

1. Introduction

There is growing consensus on the need of a gradual transition to a more sustainable economic growth and nearly all countries are facing this challenge. The transition towards a sustainable, low carbon and resource economy requires turning linear economies based on the unidirectional material flow of production-consumption-waste models into Circular Economy (CE) models relying on production–consumption–reuse frameworks. A growing interest in CE can be also highlighted in the EU policy looking for developing guidelines to support CE strategies on the national level. Since 2015, the European Commission has launched a Circular Economy Action Plan (https://ec.europa.eu/environment/circular-economy/index_en.htm) to stimulate Europe's transition towards a more circular economy, to boost global competitiveness and to foster sustainable economic growth. The proposed actions set clear targets for reduction of waste in each step of the value chain from production, to consumption, repair and re-manufacturing, waste management, and secondary raw material that are fed back into the economy. In addition, this approach establishes a long-term path for waste management and recycling.

The highlighted importance of CE has introduced a need for monitoring its performance across countries to understand and benchmark the level of success of policy initiatives. Therefore, despite the huge variety of CE index-based methodologies, where single indices prevail, aggregate indicators in terms of composite indices are increasingly demanded by policy-makers as useful tools that could be easily interpreted and communicated to the general public.

Although the CE framework is widely explored in the literature, many contributions have pointed out the relevance of well-designed CE indicators [1–4]. The state of the art shows that a deep research on CE assessment and indicators is still lacking [5]. Several index-based methodologies have been proposed to measure the CE performance. Among them, some single indicators are focused on material flows such as the Water footprint (WF) proposed by [6] and the Material Inputs Per unit of Service (MIPS) developed by [7]. Other types of index-based methods are mainly focused on energy usage as, for example, the Cumulative Energy Demand (CED) [8] and the Embodied Energy (EE) index [9]. When addressing the issue of land use and consumption, the Ecological Footprint [10,11] or the Sustainable Process Index (SPI) [12] are remarkable. Both methodologies aim to provide a measure of the environmental pressure of human activities on the biosphere. Moreover, there are some indicators contributing in life-cycle analysis methods. On one hand, there are single indicators such as the Carbon Footprint (CF) expressed as Green House Gases emissions or the Ecosystem Damage Potential (EDP) developed by the Swiss Federal Institute of Technology. On the other hand, as examples of multiple indicators, we can cite the Life Cycle Assessment (LCA), which has been standardized by the ISO14040 international guidelines and the Environmental Performance Strategy Map (EPSM) and the sustainable Environmental Performance Indicator (SEPI).

Over the last few years, the use of Multiple Criteria Decision Making (MCMD) techniques for assessing sustainability issues has risen sharply and some authors claim that these methodologies have demonstrated their usefulness to address a wide variety of environmental and management problems [13]. In fact, sustainability assessment is a complex and multidimensional problem that requires the integration of multiple indicators to form composite indices [14], and it can be said that sustainability assessment is an MCDM problem [15]. A review of MCDM works dealing with sustainability is presented in [16]. Within the huge number of MCDM approaches, one group of them are classified as distance function based methods in which TOPSIS is included. TOPSIS is the acronym of "Technique for Order Preferences by Similarity to Ideal Solutions" [17], and it is based on aggregation functions representing the relative closeness to the ideal and anti-ideal values as reference levels. It is broadly used in MCDM frameworks due to its ease of implementation and the ability to consider a non-limited number of alternatives and criteria. According to [18] in TOPSIS, "The best alternative is the one that has the shortest distance to the ideal solution. The previous definition can also be used to demonstrate that any alternative which has the shortest distance from the ideal solution is also guaranteed to have the longest distance from the negative-ideal solution". By providing the references levels for the individual indicators, the resulting CE composite index is an easy-to-interpret measure. The distances in TOPSIS are aggregated by means of a compensatory approach, using linear functions such as the arithmetic mean than overlooks unbalances that is the disequilibrium among the sub-indicators/dimensions of the composite indicator. The arithmetic mean is the most common scheme used in the development of composite indicators [19,20]. It is also recognized as the simplest strategy and the main advantage is that it can be easily replicated by others. However, this aggregation function has attracted much criticism since the arithmetic mean performs a compensation between indicators that are not-substitutable for each other [21].

The main contribution of this paper is to introduce a process oriented approach to construct a CE composite index based on TOPSIS. When constructing a composite indicator selecting appropriate weighting and aggregation methodology is challenging [22,23]. Moreover, we consider three sustainability perspectives: weak sustainability, strong sustainability, and limited sustainability. The type of sustainability is directly related to the aggregation methodology and the level of compensability that is the possibility of offsetting the shortfall in some criteria with a superior performance in other criteria. We then face the question of aggregation different criteria into a CE composite index looking at the constant elasticity of substitution (CES) [24,25] between the dimensions previously defined in the circular economy monitoring framework. Thus, an added value of our proposal is to extend the TOPSIS method to include different levels of compensability when the distances to the ideal and negative-ideal values are aggregated. We illustrate how different choices of CES function lead to three types of circular economy composite indices (CEI): (i) Weak circular economy composite index (WCEI) allowing for unlimited substitution between circular economy indicators; (ii) Limited circular economy composite index (LCEI), allowing partial substitutability; and (iii) Strong circular economy composite index (SCEI) not allowing for any compensation.

To show the potential benefits of the proposed methodology, it has been applied to measure circular economy EU countries performance using data from the EU monitoring framework set up by the European Commission. We have considered an equal weighting scheme and three levels of compensability.

In the following sections, we first justify why measuring circular economy countries performances is important, and describe the EU monitoring framework. In the same section, we also highlight weighting and aggregation methodologies as critical issues when constructing a circular economy indicator. We then present in Section 3 the multiple criteria process oriented approach. In Section 4, an application of the proposed methodology extending the TOPSIS technique to the EU data and based on the EU Circular Economy monitoring framework is presented. Conclusions and further lines of research are provided in Section 5.

2. Measuring Circular Economy at the National Level

2.1. Why Measuring Circular Economy at the National Level Is Important

It is important to be able to measure CE at national level since CE is a key driver of sustainable development growth. In this scenario, the governments play an important role in defining and implementing policies supporting the transition from linear economies to CE based systems. Germany [26] and China [4,27] are some prime examples of CE strategies focused on the national level. In recent years, the highlighted relevance of sustainability concerns in Europe has come along with a need for monitoring CE performance across countries. It is mandatory to understand and benchmark the success of policy measures in facilitating the transition to a CE and consequently to a more sustainable growth. In 2015, the European Commission put forward a package to support the EU’s transition to a circular economy contributing to boost Europe’s competitiveness, modernize its economy and industry to create jobs, protect the environment, and generate sustainable growth.

Thus, making CE a reality requires a monitoring framework to show if the policy initiatives have been successful and to identify areas where more action is needed. In 2018, a Monitoring Framework for the CE was presented [28] including ten key indicators covering four broad areas such as production and consumption, waste management, secondary raw materials, and competitiveness and innovation. The data of the indicators and sub-indicators are based on official statistics coming from Eurostat, the Joint Research Centre, and the European Patent Office. The information is disseminated by the European Commission in (https://ec.europsa.eu/eurostat/web/circular-economy/indicators/monitoring-framework) through tables and a visualization tool to develop cross-country comparison.

The individual indicators are classified in four broad thematic areas: Production and Consumption, Waste Management, Secondary Raw Material and Competitiveness and Innovation. Thus, far, this monitoring framework is based on tables, graphs, and maps that evaluate a country’s progress towards a circular economy by displaying all relevant indicators. After a brief summary of each area, in Table 1, the list of the key indicators is summarized together with their data source, the reference area, and the coverage period.

Table 1. List of circular economy indicators. Source: European Commission Monitoring Framework for Circular Economy (https://ec.europa.eu/eurostat/web/circular-economy/indicators/monitoring-framework).

	Indicator	Data Source	Reference Area	Coverage-Time
	Production and Consumption			
1	EU self-sufficient for raw material	European Commission	Only EU aggregate	
2	Green Public Procurement			
3	Waste generation			
3a	Generation of municipal waste per capita (Kg per capita)	European Statistical System	All EU Member States	>10 years (2000)
3b	Generation of waste excluding major mineral wastes per GDP unit (Kg per thousand euro, chain linked volumes (2010))	European Statistical System	All EU Member States	>10 years (2004)
3c	Generation of waste excluding major mineral wastes per domestic material consumption (percentage)	European Statistical System	All EU Member States	>10 years (2004)
4	Food waste (million tons)			
	Waste Management			
5	Recycling rates			
5a	Recycling rate of municipal waste (percentage)	European Statistical System	All EU Member States	>10 years (2000)
5b	Recycling rate of all waste excluding major mineral waste (percentage)	European Statistical System	All EU Member States	5 to 10 (2010)
6	Recycling/recovery for specific waste streams			
6a	Recycling rate of overall packaging (percentage)	Ministries of Environment	All EU Member States	>10 years (2000)
6b	Recycling rate of plastic packaging (percentage)	Ministries of Environment	All EU Member States	>10 years (2000)
6c	Recycling rate of wooden packaging (percentage)	Ministries of Environment	All EU Member States	>10 years (2000)
6d	Recycling rate of e-waste (percentage)	European Statistical System	All EU Member States	5 to 10 (2010)
6e	Recycling of biowaste (Kg per capita)	European Statistical System	All EU Member States	>10 years (2000)
6f	Recovery rate of construction and demolition waste (percentage)	European Statistical System	All EU Member States	5 to 10 (2010)
	Secondary Raw Materials			
7	Contribution of recycled material to raw materials demand			
7a	End-of-life recycling input rates (EOL-RIR) (percentage)	European Commission	Only EU aggregate	2016
7b	Circular material use rate (percentage)	European Statistical System	All EU Member States	>10 years (2010)
8	Trade in recyclable raw materials (tonnes)	European Statistical System	All EU Member States	>10 years (2004)
	Competitiveness and Innovation			
9	Private investments, jobs and gross value added related to CE sectors			
9a	Gross investments in tangible goods (percentage of GDP at current prices)	European Statistical System	All EU Member States	>10 years (2012)
9b	Persons employed (percentage of total employment)	European Statistical System	All EU Member States	>10 years (2012)
9c	Value added at factor cost (percentage of GDP at current prices)	European Statistical System	All EU Member States	>10 years (2012)
10	Number of patents related to recycling and secondary raw materials	European Patent Office	All EU Member States	>10 years (2000)

- **Production and consumption**. In a circular economy, more sustainable models of production in all sectors as well as a responsible consumption are needed. In the long term, this may contribute to a higher self-sufficiency of selected raw materials used in production processes. Statistical indicators related to the generation of different types of waste are used to better estimate the impact of production and consumption in the EU.
- **Waste management**. The action plan aims to increase the share of waste, which is recycled and returned into the economic cycle. The indicators and sub-indicators included in this dimension are the recycling rates to different products.
- **Secondary raw material**. In a circular economy, it is needed to use recycled materials instead of using newly extracted natural resources. Statistical indicators such as material use rates and trade of recyclable raw materials can help to assess the performance of this dimension.
- **Competitiveness and innovation**. When promoting a circular economy new jobs are created to contribute to a sustainable growth. Statistical indicators such gross investment in tangible goods, persons employed and value added are considered.

This monitoring framework displays information on EU countries performance for different CE single indicators. Currently, no composite CE indicator exists so far to show the big picture of the CE country performance.

2.2. Critical Issues When Developing a CE Composite Indicator

A composite indicator involves the combination of single indicators that represent different dimensions of a concept whose description is the objective of the analysis [22]. In recent years, there has also been a significant growth in the use of composite indicators for evaluating the performance of countries and institutions in several areas such as innovation, industrial competitiveness, or sustainable development [29–38]. Then, a composite indicator allows for measuring a set of multidimensional concepts that cannot be captured by a single indicator [39] and therefore can be a useful tool in policy making.

According to [20,39], constructing composite indicators implies the following stages:

1. Develop a theoretical framework, thus providing the basis for the selection of single indicators and the structure in sub-groups or dimensions.
2. Select the data in order to check the quality of the indicators and discuss their strengths and weaknesses.
3. Imputing the missing data, providing a measure of reliability of each imputed value.
4. Conduct a multivariate analysis in order to describe the statistical structure of the data set.
5. Apply a normalization procedure for comparability purposes.
6. Define the weighting and aggregation methodology according to the underlying theoretical framework, considering correlation and compensability issues among indicators.
7. Assess its robustness and conduct a sensitivity analysis.
8. Get back to the real data and reveal the main drivers for a good or bad performance.
9. Find links to other published indicators to correlate the composite indicator with other relevant measures.
10. Display the information through visualization tools that allows for presenting the results in a clear and accurate way.

In a benchmarking framework and especially for sustainability assessment, the right selection of the weighting and aggregation methodologies (step 6) is critical and can have important implications on countries' performances and rankings.

In the literature, weighting methods can be broadly categorized into the following groups: equal weighting, statistic based weights, and expert opinion based weights.

- Equal weighting is used when all the indicators are considered equally important and due to its simplicity appears in several sustainability indices such as the Human Development Index [40] and the Living Planet Index [41]. However, regardless of the benefits, its use has some drawbacks including validity and transparency.

- Statistic based weights derives the importance of the criteria according to the structure of the data. In this group, there are some multivariate statistical approaches such as the Principal Component Analysis (PCA) or the Factor Analysis (FA) in which the weights reflect the contribution of each indicator to the overall composite indicator. The Environmental Sustainability Index [42] uses weights derived from PCA to assess the information content of 15 sustainability sub-indices for agricultural systems. The main disadvantage of these methods is that it only works if the indicators are correlated [20]. In addition, included in this group is the benefit of the doubt approach (BOD) in which the weights are selected to maximize the index for each unit. For example, the Meta-index of Sustainable Development [43] applies the BOD for monitoring countries' overall performance in sustainable development.
- Participatory methodologies such as the Budget Allocation (BAL) [22], Analytical Hierarchy Process (AHP) [44], or Cojoint Analysis (CA) rely on expert or public opinion for indicators' weighting. For example, the Eco-Indicator 99 [45] applies the BAL for life cycle impact assessment. AHP methodology has been used to determine the weights [46] when developing a composite sustainability performance index for steel industry. In [47], the priorities of inhabitants are used as input for hierarchical conjoint analysis to improve the quality of life.

Another critical issue in developing a composite indicator that comes together with the weighting approach is the aggregation methodology. Taking into account that the aggregation technique is directly connected with the level of compensability, the choice of the aggregation rule allows for defining the range among weak or strong paradigms. Whereas a weak CE indicator allows for completing compensation among indicators, the strong CE index does not allow any compensation and thus it reflects the worst assessment achieved by a country. In the literature on composite indicators, by far the most used are additive techniques, but, due to their rigorous prerequisites, geometric or non-compensatory aggregation methods are often proposed at this stage:

- Additive aggregation (full compensability). The resulting composite indicator is the weighted arithmetic mean of normalized indicators. Although widely used, this aggregation entails restrictions on the nature of indicators such as preferential independence since it implies that the trade-off ratio between two indicators is independent of the values of the remaining indicators. By using the additive aggregation methodology, the Environmental Performance Index (EPI) ranks countries on 24 performance indicators covering environmental health and ecosystem vitality [48].
- Geometric aggregation (limited compensability). A lower compensability perspective relies on geometric-mean based methods. In this case, mutually preferential independence condition of indicators is required like in the previous case. This procedure is widely adopted for biodiversity composite indicators such as the Living Planet Index [49] or the geometric mean of relative abundance indices [50].
- Non compensatory multi-criteria approaches. As multidimensionality is intrinsic to the composite indicator concept, many works have proposed the use of MCDM techniques [51]. Some authors also claim that MCDM approaches are suitable to deal with environmental and management problems [13,14,52]. According to [39], the choice of non-compensatory multi-criteria approaches allows for finding a compromise solution among conflicting variables including non-compensability constraints. Furthermore, in recent years, there has been a sharp rise in the number of works aggregating sustainability criteria by using some MCDM tools [16]. In particular, a framework based on a multi-objective evaluation of Circular Economy development in China is presented in [53].

3. Circular Economy Index Construction

In this section, we describe the process oriented approach to construct a composite circular economy index. In the proposed procedure, we apply the multi-criteria TOPSIS methodology to get national rankings according to different levels of compensability of the aggregating functions representing "closeness to the ideal" where the chosen alternative should have the "shortest distance" from the ideal solution and the "farthest distance" from the "negative-ideal" solution. According to the stages to construct composites indicators described in Section 2.2, we propose the following steps:

Step 1. Taking into account the theoretical framework of the circular economy indicators, construct a decision matrix representing the data set $X = x_{ij}$ $(i = 1, \ldots, n; j = 1, \ldots m)$ where n denotes the number of countries and m the number of scoreboard indicators.

Step 2. Compute the normalized $R = r_{ij}$ $(n \times m)$ decision matrix for comparability purposes in which the normalized value r_{ij} is obtained by:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum x_{ij}^2}} \quad i = 1, 2, \ldots, n \quad j = 1, 2, \ldots m. \tag{1}$$

Step 3. Define the weight system $W = w_{ij}$ and calculate the weighted normalized decision matrix in which the v_{ij} value is:

$$v_{ij} = w_j r_{ij}, \tag{2}$$

where $w_j \in [0, 1]$ are the weights associated with each sub-criterion j and obtained according to the selected weighting system. Take into account that $\sum w_j = 1$.

Step 4. Determine the values of ideal and negative-ideal solution:

$$\begin{aligned} A_i^+ &= \{v_1^+, \ldots, v_n^+\} = \{(\max_i v_{ij} \mid j \in J_b), (\min_i v_{ij} \mid j \in J_c)\}, \\ A_i^- &= \{v_1^-, \ldots, v_n^-\} = \{(\min_i v_{ij} \mid j \in J_b), (\max_i v_{ij} \mid j \in J_c)\}, \end{aligned} \tag{3}$$

where J_b is associated with benefit criteria and J_c is associated with cost criteria.
In addition, compute the separation measures to the positive ideal $S_i{}^+$ and negative ideal $S_i{}^-$ as follows:

$$\begin{aligned} S_i^+ &= |v_{ij} - v_j^+|, \quad i = 1, 2, \ldots n, \\ S_i^- &= |v_{ij} - v_j^-|, \quad i = 1, 2, \ldots n. \end{aligned} \tag{4}$$

Step 5. Define the aggregation methodology for the separation measures. We must have in mind that the aggregation methodology can have profound implications on the overall ranking. To allow for maximum flexibility in aggregating the separation measures of the individual indicators for each dimension to the ideal and negative ideal, we use the standard constant-elasticity of substitution (CES) function [24,25] to generate the aggregated distances (D_{ij}^+, D_{ij}^-) for the country i:

$$\begin{aligned} D_{ij}^+(N_{ij}, S_{ijk}^+, \rho) &= \left[\sum_{k=1}^{Nij} \frac{1}{N_{ij}} S_{ijk}^{+\,-\rho}\right]^{-\frac{1}{\rho}}, \\ D_{ij}^-(N_{ij}, S_{ijk}^-, \rho) &= \left[\sum_{k=1}^{Nij} \frac{1}{N_{ij}} S_{ijk}^{-\,-\rho}\right]^{-\frac{1}{\rho}}, \end{aligned} \tag{5}$$

where S_{ijk}^+ and S_{ijk}^- are the separation measures to the positive and negative ideals under criteria j for country i and dimension k, respectively.

N_{ij} denotes the number of indicators for criteria in the dimension. When the aggregation is made without considering dimensions, then N_{ij} is equal to m, namely, the number of scoreboard indicators.

ρ describes the substitutability across criteria, which ranges from $-1 \leq \rho \leq \infty$.
The elasticity of substitution σ across components of the CE index is defined as:

$$\sigma = \frac{1}{1+\rho}, \tag{6}$$

with $0 \leq \sigma \leq \infty$ and

$$\rho = \frac{1-\sigma}{\sigma}. \tag{7}$$

Three special cases of CES function are proposed depending on the type of compensability allowed. A weak CE composite indicator reflects a weak sustainability perspective in which the criteria are perfect substitutes and, in this case, the CES assumes the form of the arithmetic mean (see Definition 1). On the other hand, a strong sustainability perspective occurs when the CE indicators are not substitutable, and then, when aggregating the distances in the Strong CE indicator, we opt for looking at the CES function reflecting the maximum distances to the reference levels (see Definition 2). Finally, an intermediate case of substitutability is considered reflecting the limited substitution among criteria and then the CES function becomes the geometric mean of the distances to the reference levels (see Definition 3).

Definition 1. *Weak distance. If the decision maker considers that the criteria are perfect substitutes, then $\sigma = \infty$ and $\rho = -1$. In this case, the aggregation function for the separation distances with equal weights assumes the form of the arithmetic mean:*

$$\begin{aligned} WD^{+}_{ij}(N_{ij}, S^{+}_{ijk}) &= \sum_{k=1}^{Nij} \frac{1}{N_{ij}} S^{+}_{ijk}, \\ WD^{-}_{ij}(N_{ij}, S^{-}_{ijk}) &= \sum_{k=1}^{Nij} \frac{1}{N_{ij}} S^{-}_{ijk}. \end{aligned} \tag{8}$$

Definition 2. *Strong distance. When the criteria are defined as not substitutable, then $\sigma = 0$ and $\rho = \infty$. In this case, the aggregation function for the separation distances turns into a Leontief production function and the separation measure is determined by the maximun distance to the ideal and to the negative ideal:*

$$\begin{aligned} SD^{+}_{ij}(N_{ij}, S^{+}_{ijk}) &= \max S^{+}_{ijk}, \\ SD^{-}_{ij}(N_{ij}, S^{-}_{ijk}) &= \max S^{-}_{ijk}. \end{aligned} \tag{9}$$

Definition 3. *Limited distance. For an intermediate case of substitutability, the aggregation function for the separation distances is given by the Cobb–Douglas production function with $\sigma = 1$ and $\rho = 1$. Then, the $I^{+}_{ij}(N_{ij}, I_{jk})$ and the $I^{-}_{ij}(N_{ij}, I_{jk})$ becomes the geometric mean of the criteria separation measures:*

$$\begin{aligned} LD^{+}_{ij}(N_{ij}, S^{+}_{ijk}) &= \sqcap_{k=1}^{N_{ij}} (S^{+}_{ijk})^{\frac{1}{Nij}}, \\ LD^{-}_{ij}(N_{ij}, S^{-}_{ijk}) &= \sqcap_{k=1}^{N_{ij}} (S^{-}_{ijk})^{\frac{1}{Nij}}. \end{aligned} \tag{10}$$

Step 6. Obtain the Weak Circular Economy (WCEI), the Strong Circular Economy (SCEI), and the Limited (LCEI) indices by computing the relative closeness to the ideal solution of the corresponding distances. Taking into account all the scoreboard indicators, without considering the sub-dimensions, the three types of CE indicators are computed as:

$$\begin{aligned} WCEI_i^* &= \frac{WD_i^-}{WD_i^- + WD_i^+} \quad i = 1, 2, \ldots, n, \\ SCEI_i^* &= \frac{SD_i^-}{SD_i^- + SD_i^+} \quad i = 1, 2, \ldots, n, \\ LCEI_i^* &= \frac{LD_i^-}{LD_i^- + LD_i^+} \quad i = 1, 2, \ldots, n. \end{aligned} \tag{11}$$

In this final step, we rescale the data into a 0–100 score. This process puts all indicators on a common scale that can be compared. Finally, we rank the countries according to their relative proximity to the desirable country in descending order; thus, the higher the priority, the higher the circular economy performance.

4. Measuring Circular Economy EU Countries Performances

In this section, we apply the methodology developed in Section 3 to the data of EU Member states to obtain a Circular Economy composite index for different compensation degrees. Regarding the selection of circular economy indicators, we follow the monitoring framework set up by the European Commission to measure the progress of the EU action plan for the circular economy [28]. As stated by the EU, the selected indicators have been evaluated against how they perform in terms of relevance, acceptability, credibility, easiness, and robustness (also known as RACER). In our study, we consider only the sub-indicators with information for all the EU Member States, and we discard those for which the data are aggregated as for example the indicator 1. EU-self sufficient for raw material and 7. Contribution of recycled materials to raw material demand. In addition 2. Green Public Procurement and 4. Food waste have not been considered as they are being developed currently.

We have carried out the whole procedure defined in steps 1 to 6 starting with the values of the single indicators and calculating the WCEI, LCEI, and the SCEI composite indicators using equal weights. In Table 2, we display the values and rankings across countries of the three CE composite indices.

In Figure 1, we show the effects on the ranking of using different aggregation rules. In this figure, we should draw attention to some countries. Germany, the United Kingdom, and France lies at the top positions while Malta and Estonia come in near the bottom of the rankings. There is a small difference in the positions of France, Italy, Netherlands, Spain, Ireland, Austria, Denmark, Poland, Czequia, Slovenia, Sweden, Portugal, Hungary, Croatia, Latvia, Slovakia, Greece, Romania, Bulgaria, and Estonia. However, there is a significance deviation in countries such as: Belgium, Luxembourg, Lithuania, Luxembourg, Finland, Cyprus, and Malta. For example, Belgium and Lithuania achieve a better ranking position for weak and limited circular economy indicator while the strong circular economy composite indicator assigns an inferior position. In contrast, Finland, Cyprus, and Malta get a better position in the ranking when the circular economy performance is measured using a strong compensability rule instead of the weak or limited rule.

A more in-depth analysis of comparative performances is undertaken when the country-level data on each indicator are aggregated for each dimension. We then construct four indicators scores for production and consumption, waste management, secondary raw material, and competitiveness and innovation using the same procedure proposed in Section 3. If, for example, we consider the weak sustainability perspective proposed by Definition 1 and using Equation (8) we can obtain the corresponding dimensions scores. In Figure 2, the list of ten countries are sorted by the WCEI. This figure draws attention to the issues on which policymakers must take further action. Note that Belgium, which is currently fifth in the EU, could significantly increase its circular economy performance implementing policies aimed at improving the competitiveness and innovation area. Furthermore, this analysis reveals not only weaknesses, but also the strengths of countries, such as in the case of Netherlands, which reaches the highest score in Secondary Raw Material.

Table 2. Rank and Circular Economy composite indicator score for 28 EU countries.

Weak			Limited			Strong		
Rank	**Country**	**Score**	**Rank**	**Country**	**Score**	**Rank**	**Country**	**Score**
1	Germany	67.04	1	United Kingdom	64.4	1	Germany	68.54
2	United Kingdom	61.62	2	Germany	63.18	2	France	68.06
3	France	59.74	3	Italy	61.12	3	United Kingdom	57.51
4	Netherlands	58.25	4	Belgium	57.71	4	Spain	56.88
5	Italy	55.14	5	Netherlands	56.21	5	Netherlands	55.32
6	Belgium	51.32	6	Denmark	55.18	6	Italy	54.56
7	Spain	48.74	7	Lithuania	53.77	7	Austria	53.34
8	Austria	47.49	8	France	53.09	8	Finland	53.32
9	Denmark	46.74	9	Spain	52.27	9	Denmark	53.3
10	Lithuania	46.33	10	Poland	50.25	10	Luxembourg	53.26
11	Slovenia	44.89	11	Austria	50.05	11	Czechia	52.03
12	Poland	44.13	12	Czechia	49.96	12	Ireland	51.85
13	Czechia	43.79	13	Slovenia	48.67	13	Poland	51.63
14	Ireland	43.53	14	Ireland	46.44	14	Sweden	51.23
15	Luxembourg	43.28	15	Portugal	45.69	15	Cyprus	50.87
16	Portugal	42.95	16	Sweden	44.17	16	Belgium	50.65
17	Sweden	42.9	17	Latvia	38.33	17	Malta	50.05
18	Finland	36.7	18	Hungary	38.26	18	Slovenia	49.93
19	Latvia	36.55	19	Luxembourg	37.45	19	Portugal	49.6
20	Croatia	36.31	20	Finland	34.27	20	Greece	49.32
21	Hungary	36	21	Cyprus	34.22	21	Croatia	49.3
22	Slovakia	35.72	22	Croatia	33.47	22	Hungary	49.02
23	Bulgaria	33.66	23	Slovakia	33.27	23	Slovakia	48.48
24	Romania	31.59	24	Bulgaria	33.13	24	Latvia	48.32
25	Cyprus	30.47	25	Greece	27.13	25	Lithuania	48.09
26	Greece	29.52	26	Romania	23.63	26	Romania	47.83
27	Malta	25.38	27	Estonia	22.8	27	Bulgaria	37.13
28	Estonia	21.27	28	Malta	17.74	28	Estonia	27.94

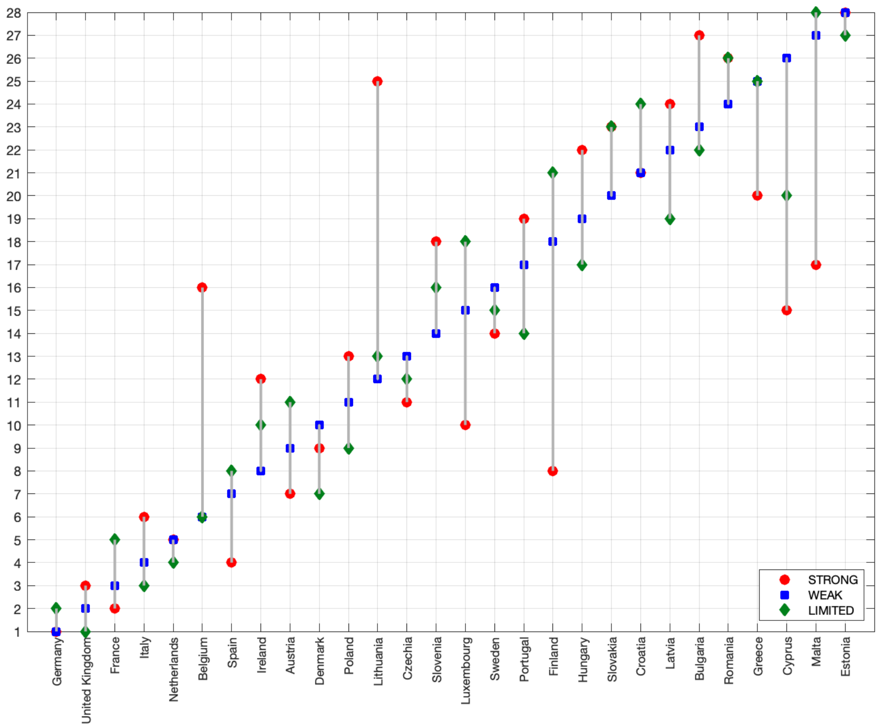

Figure 1. EU Circular Economy performance range across countries.

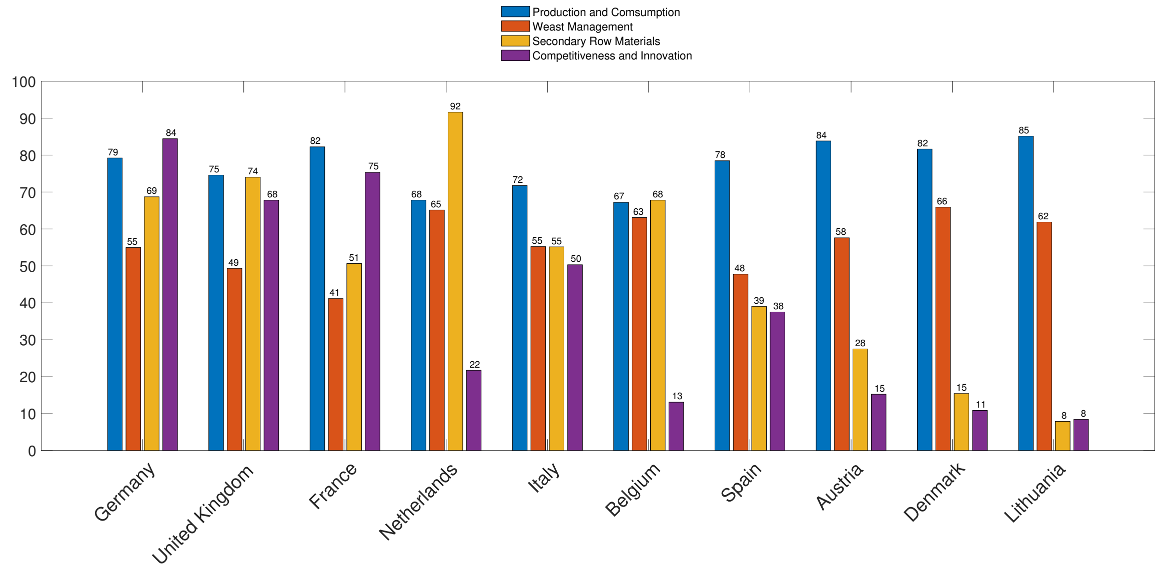

Figure 2. Top ten countries' WCEI performance for the four dimensions.

Thus, it can be concluded that, in the light of results obtained, the use of different sustainability perspectives when constructing a composite indicator affects the rankings. However, the use of three levels of compensability is highly advisable and helps to understand and interpret the results correctly. Looking at separate circular economy dimensions can be a useful tool to identify strengths and weakness at the country level.

5. Conclusions

The circular economy is now an irreversible and global mega trend [54]. A careful measurement of circular economy performance is needed to provide a foundation for effective policymaking. Recently, the European Commission has adopted a Circular Economy package trying to help businesses and consumers to make the transition to a stronger and more circular economy. However, no appropriate circular economy composite index has been developed to measure circular economy at the macro level. The main problems when constructing a composite index concern the theoretical framework, the availability of data, the selection of indicators, and how they are aggregated. Once the framework and data have been identified, we develop a process oriented approach to construct a composite circular economy index along several steps from normalization, weighting and aggregation to visualization of results. Research on composite indices provides a wide variety of aggregation methodologies, additive being the most used, although they imply a full substitutability among single indicators. In this regard, we have developed a composite indicator for different compensation degrees: weak, strong, and limited sustainability perspective.

The proposed Circular Economy Index (CEI) ranks EU countries on 17 performance indicators across ten issue categories covering production and consumption, waste management, secondary raw materials, and competitiveness and innovation. We develop a process oriented approach using the TOPSIS technique for indicator construction, which situates each country relative to the ideal and anti-ideal indicators performances. TOPSIS is a very effective method for multi-objective decision analysis due to its simplicity and its ability to consider a non limited number of alternatives and criteria in the decision-making process. The sustainability perspective varies on the choice of the level of compensability among criteria and this in turns depends on the selected aggregation technique. To this end, the aggregation is carried out by means of the constant elasticity of substitution to generate the distances to ideal and anti-ideal solutions in order to reflect three levels of compensability among individual scoreboard indicators. Moreover, the CE composite indicator has been constructed at the comprehensive level and for the four dimensions, thus providing a useful tool for policymakers to identify strengths and weaknesses of the circular economy performance at the country level.

To date, and to our knowledge, no multi-criteria circular economy composite index exists in the EU. The main advantage of our research is that, for the first time, an overall scoreboard of EU circular economy countries performance is provided. In addition, the CEI has been developed for different compensation degrees and, apart from giving an overall circular economy performance measurement, also generates early-warning signals which identity and monitor situations that warrant a higher level of concern. The CEI provides a gauge at a national scale of how close countries are to the EU circular economy strategic policy goals. The country CEI score obtained provides a scorecard in which leaders and laggards in circular economy performance are highlighted. This also leads to the identification of best practices to give additional insight and guidance for countries wishing to improve their circular economy performance.

Finally, there are several future research possibilities to overcome the limitations of our study. First, this study considers only the case of equal weighting for all the indicators and we do not check how sensitive the proposed methodology is to different weighting schemes. Thus, a Montecarlo simulation of weights could be conducted. Second, future research would be to extend the proposed model for different periods of time trying to show not only the current picture of circular economy performances at EU, but also their trends.

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Abbreviations

The following abbreviations are used in this manuscript:

EU	European Union
CE	Circular Economy
CES	Constant Elasticity of Substitution
MCDM	Multiple Criteria Decision Making
TOPSIS	Technique for Order Preferences by Similarity to Ideal Solutions
CEI	Circular Economy Index
WCEI	Weak Circular Economy Index
SCEI	Strong Circular Economy Index
LCEI	Limited Circular Economy Index

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