Special Issue Article

WM&R

Waste Management & Research
2024, Vol. 42(8) 670–680

DOI: 10.1177/0734242X241237171
journals.sagepub.com/home/wmr
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Towards circular economy indicators: Evidence from the European Union

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Abstract

The European Union (EU) is moving towards sustainable development, and a key role is played by circular economy (CE) models geared towards reducing pressure on natural resources, generating jobs and fostering economic opportunities. Indicators are able to aggregate a variety of information and their use, through the use of multi-criteria decision analysis (MCDA), allows the performance of alternatives to be monitored. This work aims to calculate the performance of the EU27 in the years 2019 and 2020 according to 15 CE indicators available on Eurostat. The results of the Analytic Hierarchy process show that the greatest impact on circularity is determined by the category 'competitiveness and innovation', which together with the category 'global sustainability and resilience' accounts for two thirds of the overall weight. The MCDA results show that Belgium prevails in both the baseline and alternative scenarios, ahead of Italy and the Netherlands respectively. In general, circular policies see western European countries excel, while the performance of eastern European countries is weaker. The implications of this work highlight the three main barriers to the development of CE models: (i) illegal waste management; (ii) lack of knowledge and low level of investment in circular technologies and (iii) low distribution of value among stakeholders. In this way, resource management based on circularity will enable Europe to meet the challenges of sustainability with less dependence on imported raw materials.

Keywords

Circular economy, Europe, indicators, multi-criteria decision analysis, resource management

Received 9th January 2024, accepted 18th February 2024 by Associate Editor Antonis A. Zorpas.

Introduction

The European Environment Agency (2016) has proposed circular economy (CE) as a central element of a green economy model that extends waste management (WM), waste prevention and resource efficiency to human well-being and ecosystem resilience. CE is "an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes" (Kirchherr et al., 2017). The concept of CE is a crucial theme towards sustainable development (Bockreis and Ragossnig, 2023; D'Adamo et al., 2023a; Zorpas et al., 2021), although the impact of each source of CE value (recycling, renewable energy, repair and reuse) varies across the three dimensions of sustainability (Knäble et al., 2022). Its implementation can be seen on a large scale driven by appropriate policies (Hartley et al., 2020) and in concrete projects that firms are implementing (Henry et al., 2020). Analysing the firm mission statements on the CE, the theme of sustainability emerges and is followed by that of technology and production and consumption (PC). However, within the sustainability theme, the social component receives less attention (Caferra et al., 2023). The topic of EC is closely related to WM, which can be declined in terms of mathematical models (Barma et al., 2022; Barma and Modibbo, 2022), local approaches (Loizia et al., 2021) and integrations in different contexts (Arbolino et al., 2021; Vacchi et al., 2021).

Circular models are not sustainable when the CE rebound occurs, where improvements in the eco-efficiency of a production system are offset by external systemic responses (Zink and Geyer, 2017). Moreover, the literature presents many works on CE but not all of them are oriented towards proposing concrete solutions, and this practice should be discouraged (Kirchherr, 2023). Different definitions of CE are proposed in the literature,

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and it can be observed that in recent years there has been an increased focus on reuse and recycling, which are proposed as basic principles of ecology (Kirchherr et al., 2023, 2017). Moreover, CE models may require not only incremental changes but also the reconfiguration of supply chains. Similar to the above explanation, more attention of CE objectives is those that tend towards sustainable development and in the future, much attention should be given to value retention and resource efficiency.

The aim of the CE is to optimise the use of natural resources by minimising the negative effects of extraction and processing on energy, health and the environment through programmes of reuse, recycling and recovery (Chiappetta Jabbour et al., 2019). In order to achieve this, WM policies have started to change from conventional (landfill-based) scenarios to novel ones (based on recycled materials and renewable energy) – (Islam et al., 2020; Voukkali et al., 2023). It is worth highlighting that the CE concept aims to give value to waste by following the 5R model: redesign–reduction–recovery–recycle-reuse (Chen et al., 2020). Life cycle analyses of different products can see which circular practices are most likely to achieve sustainability goals.

The implementation of strict WM policies requires control measures to avoid the risk of increased illegal flows (D'Amato et al., 2018) and local authorities do not always know when a waste is no longer considered as waste (Mazzanti and Montini, 2014). This aspect is recalled by some authors who point out that Europe should propose clear and indisputable criteria defining exactly when a waste obtains product (or secondary raw material (RM)) status (Ragossnig and Schneider, 2019). In this respect, a key role is played by the end of waste, that is, the process through which a waste ceases to be a waste and can be fully recovered, acquiring the status of a product (or secondary RM). The European Waste Framework Directive also defines that innovations can turn waste into a valuable resource and the fully recovered material does not cause negative impacts on the environment or human health. End of waste, together with social change, is considered an enabling factor for reuse and recycling practices. The CE in seeking to benefit from waste is also a social responsibility involving a sharing of resources (D'Adamo et al., 2022).

The need to provide clear indications to policy makers and other categories of stakeholders requires quantitative indications. In this respect, the identification of indicators is useful. A taxonomy of them makes it possible to identify 55 subdivided into levels of implementation, by cycles, by performance, by circularity perspective and by degree of transversality (Saidani et al., 2019). The scope of measurement should include technological cycles with or without a Life Cycle Thinking approach and their effects on the three dimensions of sustainability (Moraga et al., 2019). Indicators could be grouped on the basis of the three spatial dimensions of sustainability (macro, micro and meso) and on the basis of the 3R principles (reduce, reuse, recycle) – (De Pascale et al., 2021). Some authors aim to implement circularity indicators for sustainability and CE objectives. In this way, depending on their corporate objectives and business plans, firms can determine and implement the most appropriate circularity indicator (Barros et al., 2023). The comparison between countries is interesting as it can allow virtuous countries to be rewarded through international cooperation in the exchange of information, incentives for the training of workers and the sharing of knowledge and technology on recycling (De Almeida and Borsato, 2019). The circularity of European countries' performance can be obtained through multi-criteria decision analysis (MCDA) based on Eurostat data (Colasante et al., 2022), and there is a link between circularity, energy efficiency and soundness in EU countries (Zisopoulos et al., 2022).

This work aims to fill a gap in the literature where there is no CE indicator that integrates the different information from a multiplicity of indicators available on Eurostat. Through the MCDA method, the performance of the 27 EU countries in the years 2019 and 2020 is compared considering 15 indicators equally from the 5 categories identified by Eurostat. The analysis will be conducted in a baseline scenario in which these indicators will be assigned a weight based on a pairwise comparison from international academics and in an alternative scenario in which the same weight will be assigned. The work concludes with some reflections to understand what the barriers to the development of circular models may be.

Methods

The MCDA supports complex decision-making in situations where multiple (conflicting) goals can be assessed in a variety of ways. It incorporates data on how well each alternative performed (scoring criteria) and a subjective assessment of the applicability of particular criteria (weighting factor). This method appears to be widely applied in the literature to assess the performance of countries in terms of sustainability (Bączkiewicz and Kizielewicz, 2021; Colasante et al., 2022). The steps that characterise this method concerned first of all the definition of the research objective, which is represented in this study by the identification of an indicator on CE in Europe. To achieve this objective, the alternatives considered were the 27 European countries to which the European average was added as a benchmark. The alternatives need criteria in order to be evaluated. This CE indicator is dimensionless calculated for each European MSs and generated by the multiplication of a row vector (RV_{MS}) – representing a scoring criterion – and a column vector (CV) – representing a weighting factor.

$$\text{CE Indicator}_{MS} = RV_{MS} * CV * 100 \quad (1)$$

Therefore, in the second step, we had proceeded to identify suitable criteria to represent CE performance. The database provided by Eurostat, which is a powerful tool that makes available a multiplicity of data mainly on European countries, was useful in this direction (Korica et al., 2022; Zisopoulos et al., 2022). The data were obtained as follows on Eurostat's website: Data → Database → Data navigation tree → EU policies → CE indicators. Within

Table 1. List of categories and criteria.

Category	Acronyms	Criteria	Acronyms
Production and consumption	PC	Resource productivity	PC1
		Generation of MSW per capita	PC2
		Generation of packaging waste per capita	PC3
Waste management	WM	Recycling rate of municipal waste	WM1
		Recycling rate of packaging waste by type of packaging	WM2
		Recycling rate of waste of electrical and electronic equipment separately collected	WM3
Secondary raw materials	RM	Circular material use rate	RM1
		Trade in recyclable raw materials (imports)	RM2
		Trade in recyclable raw materials (exports)	RM3
Competitiveness and innovation	CI	Private investment and gross added value related to circular economy sectors	CI1
		Persons employed in circular economy sectors	CI2
		Patents related to recycling and secondary raw materials	CI3
Global sustainability and resilience	SR	Consumption footprint	SR1
		Greenhouse gases emissions from production activities	SR2
		Material import dependency	SR3

the CE indicators there are five categories: (i) PC; (ii) WM; (iii) Secondary RM; (iv) Competitiveness and Innovation (CI) and (v) Global Sustainability and Resilience (SR).

Within these categories, there were 22 indicators, from which we discarded a priori 'EU self-sufficiency for RMs (within SR category)' because it did not contain data for European countries.

The country evaluation phase can be done with the Analytic Hierarchy Process (AHP), where Saaty's method typically suggests having 7 ± 2 criteria (Saaty, 2008). In this way several criteria should be discarded; therefore, it is preferred in this study to use the local-global priority approach, which allows more criteria to be included (D'Adamo and Sassanelli, 2022). In this regard, it should be pointed out that in order to allow a fair comparison between criteria, it is suggested that the number of criteria populating the categories be the same. The category analysis had shown that there are three criteria for RM, CI and SR categories. In contrast, a larger number of criteria populated the other two categories, so it was necessary to identify an objective criterion that allowed for a fair comparison between the categories, but at the same time allowed for the robustness of the results obtained. At this point, it had become important to assess the time horizon of the values provided for these indicators. Data were missing for 2022, but even for 2021 there was no well-populated database, so the last two available years were considered: 2019 and 2020. This choice also served to allow a time comparison between countries. Through this approach, it was considered that 2019 data are missing for the indicator 'Recycling rate of all waste excluding major mineral waste' within WM category and so this indicator was discarded and three criteria are proposed also for this category. The same approach was used for PC category. In this way the following indicators were not considered: 'Waste generation per capita', 'Generation of waste excluding major mineral wastes per Gross Domestic Product (GDP) unit' and 'Food waste'. There were five indicators left available, and for the selection, the three criteria we had considered excluding two indicators that tended to be very similar to other indicators already considered: 'Generation of plastic packaging waste per capita' compared to the indicator 'Generation of packaging waste per capita' found in the same PC category and 'Material footprint' compared to the indicator 'Consumption footprint' found in SR category. Table 1 proposes the list of the 15 criteria divided into the 5 categories. A complete description of these indicators as proposed by Eurostat can be found in Supplemental Table S1.

Once the criteria had been determined, it was possible to proceed to the third step in which a weight was asked to be assigned to calculate the column vector. The CV was comprised of 15 rows, corresponding to the number of criteria. For example, c_{PC1} is the element of the vector column relative to resource productivity.

$$\mathrm{CV} = [c_{\mathrm{PC1}}\, c_{\mathrm{PC2}}\, c_{\mathrm{PC3}}\, c_{\mathrm{WM1}}\, c_{\mathrm{WM2}}\, c_{\mathrm{WM3}}\, c_{\mathrm{RM1}} c_{\mathrm{RM2}}\, c_{\mathrm{RM3}}\, c_{\mathrm{CI1}}\, c_{\mathrm{CI2}}\, c_{\mathrm{CI3}}\, c_{\mathrm{SR1}}\, c_{\mathrm{SR2}}\, c_{\mathrm{SR3}}]^T \tag{2}$$

By taking into account various decision-making factors and focusing computation from a large number of variables to a small number, it offers the best possible solution (Pophali et al., 2011). The methodology's only drawback is that discrete element analysis (e.g.) is not used to derive objective weights (Laso et al., 2018). AHP develops a weight for each criterion based on a pairwise comparison of all the criteria by the decision-makers. The more significant the criterion, the higher the weight (Awasthi et al., 2018).

The user's expertise in the relevant field will determine how well AHP works. To this end, 10 academics were selected from the Scopus database who had published works on CE with at least 10 years of experience (D'Adamo et al., 2022). However, useful approaches are also to include other categories of experts (Moktadir et al., 2020) or a mix of them (Tsui et al., 2021), so this represents a limitation of this work. For this study, an e-mail invitation was sent to a reasonable number of potential interviewees (Ladu et al., 2020), and the e-mail specified that only the first 10 would be selected. Contained within the email was the objective of the study and the methodology used. The selected panel consisted of 30% women and came mainly from Europe (Supplemental Table S2). All experts were given the chance to meet for up to an hour to discuss the criteria, and they were each sent an Excel file with the descriptions of the criteria and pairwise comparisons. According to Saaty (2008), during AHP, experts could provide a value between 1 (equally preferred) and 9 (extremely preferred) – Supplemental Table S3. Before sending the Excel file, experts were asked to check the value of the Consistency Ratio (CR), which could be a maximum of 0.10 and was automatically calculated in the file. CR was calculated as the ratio of the consistency index (obtained from $(\lambda_{max} - n)/(n-1)$ in which λ_{max} = highest eigenvalue (inner product of the row vector containing column sums and the eigen vector matrix) and n = number of factors) to the random inconsistency (Supplemental Table S4) – (Saaty, 2008).

In the fourth step, it was necessary to identify the value of the single alternatives for each criterion. The RV was comprised of 15 columns, corresponding to the number of criteria. For example, r_{PC1} is the element of the vector row relative to resource productivity.

$$RV_{(MS)} = [r_{PC1}\, r_{PC2}\, r_{PC3}\, r_{WM1}\, r_{WM2}\, r_{WM3}\, r_{RM1}\, r_{RM2}\, r_{RM3}\, r_{CI1} r_{CI2}\, r_{CI3}\, r_{SR1} r_{SR2} r_{SR3}] \quad (3)$$

The literature has already looked at how input data uncertainty affects a number of environmental assessment models (Beekhuizen et al., 2014). Particularly, results can be unreliable when there is a lack of homogeneity in the data. For this reason, as pointed out earlier, data from Eurostat had been used. Considering two reference years (2019–2020), 15 criteria and 28 alternatives 840 values were identified. However, where data were absent, the one corresponding to the most recent year was chosen (Castillo-Giménez et al., 2019). Thus, the number of data actually used was 92% of what was requested. In fact, on this percentage, it should be noted that for criterion CI3, data from all of 2020 were missing.

The criteria have different units of measurement (Supplemental Table S5), and in order to make the data comparable, they are normalised. In particular, the 0–1 approach associated with the weakest and best performance, respectively, among the different alternatives is used (Colasante et al., 2022). The other values are calculated through the interpolation model.

Results

The CE indicator is obtained from the product of the row vector and the column vector. In order to obtain the row vector, it is necessary to aggregate the different answers provided by the experts (section 'Aggregation of weights'). The next step is to aggregate the different assessments that have been collected on Eurostat (section 'Aggregation of values'). In this way, it is possible to calculate the CE indicator in both the baseline scenario (section 'Circular economy indicator – Baseline scenario') and the alternative scenario (section 'Circular economy indicator – Alternative scenario').

Aggregation of weights

The row vector is composed of the input provided by all experts (Supplemental Tables S6–S15). Once it was verified that all pairwise comparisons were robust and thus had a CR value that did not exceed 0.10. The first data collected were those for category priority – Table 2. It is worth noting that there is no correlation between the number of experts and the number reported in the different tables.

The results bring out that two categories have a weight of two-thirds of the total, so it emerges how the experts indicated a clear priority. In particular, the CI category prevails with 0.34 followed by the SR category with 0.33, and both were chosen as most relevant by five experts. It is worth noting how the experts in selecting the category also looked at the indicators that comprised them. Similarly, eight experts gave the least weight to the PC category with 0.08 while two experts gave it to the RM category with 0.11. A slightly higher value belongs to WM with 0.14.

The CE model is one that can support companies to achieve CI goals, but at the same time giving sustainable and resilient solutions as well. Thus, a complex system that is able to react to external changes, to a globalisation in which not only consumer preferences change but also the entry of new players into the market. Circular solutions may initially be an order qualifier, but they are destined to be an order winner. In fact, the balance of ecosystems requires suitable solutions for the appropriate use of resources. In this context, a complex goal cannot be achieved with only a few categories but by pursuing the help of all categories and exploiting any congruencies present among different indicators.

Once the category weights were aggregated, they proceeded to repeat the same operation with the different indicators within each category in order to calculate local priority (Table 3).

Regarding the PC category, the experts tend to give almost equal relevance to both PC2 with 0.40 and PC1 with 0.39. A choice in which the experts were equally divided. It emerges how twice as much relevance is given to municipal solid waste (MSW) as to packaging waste. The resource productivity criterion is considered not only relevant, but also hybrid with respect to CE goals since the term in the numerator refers to gross domestic product and the term in the denominator measures the amount of material used by an economy.

Regarding WM, again it emerges that two criteria tend to be chosen most. Specifically, six experts select WM1 as the most relevant with an average weight of 0.42, whereas four assign that priority to WM3, which receives an average weight of 0.38. Here, a result consistent with what was seen earlier emerges, thus a greater focus on MSW than packaging waste. Also consistent with the literature here as well, similar weight is given to e-waste compared to MSW. Recycling rate is considered an important element for the development of CE models, but nevertheless more attention is emphasised that should be given to the quality

Table 2. Aggregation of weights – category priority.

Categories	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	Avg
PC	0.09	0.11	0.08	0.08	0.07	0.05	0.11	0.06	0.07	0.11	**0.08**
WM	0.12	0.14	0.15	0.15	0.09	0.15	0.19	0.11	0.14	0.15	**0.14**
RM	0.07	0.19	0.11	0.11	0.12	0.12	0.14	0.09	0.10	0.08	**0.11**
CI	0.41	0.32	0.26	0.28	0.31	0.42	0.24	0.44	0.40	0.28	**0.34**
SR	0.31	0.24	0.40	0.37	0.41	0.27	0.32	0.29	0.30	0.37	**0.33**

Max weight Min weight. Average values are shown in bold.

Table 3. Aggregation of weights – local priority.

Criteria	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	Avg
Production and consumption											
PC1	0.49	0.49	0.31	0.31	0.49	0.31	0.49	0.49	0.31	0.20	**0.39**
PC2	0.31	0.31	0.49	0.49	0.31	0.49	0.31	0.31	0.49	0.49	**0.40**
PC3	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.31	**0.21**
Waste management											
WM1	0.49	0.49	0.31	0.31	0.49	0.49	0.31	0.49	0.31	0.49	**0.42**
WM2	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	**0.20**
WM3	0.31	0.31	0.49	0.49	0.31	0.31	0.49	0.31	0.49	0.31	**0.38**
Secondary raw materials											
RM1	0.49	0.49	0.49	0.31	0.49	0.49	0.49	0.31	0.49	0.20	**0.43**
RM2	0.31	0.31	0.20	0.20	0.20	0.31	0.31	0.49	0.31	0.31	**0.30**
RM3	0.20	0.20	0.31	0.49	0.31	0.20	0.20	0.20	0.20	0.49	**0.28**
Competitiveness and innovation											
CI1	0.49	0.49	0.49	0.31	0.49	0.49	0.49	0.31	0.49	0.49	**0.45**
CI2	0.31	0.31	0.20	0.49	0.31	0.31	0.31	0.49	0.31	0.31	**0.34**
CI3	0.20	0.20	0.31	0.20	0.20	0.20	0.20	0.20	0.20	0.20	**0.21**
Global sustainability and resilience											
SR1	0.20	0.49	0.31	0.31	0.49	0.49	0.49	0.31	0.31	0.20	**0.36**
SR2	0.31	0.31	0.49	0.49	0.20	0.31	0.31	0.49	0.49	0.31	**0.37**
SR3	0.49	0.20	0.20	0.20	0.31	0.20	0.20	0.20	0.20	0.49	**0.27**

Max weight Min weight. Average values are shown in bold.

of recycling collection, giving benefits to consumers who perform even more virtuous behaviour.

Unlike the previous categories, one criterion emerges in the second RMs over the other two. In fact, seven experts opt for RM1 with an average weight of 0.425. Similarly to what happened with PC1, this time before these judgements can also be present with opposite judgements. In fact, for one expert its weight is the least relevant. The difference in experts' know-how evidently influences such judgments. It also emerged that this criterion is considered to be directly related to one of the main outputs of the CE, namely the measurement of those recycled materials that are then fed back into a production cycle. It is therefore the emphasis on this activity that emerges and not the similarity between the other two criteria (trade in recyclable RMs) which is only apparent. In fact, RM2 is referred to imports (0.295), whereas RM3 to exports (0.28).

A scenario in terms of different results than the previous ones is manifested for the CI category. In fact, each criterion has a significant difference from another criterion. In particular, experts paid attention to the feature that all three criteria are strongly correlated with CE patterns. Particular attention is given to criterion CI1, with an average weight of 0.45 chosen as most relevant by eight experts. This criterion refers to three sectors: (i) the recycling, (ii) repair and reuse and (iii) rental and leasing. Two experts, on the other hand, gave greater relevance to CI2 (0.34) referring to the number of people impregnated related again to the above-mentioned sectors. Finally, it is pointed out that according to the experts, the other criterion CI3, with an average weight of 0.21, is also considered important, but in a pairwise comparison, the figure for patents of circular solutions comes out at a disadvantage.

Finally, the last category examined, relating to global SR, shows a situation similar to others in which two criteria are considered to be of almost equal importance. However, this is the only category where experts differed strongly in their results. Criterion SR1 is the most relevant by four experts with 0.36 as

Table 4. Global priority.

Criteria	Local priority	Ranking	Global priority	Ranking
Production and consumption (priority: 0.0847)				
PC1	0.390	2	0.0330	12
PC2	0.401	1	0.0340	10
PC3	0.209	3	0.0177	15
Waste management (priority: 0.1378)				
WM1	0.419	1	0.0577	7
WM2	0.198	3	0.0272	14
WM3	0.383	2	0.0528	8
Secondary raw materials (priority: 0.1127)				
RM1	0.425	1	0.0479	9
RM2	0.295	2	0.0333	11
RM3	0.279	3	0.0314	13
Competitiveness and innovation (priority: 0.3363)				
CI1	0.455	1	0.1530	1
CI2	0.336	2	0.1131	4
CI3	0.209	3	0.0703	6
Global sustainability and resilience (priority: 0.3286)				
SR1	0.360	2	0.1184	3
SR2	0.372	1	0.1222	2
SR3	0.268	3	0.0879	5

average weight and is slightly preceded by SR2 with 0.37 which is always opted as most relevant by four experts. Finally, the last two experts selected SR3 with 0.27. It also emerges that the lowest weight may have been assigned to all three criteria depending on the expert. The typically environmental figure for emissions turns out to be slightly more relevant than the consumption footprint, which estimates the environmental impact of five areas of consumption: food, mobility, housing, appliances and household goods. Thus, both have a strongly environmental connotation. These indicators are considered useful in assessing environmental impact, on which CE activities evidently influence only a part and are therefore indicators interpreted as more generic. Similarly, the material import dependency is seen, which measures precisely the import figure, resulting, however, in a different figure from the one proposed earlier.

The components of the row vector are shown in Table 4 where the global priority for each criterion is calculated as the product of the local priority of the specific criterion and its category priority. For example, criterion PC1 has a local priority of 0.390 and considering a category priority of 0.0847 yields the global priority of 0.0330. Similarly, criterion S3 has a local priority of 0.268 with a category priority of 0.3286 from which a global priority of 0.0879 is derived.

The results clearly show how the incidence of categories significantly influences the order of global ranking. The CI and SR categories have a weight of 0.6649 and the criteria in these two categories occupy the top six positions. Criterion CI1 excels with 0.1530 followed by SR2 and SR3 with 0.1222 and 0.1184, respectively. This indicates that in this local–global priority approach, the difference that exists between individual criteria also matters. The weight of CI is greater than SR, but the difference between the first two criteria is less in the SR category. The last three ranking positions see the presence of the last criterion in terms of local priority, which is found to be matched by the other three remaining categories, namely RM3, WM2 and PC3.

Aggregation of values

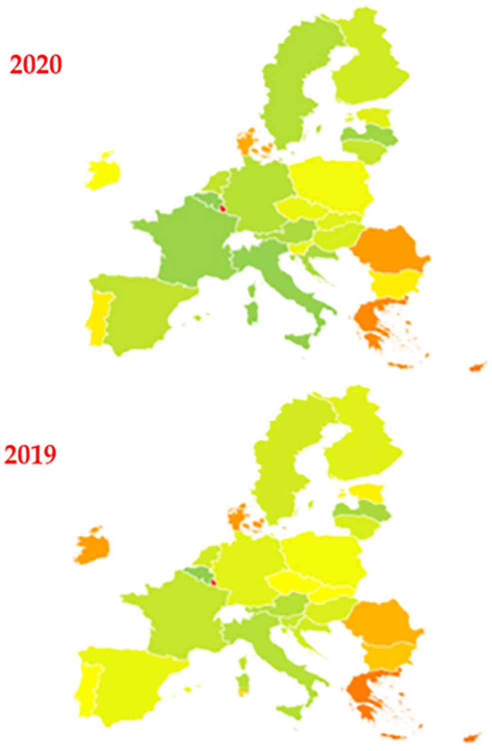
The column vector is calculated according to data from Eurostat. As explained in section 'Methods', all values are normalised with the range 0–1, and each criterion presents a specific value for the alternatives considered (27 EU countries). The analysis is repeated for the year 2019 (Supplemental Table S16) and for the year 2020 (Supplemental Table S17).

Analysis of the results shows that Belgium performs better than all in four criteria (WM2, RM2, RM3 and CI1), and this result is verified in both years examined. It is shown that this phenomenon is quite widespread in several other criteria, such as the Netherlands in criterion RM1, Sweden and Malta in criterion SR2, Romania in criterion PC2, Croatia in criterion PC3, Germany in criterion WM1, Croatia in criterion CI2, Finland in criterion CI3, Greece in criterion SR1 and Romania in criterion SR3. Variations in leadership occur in criterion WM3 with Croatia replacing Czechia and in criterion PC1 with the Netherlands replacing Luxembourg. Similarly, the negative performance recorded by some countries that turn out to occupy the last step in six criteria (Malta) and four criteria (Luxembourg) should be highlighted. Also appearing to be the worst in two criteria are Bulgaria, Greece and Romania (which in 2020 occupies the last position in three criteria). The results are objective since as mentioned in section 'Methods' in 92% are data extrapolated from Eurostat. In order to understand the normalisation value in the 0–1 range, we point out that a country's performance is evaluated by considering not only its own performance but also that of the best performing country. For example, the best performance with the most significant reduction is related to criterion CI2 in which the maximum value decreased from 3.5% to 3% Total employment. In contrast, the most significant reduction, but this time in positive terms, concerns criterion SR2 in which the minimum value decreased from 4261 to 3787 kgCO_2eq per capita. The same is also true for less performing values, and this affects the changes in the individual normalised values. In order to understand how many countries tend towards a high value, it is useful to calculate the concentration indicator (Supplemental Figure S1).

The criteria that overall have several countries with a high normalised value in 2020 are SR2 (0.67) and WM3 (0.66), followed by SR3 and SR1 with 0.64 and 0.61, respectively. In contrast, criterion RM2 (0.18) is where there is a greater concentration of countries towards weak performance. This is followed by criterion CI3 with 0.22.

CE indicator: Baseline scenario

The MCDA aims to compare different European countries in terms of CE, and this work introduced a new CE indicator in order to compare and monitor the performance of these countries



2020		2019	
Belgium	0.599	Belgium	0.635
Italy	0.595	Latvia	0.603
France	0.589	Italy	0.585
Latvia	0.581	Austria	0.585
Croatia	0.567	France	0.566
Austria	0.566	Slovenia	0.560
Sweden	0.557	Netherlands	0.547
Germany	0.555	Sweden	0.546
Spain	0.546	Croatia	0.546
Netherlands	0.543	Lithuania	0.538
Lithuania	0.537	Hungary	0.536
Finland	0.525	Finland	0.528
Hungary	0.517	Germany	0.525
Estonia	0.508	Spain	0.513
Slovakia	0.507	Poland	0.503
Slovenia	0.497	Czechia	0.488
Czechia	0.494	Portugal	0.488
Poland	0.486	Slovakia	0.484
Ireland	0.475	Estonia	0.478
Portugal	0.461	Bulgaria	0.453
Bulgaria	0.461	Romania	0.442
Denmark	0.428	Ireland	0.430
Romania	0.421	Denmark	0.426
Greece	0.411	Greece	0.409
Cyprus	0.403	Cyprus	0.405
Malta	0.387	Luxembourg	0.365
Luxembourg	0.341	Malta	0.336

Figure 1. CE indicator in the period 2019–2020 (Baseline scenario).

over time. In the baseline scenario, the weights are obtained from the AHP, whereas the values from Eurostat's normalisation process. The product of the column vector (Supplemental Tables S16–S17) and the row vector (Table 4) allows this indicator to be calculated for each alternative – Figure 1.

The ranking is led by Belgium, which has a value of 0.599 in 2020 and is just ahead of Italy (0.595), France (0.589) and Latvia (0.581). In 2019, Belgium also holds the record, albeit with a higher value (0.635). In order to understand these differences, they are analysed on a criterion-by-criterion basis (Supplemental Table S18). It emerges that on the one hand there is a decrease in the value related to not only criteria PC2 and SR1, but also WM1 which is not balanced by the increase in criterion CI2. Although Latvia has a high position in the ranking, it loses two positions compared to the 2019 figure. The contribution associated with criterion CI1 decreases and is offset by the increase in that for CI2. However, significant reductions are also verified for SR1. Instead, Italy gains one position in the ranking due to the contribution of CI2 and France due to that of the contribution of CI1. The comparison between the 2 years shows several variations and only four countries do not change their position. In terms of ranking, Spain and Estonia gain five positions and Croatia, Slovakia and Ireland also show an increase of three positions. The situation is diametrically opposite for the Netherlands, Poland and Portugal; however, the negative record belongs to Slovenia, which loses ten positions. In fact, if we analyse the numerical value, it is Slovenia that has the largest decrease (−0.0634) followed by Belgium (−0.0367) and Portugal (−0.0269). The country that, on the other hand, has the most significant increase is Malta (+0.0509) followed by Ireland (+0.0445) and Spain (+0.0326). Weak performances in multiple indicators lead Cyprus, Malta and Luxembourg to close the European ranking.

It is possible to conduct a disaggregation analysis at the category level to assess their contribution on the overall results – Supplemental Figure S2. It emerges that the SR category prevails in 22 countries. In contrast, Belgium, Denmark, Luxembourg, Malta and Netherlands see the CI category prevail. The combined weight of the two categories impacts 58% of Luxembourg's final value and 93% of Malta's.

CE indicator: Alternative scenario

In order to give robustness to the results obtained, an alternative scenario is considered. The values have an objective nature and therefore are not changed, whereas the weights were assigned by means of the AHP. An alternative scenario can be considered in which all criteria have equal importance and thus the row vector will no longer be composed of what is shown in Table 3 (Figure 2). Thus, if in the baseline scenario the PC3 criterion weighed 0.0177 and the CI1 criterion 0.1530, in this alternative both will have a weight of 0.0667.

The results show that between 2019 and 2020, the ranking positions remain identical in only four cases, including Belgium confirming its leadership followed by the Netherlands and Malta closing the ranking. When evaluating the alternative scenario, it is useful to compare the performance and ranking position with the baseline scenario – Table 5.

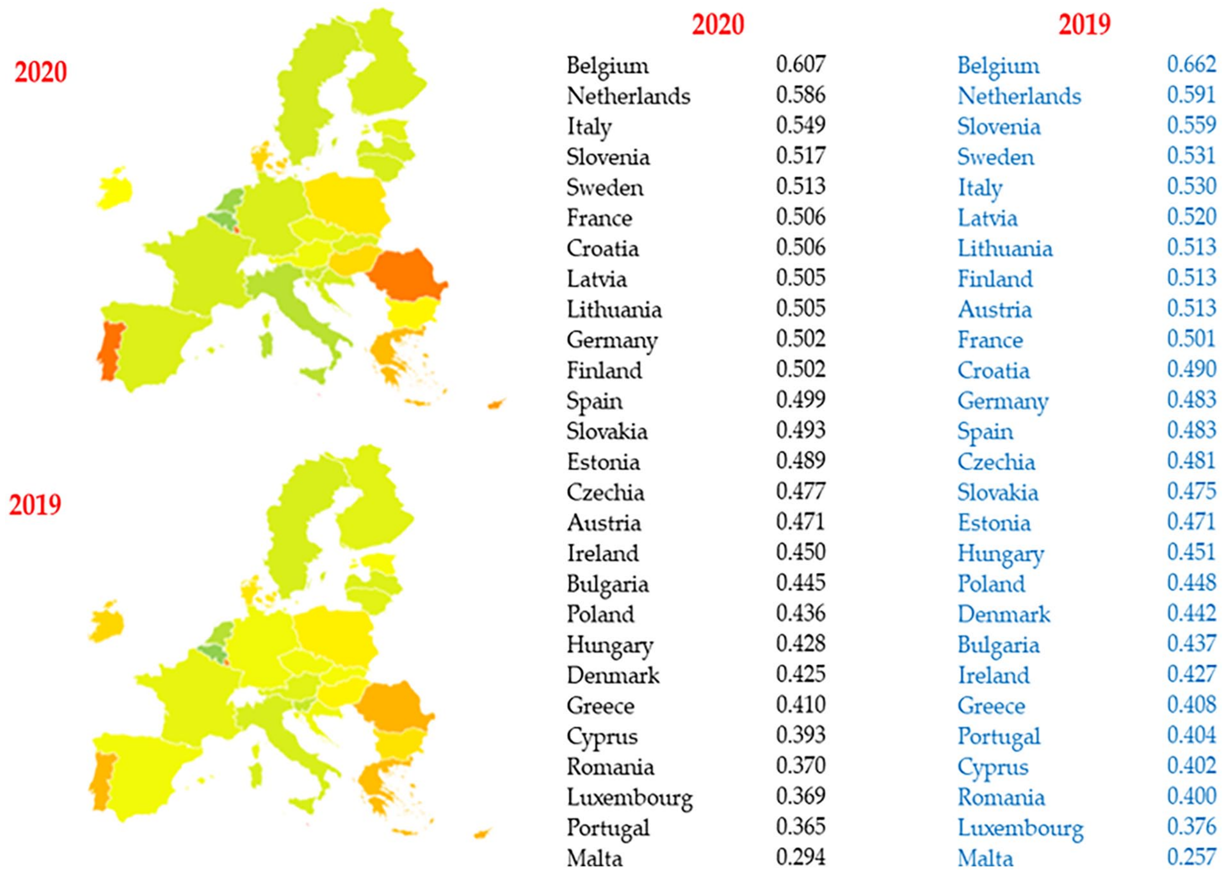


Figure 2. CE indicator in the period 2019–2020 (Alternative scenario).

Table 5. Summary circular economy indicator.

Baseline Rkg	Country	Baseline value	Alternative value	Δ Alternative-baseline value	Δ Alternative-baseline Rkg
1	Belgium	0.599	0.607	0.008	0
2	Italy	0.595	0.549	−0.046	−1
3	France	0.589	0.506	−0.083	−3
4	Latvia	0.581	0.505	−0.075	−4
5	Croatia	0.567	0.506	−0.061	−2
6	Austria	0.566	0.471	−0.095	−10
7	Sweden	0.557	0.513	−0.044	2
8	Germany	0.555	0.502	−0.052	−2
9	Spain	0.546	0.499	−0.047	−3
10	Netherlands	0.543	0.586	0.044	8
11	Lithuania	0.537	0.505	−0.032	2
12	Finland	0.525	0.502	−0.023	1
13	Hungary	0.517	0.428	−0.088	−7
14	Estonia	0.508	0.489	−0.019	0
15	Slovakia	0.507	0.493	−0.014	2
16	Slovenia	0.497	0.517	0.021	12
17	Czechia	0.494	0.477	−0.017	2
18	Poland	0.486	0.436	−0.050	−1
19	Ireland	0.475	0.450	−0.025	2
20	Portugal	0.461	0.365	−0.096	−6
21	Bulgaria	0.461	0.445	−0.016	3
22	Denmark	0.428	0.425	−0.003	1
23	Romania	0.421	0.370	−0.051	−1
24	Greece	0.411	0.410	−0.001	2
25	Cyprus	0.403	0.393	−0.011	2
26	Malta	0.387	0.294	−0.093	−1
27	Luxembourg	0.341	0.369	0.028	2

Besides Belgium, whose value increases by 0.008, the only other country that does not change its position is Estonia placed 14th. Italy loses one position but remains on the podium, while it is the Netherlands that gains well by placing second. France, on the other hand, falls off the podium. The comparison between the alternative and baseline scenarios shows that the value of Austria, Portugal and Malta decreases more than 0.09, whereas it is the Netherlands that has the greatest growth with a value of more than 0.04. In terms of ranking, Slovenia stands out, rising to the edge of the podium by gaining 12 positions, whereas it is Austria that marks the steepest decline by losing 10 positions. The alternative scenario gives greater weight to the three categories (PC, WM and RM) that perform the least in the AHP. Thus, those who excel in these criteria improve their rankings and likewise the better performance associated with those who perform well in the CI and SR categories is reduced.

Again, to understand this figure, it is useful to propose disaggregation analysis – Supplemental Figure S3.

The SR category remains the most relevant, but only in 15 of the 27 countries surveyed. The reason for this is the largest concentration indicator concerning the three related criteria – Figure 1. For the same reason, it is the largest in the WM category for nine countries (Czechia, Denmark, Germany, Italy, Luxembourg, Austria, Slovenia, Slovakia and Finland). Finally, the RM category prevails for the first two countries in the alternative ranking (Belgium and Netherlands) and the CI category in Malta.

Discussion

The CE is a model in which the aim is to give value to waste that can be fed back into the production cycle. The literature has highlighted how relevant the issue of end-of-waste is and how this is not always easy to define (Antoniou and Zorpas, 2019; D'Adamo et al., 2022; Papamichael and Zorpas, 2022). There are three aspects that undermine effective resource management. The first concerns illegal waste, which may contain toxic and hazardous substances that would require significant costs to be properly managed, pushing some firms to opt for unsuitable management paths. The second is the lack of expertise on the subject where it is not understood that we need to think about the end of life of the product not at the end of its useful life but at the beginning, and we also need to have professionals who are familiar with the technological resources that can deal with this waste and promote research and development programmes to find solutions. The third is the sharing of value to be distributed among the different categories of stakeholders in order to understand that we need to reward the actions of citizens by thinking no longer of the concept of separate collection but of that of good separate collection capable of reducing impurities and thus of proper WM.

In this framework, one cannot think that all waste can be reused and recycled, and sometimes recovery is an action to be taken if this means avoiding waste going to landfill according to the waste hierarchy (Lombardi et al., 2021; Quicker et al., 2020; Shooshtarian et al., 2022). In a context where the RMs most in demand for sustainable development are not concentrated in Europe, the CE model could be a strategy to reduce foreign dependence. However, this is possible when RMs are obtained whose degree of purity does not compromise the functionality of products, and these RMs become substitutes for those that originate from the extraction of RMs. The risk of CE rebound is an incorrect sustainable approach in which circular models are implemented, but then no change in consumption patterns follows (Caferra et al., 2023; Kirchherr, 2022).

The relationship between the different criteria proposed in this work can be explored by means of a correlation matrix in which an average value emerges for the following relationships (Supplemental Table S19): PC1–PC3, WM1–WM2, RM2–RM3 and PC1–RM1. The correlation coefficient varies between 0.63 and 0.67 and becomes 0.75 for the variables PC1–SR3. This clearly identifies a relationship between the gross domestic product and the import dependency of materials. The use of recovered materials could help reduce Europe's dependence on imported RMs, improving security of supply and reducing the environmental impact associated with extracting and transporting these resources. This could also lead to greater economic stability and reduced vulnerabilities to global RM price fluctuations (D'Adamo et al., 2023b; Romano et al., 2022). An equally interesting aspect to examine is the behaviour that both citizens and companies could adopt to successfully promote the transition to the circular model. On the one hand, citizens could contribute significantly to the change by supporting recycling and the purchase of circular products. On the other hand, some firms might have to deeply review their business model to successfully adapt to this new perspective. Moreover, the latter promote the creation of new jobs.

To this end, a balanced scorecard approach is useful for assessing the contribution of different factors (Ioppolo et al., 2012) in order to develop a strategic plan towards sustainable development (Zorpas et al., 2018) in a context where reshoring and nearshoring are key to identifying a resilient solution (Fernández-Miguel et al., 2022). The study's primary goal is to conduct an aggregate assessment of the degree of CE advancement in the European nations. We used MCDA to express this level using the Eurostat indicators that are currently available for the Europe zone. But the present study is not perfect and can be improved. The small number of indicators, especially in the CI domains, is a study limitation. The absence of indicators for the social component of CE is another drawback. Future developments of the Eurostat database or the use of other current databases, such as those maintained by the World Bank or the OECD, may be able to remove these restrictions. Nevertheless, certain data pertaining to CE indicators for some EU member states are absent from these databases. Moreover, when indicators are observable in all data bases, the values are often unfortunately discordant. For this reason, it was decided to use a single source (Eurostat) considering a smaller but significant number of indicators. As the European Commission has recently approved several ambitious policies and practices related to the implementation of the CE and to measure its advancement, we think that in the future the database on CE indicators will be much larger and more comprehensive.

Conclusions

The CE can be supportive of sustainable development, and this is the direction in which the experts' judgements in the elaboration of the AHP point. The results obtained from the local–global approach identify a relevance ranking among the 15 indicators proposed by Eurostat. The role of the category priority greatly affects the final value since the two categories 'CI' and 'global SR' account for two-thirds of the weight, and the respective criteria occupy the first six positions in the global ranking. The criterion 'private investment and gross added value related to CE sectors' is the one that prevails and highlights that sustainability is not a happy degrowth as it must aim at a change in both PC habits. In a context of resource scarcity, one must optimise one's use and recover these RMs where they have already been used. Investment in these technologies is needed in this direction. However, the CE model is not only about protecting the environment, but is geared towards creating economic opportunities, so it must be monitored whether the investment produces wealth. In this respect, the presence of critical and/or valuable materials makes a project profitable. However, this change does not only affect the firms called upon to implement such projects but also involves the consumers who deliver products to the appropriate places. The common goal is to minimise the use of landfill and to opt among circular solutions for the one that is the most sustainable. Thus, the first limitation highlighted by this work is that there can be more than one option within circular models and that life cycle analyses of all three components of sustainability are needed.

The results of the MCDA highlighted the performance of European countries where important performances emerge for Western European countries, whereas Eastern European countries lag behind. The leading country is Belgium in both the baseline and alternative scenarios for both years examined. At a very close distance are Italy, France and Latvia in the baseline scenario, which thus perform very well in 2020. In the alternative scenario, where the 15 starting indicators all have the same relevance, it is the Netherlands that occupies second place in the ranking ahead of Italy. These results show how the chosen methodology is able to propose different results since only two of the 27 countries hold the same position in the ranking. Here, the second limitation of the work emerges, as other categories of stakeholders could be involved by providing a broader view and also determining different weights.

The implications of this work indicate that the circularity performance within European countries is very different, calling for more collaboration to achieve technology neutrality in terms of emissions and resource circularity. The goal cannot only be to be an emission-neutral continent, but to have companies and citizens be part of this change. For this to happen, in our view, three limits must be overcome:

1. The reduction of illegal waste in order to apply the principles not only of prevention but also those of proximity.
2. Greater investment in circular technologies by investing in human capital and promoting the development of start-ups and youth-led small- and medium-sized enterprises.
3. A more sustainable distribution of the benefits obtained from circular models to the different categories of stakeholders.

This study needs to be replicated over the years to monitor the performance of European countries and can be extended globally because the goal of sustainability can only be achieved through the contribution of all countries.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study was carried out within the PEACE (Protecting the Environment: Advances in CE) which received funding from the 'Fondo per il Programma Nazionale di Ricerca e Progetti di Rilevante Interesse Nazionale (PRIN)' Investimento 1.1-D.D. 104.02-02-2022, 2022ZFBMA4 funded by the European Union – Next-Generation EU. This manuscript reflects only the authors' views and opinions, and can be considered responsible for them.

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Supplemental material

Supplemental material for this article is available online.

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