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Measuring the circular economy in Europe: Big differences among countries, great opportunities to converge

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Abstract

The main aim of this article is to analyze the circular economy (CE) transition of European countries between 2014 and 2021, using the European Commission approach of production and consumption, waste management, secondary raw materials, and competitiveness and innovation. To do so, we have built a multidimensional Circular Economy Index that classifies European countries according to their progress towards a circular economy. We used data from the Eurostat database and extracted all circular economy indicators for the EU27 countries plus Liechtenstein, Norway, Switzerland, the United Kingdom, and Iceland. The time series starts in 2014 and ends in 2021 and we have used 15 variables grouped in four dimensions by means of a second order factor analysis with a Promax rotation. We have also applied a hierarchical cluster analysis to group countries by circular economy performance. Our results suggest an improvement in circular economy performance between 2014 and 2021 in Europe. We likewise find there is a 'four-speed Europe' in terms of a circular economy, highlighting the good results of the Netherlands, Germany, Italy, and Belgium.

KEYWORDS
circular economy, Europe, indicators

1 | INTRODUCTION

The linear economy model extracts resources and obtains production and consumer goods with a "take-make-dispose" system (Merli, Preziosi & Acampora, 2018). This model in industrialized nations achieved significant success in material wealth generation until the twentieth century, but its sustainability is questionable (Sariatli, 2017). Not only does it pose environmental harm, but it lacks the capability to meet the resource demands of a growing global population without making substantial changes to the underlying economic paradigm. The linear economy model massively consumes non-renewable resources that exceed the earth's carrying capacity (Lieder & Rashid, 2016; Steffen et al., 2015). The need to find a model of growth that is more sustainable has led to the debate about other models like the Circular Economy (CE).

This model provides a promising alternative to the traditional linear economy model because it helps to reduce resource consumption and overexploitation and has a positive effect on the planet's ecosystems (Ghosh, 2020). The CE encourages the reduction of virgin materials and the adoption of clean technologies which will bring benefits not only by using the environment a reservoir for waste also as it entails limiting or reducing the use of depleting materials in production processes (Andersen, 1997, 1999, 2007).

The concept of a Circular Economy was coined by the environmental economists Pearce and Turner in 1990 with the idea of showing that the environment is a fundamental system of life support and not just a provider of resources. The circular economy model decouples economic growth from resource use and not only makes the economy more sustainable but also more competitive by using resources more efficiently. In recent years, attention to this model has increased in the scientific literature and in governments, companies, and the public.

To accelerate the transition to a circular economy, many policies have been approved around the world, many circular businesses have been launched, and many scientific papers have been published. However, now we also need to measure the results to determine the progress towards a CE. Indicators are required to provide us with information on the results of the measures that have been applied to encourage the transition towards this model. While there is no consensus on a singular definition of the Circular Economy (CE), there is a unanimous recognition of the necessity to utilize CE-related indicators to guide and bolster progress in the circular economy (Moraga et al., 2019; Saidani et al., 2019). While there are many circular economy indicators, there are no standardized metrics used for measuring EC-focused strategies, which differ between country and region (De Pascale et al., 2021).

In the European Union, CE is a priority and part of the EU's industrial strategy ever since it developed an action plan in 2015 to support the transition to a Circular Economy (European Commission, 2015b; Hartley et al., 2020; Mazur-Wierzbicka, 2021a; Ūsas et al., 2021). The plan, included in the document 'Closing the loop—an EU Action Plan for the Circular Economy', recognizes that the goal is to achieve a more sustainable and competitive economy, create new jobs through the CE, and incorporate recommendations for actions to be undertaken within the European Union in the upcoming years.

The need to monitor the progress in implementing circular economy is fundamental but it is not an easy task for several reasons. Firstly, there are no universally accepted set of indicators (European Environmental Agency, 2016). Secondly, there is variation in indicator systems used by different organizations, countries, and researchers, making it challenging to facilitate comparisons between countries or regions (De Pascale et al., 2021).

The European Commission has emphasized the importance of monitoring progress towards a circular economy, leading to the development of a comprehensive set of ten indicators, some of which are further subdivided into sub-indicators. These indicators can be categorized into four dimensions: production and consumption, waste management, secondary raw materials, and competitiveness and innovation. These indicators are designed to assess the progress of initiatives directed towards the transition to CE across all phases of the life cycle of raw materials, goods and services. They also encompass aspects related to innovation and competitiveness.

The main aim of this research paper is to build a multidimensional circular economy index (CEI) to analyze the circular economy performance between 2014 and 2021 in the European countries. Based on the European Commission approach, we study the production and consumption, waste management, secondary raw materials, and competitiveness and innovation related to circular economy in Europe. The first specific goal is to construct a synthetic indicator to measure the circular economy; the second one is to create groups of European countries by CE performance; and the third one is to identify some best practices that may be extended to other European countries. The results offer an opportunity to boost the CEI performance by country and to advance the convergence across economies.

The contribution of this research article is two-fold. First, we applied two multivariate analytical techniques of interdependence: (1) a second order factor analysis with a non-orthogonal rotation (Promax) and (2) a hierarchical cluster analysis using Euclidean distance and intergroup linkages. This combination of these specific methods has not been implemented before, at least so far as we know, to build a circular economy index and to compare the performance of European countries. Secondly, we offer a cross-sectional data comparison (2014 vs. 2021) to assess the circular economy by country before and after the first circular economy action plan launched by the European Commission in 2015. This analysis allows us to identify opportunities of convergence among countries.

The rest of the paper is organized into five sections. First, we present the literature review. Second, we describe the methodology used in the paper. The third section presents the main empirical results of the study. Then we discuss our results and include some concluding comments.

2 | LITERATURE REVIEW

The concern about the massive consumption of resources and the environmental damage caused by monocultures and the excessive use of toxic substances was revealed in 1962 with the publication of the book 'Silent Spring' (Carson, 1962). Since then, concern for sustainability has only grown. Sustainability has been approached from social, environmental, and economic perspectives since the Brundtland report defined sustainable development in 1987 as "… development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, p. 43). Mebratu (1998) showed that environmental sustainability affects both social sustainability and economic sustainability, while Lozano (2008) incorporated the dimension of time and the need to differentiate between short, medium, and long-term actions. In this time, all economic agents have initiated actions to ensure sustainability.

The need to secure the possibilities available to future generations has raised questions on the linear model of industrial production. The "take-make-dispose" system extracts resources, obtains production, and consumes the goods (Merli, Preziosi & Acampora, 2018). However, this model massively consumes non-renewable resources, produces short-lived goods, and generates an abundant amount of waste. This is incompatible with the commitment to sustainability and therefore the commitment to another model such as the one proposed by the Circular Economy (CE) (see Table 1). Comparative studies between the Linear and Circular models have since been approached from different perspectives. Some of these studies underscore the limitations of the linear model and the advantages offered

TABLE 1 Summary of previous studies on circular economy and indicators in Europe.

Issues	Authors	Years of publication	Keywords
Comparison Linear-Circular Economy	Sariatli; Didenko, Klochkov and Skripnuk; Sharma, Govindan, Lai, Chen & Kumar; Neves and Marques; Kirchherr, Piscicelli, Bour, Kostense-Smit, Muller, Huibrechtse-Truijens & Hekkert.	2017–2022	Circular economy; linear economy; environment; sustainability; barriers.
Circular Economy definition	Rizos, Tuokko & Behrens; Geisendorf and Pietrulla; Kirchherr, Reike & Hekkert; Awan, Kanwal & Bhutta; Nobre and Tavares; Piscicelli, Bour, Kostense-Smit, Muller, Huibrechtse-Truijens & Hekkert; Prieto-Sandoval, Jaca & Ormazabal; Korhonen, Nuur, Feldmann and Birkie; Korhonen, Honkasalo and Seppälä; Alhawari, Awan, Bhutta & Ülkü.	2017–2021	Definitions; circular economy; 4R framework; sustainable development.
Circular Economy and Sustainability	D'Amato; Corvellec, Böhm, Stowell & Valenzuela; Winans, Kendall & Deng; Ghisellini, Cialani & Ulgiati; Su, Geng & Yu; Hysa, Kruja, Rehman & Laurenti; Chen, Kim, Pan, Tseng, Lin & Chiang; Schöggl, Stumpf and Baumgartner; Kravchenko, McAloone and Pigosso; Schroeder, Anggraeni & Weber; Fatimah, Govindan, Murniningsih & Setiawan; Panchal, Singh, & Diwan; Belmonte-Ureña, Plaza-Úbeda, Vazquez-Brust & Yakovleva.	2013–2021	Sustainability; sustainable development; Sustainable development goals (SDG's); Waste management; circular economy; environmental indicators/policy.
CE monitor, indicators	Kristensen and Mosgaard; Saidani, Yannou, Leroy, Cluzel & Kendall; Reich, Vermeyen, Alaerts & Van Acker; Potting, Hekkert, Worrell & Hanemaaijer; Azevedo, Godina & Matias; Bocken, Olivetti, Cullen, Potting & Lifset; Linder, Sarasini & van Loon.	2017–2023	Circular economy; indicator; sustainability; circularity indicators; circularity assessment.
Micro/Macro studies	Wiebe, Harsdorff, Montt, Simas & Wood; Alonso-Almeida and Rodríguez-Antón; Mazur-Wierzbicka; Aguilar-Hernández; Rodrigues and Tukker; Potting, Hekkert, Worrell & Hanemaaijer; Ghisellini & Ulgiati; Moraga, Huysveld, Mathieux, Blengini, Alaerts, Van Acker & Dewulf; Silvestri, Spigarelli and Tassinari; de Oliveira and Oliveira; European Commission; Halog & Anieke.	2016–2023	Global circular economy; EU countries; business models, sustainable innovation; circular economy.
CE progress at EU level	Loonela and Stoycheva; Mazur-Wierzbicka; Friant, Vermeulen & Salomone; Kirchherr, Piscicelli, Bour, Kostense-Smit, Muller, Huibrechtse-Truijens & Hekkert; Hartley, van Santenb & Kirchherr; Mhatre, Panchal, Singh & Bibyan; European Commission, European Parliament.	2018–2023	Circular economy; EU countries; European Union; sustainability; public policy

by the Circular Economy (Sariatli, 2017). Others, such as Didenko, Klochkov & Skripnuk, (2018) have used econometric models to study the environmental impact of the linear economy, obtaining a model that describes it. Sharma, Govindan, Lai, Chen & Kumar (2021), Neves and Marques (2022) and Kirchherr, Reike & Hekkert (2018), among others, focus on the transition from one model to another, highlighting the barriers and impediments to this process.

Although the concept was coined by the environmental economists Pearce and Turner in 1990, over the years this model has received increasing attention in the literature and by governments and economic agents. In recent years, the scientific literature on circular economy definitions has increased (Awan et al., 2020; Geisendorf & Pietrulla, 2018; Kirchherr et al., 2017; Nobre & Tavares, 2021; Rizos et al., 2017). Some authors have proposed a consensus on the definition of what a CE is (Kirchherr et al., 2017; Prieto-Sandoval et al., 2018) but there are others who consider that no single consensus—and thereby definition—can be found (Korhonen, Honkasalo, & Seppälä, 2018; Korhonen, Nuur, et al., 2018). The most comprehensive definition is provided in the work of Kirchherr et al. (2017), where an analysis of 114 definitions of the Circular Economy resulted in a meta-definition, which describes CE as an economic system that changes the "end-of life" characteristics of the linear economy, by reducing, reusing, recycling materials and resources in the production and consumption processes to accomplish sustainable development and beneficial to the future generations. Although there are some differences in the definitions of CE, it can be said that a CE is a set of practices that seeks to ensure that products can be used for as long as possible, even after the end of their useful life (Alhawari et al., 2021).

With the impetus of the creation of the Ellen MacArthur Foundation in 2010, the transition to a Circular Economy as an instrument of sustainability has been posed as a challenge (Corvellec et al., 2020; D'Amato, 2021; Ghisellini et al., 2016; Su et al., 2013; Winans et al., 2017). Some papers have shown that a CE provides instruments through which to achieve several sustainable development goals (Chen et al., 2020; Hysa et al., 2020; Kravchenko et al., 2019; Schöggl et al., 2020; Schroeder et al., 2018) while others affirm that the ultimate goal of a CE is to achieve sustainable development (Belmonte-Ureña et al., 2021; Fatimah et al., 2020; Panchal et al., 2021; Schroeder et al., 2019). The analysis of a CE can be carried out at the level of microproducts, companies, consumers (micro), eco-industrial parks (meso), and the city, region, and nation (macro). Despite the growth of scientific knowledge (Aguilar-Hernandez et al., 2021; Alonso-Almeida & Rodríguez-Antón, 2020; Mazur-Wierzbicka, 2021b; Wiebe et al., 2019), studies at the macro level are necessary because they are the least represented in scholarly publications.

The Circular Economy is strongly driven by the European Commission. In 2015, the EC adopted an action plan to support the transition to Circular Economy (European Commission, 2015a). The goal was to make the economy more sustainable and competitive and to create new jobs. To do this, it was necessary to ensure that the products, materials, and resources from one product cycle are incorporated into another product cycle at the end of their use. In this plan, the European Commission recognized the need for circularity indicators to monitor the progress towards a circular economy. The EC started to elaborate on a set of ten indicators, some of which are broken down into sub-indicators, to measure the transition to a CE in the EU as a whole and in member states.

In December 2019, the European Commission presented the Green Deal that included a strengthened circular economy strategy with the goal of contributing to a more sustainable economy and society in the European Union (European Commission, 2019); in 2020, it adopted the New Circular Economy Action Plan to ensure that any resources used are kept for as long as possible in EU countries (Loonela & Stoycheva, 2020). In 2021, the European Parliament adopted a resolution on the new circular economy action plan to achieve a fully circular economy by 2050 (European Parliament, 2021). In March 2022, the European Commission released the first package of measures to accelerate advancement towards a circular economy (European Commission, 2022a) and in November 2022, it proposed new EU-wide rules on packaging to reduce packaging waste (European Commission, 2022b).

Many works have analyzed the progress of CE at the European Union level. For example, Mazur-Wierzbicka (2021a, 2021b) studies the progress towards CE in the EU countries in the period 2010–2018. Others works focus on the CE policies by the EU and compare them with the real actions implemented in this region (Friant et al., 2021; Kirchherr et al., 2018). Hartley et al. (2020) present a set of CE policy recommendations based on interviews with public and private actors who focus on their expectations of the circular economy. Other papers analyze the implementation of circular practices in the EU through a systematic literature review on the circular economy progress (Mhatre et al., 2021).

Following the implementation of measures to move towards the CE, the next step is to monitor this progress. Thus, it is necessary to have indicators that allow us to evaluate the results obtained, even though there is no single way to measure a circular economy (Kristensen & Mosgaard, 2020). The indicators are needed to achieve a deeper understanding and integration of the CE. Although the literature shows an increase in the number of works on circularity indicators in recent years, there is still an insufficient number of studies on them. We can find works that have performed a taxonomy of CE indicators (Saidani et al., 2019), studied the indicators to measure the progress of the transition towards a CE (Azevedo et al., 2017; Potting et al., 2016; Reich et al., 2023), measured circularity in companies and economies (Bocken et al., 2017), and measured circularity at the product level (Linder et al., 2017). Some research articles focus on CE progress indicators at the country level (Ghisellini & Ulgiati, 2020; Potting et al., 2016) or at the regional level, in particular at the European Union level (Moraga et al., 2019; Silvestri et al., 2020). Other papers examine whether circularity indicators can effectively assess the three pillars of sustainability at the nano and micro levels, with the aim of identifying potential gaps (de Oliveira & Oliveira, 2023).

The European Commission has underscored the significance of monitoring progress towards a circular economy, resulting in the creation of an extensive set of ten indicators (European Commission, 2018). Considering the impressive adoption of measures in the CE to speed up the transition to a circular economy in the EU, as well as macro-level studies being the least represented in scholarly publications, it was determined necessary to carry out a study concerning a Circular Economy Index able to classify the EU countries according to their progression towards a circular economy. This map of European countries, organized by Circular Economy performance, will be noteworthy not only to find out the differences between the countries but also to recommend policy measures to determine the convergence from lower to higher levels of CE. Meanwhile, learning of what the good practices are among countries will be key.

3 | METHODOLOGY

3.1 | Data

We used data from the Eurostat database, the statistical office of the European Union. We extracted all circular economy indicators that were published yearly for the different European countries (all EU27s plus Liechtenstein, Norway, Switzerland, the United Kingdom, and Iceland). The time series started in 2001 and ended in 2021; however, we focused on a cross-sectional data comparison (2014 vs. 2021) for two main reasons: (1) there are numerous missing values before 2014, making it difficult to compare figures and countries, and (2) we selected a before and after criteria to evaluate the circular economy situation, considering the first circular economy action plan launched by the European Commission (2015a, 2015b). As aforementioned, the plan from 2015 included measures to boost Europe's transition towards a circular economy, to increase global competitiveness, to encourage sustainable economic growth, and to generate new jobs.

3.2 | Variables

To build the Circular Economy Index (CEI), we used 15 variables grouped into four dimensions that were integrated into the final index. These variables are set and published by Eurostat. Table 2 presents the definition of each variable.

3.2.1 | Descriptive analysis

The 15 variables used to construct the CEI do not maintain the same relationship with the circular economy development. In Table 3, the variables that present a negative association with CE show that the lower the value, the better for the circular economy; and the variables with a positive connection indicate that the higher the value, the better for the circular economy.

Table 3 also displays the behavior of each variable in 2014 and 2021. Almost all indicators show a minimum of 0 (2014 and 2021), except for the trade in recyclable raw materials. The maximum increases are found between 2014 and 2021 for all variables excluding material footprint and the recycling rate of e-waste.

The mean rises between 2014 and 2021 for all indicators, except for private investment and patents. The mean rising should be interpretated cautiously, because in some cases might provoke a decrease in circular economy development. For example, the material footprint goes up from 14.61 to 16.33 tons per capita, but it is not beneficial for the circular economy.

Through this table, we appreciate a boost in CE due to the enhancement in resource productivity, recycling of waste, recovery rate of construction and demolition waste, circular material use rate, and trade in recyclable raw materials (see green arrows). Nonetheless, we observe a worsening in CE mainly because of an increase in material footprint and generation of waste, but also by the decline in private investments and patents related to recycling and secondary raw materials (see red arrows).

Finally, the scatter is high in 2014 and 2021, which implies CE inequality among the sampled countries.

3.3 | Multivariate techniques applied

3.3.1 | Factor analysis

To aggregate the 15 variables for building the Circular Economy Index (CEI), we applied a second order factor analysis (principal component) with a Promax rotation (non-orthogonal rotation). The reason why we choose this kind of rotation lies in the certain correlation generated among the dimensions concerning what is typical for the social and economic variables. The factor analysis focused on elaborating on the latent variable by reducing the dimensions.

To apply the factor analysis, we considered our series of variables (X_1, X_2, ... X_{15}) in our group of observations and we calculated from them a new set of variables F_1, F_2 ..., F_p, which are slightly correlated and the variances of which progressively decrease. Each F_j (where $j = 1, \dots p$) is a linear combination of the original X_1, X_2, ... X_{15}, that is:

$$F_j = a_{j1}X_1 + a_{j2}X_2 + \dots + a_{j21}X_{15}$$

where a'_j is a vector of constants.

Factor analysis has been broadly used to construct indicators (Grupp & Mogee, 2004; Kodama, 1987; Niwa, 1995; Poza & Monge, 2020) because it allows researchers to build multivariate indexes by means of linear combinations with non-arbitrary weights (Munda & Nando, 2005). According to this technique, we were able to identify the most important variables through the original correlation matrix. Diebold (2000) pointed out that the principal component methods are rather more sophisticated, not requiring a sharp "in" or "out" decision for each variable and instead allowing all variables to contribute to an extraction or forecast. In other words, as composite scores and country rank positions can vary considerably depending on the selection process (Grupp & Mogee, 2004), the use of scoreboards leaves room for manipulation in the policymaking system. Thus, this technique avoids any interference of researchers' bias. It is based on the principle to let data speak for themselves (Gould, 1981).

Moreover, factor analysis is useful not only for generating weights, but also for condensing information. According to Hair et al. (2007), factor analysis is a statistic approximation that may be applied to analyze interrelationships among a big number of variables and explain these variables in terms of their core dimensions (called factors). The aim is to find the way of condensing all the information contained in the original variables into a fewer number of variables (factors) with a little loss of information.

Considering that we start with a matrix of 480 cells (15 variables by 32 countries), factor analysis becomes essential to reduce information and make key conclusions.

3.3.2 | Cluster analysis

Cluster analysis is an interdependence technique that consists of classifying observations into groups that are not known a priori by the

TABLE 2 Variables to build the CEI.

N	Variables	Eurostat's definitions
1	Material footprint (Tons per capita)	The indicator quantifies the worldwide demand for material extractions (biomass, metal ores, non-metallic minerals, and fossil energy materials/carriers) triggered by consumption and investment by households, governments, and businesses in the EU.
2	Resource productivity (Euro per kg, chain linked volumes 2015)	The indicator is defined as the gross domestic product (GDP) divided by domestic material consumption (DMC). DMC measures the total amount of material directly used by an economy.
3	Generation of municipal waste per capita (Kg per capita)	The indicator measures the waste collected by or on behalf of the municipal authorities and disposed of through the waste management system. It consists mostly of the waste generated by households, although similar wastes from sources such as commerce, offices and public institutions may be included.
4	Generation of packaging waste per capita (Kg per capita)	'Packaging' in this context means all products made of any materials of any nature to be used for the containment, protection, handling, delivery, and presentation of goods, from raw materials to processed goods and from the producer to the user or consumer.
5	Generation of plastic packaging waste per capita (Kg per capita)	This indicator includes plastic packaging waste. 'Packaging' in this context means all products made of any material of any nature to be used for the containment, protection, handling, delivery, and presentation of goods, from raw materials to processed goods, from the producer to the user or consumer.
6	Recycling rate of municipal waste (Percentage)	The indicator measures the share of recycled municipal waste in relation to the total municipal waste generation. Recycling includes material recycling, composting and anaerobic digestion. The ratio is expressed in percent (%) as both terms are measured in the same unit, namely tons.
7	Recycling rate of all waste excluding major minerals (Percentage)	The indicator is calculated as recycled waste (RCV_R) divided by total waste treated excluding major mineral wastes (TRT), multiplied by 100. It is expressed in percent (%) as both terms are measured in the same unit, namely tons. Recycled waste is the treated waste sent to the recovery operation rather than energy recovery and backfilling.
8	Recycling rate of packaging waste by type of packaging (Rate)	The indicator is defined as the share of recycled packaging waste in relation to all generated packaging waste. Packaging waste covers the wasted material used for the containment, protection, handling, delivery, and presentation of goods from raw materials to processed goods, from the producer to the user or the consumer, excluding production residues.
9	Recycling rate of e-waste (Percentage)	The indicator is calculated by multiplying the 'collection rate' with the 'reuse and recycling rate' where 0 for the 'collection rate' equals the volume collected in the reference year divided by the average quantity of electrical and electronic equipment put on the market in the previous three years (both expressed in mass unit).
10	Recycling of biowaste (Kg per capita)	The indicator is indirectly measured as the ratio of composted/methanized municipal waste (in mass unit) over the total population (in number). The ratio is expressed in kg per capita. The underlying assumption is that, by and large, the only reasonable treatment of biowaste is through composting or anaerobic digestion.
11	Recovery rate of construction and demolition waste (Percentage)	The indicator is the ratio of construction and demolition waste prepared for re-use, recycled or subject to material recovery, including through backfilling operations, divided by the construction and demolition waste treated.
12	Circular material use rate (Percentage)	The indicator measures the share of material recycled and fed back into the economy—thus saving on the extraction of primary raw materials—in overall material use. The circular material use, also known as the circularity rate, is defined as the ratio of the circular use of materials compared to the overall material use. The overall material use is measured by summing up the aggregate domestic material consumption and the circular use of materials.
13	Trade in recyclable raw materials (Tons)	The indicator measures the quantities of selected waste categories and by-products that are shipped between the EU Member States (intra-EU) and across the EU borders (extra-EU). Five classes have been selected: plastic; paper and cardboard; precious metal; iron and steel; copper, aluminum, and nickel. The indicator is as follows: • Intra EU trade of selected recyclable raw materials (measured as the Imports from EU countries). • Imports from non-EU countries and exports to non-EU countries of selected recyclable raw materials (in regard to extra-EU trade).

TABLE 2 (Continued)

N	Variables	Eurostat's definitions
14	Private investments, jobs and gross value added related to circular economy sectors (Euro)	The indicator includes "Gross investment in tangible goods", "Number of persons employed" and "Value added at factor costs" in the recycling sector, repair and reuse sector, and rental and leasing sector.
15	Patents related to recycling and secondary raw materials (Number)	The indicator measures the number of patents related to recycling and secondary raw materials.

Source: Eurostat (2023).

researcher. Its final objective is to generate groups of observations that are very homogeneous within themselves and very heterogeneous among them. When the groups are formed, it not only generates clusters according to homogeneity but also gives us the reasons why these groups were formed.

According to Hair et al. (2007), the objective of cluster analysis is to classify a sample of entities (individuals or objects) into a small number of mutually exclusive groups based on the similarities among the entities. In cluster analysis, unlike discriminant analysis, the groups are not predefined. Instead, the technique is used to identify the groups. This attribute is essential for detecting groups of European countries considering the CEI and its components. Moreover, as we reduce the number of observations from 32 countries to 4 clusters, we can highlight similar characteristics and facilitate the interpretation. The countries that belong to the same group will present similar characteristics in terms of circular economy, what is necessary to find common best practices. Many authors have used this technique to group countries and form conclusions (Mathrani et al., 2023; Russell et al., 2018; Zarikas et al., 2020).

The method used in this technique was that of distance and similarities (Euclidean distance). Thus, the longer the distance between objects, the lesser the similarity among the objects, and vice versa. Again, there is no researcher' bias to group countries. Similarities among countries (based on data) explain the clusters.

Using a similar approach to Grein et al. (2010), we apply a factor analysis and cluster analysis over time to compare CEI results. As the importance of variables for measuring CE is changing year by year, it is necessary to update the weights to provide meaningful information. The idea is like the Consumer Price Index methodology. It is needed to refresh as quick as possible the weight of each variable to measure inflation accurately. In our case, the correlation matrix of all original variables will give us this information. We expect slightly modifications year over year.

3.3.3 | ANOVA

The analysis of variance is a hypothesis test that is used to compare several groups with respect to a quantitative variable. The ANOVA compares whether there are differences between the means of the different groups (Hair et al., 2007). In our case, we used it to assess whether there are significative differences among the European clusters based on CEI.

4 | EMPIRICAL RESULTS

4.1 | The circular economy index (CEI)

Once we applied the second order factor analysis utilizing the 15 variables previously defined, we generated 4 factors that concentrated all the information to build the final indicator. The 4 dimensions or latent variables were the following: Production and Consumption, Waste Management, Secondary Raw Materials, and Competitiveness and Innovation. The factor analysis was applied for 2014 and 2021 because the weights of the variables slightly changed over the years. The results are displayed across Diagram 1.

The factor analysis applied was consistent with the KMO and Bartlett tests (Table A1). The levels of the KMO were high enough and the Bartlett tests were significant at a 99% level of confidence. Furthermore, the CEI weights were derived from the component matrices that determined the significance of each primary variable within the overall factor.

The two most influential dimensions were production and consumption (0.334) and waste management (0.400), followed by secondary raw materials (0.133) and competitiveness and innovation (0.133).

Within the production and consumption factor, material footprint was the most important primary variable (−0.22 in 2014 and −0.23 in 2021). Concerning the waste management dimension, the variable recycling rate of municipal waste was the most relevant (0.20 in 2014 and 0.18 in 2021). Regarding the other two factors, the weights were similar (0.50).

Table 4 shows the enhancement of the circular economy between 2014 and 2021 in Europe according to our indicator. This has similarities to the study from Pintilie (2021), who observed an improvement between 2014 and 2018 but applied a different methodology. All green plans mentioned in the literature review seem to explain this positive evolution. OECD (2020) show more details of the national, regional, and local CE strategies to boost the circular economy performance. Moreover, the enhancement was also observed in terms of the convergence among countries, considering the Standard Deviation figures.

In 2014, the minimum value of CEI was 4.02 and the maximum 39.19. These figures are dimensionless because factor analysis normalizes all variables. We use the numbers to compare different situations. Thus, we observe an increase of 9% in the CEI mean between 2014 and 2021 (the higher the CEI, the better the circular economy development). Moreover, if we compare the min and the max in these

TABLE 3 Descriptive analysis of primary variables.

Variables	N	Relationship with circular economy	Min. 2014	Min. 2021	Max. 2014	Max. 2021	Mean 2014	Mean 2021	SD 2014	SD 2021	Circular economy trend
Material footprint	32	Negative	0.00	0.00	33.93	29.50	14.61	16.33	8.05	8.46	↘
Resource productivity	32	Positive	0.00	0.00	6.11	7.35	1.92	1.98	1.36	1.57	↗
Generation of municipal waste per capita	32	Negative	0.00	0.00	808.00	834.00	463.03	478.41	151.03	228.13	↘
Generation of packaging waste per capita	32	Negative	0.00	0.00	227.03	227.98	131.43	141.04	52.51	55.08	↘
Generation of plastic packaging waste per capita	32	Negative	0.00	0.00	59.32	64.67	27.53	30.30	12.08	12.82	↘
Recycling rate of municipal waste	32	Positive	0.00	0.00	65.60	68.30	33.27	35.85	15.47	18.96	↗
Recycling rate of all waste excluding major mineral	32	Positive	0.00	0.00	81.00	82.00	40.75	42.41	24.85	25.30	↗
Recycling rate of packaging waste by type of packaging	32	Positive	0.00	0.00	81.30	83.50	59.38	58.90	14.06	18.52	↘
Recycling rate of e-waste	32	Positive	0.00	0.00	117.80	89.80	37.25	39.29	20.02	23.57	↗
Recycling of biowaste	32	Positive	0.00	0.00	175.00	186.00	57.50	70.91	49.56	58.45	↗
Recovery rate of construction and demolition waste	32	Positive	0.00	0.00	100.00	100.00	72.91	78.06	33.35	30.73	↗
Circular material use rate	32	Positive	0.00	0.00	26.60	30.90	7.40	8.60	6.23	7.80	↗
Trade in recyclable raw materials	32	Positive	1928	1247	81,54,157	89,28,527	15,56,602	17,34,749	20,64,484	21,69,890	↗
Private investments related to circular economy sectors	32	Positive	0	0	28,363	37,773	4669	4404	8086	8383	↘
Patents related to recycling and secondary raw materials	32	Positive	0.00	0.00	82.99	85.70	12.56	11.33	20.25	17.77	↘

Note: The "minimum" refers to the lowest value of the variable in the year analyzed and for the sample of countries studied. The "maximum" is the highest value of the variable.
Source: Own elaboration from Eurostat (2023).

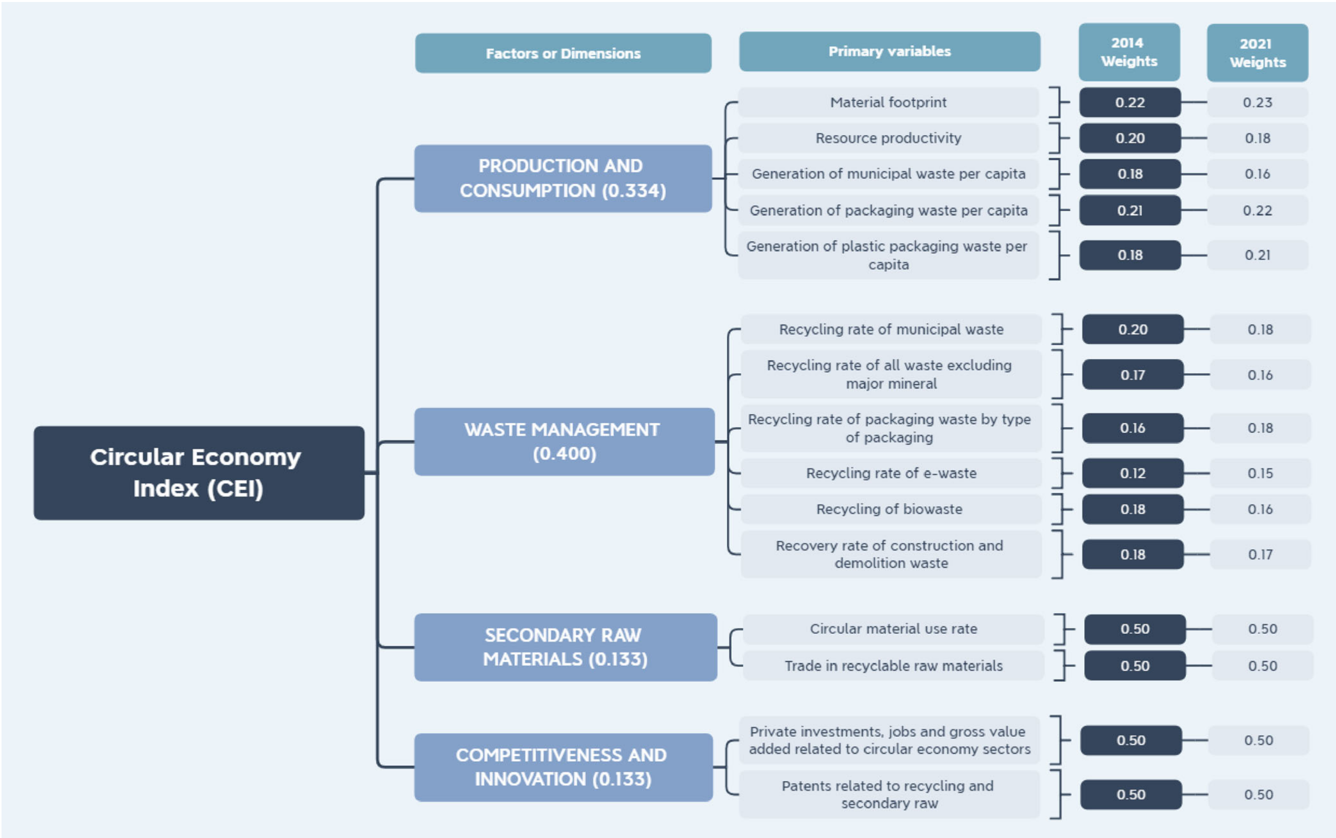

DIAGRAM 1 The circular economy index (CEI). The CEI is composed of 4 factors, obtained from 15 primary variables (extracted from Eurostat). This diagram shows the variables' weights in 2014 and 2021 identified through a factor analysis. Source: Own elaboration from Eurostat.

TABLE 4 Main results of CEI.

	Number of countries	Minimum	Maximum	Mean	SD
CEI 2014	32	4.02	39.19	16.768	8.461
CEI 2021	32	7.24	39.00	18.395	7.682
N valid	32				

Note: The CEI shows an improvement between 2014 and 2021, what means a better circular economy development.

years (4.02–39.19 in 2014 vs. 7.24–39.00 in 2021), we appreciate a lesser range. The result is consistent with the reduction in Standard Deviation.

4.2 | Circular economy by country in Europe

After applying the cluster analysis, we observed 4 groups of European countries in terms of CEI performance. They are very homogeneous internally but very heterogeneous between themselves (Table A2). Organized from best to worst, we note: Group 1 (highest performance), Group 2 (high performance), Group 3 (Medium performance), and Group 4 (Low performance) in 2014 and 2021. This classification differs from Mazur-Wierzbicka (2021a), which states there is evidence of a "two-speed Europe" in relation to the progress of European Union member states towards achieving CE. However, it is in line with Pintilie (2021), who also differentiates 4 groups considering a CE index.

Diagram 2 represents the composition of each group or cluster in 2014 before the green plans in Europe. Group 1 was the best and composed of the Netherlands and Germany. Group 2 was the second best and consisted of France, Italy, Switzerland, and the United Kingdom. Group 3 was for "medium performance", and we saw countries present such as Czechia, Austria, Denmark, Liechtenstein, Slovenia, Spain, Belgium, Luxembourg, Norway, Poland, and Sweden. Finally, Bulgaria, Cyprus, Estonia, Finland, Ireland, Malta, Portugal, Romania, Croatia, Greece, Hungary, Iceland, Latvia, Lithuania, and Slovakia, correspond to Group 4 (low performance).

Diagram 3 lays out the composition in 2021 after the first circular economy action plan launched by the European Commission in 2015. We observed four clusters with a different composition. Group

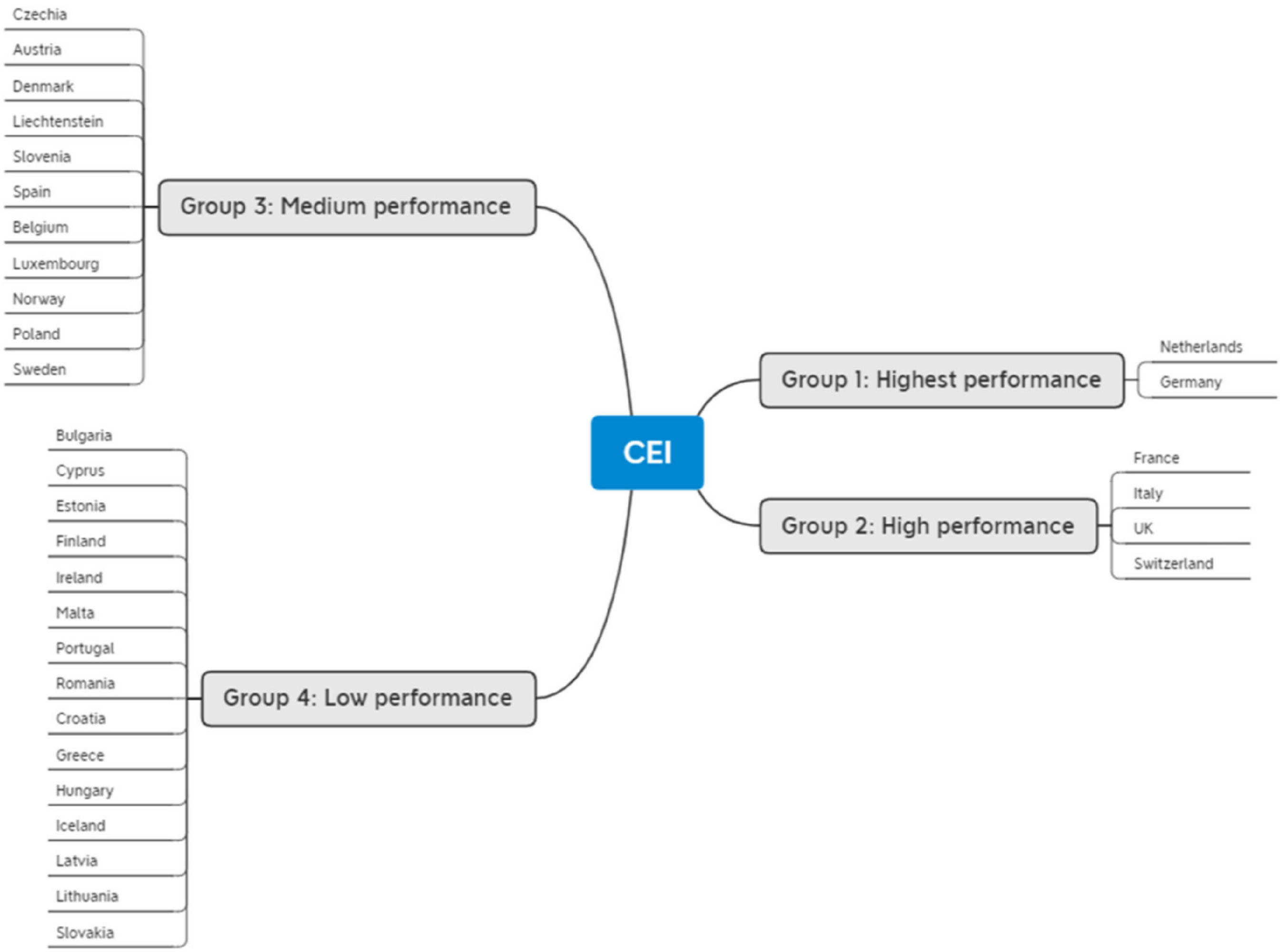

DIAGRAM 2 CEI clusters of european countries in 2014. Using the CEI performance and applying a cluster analysis (2014), we have identified 4 groups of European Countries. Number 1, the best; Number 4, the worst. Source: Own elaboration from Eurostat.

1 (highest performance) only contained the Netherlands. Group 2 (high performance) was composed of Germany (it slightly worsened in comparison with 2014, as seen in Pintilie, 2021 because of worse waste management), Italy, and Belgium (it strongly improved, also coincident with Pintilie, 2021). Group 3 (medium performance) constituted Czechia, Austria, Denmark, Liechtenstein, Slovenia, Spain, France, the UK, and Switzerland. The last three countries experienced a decline in CEI score and a downgrade from Cluster 2 to 3 between 2014 and 2021. Group 4 gathered a pool of low performance countries in terms of a circular economy: Bulgaria, Cyprus, Estonia, Finland, Ireland, Malta, Portugal, Romania, Croatia, Greece, Hungary, Iceland, Latvia, Lithuania, Slovakia, Luxembourg, Norway, Poland, and Sweden. The last four economies belonged to Group 3 in 2014. These results, in most cases, are in line with Mazur-Wierzbicka (2021a), Pintilie (2021), and Mitrovic and Veselinov (2018).

According to Mazur-Wierzbicka (2021a), the nations at the forefront of implementing operations corresponding to CE principles are Germany, Belgium, Spain, France, Italy, the Netherlands, and the United Kingdom. The second pole encompasses European Union member states that are seeing the most gradual progress in their transition towards a common European currency. This category mostly comprises nations located in Central and Eastern Europe, as well as those situated in the southern region of Europe (data from 2018).

Pintilie (2021) also observes four groups of European countries in terms of CE in 2018. The number 1 (high level) group is composed of the Netherlands, the UK, Germany, Belgium, Denmark, Luxembourg, and Austria; the number 2 (good level) group consists of Italy, Sweden, France, Spain, Ireland, Slovenia, and Czechia; the number 3 (mid-level) group is represented by Hungary, Finland, Lithuania, Poland, Latvia, Estonia, and Croatia; and the number 4 (low level) group includes Portugal, Greece, Slovakia, Malta, Bulgaria, Romania, and Cyprus.

Mitrovic and Veselinov (2018) construct a circular economy index by means of a DEA model and show that Luxembourg, Finland, Sweden, Germany, and Slovenia are the best five countries, considering they do not present information for France, the Netherlands, the United Kingdom, and Spain. Latvia, Bulgaria, Cyprus, Malta, and Romania are ranked in the last positions.

The contradictions are mainly explained by the analyzed year (our research is more recent), but also by the type of technique applied

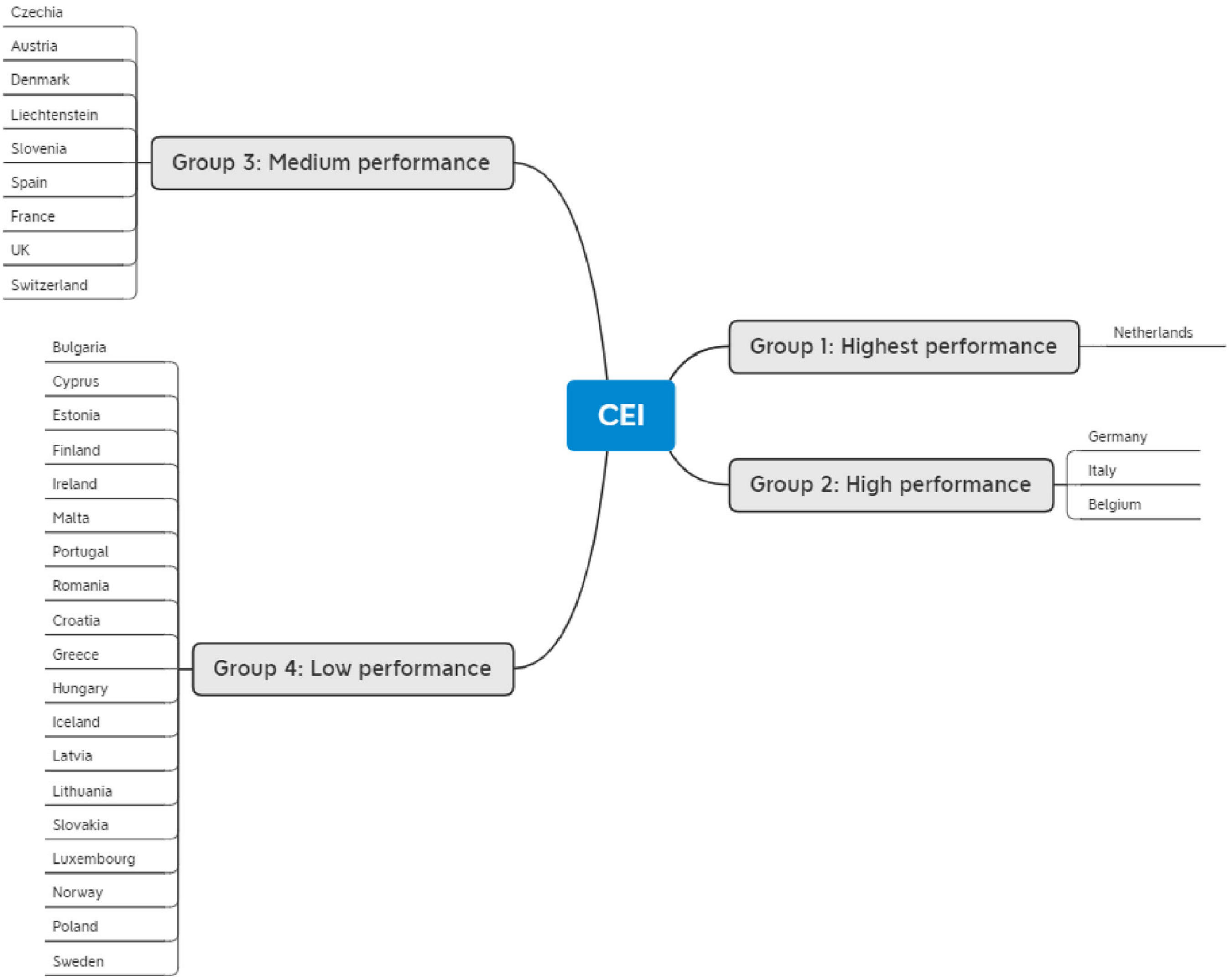

DIAGRAM 3 CEI clusters of European countries in 2021. Applying a new cluster analysis (2021), we have identified another 4 groups of European countries, but with a different composition. Source: Own elaboration from Eurostat.

and the sample used. The results of Mitrovic and Veselinov (2018) are slightly different due to the DEA model and fewer number of countries studied.

After comparing these years, we observed that there were a smaller number of countries in the medium, high, and highest performance groups in 2021 than in 2014. As a result, there were a greater number of countries with a low performance in 2021 than in 2014. Nevertheless, 20 out of 32 countries have increased their CEI performance (see Chart 1), and 12 out of these 20 economies belonged to G4. Thus, although the number of countries in G4 (Low Performance) has risen, the CEI G4 average is notably higher between 2014 and 2021 (see Chart 2). Therefore, the net mean score of all clusters improved between this period, but more so in group 4 (Chart 2). In the end, we observe a convergence among the European countries.

In addition, we applied an ANOVA (Table A3) that confirmed the significant differences in the means among the groups in 2014 and 2021. This shows evidence of the aggrupation efficiency, meaning that there is homogeneity within the clusters (the countries are similar) and heterogeneity among the groups (the countries are dissimilar).

Chart 3 shows the comparisons made between CEI dimensions by group and year in the period of 2014–2021. In 2014, G1 notably presents more capacity for managing waste and a better use of secondary raw materials than the rest of the groups, particularly in comparison with G4. This is mainly since the Netherlands and Germany performed highly in these dimensions in this year (see Table A4). G1 and G2 markedly show more competitiveness and innovation than G3 and G4 (again the Netherlands and Germany, but also France, Italy, UK, and Switzerland present a relatively high performance in this dimension because of the higher circular economy investment) (see Table A4). These big differences among the clusters are not perceived in the production and consumption dimension.

In 2021, we appreciate that there is the same pattern as in 2014 but with an exception: G1 showed a reduction in the production and

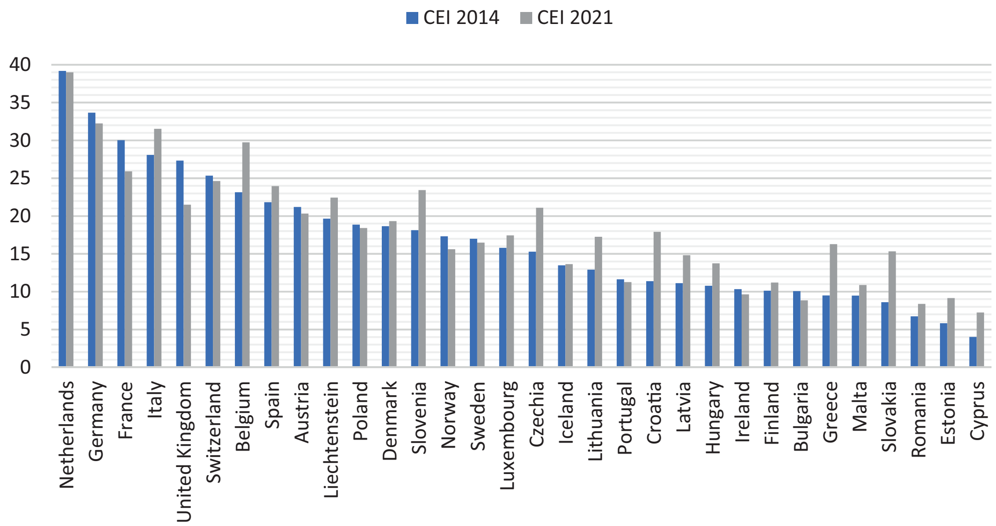

CHART 1 Mean of CEI by European countries (2014 vs. 2021). The figures are dimensionless, thus useful for comparison between different situations. Data show 20 out of 32 countries have increased CEI. Source: Own elaboration from Eurostat.

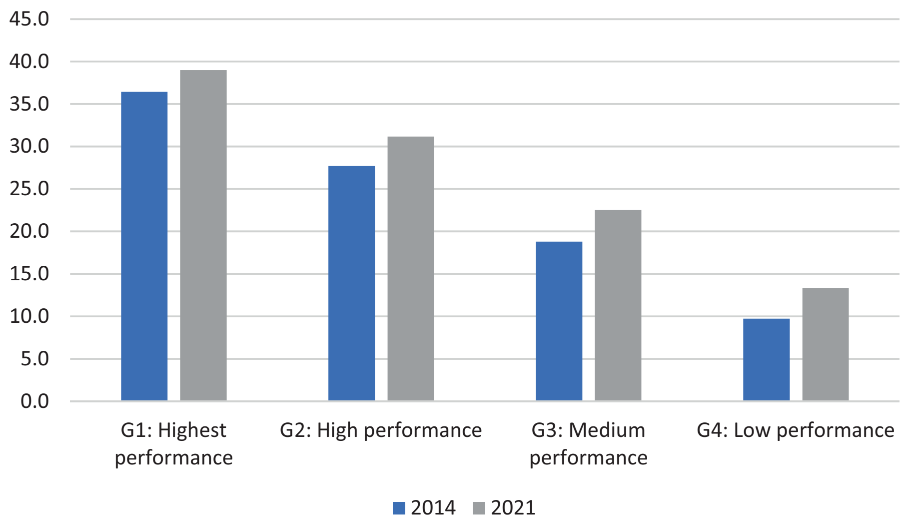

CHART 2 Mean of CEI by group of European countries (2014 vs. 2021). The figures are dimensionless, thus useful for comparison between different situations. Data show all the groups have improved between 2014 and 2021, in terms of circular economy. Source: Own elaboration from Eurostat.

consumption factor, as well as in the competitiveness and innovation dimension, mainly because Germany belonged to G1 in 2014 but not in 2021. This country has suffered a slight decrease in CEI performance, as aforementioned.

If we observe the CEI dimensions country by country in the period 2014–2021 (Table A4), we can highlight that all countries have worsened in the production and consumption factor; however, most of them have improved in the waste management dimension (except for Austria, Bulgaria, and Norway). The use of secondary raw materials presents a net enhancement in Greece, Estonia, and Czechia. And finally, the competitiveness and innovation factor have experienced a small net decrease. Nevertheless, some Eastern European countries such as Czechia, Slovenia, Romania, Croatia, Lithuania, and Slovakia have improved their investments. However, this dimension has plummeted in France and the UK because of the decrease in CE private investment and patents, what explains the fall from G2 to G3 between 2014 and 2021.

5 | CONCLUSIONS AND POLICY DISCUSSIONS

In response to the importance of measuring the circular economy in Europe and the necessity of disaggregating this performance among all countries, we have created a composing circular economy index (CEI) through a second order factor analysis and identified groups of European countries using a cluster analysis and the CEI.

The main contribution of the CEI is to provide a measure of circular economy performance from a multidimensional approach. This offers a more comprehensive perspective than other studies such as Mazur-Wierzbicka (2021a), Pintilie (2021), and Mitrovic and Veselinov (2018). Moreover, the CEI has been built for the years 2014 and 2021 to compare results and assess advances after the European green plans. Finally, the classification of countries by the CEI permits us to synthetize information in groups that share similar performance and green policymaking. This facilitates the identification of best practices that other countries could take on.

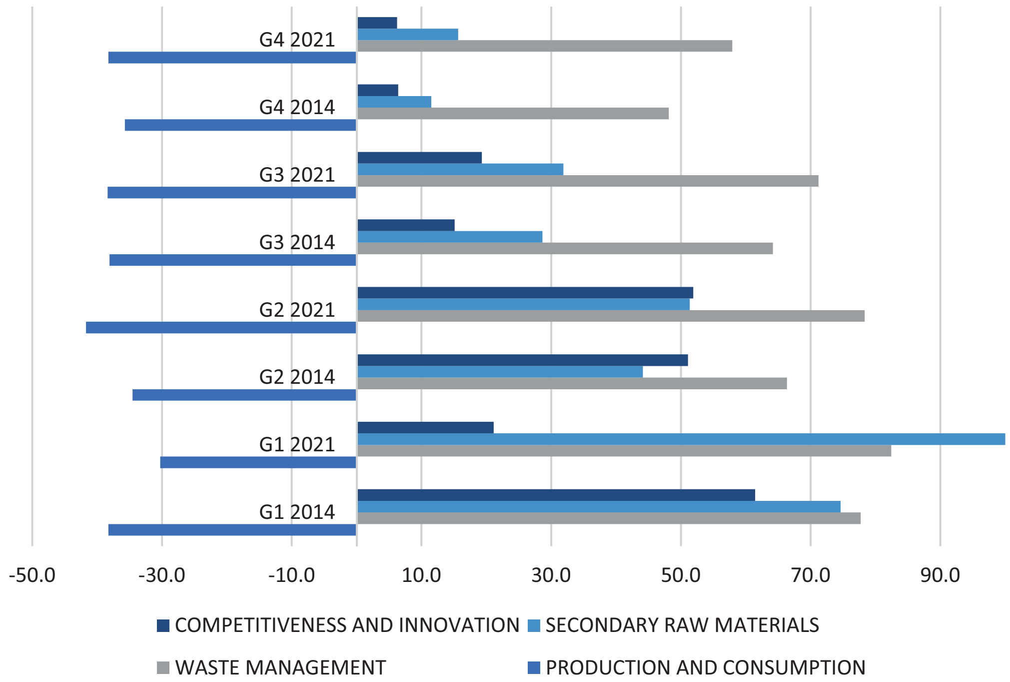

CHART 3 Comparisons of CEI dimensions by groups and years 2014–2021. The figures are dimensionless, thus useful for comparison between different situations. Negative data indicate that "production and consumption" reduces CEI. Positive data imply a more circular economy. For example, an increase in generation of waste (as part of "production and consumption") decreases CEI, but a rise in the rate of waste recycling (as part of "waste management") boosts CEI. Source: Own elaboration from Eurostat. In this paper, in the case of Production and Consumption, the lower the value of the indicators, the better the performance for the countries. Additionally, in the cases of Competitiveness and Innovation, Secondary Raw Materials, and Waste Management, the higher the value of indicators, the better the performance for the countries.

After the application of the methodology, we highlight the main results as follows:

- The CEI is composed of 4 dimensions: Production and Consumption, Waste Management, Secondary Raw Materials, and Competitiveness and Innovation. The two most important factors are production and consumption (0.334) as well as waste management (0.400), followed by secondary raw materials (0.133) and competitiveness and innovation (0.133).
- Based on the principle "let data speak for themselves" (Gould, 1981), the factor analysis has identified the "material footprint" as the most important variable within the production and consumption dimension. This technique has generated the weights from the correlation matrix. The more the variable is correlated with other variables, the more weight will have to represent this importance. Regarding the waste management factor, the recycling rate of municipal waste becomes the most significant.
- We observe an improvement in circular economy performance between 2014 and 2021 in Europe, in line with other studies such as Pintilie (2021). An enhancement was also noted in terms of a convergence among the sampled countries, although the level of inequality remains high.
- We also appreciate that there is a four-speed Europe in terms of the circular economy concept: (1) highest performance, (2) high performance, (3) medium performance, and (4) low performance (the same as Pintilie (2021), but different to Mazur-Wierzbicka (2021a)). We highlight the results of the Netherlands, Germany, Italy, and Belgium in this case. They present more capacity for managing waste and making better use of secondary raw materials than the rest of the countries. Furthermore, the Netherlands belongs to the G1 during the whole period as a consequence of its increase in recycling rates of municipal waste, packaging waste, e-waste, and biowaste. They have also risen the circular material use rate and the trade in recyclable raw materials.
- Moreover, all groups (G1, G2, G3 and G4) have improved between 2014 and 2021. However, we continued observing big inequalities among the clusters.
- We perceive an increase in waste management and use of secondary raw materials factors, but a decrease in production and consumption dimension. The competitiveness and innovation factor has also fallen slightly. As "production and consumption" is one of most important dimensions and its performance has decreased between 2014 and 2021, we could infer that green plans have not worked as good as expected from this point of view. To some extent, companies and consumers have not modified their patterns in these years. Nonetheless, as "waste management" is the most important factor and most countries have improved it during the period 2014–2021, we can state that existing policies have had a reasonable success from a recycling perspective. In conclusion, we

observe that people are more aware of recycling, but we should progress in terms of production and consumption austerity.

- When examining the CEI dimensions on a country-by-country basis throughout the period of 2014–2021, it becomes evident that there has been a decline in the production and consumption component across all countries. However, it is worth noting that the waste management dimension has shown improvement in most nations, with the exception of Austria, Bulgaria, and Norway. The utilization of secondary raw materials offers a significant overall enhancement, specifically observed in Greece, Estonia, and Czechia. Lastly, there has been a little overall decline in the levels of competitiveness and innovation. However, some Eastern European nations, including Czechia, Slovenia, Romania, Croatia, Lithuania, and Slovakia, have made significant advancements in their investment strategies. However, it is noteworthy that this particular dimension has seen a significant decline in both France and the United Kingdom. This decline may be attributed to a drop in private investment and patents within the CE sector.

The varied degrees of progress made by different countries in their transition towards a Circular Economy can be attributed, among other factors, to the adoption of diverse development strategies by these nations. These strategies have been recommended by EU ministers at the Environment Council in June 2016. Additionally, disparities in social and economic development also contribute to the differences observed in the advancement of countries towards a Circular Economy.

These results offer an opportunity to boost the CEI performance by country. The ones that belong to the worst group may catch up to the good practices engaged in by the ones that conform within the best two groups. The Netherlands, Germany, Italy and Belgium, have established dedicated national policies, some of which have been in place for several decades. The Netherlands stands as a leading example in the realm of the circular economy, with a primary goal of realizing a fully circular economy for the Dutch nation by 2050. Circularity is of utmost significance within this nation, which is why Dutch companies hold a prominent position in the recycling industry (Hanemaaijer & Kishna, 2023). As early as 1972, Germany enacted its initial waste law to mitigate environmental degradation and later introduced legislation on the circular economy in 1996. Moreover, in 2012, the country further revised and expanded its waste laws to align with the guidelines laid out by the European Union (Ogunmakinde, 2019). In Italy, various types of organizations including both for-profit and non-profit companies, research centers, and universities are involved in the transition to CE, particularly in recycling. It is worth noting that numerous companies are actively involved in promoting the culture of the Circular Economy (CE) and encompass the dissemination of CE principles and concepts, with a specific focus on waste prevention, reduction, and the preservation of product value (Ghisellini & Ulgiati, 2020). Finally, our results show the significant advancements made in the Circular Economy (CE) in Belgium since 2014. During this year, this country introduced a national Circular Economy (CE) strategy titled "Towards a Belgium as a Pioneer in the Circular Economy". This strategy encompasses 21 measures designed to enhance the circular economy's capacity through the sharing and repair of products, as well as the promotion of sustainable waste management (Federal public service Health, Food Chain Safety and Environment Belgium Federal Government, 2016). This strategy would explain the great progress made in Belgium in terms of circular economy from 2014 to 2021 and is shown by our results.

The countries that belong to the worst group may catch up to the good practices engaged in by the countries in the best two groups. In particular, countries such as Bulgaria, Cyprus, Estonia, Finland, Ireland, Malta, Portugal, Romania, Croatia, Greece, Hungary, Iceland, Latvia, Lithuania, Slovakia, Luxembourg, Norway, Poland, and Sweden could intensify some of their policy measures focused on recycling and the use of secondary raw materials and encourage competitiveness and innovation (investment) related to the circular economy. In groups 3 and 4, different situations are found. On the one hand, there are some Eastern European countries that began their transition to a market economy in the 1990s and where the effects of massive resource consumption were felt later than in other countries. This reason, together with the lack of adequate infrastructure for circularization, would explain why progress in CE matters is slower (Mazur-Wierzbicka, 2021b).

As for the countries that have strong economies but are in groups 3 and 4, it should be said that cases such as Austria, Finland or the United Kingdom are making very important efforts in the field of CE. However, they joined late, meaning the results are still improvable. In the case of the UK, the government does not play a strategic role in building a transitional pathway and economic relationships complicate efforts to promote a Circular Economy (Flynn et al., 2019; McDowall et al., 2017). Austria and Finland are firmly committed to the CE and have strategies to boost the CE, but greater efforts are needed in terms of policy coherence. Furthermore, these countries bear the risk of conflicts of interests between competing societal goals (Domenech & Bahn-Walkowiak, 2019; Bahn-Walkowiak & Steger, 2015; Bastein et al., 2014). Other countries are making efforts and progressing as well, albeit at varying paces due to factors like later initiation, as seen in the cases of Cyprus or Greece.

While the results of the different circular economy action plans, the building blocks of the European Green Deal, are positive, it is necessary to step up actions to help create a market for secondary raw materials, boost innovation and digitalization for the transition to the CE, and reduce waste. This is to strengthen and balance the European transition towards the implementation of a circular economy.

We can derive other practical recommendations from our findings. While a European-level policy is crucial, there is also a clear need for policies at the national and regional levels. The countries need to adopt an ambitious national CE strategy and can foster a favorable climate for stakeholder engagement in the transition to the CE (Camilleri, 2019; Camilleri, 2020; Milios, 2018; Salem et al., 2018). The interaction between policymakers and companies is vital in facilitating the transition at the corporate level (Levänen et al., 2018). A company culture that understands the economic opportunities of this model and designs their circular business models is necessary to advance the development of the CE (Centobelli et al., 2020). It is also crucial that the population is convinced of the need for the CE and its opportunities. Initiatives at the individual level need to go hand in hand with the actions of governments and businesses. An examination of principles and behaviors is vital to bring about an effective transition to the circular economy model (Gregson et al., 2015; Salvioni & Almici, 2020). All social partners must be committed to the changes required by the transition to the CE. The countries that lead the advances in the circular economy according to our results meet these three requirements.

The conviction that a paradigm shift is possible is the driving force behind the radical changes needed to transform linear production methods and instill circular awareness in citizens, governments, and businesses alike.

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APPENDIX A

TABLE A1 Factor analysis tests.

2014					
	FA1	**FA2**	**FA3**	**FA4**	**Final FA**
KMO	0.650	0.620	0.500	0.500	0.500
Bartlett test	0.000	0.000	0.000	0.000	0.000
2021					
	FA1	**FA2**	**FA3**	**FA4**	**Final FA**
KMO	0.567	0.702	0.500	0.500	0.500
Bartlett test	0.000	0.000	0.000	0.000	0.000

Note: The Kaiser-Meyer-Olkin (KMO) is a measure of factor analysis adequacy. When KMO is equal or higher than 0.5, a factor analysis might be appropriate. Then, we can confirm the adequacy by means of Bartlett test of sphericity, that is a statistical test for the presence of correlations among the variables. It provides the statistical significance that the correlation matrix has significant correlations among at least some of the variables.

TABLE A2 Cluster analysis.

Cluster of belonging		
Case	4 clusters (2014)	4 clusters (2021)
1:Austria	3	3
2:Czechia	3	3
3:Denmark	3	3
4:France	2	3
5:Liechtenstein	3	3
6:Slovenia	3	3
7:Spain	3	3
8:Switzerland	2	3
9:United Kingdom	2	3
10:Belgium	3	2
11:Germany	1	2
12:Italy	2	2
13:Bulgaria	4	4
14:Cyprus	4	4
15:Estonia	4	4
16:Finland	4	4
17:Ireland	4	4
18:Malta	4	4
19:Portugal	4	4
20:Romania	4	4
21:Croatia	4	4
22:Greece	4	4
23:Hungary	4	4
24:Iceland	4	4
25:Latvia	4	4
26:Lithuania	4	4
27:Luxembourg	3	4
28:Norway	3	4
29:Poland	3	4
30:Slovakia	4	4
31:Sweden	3	4
32:Netherlands	1	1

TABLE A3 ANOVA test.

2014	Sum of squares	DF	Root mean square	F	Sig.
Inter-groups	2038.629	3	679.543	105.339	**.000**
Intra-groups	180.629	28	6.451		
Total	2219.258	31			
2021	**Sum of squares**	**DF**	**Root mean square**	**F**	**Sig.**
Intra-groups	1551.772	3	517.257	52.156	**.000**
Intra-groups	277.691	28	9.918		
Total	1829.464	31			

Bold indicates Snedecor F.

TABLE A4 CEI in detail by dimensions and countries.

	Production and Consumption		Waste Management		Secondary Raw Material		Competitivenss and Innovation	
European Countries	2014	2021	2014	2021	2014	2021	2014	2021
Austria	−47.07	−49.23	81.46	81.06	20.06	21.39	12.14	10.76
Czechia	−30.03	−31.38	54.36	67.02	13.32	22.1	13.34	13.45
Denmark	−50.47	−51.92	74.87	79.8	32.14	27.84	9.27	7.49
France	−38.39	−40.69	60.37	61.74	58.67	58.46	81.73	52.56
Liechtenstein	−35.47	−36.97	63.81	72.86	25.43	26.2	19.21	15.91
Slovenia	−31.81	−33.04	63.56	74.22	22.61	27.24	2.23	8.44
Spain	−30.42	−32.52	53.77	60.47	46.11	51.35	32.46	28.31
Switzerland	−29.29	−32.15	72.91	74.36	25.43	26.2	19.21	15.91
United Kingdom	−34.37	−37.58	64.6	69.45	35.86	26.2	61.36	20.72
Belgium	−33.2	−35.49	66.61	83.74	44.61	50.52	12.16	10.14
Germany	−48.58	−50.82	75.04	75.05	49.23	43.92	100	100
Italy	−36.13	−38.81	67.5	76.2	56.63	59.6	42.08	45.56
Bulgaria	−29.78	−30.06	47.42	45.09	5.92	5.33	1.76	0.94
Cyprus	−33.53	−34.17	32.86	44.26	4.64	6.51	10.74	0.32
Estonia	−53.51	−56.33	48.02	57.78	20.87	28.29	12.54	7.86
Finland	−48.17	−49.82	55.76	61.04	16.39	12.87	12.67	12.51
Ireland	−52.56	−55.84	60.9	62.09	13.96	13.56	12.34	11.94
Malta	−31.74	−32.63	42.42	47.49	12.04	12.79	11.19	7.86
Portugal	−41.6	−43.41	59.64	60.71	10.1	7.27	2.21	3.47
Romania	−27.71	−28.72	36.08	40.87	6.7	6.45	4.82	5.46
Croatia	−20.63	−21.1	41.77	58.07	10.85	11.52	0.92	1.28
Greece	−28.16	−28.76	44.9	58.59	5.61	17.33	1.39	0.97
Hungary	−32.77	−34.06	49.56	56.56	10.71	15.85	3.3	2.68
Iceland	−41.66	−43.93	53.51	59.18	25.43	26.2	19.21	8.4
Latvia	−31.08	−32.25	49.72	60.17	11.5	10.72	0.47	0.4
Lithuania	−36.41	−37.58	59.39	70.58	9.02	10.21	0.61	1.39
Luxembourg	−55.41	−59.45	73.59	82.91	21.38	22.15	14.71	8.44
Norway	−35.8	−38.2	59.51	57.67	25.43	26.2	15.4	13.46
Poland	−33.34	−34.87	52.72	57.72	41.59	35.83	25.22	16.41
Slovakia	−26.62	−27.77	40.01	56.83	9.26	10.67	1.69	3.14
Sweden	−36.13	−37.85	61.76	62.99	22.4	17.85	10.08	11.51
Netherlands	−27.96	−30.29	80.38	82.44	100	100	22.89	21.12

Note: Red → a decline in circular economy with respect to 2014. Green → an improvement in circular economy with respect to 2014 (according to the 4 CEI dimensions).