ORIGINAL PAPER

Inventory and Comparison of Performance Indicators in Circular Economy Roadmaps of the European Countries

Marzena Smol[1] ⬤

Abstract

European Union (EU) is in the process of transformation toward a circular economy (CE), which is a regenerative growth model that gives back to the planet more than it takes. Member States are key players in this process; therefore, next to the EU Action Plan, they developed national strategies (roadmaps) toward the CE. The paper presents an inventory of performance indicators, which have been indicated in the selected CE national strategies. The EU countries strongly underline the necessity to access the transformation progress with the use of CE indicators at different levels (macro, meso, or/and micro) or for different actions or objectives. There is a lack of one universal indicator which measures a level of the CE transformation at the national level due to the complexity of this issue and the diversity of key sectors and economic actors in the individual countries. There are some proposed indicators that could be used in other countries, to shape national monitoring frameworks by policy-makers. However, to access the transformation process on the European level showing the comparison between different countries, it is recommended to use the CE monitoring framework because it contains the set of CE indicators that provide uniform data and holistic view of all countries in Europe.

Keywords Circular economy (CE) · Monitoring · Indicators · Roadmap · Strategy · Europe

Introduction

In 2014, the European Commission (EC) officially announced a circular economy (CE) as a new economic model for European Union (EU). The indicated *zero waste programme* was a response to unsustainable resource management across the European economy. The CE was defined as the *system which keep the added value in products for as long as possible and eliminates waste* [1]. In 2015, in the first CE Action Plan for the EU, this definition was modified to the system *where the value of products, materials, and resources is maintained in the economy for as long as possible, and the generation of waste minimized* [2]. Undoubtedly, in the European context, the main message of the CE system is

✉ Marzena Smol
 smol@meeri.pl

1   Mineral and Energy Economy Research Institute, Polish Academy of Sciences, Wybickiego 7a str., 31-261, Cracow, Poland

better management of resources—both of primary and secondary origin (i.e., waste) [3]. The CE was also highlighted as an essential element of delivering the resource efficiency agenda [1], which was established under the Europe 2020 Strategy for smart, sustainable, and inclusive growth [4]. Currently, the CE is one of the key blocks of the European Green Deal (EGD), which is the newest strategy for sustainable growth in the EU [5] and aims to achieve climate neutrality on the continent by 2050. The second CE Action Plan, which was announced in 2020, defines the CE as *a regenerative growth model that gives back to the planet more than it takes* [6]. The purpose of this model is to stimulate the economic growth while keeping resource consumption within planetary boundaries and striving to reduce advanced consumption footprint and double its circular material use rate.

The European CE Action Plans included key elements and assumptions of the transformation process towards the CE model in the EU. It was also recommended that the Member States should develop national strategies (so-called roadmaps) for the CE implementation [7]. This is due to different socio-economic conditions in the individual countries, for which the CE transformation action plans should be adapted. Consequently, most of the European countries have developed the CE roadmaps, which are systematically published on the European Circular Economy Stakeholder Platform (ECESP), which has been created to facilitate civil society consultation; collaboration between national, regional, and sectoral networks; and exchange of expertise, information, and best practices [8]. The special dedicated Knowledge Hub includes an inventory of Good Practises in the CE implementation—strategies/roadmaps, innovative processes, and learning from experience examples. It should be pointed that the EC officially adopted the CE as the economic priority in 2014 [1]; therefore, the European national CE roadmaps were developed after this year. Since 2014, a minimum of 47 CE national and regional strategies have been adopted, and others are under development [8]. Moreover, some sector CE strategies are also under development [9]. To assess the progress of the transformation towards the CE model in individual countries, the EC proposed a set of 10 key CE indicators, grouped into four areas: (i) production and consumption, (ii) secondary raw materials, (iii) waste management, and (iv) competitiveness and innovation [10]. The CE indicators are systematically updated and made available on the European Statistical Office's website—Eurostat [11].

Monitoring progress toward the CE is a challenging task due to the transformation process is not limited to certain raw materials or sectors [12]. There are several indicators which can be used for the evaluation of different aspects of the CE implementation, being at the same time useful tools to support the development of policies in providing information, reducing environmental pressures and impacts through circular processes [13]. The CE indicators which could be also called "C-indicators" are systematically proposed by scholars, consulting companies and governmental agencies, while the selection of appropriate indicators (macro, meso, or/and micro level) is based on the specific user's needs and requirements [14].

There is no possibility to create one universally recognized indicator of "circularity." In this context, the EC used the existing indicators and chose those that best reflect the key areas of transformation toward the CE at the European level [10]. In 2018, the EC proposed 10 indicators that are reported by individual countries. The list of these indicators is open and expanded by the EC. The CE indicators provide a holistic knowledge on the level of the transformation toward the CE in all Member States. However, due to various socio-economic and technological conditions in the individual countries, the country-specific indicators have been proposed in the national CE roadmaps. Therefore, the main objective of this study is to revise the CE indicators, which have been proposed in the national CE roadmaps in the European countries. The paper also provides a comparison of the

countries' performances in the transition towards the CE model, on the basis of selected CE indicators included in the European monitoring framework. The inventory of the CE indicators that have been proposed by the selected countries could be used by other countries (policy-makers) to shape national monitoring frameworks, by entrepreneurs—to adapt business and technological changes allowing for transformation towards the CE, and by scientists—to shape the direction of scientific research and technological progress, allowing for the acceleration of the transformation towards CE in Europe. The paper contains six sections. The first section provides clarification of the importance of monitoring progress toward the CE model in the European countries. The second section describes the materials and methods used in this paper. The third section presents an overview of the national CE roadmaps in the European countries. The next section includes an inventory of the CE indicators in the national CE roadmaps. The fifth section contains a comparative analysis of the CE indicators proposed by individual countries and implications for the CE monitoring. In the last section, the key conclusions are presented, underlining the importance of both European and national indicators.

Materials and Methods

The research was divided into three individual steps. The framework of the research is presented in Fig. 1.

Step I—in the first step of research, the national strategies (roadmaps) toward the CE implementation were identified. The selection included the European countries. For this purpose, a detailed review of the CE strategies on the webpage of the European Circular
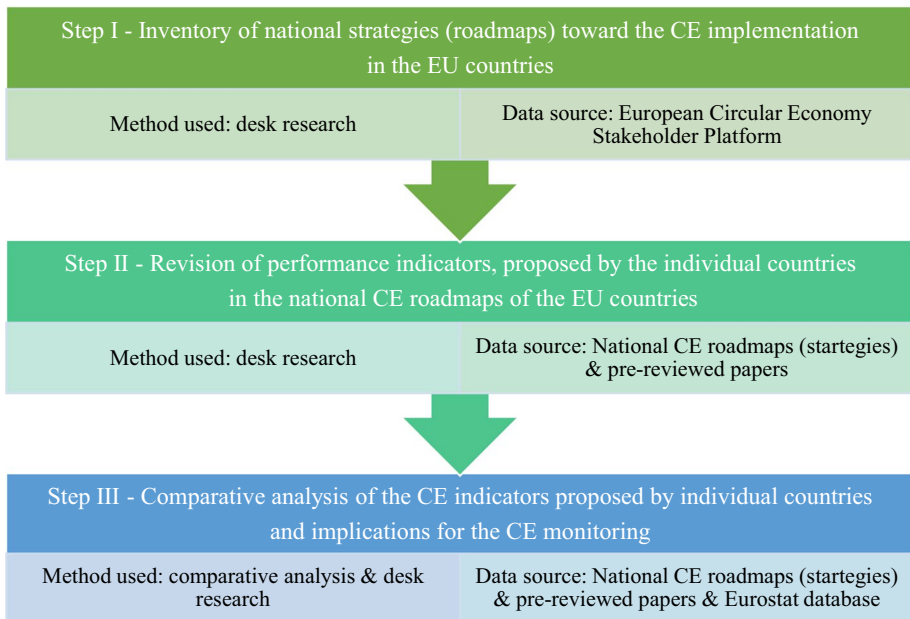

Fig. 1 The research framework

Economy Stakeholder Platform was carried out. The national strategies were available in the section Knowledge Hub, sub-section Strategies (circulareconomy.europa.eu/platform/en/strategies). This sub-section provides the existing strategies for the transition to the CE at the national, regional, or local level, adopted by public authorities. Currently, there are 47 strategies, which have been categorized into three types: (i) integrated strategies (as national and regional strategies focus on horizontal tools and policies), (ii) strategies with a restricted sector focus, and (iii) all-encompassing strategies with a clear setting of priorities [15]. The list of analyzed strategies, including their national language titles, English titles, year of publication, and public authority responsible for the development of the document is provided in Table 1. In this step of research, the main objectives and key areas of the CE implementation on the national level were identified and described.

Step II—in the second step of research, the detailed revision of performance indicators, proposed by the individual countries in the national CE roadmaps, was conducted. This inventory was based on the full text of the CE roadmaps, which have been revised in the first step of the current research. The research was associated with the use of few keywords through these documents, as "indicator," "monitoring," "measure," "index," "rate," "ratio," and "measuring circularity." The identified indicators and their context in the light of assumed objectives and areas of the CE implementation on the national level were discussed. The discussion has been supported by the comprehensive analysis of available reviewed scientific papers published on international platforms such as Elsevier Scopus, Elsevier Science Direct, Springer Nature, Google Scholar, and Multidisciplinary Digital Publishing Institute (MDPI) database. These publications were related to the topic of the CE in the national context.

Step III—the third step of research included a comparative analysis of the CE indicators proposed by individual countries and implications for the CE monitoring. Moreover, an analysis of the progress towards CE for selected indicators from the EU monitoring framework was discussed. The CE indicators were analyzed with the use of statistical data published by the European Statistical Office—Eurostat (ec.europa.eu/Eurostat). In the current paper, three indicators were analyzed. The criterion for selecting indicators was compliance with the key areas of CE implementation in national roadmaps. Thus, the following indicators were selected for further analysis:

- Municipal waste generation (as an indicator for consumption aspects), in the area of production and consumption
- Recycling rate of municipal waste (the share of municipal waste which is recycled), in the area of waste management
- Circular material uses rate (the share of total material use) in the area of secondary raw materials.

However, it should be highlighted that a detailed analysis of the achieved values for the CE indicators (and their determinants) is not the aim of the current study.

The whole paper is followed by conclusions.

National CE Roadmaps in the European Countries

The national CE strategies or roadmaps are comprehensive documents, which address the transformation process from multiple points of view in one officially adopted paper. Currently, there are 27 EU countries—Austria, Belgium, Bulgaria, Croatia, Republic of

Table 1 List of CE national strategies in the European countries, identified for the study

No	Country	Strategy title		Issuing Public Authority	Year of publication
		National language	English translation		
1	Belgium	Vers une Belgique pionière de l'économie circulaire	Towards a Belgium as pioneer in the circular economy	Government of Belgium	2014
2		Ensemble faisons tourner l'économie en développant l'économie circulaire en Belgique	Let's make the economy work by developing the circular economy in Belgium	Government of Belgium	2016
3	Czech Republic	Cirkulární Česko 2040	Circular Czech Republic 2040	Ministry of the Environment	2020
4	Denmark	Strategi for circulær økonomi	Strategy for circular economy	Ministry of Environment and Food, Ministry of Industry, Business and Financial Affairs	2018
5	Finland	Kierrolla kärkeen: Suomen tiekartta kiertotalouteen 2016–2025	Leading the cycle: Finnish road map to a circular economy 2016–2025	Sitra	2016
6	France	Feuille de route Économie circulaire: 50 mesures pour une économie 100% circulaire	Roadmap for the circular economy—50 measures for a 100% circular economy	Ministry for Ecological and Solidary Transition	2018
7		La loi anti-gaspillage pour une économie circulaire	The anti-waste law for a circular economy		2020
8	Germany	Deutsches Ressourceneffizienzprogramm II: programm zur nachhaltigen Nutzung und zum Schutz der natürlichen Ressourcen	German Resource Efficient Programme II: programme for the sustainable use and conservation of natural resources	Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety	2016
9	Greece	Εισήγηση στο Κυβερνητικό Συμβούλιο Οικονομικής Πολιτικής (ΚΥ.Σ.ΟΙ.Π) Κυκλική Οικονομία	Transition to a circular economy model for sustainable production and consumption patterns	Governmental Economic Policy Council	2018
10	Italy	Verso un modello di economia circolare per l'Italia	Towards a Circular Economy Model for Italy	Ministry for the Environment, Land and Sea Ministry of Economic Development	2017
11	Ireland	Waste Action Plan for a Circular Economy, Ireland's National Waste Policy 2020–2025	Waste Action Plan for a Circular Economy, Ireland's National Waste Policy 2020–2025	Government of Ireland, Climate Action and Environment	2020
12	Luxembourg	Plan national de gestion des déchets et de ressources	National Waste and Resource Management Plan	Government of the Grand Duchy of Luxembourg	2018
13	Netherlands	Nederland circulair in 2050	A Circular Economy in the Netherlands by 2050	Government of the Netherlands	2016

Table 1 (continued)

No	Country	Strategy title		Issuing Public Authority	Year of publication
		National language	English translation		
14	Poland	Mapa drogowa Transformacji w kierunku gospodarki o obiegu zamkniętym	Road map—transformation towards a circular economy	Ministry of Economic Development	2019
15	Portugal	Liderar a transição: plano de ação para a economia circular em Portugal 2017–2020	Leading the transition: a circular economy action plan for Portugal 2017–2020	Ministry of Environment, Portugal	2017
16	Slovenia	Kažipot prehoda v krožno gospodarstvo Slovenije	Roadmap towards Circular Economy in Slovenia	Ministry of Environment and Spatial Planning, Republic of Slovenia & Circular Change Platform	2018
17	Spain	España Circular 2030. Estrategia española de economia circular	España Circular 2030. Circular Economy Spanish Strategy	Government of Spain	2020
18	Sweden	Cirkulär ekonomi—strategi för omställningen i Sverige	Circular economy—strategy for the transition in Sweden	Ministry of the Environment	2020
19	Norway	Hvitt Papir	White paper	Ministry of Climate and Environment	2017
20	Serbia	Mapa puta za cirkularnu ekonomiju u Srbiji	Roadmap for circular economy in Serbia	Ministry of Environmental Protection of the Republic of Serbia	2020
21	United Kingdom	Our waste, our resources: a strategy for England		Her Majesty's Government	2018

Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden. Out of 27 Member States, 16 countries have already published strategies, and most of them are available on the webpage of the European Circular Economy Stakeholder Platform. The following countries published their CE strategies Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Poland, Portugal, Slovenia, Spain, and Sweden. The specific areas and groups of resources in the individual Member States are summarized in Table 2.

The scope of the presented strategies depends on the socio-economic situation in a given country. Most of the strategies include plans for more sustainable resource management that are available in a given country. In most of the national documents, the key areas of the CE implementation are described, and specific actions for those areas are proposed. In addition, the individual sectors and raw materials are also included in the plans for the CE implementation. In general, most of the national CE roadmaps focuses on the areas directly connected with the groups of the CE indicators provided by the EC:

- More sustainable and circular production (including eco-design)
- More sustainable and circular consumption and changes in consumer behavior
- More sustainable and circular waste management (including the creation of a market for recovered raw materials)
- Further research, development of innovation, and digitalization for the CE
- Citizen engagement, raising CE awareness, and education for the CE
- Development of national policies to accelerate the implementation of circular solutions
- Development of CE business models throughout the value chain
- Identification of specific bodies responsible for the CE implementation
- Development of the CE indicators.

There are also some EU countries which do not present the individual strategies for the CE implementation, but their various documents focus on the implementation of the CE assumptions (in waste management, circular public procurement, circular business models etc.), such as Austria. New national strategies are expected in other European countries, or some of the CE aspects are already incorporated in the national documents. Austria does not provide the national CE strategy; however, many national documents include the CE principles and the transition to the CE model were incorporated in the national government program for 2020–2024 as one of the priority targets [35]. In Bulgaria, the Ministry of Environment and Water signed a contract for the preparation of a national strategy for the period 2021–2027 [36]. The CE principles are also incorporated into Croatia's post-2022 National Waste Management Plan (NWMP), which is the obligatory document in the EU countries [37]. Cyprus does not provide the national CE strategy; however, the CE was mentioned in the national agenda with the Ministry of Energy, Commerce & Industry, and Ministry of Agriculture, Rural Development & Environment [38]. The Hungarian government did not develop a strategy dedicated to CE; however, many national documents include the CE principles [39] and the national Circular Economy Platform was already established in Hungary. In Lithuania, the renewed National Strategy for Climate Change introduced goals linked to the CE and use of circular materials. In Malta, several policy measures and initiatives aim at fostering the CE, including ambitious 10-year waste management plans. In Romania, in 2019 Institute for Research in Circular Economy and Environment "Ernest Lupan" (IRCEM), a member of the ECESP Coordination Group has

Table 2 Key areas and scope of the CE national strategies in the European countries

Country	Key areas/scope of the CE national strategies	Source
Belgium	Fossil fuels, mineral ores, industrial, construction minerals, bio-products, food, fuels	[15–17]
Czech Republic	40 implementation actions in the areas of more circular production and design; more circular consumption and consumer behavior; more circular waste management; research, innovation, and digitalization for circular economy; and education and knowledge for CE	[18]
Denmark	Strengthen enterprises as a driving force for circular transition, support CE through data and digitalization, promote CE through design, change consumption patterns through CE, create a properly functioning market for waste and recycled raw materials, and more value out of buildings and biomass	[19, 20]
Finland	Sustainable food system; forest-based loops; technical loops; transport and logistics, and one additional area; common actions for policy-makers, companies, universities, and research institutes, consumers and citizens, and vibrant regions	[21]
France	Better production, better consumption, better waste management, and mobilizing all actors	[22, 23]
Germany	Combining ecological necessities with economic opportunities, innovation focus, and social responsibility; seeing global responsibility as a key guide of national resource policy; making economic and production activities in Germany depend less and less on primary resources, and developing and expanding the CE; securing sustainable resource use for the long term by guiding society towards quality growth	[24]
Greece	Twenty-three actions in the area of regulatory and legislative reforms; two actions to improve financing, six know-how and information actions, and three governance actions, with identification of specific bodies responsible for the implementation	[25]
Ireland	Over 200 measures across various waste areas including a holistic approach to the CE, municipal waste, consumer protection and citizen engagement, plastics and packaging, construction and demolition, textiles, green public procurement, and waste enforcement	[26]
Italy	Transformation of waste into high-value-added resources; development of creative technologies, processes, services, and business models that shape the future of national economy and society	[27]
Luxembourg	Measures that will be taken to ensure the re-use, recycling, recovery, and disposal of waste in the most environmentally friendly conditions while remaining in line with the national and European legislative context	[28]
Netherlands	Biomass and food, plastics, manufacturing industry, construction sector, and consumer goods	[29]
Poland	Sustainable industrial production, sustainable consumption, bioeconomy, and new business models	[30]
Portugal	Design, repair, reuse: extended producer responsibility; incentivizing a circular market; educating for CE; eat without waste: sustainable production for sustainable consumption; new life for waste; regenerating resources: water and nutrients; and researching and innovating for CE	[31]

Table 2 (continued)

Country	Key areas/scope of the CE national strategies	Source
Slovenia	Circular economy (business models), circular change (government policies), and circular culture (citizens)	[32]
Spain	Construction; farming, fishing, and forestry; industry; consumer goods; tourism; and textile and garment	[33]
Sweden	CE through sustainable production and product design; CE through sustainable ways of consuming and using materials, products, and services; CE through non-toxic and circular material cycles; and CE as a driving force for the business sector and other actors through measures to promote innovation and circular business models	[34]

launched a project to support the development of a national roadmap [8]. Moreover, the Slovak Environmental Strategy underlined the transition to the CE [8]. In Estonia and Latvia, the national CE action plans are under development [40].

The key added value of the already developed and published strategies is an integration of all stages of the value chain in one document—from production, through consumption, waste management, and secondary raw materials, to innovation and investments. This coincides with the monitoring framework indicated by the EC [10].

Performance Indicators in National CE Roadmaps

This section provides an inventory of performance indicators included in the national strategies toward the CE.

In the Belgian strategy from 2014, the CE-related indicators refer to the Europe 2020 strategy [4] and already existing European indicators—two main indicators (productivity of resources and domestic consumption of materials) and eight indicators relating to land–water-carbon, and twenty complementary indicators. It was strongly underlined that further efforts have to be taken at the European level (by the European Environment Agency—EEA, and Eurostat), as well as at the national level, to develop better indicators [16]. It has to be clarified that these indicators refer to the CE aspects, but they were not called "CE indicators." In 2016, in the second national-level document on the CE implementation in Belgium, the CE indicators were pointed as the essential to assess the transition to the CE, and these indicators should be developed in the following years [17].

The CE strategy of the Czech Republic, despite many examples of good practices in several companies (with practical ways of implementation of the CE in the country), does not provide the specific information of the CE indicators or monitoring framework [41]. The roadmap is currently under public consultation.

In the Danish strategy, no specific indicators are provided. The strategy includes information on the national resource productivity and the share of recycling of total waste arisings. These indicators are used to show the Danish situation (based on Eurostat data), but they are not specific CE national indicators. The resource productivity shows an economic value which is generated from the materials used in the production of products and services. In the Danish strategy, resource productivity is based on domestic material consumption (DMC) in relation to economic growth (GDP). Due to the fast technological developments in the digital field, the massive amounts of data are generated constantly about different material flows, which could be used by the different bodies in order to reduce the material usage or transport costs and thus increase the economic profit from recycling. It suggests that there is a strong recommendation to better measurement of material consumption, quality, and quantity; hoverer, no specific CE indicators are provided [20].

The Finish strategy provides the information on the necessity of the CE development on the national level. They should provide a comprehensive knowledge that describes the development of Finland's circular economy. The Finish government announced that it would like to be a pioneer in terms of the development of the CE indicators in the EU. The indicators should produce information concerning new perspectives on the CE, including sharing economy, resource loops, and systemic changes and innovations. The indicators are also part of the Findicator service that describes social development. The quantitative and qualitative indicators based on the main principles in the roadmap were planned to be developed [21].

The French government proposed a new indicator, called the "repairability index," that allows the consumer to know whether his product is repairable, difficult to repair, or non-repairable. The objective is to achieve a 60% repair rate for electric and electronic products within 5 years (from 2018). It was planned to develop a simple index (a score out of 10) affixed directly on the product or its packaging and at the point of sale (alongside the price of the product for example). It focuses on five categories of "pilot" products, including washing machines, TV sets, smartphones, laptops, and mowers. This generic index should be easily applied to other categories of electric and electronic equipment. There was also a plan to make progress towards a durability index [22]. France announced that will be responsible for the development of the repairability index, to make this information on the reparability of products a harmonized European obligation. The importance of the regional authorities in the monitoring progress was also indicated, with a special focus on resource flows, waste management and job creation. It will be called "material flow inventories". There is also a plan to develop a specific monitoring system for the waste produced by the public units and the community canteens that depend on it. It will take into account a circularity element in this system, and it will be the model solution (new incentive device) to mobilize public services and promote good practice. This monitoring system is planned to be a part of the inter-ministerial "exemplary administration " system [22, 23]. Despite the lack of specific indicators in the French CE roadmap, the national body in 2015 proposed a set of 10 indicators to measure the progress toward the CE [42]. They are grouped into three following areas: supply from economic stakeholders, consumer demand and behavior, and waste management. Finally, in 2016, the Monitoring and Statistics Directorate of France provided the list of the CE indicators under the seven CE pillars, based on the latest legislative measures. These performance indicators refer to all stages of the cycle (Table 3)

Table 3 The proposed CE indicators in France

Circular economy pillar	CE indicator	Unit
Extraction/operation and sustainable supply chains		
	Domestic material consumption per capita	Mg/capita
	Resource productivity	EUR/kg
Eco-design (products and processes)		
	Ecolabel holders	piece
Industrial and territorial ecology		
	Industrial and territorial ecology projects	piece
Functional Economy		
	Car-sharing frequency rates	%
Responsible Consumption		
	Waste quantities	kg/capita/year
Extension of product lifespan		
	Household spending on maintenance and repair	%
Recycling (materials and organic matter)		
	Waste sent to landfill over time	%
	Use of secondary raw materials	%
7 pillars as a whole		
	Employment in the circular economy	piece

Source: [42]

and are followed by the CE indicator examining employment in the CE naturally addresses the cycle as a whole.

The German government underlined that the development and monitoring of economic indicators to track resource efficiency should include Germany's existing situation as an industrial and manufacturing base with the primary extractive industry that this involves. The government proposes to establish a regular monitoring of market developments in resource-efficient products, including the introduction of a market index. The strategy provides information on raw material productivity and economic growth. The specific indicators for recycling and recovery of raw materials include [24] the percentage of waste recycled, recycling rate for plastic waste, percentage of recycled aggregate used as concrete aggregate relative to the total volume of mineral recycled construction materials, percentage of recycled material in the manufacture of gypsum board (plasterboard), mass of separated automotive electronics per end-of-life vehicle, ratio of total weight of collected WEEE to the average weight of electrical and electronic equipment placed on the market in the three preceding years, quantity of organic waste collected, and recovery rate of phosphorus from wastewater/sewage sludge.

The Greece strategy includes recommendations for the monitoring of the transformation toward the CE. It should provide measurable indicators of the incorporation of the CE in investment plans and the actual economy. Moreover, socioeconomic indicators for materialization and monitoring of actions are indicated to be taken into account for mountainous, barren areas and islands, and for economically weak social groups. The monitoring framework shall provide economic, environmental, and social indicators due to it refers to both the CE and Sustainability Indices. The development of the CE indicators is mentioned as one of the specific actions in the national strategy (Action 1.8). The monitoring framework proposed by the EC was indicated as an effective tool for monitoring transition, trends, and for assessing the effectiveness of measures and policies. It could be also further used to identify good practices in the EU countries. An Action 1.9 focuses on the development of a methodology to measure and monitor food waste until now, and data sets on this issue are not always comparable or transparent at the national and European levels [25].

The Irish strategy does not provide the set of indicators for the CE. However, there are focus areas in this context—waste data and data flows in the context of monitoring the transformation progress. The government established the National Waste Statistics web resource to provide more timely indicators of waste generation and management. For now, the available data includes quarterly figures on municipal waste accepted at landfills and thermal treatment facilities, supported by data on preliminary annual information on waste accepted at landfills. The National authorities use the Environmental Protection Agency (EPA) works, which currently continues to include more early waste indicators as data becomes available. Moreover, the National Waste Collection Permit Office and the EPA integrated efforts to harmonize reporting requirements and reduce the reporting burden for the Local Authority permit holders. It could bring added benefits to licensees and permit holders and improve the quality and timeliness of waste statistics [26].

Italy was one of the first European countries to present a set of indicators for the CE. There is the proposition to develop a single "circularity index" which should allow to easy comparison of the economic aspects. This index should take into account the circularity flow of resources used (including input and output) and the circularity of the use of product or product-service (including input and output). There is a recommendation to evaluate the circularity on macro level (as an instrument applied to the country system) and micro level (as an instrument applied to the system of companies and other public and private activities). The macro indicators can be assessed with the use of a set of indicators proposed by

the EC in 2018, while the macro indicators focus on companies, public administration, and other private bodies, to assess, through a budget, the quantities of natural resources used in relation to the economic and environmental sustainability. This could help companies to draw up their own circularity balance and possibly involve their suppliers and customers throughout the supply chain. In the context of raw material usage, two main indicators must characterize the possibility of making strategic choices based on the reliable market scenario—economic indicator and physical indicator (relative to the resources used). On the sector level, the CE indicators should be developed with strong engagement of companies and identify the most appropriate reference indicators by sector, also in relation to their applicability to micro and small businesses. There could be some problems with the comparability of physical indicators (e.g., used materials and produced waste), with indicators of use (e.g., load factor). Moreover, it is challenging to include both material and energy resources in the physical indicators, therefore adopting Key Performance Indicators (KPIs), which allow to relate all the key elements of the CE (physical and use factors) is proposed. To develop the specific indicators for Italy, the Ministry for the Environment and for the Protection of the Territory and the Sea set up a "Technical Table" responsible to identify suitable indicators to measure and monitor the CE transformation and the efficient use of resources at macro, meso, and micro level [27].

In Luxemburg, the strategy does not provide the set of the CE indicators. However, the importance of the data flow measurement is underlined. It is included in a concept of product potential. Traditionally, reverse production facilities are assessed on the basis of recycling and recovery percentages. During this procedure, only the input streams in a recycling process are taken into account. The concept of product potential certification takes into account the idea of resource efficiency and uses the resource indicator. The use of the resource indicator makes it possible to show the actual quantities of recycled raw materials and the energy percentage used and thus to visualize the resource potential for the saving of primary resources [28].

The necessity of monitoring of the progress toward the CE is strongly underlined in the CE strategy in the Netherlands. The country has already created the Material Flows Monitor, which provides data on material used in the Netherlands linked to the Environmental Accounting—data on water consumption, ownership ratios, and international value chains. Based on this work, the supply security risk for 64 metals and minerals for the Dutch economy could be brought to light. The circular potential of 1100 abiotic product groups can now also be determined in terms of quantity. The monitor is being continued on the same basis, i.e., with the environmental accounting linked to the material flows monitor. There is a plan to develop indicators for monitoring and quantifying the progress of the CE implementation and the CE national program (Key Performance Indicators). Moreover, the integrated knowledge bank is proposed as the tool supplementing the material flows monitor with other available information (e.g., degree of toxicity of materials and products, and national use of raw materials related to planetary boundaries). The produced data should be disseminated via the raw materials tool for companies and the regional tool under development. The better monitoring of food waste and plastic waste is also proposed [29].

In the Polish roadmap, the monitoring of the CE implementation is an important aspect. Due to the complexity of the CE concept itself, a set of indicators is planned to be developed in the coming years. The Polish government provides two approaches for the monitoring progress—evaluation of the progress of transformation towards CE in Poland, and evaluation of the impact of CE on social and economic development at the mesoeconomic (regional) and macroeconomic (national) levels. The better monitoring of food waste is also recommended [30]. The assessment of activities in the field of transformation towards

the CE may be carried out with the use of aggregated indices—separately for sustainable production and consumption—but based on the main, auxiliary, and contextual indicators. To date, there is the available proposition of the set of indicators distributed into these three areas [43]:

- Main indicators—they result directly from the CE concepts and focus on the retention of economic value in the economy, the consequence of which is the reduction of waste, and the optimization of the amount of new production and consumption; they should be holistic and replicable and refer to strategic objectives
- Auxiliary indicators—designed to supplement the basic criteria set for the main indicators
- Contextual indicators—provide insight into systemic changes in the structure of the economy, but do not have to be directly related to the CE; indicators of the condition of the natural environment, which directly depend on anthropogenic impacts, and thus also on the current economic model.

The specific types of the CE indicators proposed, as a part of the national project toward their development, are presented in Table 4. This set of indicators is currently discussed among selected stakeholders in Poland, and the list of final indicators should be available by the end of 2021 [30].

In the Portuguese CE roadmap, it is clearly indicated that at the moment there is a lack of indicators to measure how fully circular an economy is. The monitoring of progress toward the CE model as well as the current circularity of the economy may not be feasible with the available data. Therefore, it is important to develop a set of the CE indicators, which focus not only on material inputs, production, and emissions, but other important areas of the CE, as sharing, reusing, and repairing. The established national the Coordination Group will be responsible for the identification of complementary indicators to show the state of transition at the national level, by sector and intervention area. The plan is to use existing knowledge (e.g., published by the Ellen MacArthur Foundation, supported by the Eurostat data) to propose the CE indicators. These indicators should be measured, according to an established methodology to monitor the outcomes associated with the process of transformation toward the CE model in the country. For the specific actions proposed in the national CE roadmap, complementary indicators are proposed. They are summarized in Table 5 [31].

The Spanish government declared to promote the adoption of common, transparent, and accessible indicators that can show the level of the CE implementation, with a special focus on social and environmental impacts. Therefore, on the country level, the already developed European CE indicators are used to evaluate the transition process, and one additional indicator on greenhouse gas emissions. This set of 10 indicators provide information on the results of the application of public policies, the adoption of sustainability and "circularity" systems by the productive sector, and consumer's choice of products and services considering sustainability criteria. Additionally, the behavior of citizens as a whole shall be also considered. The comprehensive assessment of results will be conducted every 3 years. In any case, the assessment shall be coordinated with the updating of the corresponding Action Plans, so that there is sufficient information about the results, effects, and impacts with regard to the CE as to appropriately carry out the relevant revision, updating, or preparation of a new action plan [33]. The set of Spanish indicators is presented in Table 6.

In the Swedish strategy, the progress to achieve the overall goal of the transition to the CE model will be tracked through a selection of the indicators in existing tracking systems

Table 4 The proposed CE indicators in Poland

Type of indicators	CE indicator	Unit
Main indicators		
	Resource productivity	GDP/DMC
	Share of renewable energy in the gross final energy consumption of enterprises	%
	Expenditure on R&D in relation to GDP	%
Auxiliary indicators		
	Productivity of water resources	%
	Amount of industrial waste generated in relation to GDP	%
	Share of produced secondary raw materials in total production	
	Greenhouse gas emissions from industrial activities in CO_2 equivalent	CO_{2e}/year
	Number of e-state services for entrepreneurs	Piece
	Number of environmental certificates	Piece
Contextual indicators		
	Share of expenditure on fixed assets for environmental protection in investment expenditure of the economy	%
	Share of full-time jobs in entities related to the activity of the CE in relation to total employment	%
	Value of public circular procurement in public procurement in total	%

Source: [43]

Table 5 The proposed CE indicators in Portugal

CE actions	CE indicator	Unit
Action 1 Design, repair, and reuse: extended producer responsibility [product–consumption]		
	Ratio of shops offering repair services to the total number of shops	%
	Repair cafés and/or local actions realized	Piece
	Users of the services made available	Piece
	Ratio of products repaired to new products sold (including reused vs. new school books)	%
	Saving per student on the price of a basket of school books for each school year	%
	Partnerships with municipalities/distribution	Piece
	Awareness-raising actions and their respective impact	Piece
Action 2 Incentivizing a circular market [product–consumption]		
	Impact of the tax benefit awarded	%
	Gross value added (GVA) generated	EUR
	Companies or products with tax benefits	Piece
	Investments in the CE projects	EUR
Action 3 Educating for a circular economy [consumption–knowledge]		
	Assessment and monitoring system will be developed during the course of implementing the National Environmental Education Strategy (ENEA) 2020	
Action 4 Eat without waste: sustainable production for sustainable consumption [consumption–waste, by-products, secondary raw materials]		
	Indicators considered via the National Strategy to Fight Food Waste (ENCDA) and the respective action plan	
Action 5 A new life for waste! [waste, by-products, secondary raw materials]		
	New types of waste classified as by-products and with end-of-waste status;	Piece
	Average time to process a by-product classification decision	

Table 5 (continued)

CE actions	CE indicator	Unit
Action 6		
Regenerating resources: water and nutrients [consumption–waste, by-products, secondary raw materials]		
	Agreements established and countries covered	Piece
	Actions taken to disseminate the guidance document	Piece
	Directives adopted	Piece
	Awareness actions and their respective impact	Piece
Action 7		
Researching and innovating for a circular economy [knowledge]		
	Actions to divulge the guidance document	Piece
	Directives adopted	Piece
	Awareness actions and their respective impact	Piece
	Number and investment in circular-economy-related R&I projects	Piece / EUR
	PhD and post-PhD grants and contracts in scientific employment	Piece
Action		
Built environment: greater efficiency and material productivity		
	Voluntary agreements signed and sectors covered	Piece
	Guides developed	Piece
	Reuse initiatives	Piece
	Quality protocols developed (materials from construction and demolition waste)	Piece
	Projects incorporating smart design	Piece
	Rate of compliance with the obligation to use at least 5% of recycled materials in construction contracts under the Public Contracts Code	%
Action		
Green and circular public procurement		
	Products/services covered by circularity criteria	Piece
	Good practices identified and disseminated	Piece

Table 5 (continued)

CE actions	CE indicator	Unit
	Environmental and economic impact: reduced emissions, waste, costs vs. the traditional option	
Action		
Responsible business hubs (RBH-ZER)	Industrial symbioses/no. of industrial businesses set up in RBHs	Piece
	Quantity of materials and energy transacted between businesses/no. Of industrial businesses in RBHs involved	
	Savings in consumption and corresponding economic saving associated with the efficient use of resources	Mg, kW

Source: [31]

Table 6 The proposed CE indicators in Spain

CE area	CE indicator	Unit
Production and consumption	National consumption of materials	Mg
	Self-sufficiency in the production of critical raw materials in the EU	%
	Ecological public procurement	Piece, EUR
	Residuous generation	
	• Municipal waste generation per person	kg/capita
	• Generation of waste (without considering waste from mineral waste) with respect to GDP	kg/EUR
	• Generation of waste (without considering waste from mineral waste) with respect to domestic consumption of materials	%
	Food waste	Mg
Waste management	Preparation for reuse	%
	Recycling fees	
	• Municipal waste recycling rate	% (Mg)
	• Waste recycling rate excluding mineral waste recovery/recycling by waste streams	% (Mg)
	• Packaging waste recycling rate	% (Mg)
	• Plastic packaging waste recycling rate	% (Mg)
	• Wood packaging waste recycling rate	% (Mg)
	• Recycling rate for waste electrical and electronic equipment	% (Mg)
	• Organic waste recycling rate	% (mass)
	• Construction and demolition waste recycling rate	kg/capita
Secondary raw materials	Contribution of recycled materials to the demand for raw materials	
	• End-of-life product waste recycling rates	%
	• Circular material rate	%
	Trade in recycled raw materials	

Table 6 (continued)

CE area	CE indicator	Unit
	• Imports from third countries	
	• Exports to third countries	
	• Intra-community imports	
	• intra-community exports	
Competitiveness and innovation		
	Private investment, employment, gross value added relative to circular economy sectors	
	Gross investments in tangible assets	%
	CE-related job places	%
	Added value at factor cost	%
	Patents related to recycling and secondary raw materials as a representation of innovation	Piece
Greenhouse Gases Emissions in the waste sector		
	National inventory of greenhouse gases	Piece
	• Contribution of greenhouse gases in the waste sector	CO_{2eq} (kt)

Source: [33]

for the specific goals and objectives indicated the focus areas of the CE implementation in the country, which correspond to the SDGs in the 2030 Agenda. The indicators, which are planned to be evaluated, are available for selected SDGs indicated in the national CE strategy [34].

Discussion and Implications for the CE Monitoring

Most of the national CE strategies include statements that the monitoring of the transformation process toward the CE model is an important element of this process. The individual countries recognize that the implementation of the CE requires monitoring of this process throughout the life cycle. Moreover, it should be connected with the specific actions, objectives, and pillars included in the national CE documents. The importance of the monitoring progress is supported by the conduction of national projects that focus on the development of the CE indicators, as in the strategy of Belgium, Germany, Finland, Greece, Netherlands, or Poland. Another national documents underline the necessity of the transformation toward the CE model, without any specific information about monitoring progress, as Czech Republic. In general, there is no possibility to propose one universal indicator which measures a level of the transformation toward the CE at the national level. This is due to the complexity of this issue and diversity of key sectors and economic actors in the individual European countries. However, Italy announced to develop a single CE indicator called "circularity index" in the following years. It should integrate and compare resources and economic aspects—circularity flow of resources used and circularity of the use of product or product—service. Germany also proposed an integration of economic aspects with the resources usage in the new "market index."

The CE indicators could be also provided in the form of key performance indicators—as it was proposed in the Netherlands and Italy. Anyway, the methodology for their development and monitoring should be firstly harmonized and published. An interesting proposition is also a French indicator, called "repairability index" that should allow the consumer to know whether his/her product is repairable, difficult to repair, or non-repairable, followed by "durability index." An important aspect of the monitoring progress is the way of data collection and management, which should contain high-quality data, as was underlined in the CE strategies of Ireland and Luxemburg. A set of specific indicators in the national roadmap was proposed by Portugal. It was strongly underlined that there is a lack of specific CE indicators to date (on EU level); therefore, the Portuguese government proposed the set of CE indicators, grouped in the actions indicated in national strategy toward the CE.

Some of the EU countries present the CE progress with the use of EC indicators, developed under the CE monitoring framework (as Denmark and Spain) or the SGDs (as Sweden). Finally, the comparison of the transformation progress toward the CE model of the individual Member States could be possible with the use of a common monitoring framework for all European countries. Therefore, to access the transition on the international level (comparison different countries), it is recommended to use the monitoring framework proposed by the EC in 2018. Monitoring progress toward the CE model in the European countries is based on the four groups, which include 10 indicators, some of which are broken down into sub-indicators [10]. Data on the mentioned CE indicators are systematically updated and made available on the Eurostat [11]. Those indicators have been chosen based on their comparability at the European level.

One of the most important CE indicators, which is mentioned in national strategies (as direct indicators or indicator needed to measure more complex index), is the amount of municipal waste generated by residents. The amount of waste generated in the individual countries depends on, among others, the structure of production [44, 45] and consumption patterns [46]. The current study shows that the official adoption of the CE strategy does not significantly impact the amount of municipal waste generated in individual countries. Data on changes in the generation of this waste stream is presented in Fig. 2. In the case of developed countries, like Belgium, Sweden, and the Netherland, which were one of the first countries with the national CE strategies, an improvement in the amount of municipal waste generated (decrease) is observed. These countries have ambitious goals in terms of implementing CE. There is also a clear reduction in the generation of municipal waste in Luxemburg and Germany after the adoption of the CE strategy; those countries have been pursuing a policy of reducing the amount of waste generated and increasing resource efficiency for many years, which is in the line with the CE principles [47]. The improvement in the area of municipal waste is therefore mainly noticed among well-developed countries with high innovation rates [48]. In most other counties, even with the adopted CE strategy, the amount of municipal waste consistently increases in the last years. The implementation of measures indicated in the CE national strategies in the European countries should improve this situation in the coming years.

Most of the indicators proposed in the national documents and also the EU indicators show the economic and technological aspects [49]. They focus on the preservation of materials, including indicators presenting recycling rates and recycled materials to the raw materials' demand [50]. The European CE framework provides the rate of municipal waste recycling (Fig. 3). The countries with adopted CE strategies show the increase in recycling of municipal waste between 2014 and 2019. Despite Poland has one of the lowest per capita generation of municipal waste among the EU countries, the recycling rate is far below the EU average and unfortunately, it does not increase systematically, as a consequence of lack of developed recycling infrastructure [51]. Moreover, Portugal also faces some problems to increase the recycling of municipal waste. For many years, Germany is the lead country in the municipal waste recycling, reaching almost 70%, followed by the Netherlands, Belgium, Austria, and Slovenia.
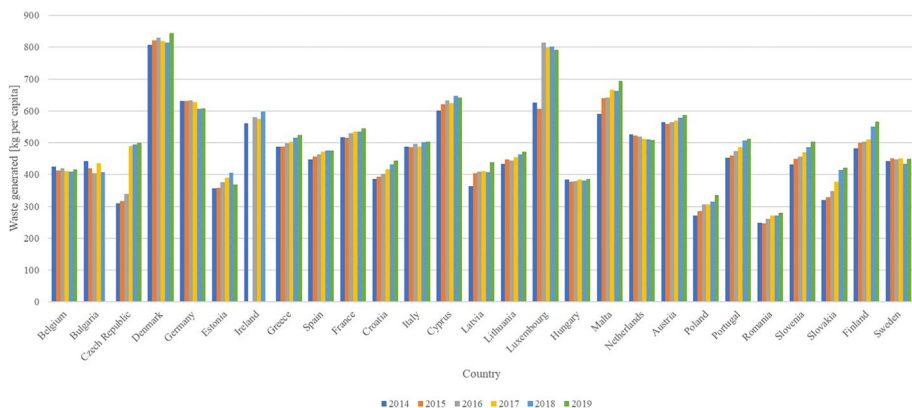

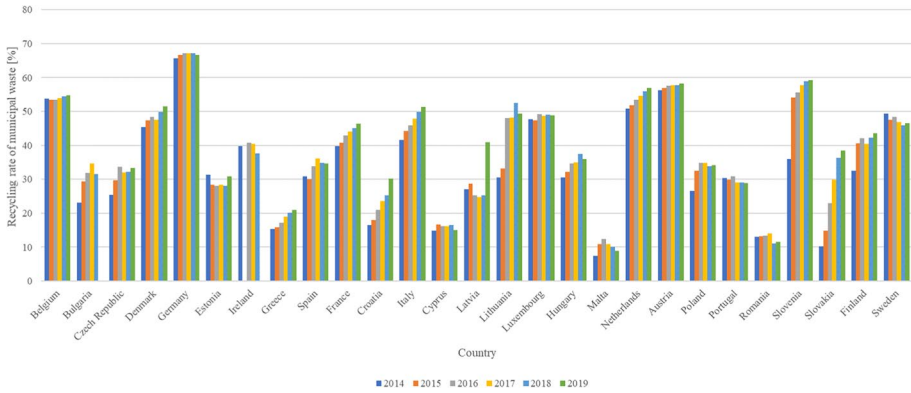**Fig. 2** Changes in the generation of municipal waste in the EU countries in 2014–2019

Fig. 3 Changes in the municipal waste recycling in the EU countries in 2014–2019

In the area of secondary raw materials, the most popular indicator is circular material use rate. In the transition to the CE model in Europe, the Netherlands is at the forefront (Fig. 4). The systemic actions and initiatives lead also to a significant increase in the circular materials usage. The visible improvement is also observed in Belgium, France, and Italy, followed by Germany, Estonia, Spain, and Slovenia. In most of these countries, the CE roadmaps already exist.

In the context of the implementation of the SD principles, which is strongly underlined in the European Green Deal strategy, it is important to integrate also the social aspects. Those aspects are mainly incorporated in the CE strategies of cities, such as Paris, Amsterdam, and London [15]. They address social indicators that affect people, such as the quality of life, health, and well-being. To date, there is a little framework for the CE indicators to measure these categories. The existing framework for monitoring the CE also does not reflect the progress of policy implementation towards the CE. Moreover, based on the list of the existing CE indicators, there is no possibility to define opportunities and barriers for accelerating transitions.
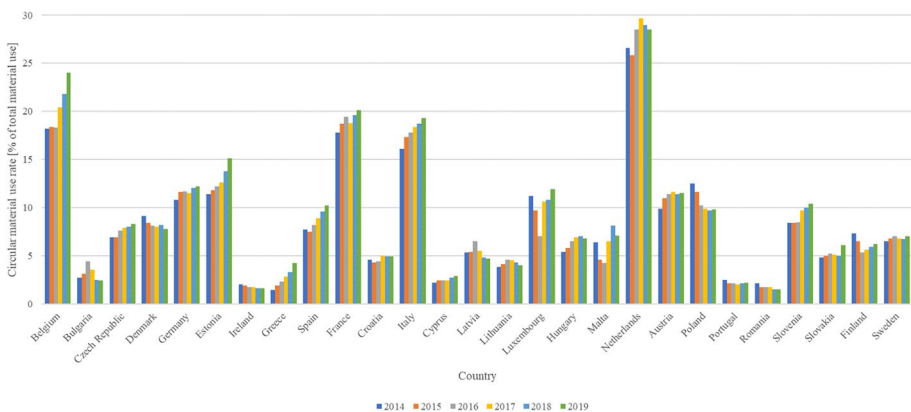
Fig. 4 Changes in the circular material use rate in the EU countries in 2014–2019

The transformation toward the CE model is a continuous process which requires the constant monitoring of impacts, introducing preventive and corrective action whenever necessary [52]. Therefore, it is strongly recommended to monitor the progress toward the CE at three possible levels [53]:

- Macro level indicators supporting strategic policy decisions in the specific areas of the economic activity, as trade and environmental policy integration, resource conservation policies, waste management policies, sustainable development, and Green Deal strategies and action plans; macroeconomic indicators can provide the holistic information about the country or larger region
- Meso level indicators provide detailed analysis of material flows within the economy, distinguishing categories of materials, industries or branches of the production, and categories of the consumption
- Micro level indicators provide detailed information for specific decision processes at the business or local level or concerning specific substance or individual product.

In the process of transformation toward the CE model, it is important to monitor all indicated levels of the economy, which requires the collection and management of several data [54]. There are several approaches to measure CE-related activities [55]. For example, the Organisation for Economic Cooperation and Development – OECD collected 474 circular-economy-related indicators, between 2018 and 2020, providing four key objectives in measuring the state of the art, progress, and impacts of a circular economy: raise awareness, make the case for the CE, trigger actions, and monitor performance and evaluate results [56]. Moreover, based on the evaluation of the several indicators at indicated levels, the recommended action is to evaluate a limited number of indicators (grouped into specific areas) to assess the progress of transformation toward CE instead of a single indicator [50].

In the European context, circularity and sustainability should characterize all stages of the value chain in order to achieve a fully CE, from design, through production, to the consumer [57]. In the new CE Action Plan, the EC proposed seven key areas necessary to achieve the CE. These are plastics, textiles, e-waste, food, water and nutrients, packaging, batteries and vehicles, and buildings [6]. It can be expected that the EC will propose the new CE indicators for these sectors in the following years.

Conclusions

The European countries are in the process of transformation toward the CE model, which is the priority of the economic policy of the EU. The individual countries developed special dedicated documents (strategies/roadmaps) to accelerate the transformation process and indicate the boundaries of further actions in this field. This transformation process has to be evaluated with the use of the CE indicators, which could determine the main trends and future perspectives. On the European level, the EC proposed a set of 10 CE indicators, some of which are broken down into sub-indicators. The added value of this monitoring framework is the possibility to compare different European countries in their achievements toward the CE. The CE monitoring progress includes four key areas of the CE implementation, production and consumption, secondary raw materials, waste management, and competitiveness and innovation.

These are indicators that have already been developed and used by Eurostat and are constantly being refined and reported by all Member States.

Most of the European countries strongly underlined the necessity to access the transformation progress with the use of indicators, based on national conditions and internal characteristics. Many countries (as Belgium, Germany, Finland, Greece, Netherlands, or Poland) decided to conduct the national projects to develop the CE indicators that can show the progress toward the CE in the country at different levels (macro, meso, or/and micro) or for different actions or objectives defined. It should be underlined here that there is no possibility to propose one universal indicator which measures a level of the transformation toward the CE at the national level. This is due to the complexity of this issue and the diversity of key sectors and economic actors in the individual Member States followed by different levels of advance, size, and specificity of the industry (producer or service). Therefore, it could be quite challenging for countries that declared to develop a single CE indicator called "circularity index" in the following years (e.g., Italy). In France, Germany, Poland, Portugal, and Spain the initial lists of the CE indicators already exist. The common indicators are these showing the municipal waste generated per capita and its recycling rate, followed by productivity, and dependence on DMC and GDP. It is suggested that each country should establish its lists of CE indicators internally, taking into account key industries. This could allow not only to monitor the implementation process of activities included in CE roadmaps, but also to identify the CE areas which require the greatest involvement by various groups of stakeholders in the given country. The already proposed countries' performance CE indicators could be also used by central governments in the other countries to shape national monitoring frameworks, but also by other stakeholders, as entrepreneurs—to adapt business and technological changes toward the CE, and by scientists—to shape the direction of scientific research and technological progress. However, to access the transformation process on the European level, it is recommended to use the already developed CE monitoring framework because it contains the CE indicators that provide a holistic view of all countries, independent of their economic differences.

Data Availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics Approval and Consent to Participate Not applicable.

Conflict of Interest The author declares that she has no conflict of interest.

References

1. European Commission, Communication from the Commission - Towards a circular economy: a zero waste programme for Europe, (2014) (COM no. 398, 2014). https://ec.europa.eu/environment/circular-economy/pdf/circular-economy-communication.pdf. Accessed 20 September 2021
2. European Commission, Communication from the Commission. Closing the loop - an EU action plan for the Circular Economy, (2015) (COM no. 614, 2015)
3. Nikolaou IE, Jones N, Stefanakis A (2021) Circular economy and sustainability: the past, the present and the future directions. Circ Econ Sustain 1:783–783. https://doi.org/10.1007/s43615-021-00054-9
4. European Commission, Communication from the Commission. Europe 2020. European strategy for smart, sustainable and inclusive growth, (2010) (COM no. 2020, 2010)
5. European Commission, Communication from the Commission: the European Green Deal, (2019) (COM no. 640, 2019)
6. European Commission, Communication from the Commission. Circular Economy Action Plan for a cleaner and more competitive Europe, (2020) (COM no. 98, 2020). https://ec.europa.eu/environment/circular-economy/pdf/new_circular_economy_action_plan.pdf. Accessed 20 September 2021
7. Smol M, Duda J, Czaplicka-Kotas A, Szołdrowska D (2020) Transformation towards circular economy (CE) in municipal waste management system: model solutions for Poland. Sustain 12:456. https://doi.org/10.3390/su12114561
8. ECESP, European Circular Economy Stakeholder Platform - Strategies, (2021) circulareconomy.europa.eu/platform
9. Lopes R, Santos R, Videira N, Antunes P (2021) Co-creating a vision and roadmap for circular economy in the food and beverages packaging sector. Circ Econ Sustain. https://doi.org/10.1007/s43615-021-00042-z
10. European Commission, A monitoring framework for the circular economy (2018) (COM no. 29, 2018). http://ec.europa.eu/environment/circular-economy/index_en.htm. Accessed 20 September 2021
11. European Commission, Eurostat, Ec.Europa.Eu/Eurostat (2021)
12. Bianchini A, Rossi J, Pellegrini M (2019) Overcoming the main barriers of circular economy implementation through a new visualization tool for circular business models. Sustain 11:6614. https://doi.org/10.3390/su11236614
13. De Pascale A, Arbolino R, Szopik-Depczyńska K, Limosani M, Ioppolo G (2021) A systematic review for measuring circular economy: the 61 indicators. J Clean Prod 281:124942
14. Saidani M, Yannou B, Leroy Y, Cluzel F, Kendall A (2017) A taxonomy of circular economy indicators. J Clean Prod 2019:542–559
15. European Economic and Social Committee, Circular economy strategies and roadmaps in Europe: identifying synergies and the potential for cooperation and alliance building, 2019. https://www.eesc.europa.eu/sites/default/files/files/qe-01-19-425-en-n.pdf. Accessed 20 September 2021
16. Government of Belgium, De L' Économie Circulaire, (2014) (in French)
17. Government of Belgium, Ensemble faisons tourner l'économie en développant l'économie circulaire en Belgique, (2016) (in French)
18. J. Maršák, Preparation of circular economy strategy in the Czech Republic, (2020)
19. SB Insight, The Nordic Market for Circular Economy - Attitudes, Behaviours & Business Opportunities, (2019)
20. Goverment of Denmark, Strategy for Circular Economy. More value and better environment through design, consumption, and recycling, (2018). https://stateofgreen.com/en/uploads/2018/10/Strategy-for-Circular-Economy-1.pdf. Accessed 20 September 2021
21. Sitra, Leading the cycle – Finnish road map to a circular economy 2016–2025, Sitra Stud. 121. (2016). https://www.sitra.fi. Accessed 20 September 2021
22. Government of France, Roadmap for the Circular economy - 50 measures for a 100% circular economy, (2018)
23. Government of France, The anti-waste law in the daily lives of the French people, what does that mean in practice? (2020). https://www.ecologique-solidaire.gouv.fr/loi-anti-gaspillage. Accessed 20 September 2021

24. Goverment of Germany, German Resource Efficiency Programme II - programme for the sustainable use and conservation of natural resources, (2016). https://www.bmu.de/fileadmin/Daten_BMU/Pools/Broschueren/german_resource_efficiency_programme_ii_bf.pdf. Accessed 20 September 2021
25. Government of Greece, National Circular Economy Strategy, (2018)
26. Government of Irleand, A waste action plan for a circular economy Ireland's National Waste Policy, (2020). https://www.dccae.gov.ie/en-ie/environment/publications/Documents/55/Waste_Action_Plan_for_a_Circular_Economy.pdf. Accessed 20 September 2021
27. Government of Italy, Towards a model of circular economy for Italy - overview and strategic framework, (2017). https://circulareconomy.europa.eu/platform/sites/default/files/strategy_-_towards_a_model_eng_completo.pdf. Accessed 20 September 2021
28. Government of Luxembourg, National Waste and Resource Management Plan in Luxemburg, (2018). http://marefateadyan.nashriyat.ir/node/150. Accessed 20 September 2021
29. Government of the Netherlands, A circular economy in the Netherlands by 2050, (2016). https://www.government.nl/binaries/government/documents/policy-notes/2016/09/14/a-circular-economy-in-the-netherlands-by-2050/17037+Circulaire+Economie_EN.PDF. Accessed 20 September 2021
30. Goverment of Poland, Roadmap transformation towards a circular economy, (2019)
31. Goverment of Portugal, Leading the transition - action plan for circular economy in Portugal: 2017–2020, (2017). https://circulareconomy.europa.eu/platform/sites/default/files/strategy_-_portuguese_action_plan_paec_en_version_3.pdf. Accessed 20 September 2021
32. Goverment of Slovenia, Roadmap towards the circular, (2018)
33. Government of Spain, España Circular 2030. Circular Economy Spanish Strategy, (2020). https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/temas/economia-circular/espanacircular2030_def1_tcm30-509532.PDF. Accessed 20 September 2021
34. Government of Sweden, Circular economy – strategy for the transition in Sweden, (2020). https://www.government.se/4ad42c/contentassets/d5ab250cf59a47b38feb8239eca1f6ab/circular-economy--strategy-for-the-transition-in-sweden. Accessed 20 September 2021
35. Circle Economy, National circularity gap report - Austria, (2019)
36. REDUCES Interreg Europe, Bulgaria on its journey to circular economy, (2020). https://www.interregeurope.eu/reduces/news/news-article/10. Accessed 20 September 2021
37. Gelo T, Andabaka A, Beg M (2018) Challenges of Circular Economy in Croatia. Int J Multidiscip Bus Sci M-Sph 4:115–126
38. SwitchMed, Cyprus Country Profile, (2020)
39. Fogarassy C, Horvath B, Borocz M (2017) The Interpretation of Circular Priorities to Central European Business Environment with Focus on Hungary, Visegr. J Bioeconomy Sustain Dev 6:2–9. https://doi.org/10.1515/vjbsd-2017-0001
40. Government of Estonia, Circular economy, (2021) ringmajandus.envir.ee/en/circular-econom
41. INCIEN, Circular Czech Republic 2040, Inst. Cirkulární Ekon. (2020). https://incien.org/wp-content/uploads/2018/08/WP_CE.pdf. Accessed 20 September 2021
42. Monitoring and Statistics Directorate of France, 10 Key Indicators for Monitoring the Circular Economy, DataLab. (2017) Paris. http://www.statistiques.developpement-durable.gouv.fr/fileadmin/documents/Produits_editoriaux/Publications/Datalab/2017/datalab-18-economie-circulaire-Edition-2017-anglais.pdf. Accessed 20 September 2021
43. Nowaczek A, Kulczycka J, Bączyk A (2020) Proposed indicators for measuring transfromation Polish economy towards circular economy, in: Monogr. Circ. Econ. Monit. Indic., pp 37–56 (in Polish)
44. Campoy-Muñoz P, Cardenete MA, Delgado MC (2017) Economic impact assessment of food waste reduction on European countries through social accounting matrices. Resour Conserv Recycl 122:202–209. https://doi.org/10.1016/j.resconrec.2017.02.010
45. Židonienė S, Kruopienė J (2015) Life Cycle Assessment in environmental impact assessments of industrial projects: towards the improvement. J Clean Prod 106:533–540
46. Lakatos ES, Cioca LI, Dan V, Ciomos AO, Crisan OA, Barsan G (2018) Studies and investigation about the attitude towards sustainable production, consumption and waste generation in line with circular economy in Romania. Sustainability 10:865. https://doi.org/10.3390/su10030865
47. Marino A, Pariso P (2020) Comparing European countries' performances in the transition towards the Circular Economy. Sci Total Environ 729:138142. https://doi.org/10.1016/j.scitotenv.2020.138142
48 Generowicz A, Gaska K, Hajduga G (2018) Multi-criteria analysis of the waste management system in a Metropolitan Area. E3S Web Conf 44:1–8. https://doi.org/10.1051/e3sconf/20184400043
49. Avdiushchenko A, Zajaç P (2019) Circular economy indicators as a supporting tool for european regional development policies. Sustain 11:3025. https://doi.org/10.3390/su11113025

50. Moraga G, Huysveld S, Mathieux F, Blengini GA, Alaerts L, Van Acker K, de Meester S, Dewulf J (2019) Circular economy indicators: what do they measure? Resour Conserv Recycl 146:452–461. https://doi.org/10.1016/j.resconrec.2019.03.045

51 Gaska K, Generowicz A, Ocłoń P, Stelmach S (2021) Location of the waste incineration plant with particular emphasis on the environmental criteria. J Clean Prod 303:126887

52. Wisse E (2016) Assessment of indicators for Circular Economy; The case for the metropole region Amsterdam, Master Thesis, Fac. Geosci. Utr. Univ. https://dspace.library.uu.nl/handle/1874/337187. Accessed 20 September 2021

53. Van Hoof V, Maarten C, Vercalsteren A (2018) Indicators for a Circular Economy, Flanders State Art. https://circulareconomy.europa.eu/platform/sites/default/files/summa_-_indicators_for_a_circular_economy.pdf. Accessed 20 September 2021

54 Smol M, Kulczycka J, Avdiushchenko A (2017) Circular economy indicators in relation to eco-innovation in European regions. Clean Technol Environ Policy 19:669–678. https://doi.org/10.1007/s10098-016-1323-8

55 Smol M, Adam C, Preisner M (2020) Circular economy model framework in the European water and wastewater sector. J Mater Cycles Waste Manag 22:682–697. https://doi.org/10.1007/s10163-019-00960-z

56 OECD (2020) The circular economy in Cities and Regions. Synth Rep. https://doi.org/10.1787/10ac6ae4-en

57. Bianchini A, Rossi J (2021) Design, implementation and assessment of a more sustainable model to manage plastic waste at sport events. J Clean Prod 281:125345. https://doi.org/10.1016/j.jclepro.2020.125345