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Benefits and Limitations of Indicators for Monitoring the Transformation towards a Circular Economy in Poland

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Abstract: More and more attention is paid to the circular economy (CE) and indicators that enable the monitoring and verification of the progress of transformation at various levels (the European Union, countries, regions, companies, etc.). Many analyses of CE indicators for different levels have been presented in the literature, but the benefits of their implementation and their limitations have not been discussed individually. The aim of the work is to identify and verify, based on the research conducted, CE indicators relating to sustainable production, along with their advantages and limitations. The article presents the selection process as well as the potential benefits and limitations of using indicators to assess the transformation towards a CE as identified for the Polish economy. The practical aim is to apply the indicators identified to different sectors of the economy. An important element of the work is the proposal for the process of selecting CE indicators that monitor the CE transformation based on their advantages and limitations, taking into account the goals and obligations set out in the main strategic documents of Poland and the EU, the process of consultations with industry, and the structure of the economy.

Keywords: monitoring of circular economy; indicators; benefits and limitations

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1. Introduction

Transitioning to a climate-neutral, resource-efficient, clean CE in a just and inclusive manner and achieving the environmental objectives of the United Nations' Agenda 2030 and its Sustainable Development Goals, fully endorsing the environmental and climate objectives of the European Green Deal, is the overarching aim of the Eighth Environment Action Programme (8th EAP) in the European Union (EU) and many strategies and policies in member states [1]. These require long-term objectives and measured indicators to monitor and verify progress. In recent years, many efforts have been made to select the best set of CE indicators that can monitor circularity at different levels:

- Macro-level (EU and individual countries);
- Meso-level (region, sector);
- Micro-level (city, company, product).

At the micro (company) level, a response to global challenges related to development through the management of environmental, social, and corporate governance factors is the new ESG reporting system. A smaller but carefully selected set of indicators is to be used to help companies focus reporting on key ESG areas in line with current and upcoming regulations and risks and opportunities relevant to their sector of activity. In recent years, the EU has adopted a number of regulations to support actions for a sustainable EU economy and to mitigate the effects of climate change, including the Non-Financial Disclosure Directive (NFRD, Directive 2014/95/EU), EU Taxonomy (Regulation 2020/8529), and the SFDR Sustainable Investment Disclosure (Regulation 2019/208810). The draft EFRAG (European Financial Reporting Advisory Group) report "Resource use and circular economy" [2] describes in detail the information requirements that will enable reporting on the non-financial activities of the company, including an indication of how the company affects the use of resources, the depletion of non-renewable resources, and the adaptation of its business model, plans, and operations to CE principles.

Moreover, at the end of 2021, ISO (International Organization for Standardization) published an updated version of the Guidelines for the design and use of environmental performance evaluation within an organization (Environmental management—Environmental performance evaluation—Guidelines ISO 14031:2021). The document describes two categories of indicators: environmental condition and environmental performance indicators, which can be used to demonstrate how the organization shows the relationship between the organization's management, its operations, and environmental conditions. Previous literature focusing on CE at the micro-level has attempted to assess the transition from a traditional linear business model to a CE model [3], using indicators based on:

- An eco-innovation model [4,5];
- Recyclables and waste recovery [6];
- Waste treatment and recycling [7];
- Eco-design and resource productivity [8,9];
- Other activities, i.e., industrial symbiosis [6,10,11];
- Taxonomy [12];
- The level of product circularity using resource efficiency [13,14].

At the meso- and macro-levels, it is necessary to include a wider spectrum of thematic categories, i.e., economic development, material and waste management, the quality of people's lives, and CE business models. However, as shown in the report Indicators for a Circular Economy [15], existing indicators focus primarily on physical parameters, such as kilograms, which are more related to technology. This is particularly important in the current political situation, with a 40-year historically intensive increase in the consumption of raw materials in the world [16] and a plan for this to be doubled over the next 40 years [17]. The transition to a CE is seen as a solution that supports sustainable consumption, the security of resources, and well-being. Therefore, the indicators based on resource consumption and waste generation are often compared with the gross domestic product (GDP) or GDP per capita of individual countries; however, at the regional level, it is more challenging due to a lack of data on import and export. Moreover, as GDP is a measure of the value added created through the production of goods and services, and as the production of goods is usually more material intensive, it would also be worth measuring the resource productivity for the production element alone, not the total GDP value.

It is important that CE indicators should, to some extent, respond to the main challenges of CE, i.e.,

- Decoupling economic growth from negative environmental impacts;
- Increasing the efficiency of the use of natural resources;
- Reducing the environmental impact at all stages of the product's (goods and services) life cycle, including minimising waste generation;
- Increasing people's well-being.

However, indicators focusing on socio-institutional aspects (e.g., collection systems) are still not sufficiently defined and are less frequently included in the CE monitoring framework. The same applies to high-level strategies for circularity. Very few indicators capture the effect of strategies that relate to the smarter use of products and the manufacture and extension of the life span of products [15]. In Poland, many measures coherent with a CE have already been implemented in strategies and policies, continuing the application of sustainable development policy. Further to the above, these should be considered when developing indicators, targets, and proposals for CE monitoring. Typically, such indicators cover environmental, social, and economic aspects, but they should also account for new business models and assessments of innovation. In general, the CE indicators proposed in the documents fall into three categories [18]:

- Indicators related directly to specific strategies or materials, e.g., recycling rates for selected materials;

- Direct indicators embracing more than one strategy, e.g., reduced water consumption;
- Indirect indicators containing information about the CE but not referring directly to CE goals, e.g., the eco-innovation indicator measuring effective management of resources.

During the development of CE indicators, factors influencing the direction of their changes and the tempo are important [19]. This applies, in particular, to indicators affecting the volume of resources consumed, their environmental impact, and economic aspects. The importance of resource productivity and economic indicators in the transition towards a CE has been widely recognized by many scientists, industries, and institutions [20–24] as it remains key to the transition towards a more circular economy. It is worth noting that the value of a CE indicator also depends on:

- Technological progress—growing productivity allows one to manufacture the same number of products and services with reduced consumption of resources. Similarly, it is possible to substitute rare or hazardous resources with "greener" ones; at the same time, the overall impact of technical progress on demand for materials may vary in nature (depending on the industry, type of material, etc.).
- Structural changes—a higher share of the service sector and new technologies may lead to a reduction in the demand for resources per GDP unit, while a high share of material-consuming sectors (e.g., industry or construction) increases the demand for resources.
- With infrastructural saturation developing as the country's economic growth continues, demand for investment in infrastructure may decline. Note that the maintenance of the existing infrastructure also requires the consumption of resources.
- Environmental regulations—increased environmental awareness and more restrictive environmental regulations in developed countries may cause a transfer of industries to developing countries (i.e., carbon leakage).
- Factors related to the availability of resources, the climate, topography, and demography (including the density of the population), which can be affected only slightly over a relatively short period.
- Economic tools—a change in taxes, methods of subsidy, or support and aid programs —should affect the demand and supply of CE products and services.

In CE monitoring, it is also essential to distinguish between goals in industry-adopted strategies and those arising from consumer behavior. For this reason, the paper proposes to group indicators into two groups: those applicable to sustainable production and those applicable to sustainable consumption. A new challenge is the identification of indicators assessing the growing role of services used in a transformation towards a CE.

The aim of the work is to identify and verify, based on the research conducted, CE indicators relating to sustainable production, along with their benefits and limitations. Many analyses of CE indicators have been presented in the literature, referring to different levels [3–24], but their benefits and limitations have not been individually discussed. Therefore, this paper presents the process of selection and the potential benefits and limitations of indicators used for assessing transformation towards a CE that have been identified for the Polish economy in the area of sustainable production.

The most common limitations of CE indicators are:

- A lack of an indicator assessing the holistic impact on the environment, e.g., by using the methodology for life cycle assessment;
- The impact assessment does not take other or multiple reuses of both products and shared infrastructure into account;
- The indicators do not reflect the complexity of recycling, types of waste, and the demand for key/critical materials in the economy;
- There is no reference to the issue of competitiveness and the changes arising from the introduction of business models and the scale of business related to the rapid introduction of CE.

The practical goal is to apply the indicators identified to various sectors of the economy. The novelty of this article is a proposal for a process for the selection of CE indicators for monitoring the transformation to a CE based on their benefits and limitations. It takes into account the aims and obligations defined in the main strategic Polish and EU documents, the process of consultation with industry, and the structure of the economy. As in Poland (and in most Central and Eastern European countries), the share of services in the creation of GDP is relatively low (55%, whereas in old EU members, it is about 70%). (Services correspond to ISIC divisions 50–99 and include value added in wholesale and retail trade (including hotels and restaurants), transport, and government, financial, professional, and personal services such as education, health care, and real estate services. https://www.theglobaleconomy.com/rankings/share_of_services/, assessed on 9 January 2023), an additional indicator of resource productivity has been proposed, i.e., resource productivity calculated for the part of GDP connected only with production (i.e., without taking into account the service part). Currently, the resource productivity indicator in Poland is significantly below (about 70%) the EU average, whereas the overall circular use rate of the economy is relatively high—10.3% [25].

2. Materials and Methods

In recent years, various organizations have developed CE indicators, and some individual countries [26–28] have already chosen them in order to monitor CE policy. Most of them were divided into specific thematic groups, for example, according to the perspective of sustainability—economic, social, and environmental indicators proposed by the Global Reporting Initiative (GRI) or based on the seventeen individual Sustainable Development Goals (SDGs) proposed by the United Nations (UN). A holistic picture of the level of transformation towards a CE in European countries is indicated by the CE monitoring framework, developed by the European Commission (EC) in 2018. It proposes four groups of indicators, divided according to the key areas of CE implementation in the EU, such as production and consumption, waste management, secondary raw materials, competitiveness, and innovation. Other organizations group indicators according to specific industries, environmental problems, individual elements of the life cycle, or components of the environment. Nevertheless, they are proposed for application at the micro-, meso-, and macro-levels.

Therefore, a detailed review of the literature was first carried out, and it was found that the proposed indicators in scientific publications are consistent with key strategic documents at the international level as well as Polish ones. When selecting indicators for monitoring the transformation towards a CE in the area of sustainable production, the indicators from the public statistics of Poland were analyzed first. In particular, the existing sustainable development, waste management, and eco-innovation indicators calculated by the Polish Central Statistical Office and the indicators proposed in the strategies at the EU and national levels were assessed. In total, more than 100 indicators grouped into different thematic, CE-related areas were identified (Table 1).

Table 1. Proposed CE indicators in EU and Polish documents and statistics.

Programme	Thematic Area	Number of Indicators Identified	Source
EUROSTAT. Circular Economy indicators	1. Production and consumption; 2. Waste management; 3. Secondary raw materials; 4. Competitiveness and innovation.	10	[29]
17 Sustainable Development Goals (SGDs)	1. Affordable and clean energy; 2. Decent work and economic growth; 3. Industry, innovation, and infrastructure; 4. Responsible consumption and production; 5. Climate action; 6. Life below water.	35	[30]

Table 1. *Cont.*

Programme	Thematic Area	Number of Indicators Identified	Source
European Environment Agency (EEA). Circular economy in Europe	1. Material input; 2. Eco-design; 3. Production; 4. Consumption; 5. Waste recycling.	15	[31]
Global reporting initiative (GRI)	1. Environmental; 2. Economic; 3. Social.	12	[32]
Strategic documents for Poland: 1. Ministry of Climate and Environment, National Waste Management Plan 2022, 2016, 2. The National Plan for Energy and Climate 2021–2030 3. Ministry of Development and Technology, Productivity Strategy 2030	1. Climate state and impact indicators; 2. Air pollutant emissions; 3. Energy indicators; 4. Industrial pollution indicators; 5. Land and soil indicators; 6. Sustainable consumption and production; 7. Transport and environment reporting mechanism; 8. Water resource efficiency indicators.	30	[33–35]

The proposed indicators and their target values used to measure the transformation towards a CE were selected at the following stages of the research:

1. In the first step, a detailed analysis of published research was conducted using the desk research method. This state-of-the-art analysis was based on the review approaches used in [36] to conduct searches and eligibility screening of the available literature while retaining the procedural scope of the analysis and ensuring that the review process is objective. The objective of this step of the research was to review the indicators (economic, social, technological, and environmental) from national and international organizations.
2. An analysis of the existing indicators and available data for monitoring activities similar to the CE, as reported by the Central Statistical Office and Eurostat.
3. An analysis of the indicators proposed in government documents (strategies and "The Roadmap for Transformation Towards the Circular Economy") and strategies.
4. Breakdown of the indicators into the main, auxiliary, and contextual indicators based on internal consultations with experts from the National Smart Specializations CE group and with scientists, experts in the fields of economics, environment, and statistics, in order to select indicators arising from the definition and scope of the CE.
5. Building a questionnaire and sending it out to selected industries, i.e., those with the lowest resource productivity and the highest importance for the economy. The questionnaire made it possible to identify respondents by company name, industry/sector, and respondent's position. Two forms of selection were used to choose the survey sample: simple random selection—the required number of sample elements was drawn directly from the population, which guaranteed that they were highly representative—and volunteer selection—the questionnaire was posted on the Internet. Linkert's scale was used to develop the questionnaire. A five-point assessment scale was used to obtain answers on the degree of acceptance of a given phenomenon and view. The scale range was from 1 to 5: 1—not important, 2—rather not important, 3—do not know, 4—somewhat important, and 5—important.
6. Revision of the proposed indicators in terms of their goals, targets, and directions for the development of the Polish economy, accounting for CE in the strategic documents, and proposals for CE indicators for the Polish economy by the expert group.
7. Evaluation of the importance of the indicators and the rates and directions of their change on the basis of a wide range of social consultations. At the next stage of the research, new indexes may be developed based on aggregated data, taking into account, for example, the product life cycle and LCA methodology for environmental impact assessment. This may require the building of some additional databases [37].

In the last stage of the analysis, the potential applicability of CE indicators was assessed. Figure 1 presents the stages of the research.

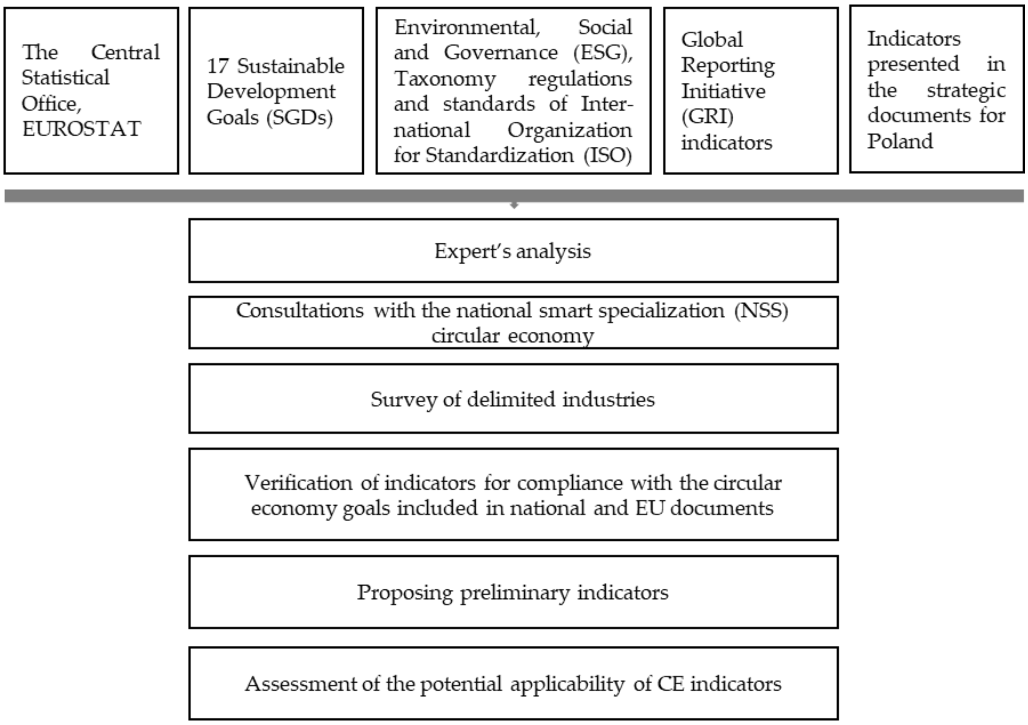

Figure 1. The structure of the research to identify the indicators of transformation of the Polish economy towards a CE.

3. Results

3.1. Transformation toward a Circular Economy in Polish Strategic Documents

3.1.1. The 2030 National Environmental Policy

The strategy for development in the area of the water environment and administration, the 2030 National Environmental Policy [38], has addressed many opportunities in the context of the development of rural areas that allow for a move away from a linear model of the economy towards the introduction of a CE. The assumption presented above has translated into the self-sufficiency of non-urbanized areas, particularly in terms of power supply, owing to the consumption of renewable energy sources (RES) coupled with care for extending the use and functioning of materials and services in the economy as long as possible. Moreover, the CE has assumed full recycling is done locally. "The Environmental Policy" has defined the CE goals. Many of these goals are consistent with CE assumptions, including, in particular, the direction of the "Waste Management Towards the Circular Economy" project, which supports the introduction of eco-innovation and disseminates the best available BAT techniques.

3.1.2. The National Energy and Climate Plan 2021–2030

The National Energy and Climate Plan 2021–2030 [34] has set out the following climate and energy objectives for 2030:

- 21–23% share of RES in the final gross energy consumption;
- A 23% growth in energy efficiency when compared with the PRIMES 2007 forecasts;
- A 50–60% reduction in the share of coal in electricity generation.

The document has mentioned potential methane recycling as an action fitting into the CE concept and potential cost efficiencies in the farming and food-producing sectors or for specific waste management activities in the mining sector.

3.1.3. The Productivity Strategy 2030

The Productivity Strategy 2030 has been adopted [35], in which one of the most important areas has been natural resources, with the main objectives including an increase in the resource efficiency of the economy (resource productivity—1.6 EUR PPS/kg in 2030) and an increase in the use of renewable resources and biomass in the economy (by 77% in 2030). Resource productivity in Poland is relatively high due to a significant share of industry in the GDP. For these countries, resource productivity could be calculated not only in relation to total GDP but also to the GDP from industrial production (manufacturing, mining, construction, agriculture, and transport).

3.1.4. Other Documents

Similarly, the national CE monitoring system must be compliant with the following pieces of legislation:

- The National Strategy for Regional Development 2030;
- The Sustainable Transportation Development Strategy to 2030;
- The Strategy for the Sustainable Development of Rural Areas, Agriculture, and Fisheries to 2030.

There are also other documents of significant importance for defining the areas falling under CE monitoring:

- The Roadmap for the Transformation Towards the Circular Economy, specifying four key areas of transformation: sustainable industrial production, sustainable consumption, bio-economy, and new business models;
- National Smart Specializations, including the NSS Circular Economy—Circular Economy—water, fossil fuels, and waste;
- Key Assumptions for the 2021–2027 Partnership Agreement, emphasizing the importance of Industry 4.0. (Only 10% of domestic enterprises generate at least 1% of their revenues from online sales, which is why it will be important to support investments that increase the digitization, automation, or robotization indicators of enterprises).

In Poland, the National Reporting Platform for SDGs (Sustainable Development Goals) has been set up. The Platform measures the national input in the achievement of each goal. In addition, six priority SDGs were specified for Polish businesses, as were 30 key indicators measuring the most important areas impacted by Polish business organizations [39]. On the platform, rates and indicators are CE-consistent:

- The added value of business organizations per employee;
- Capex to sales;
- % of investment in sustainable solutions in the total investment in innovation;
- The number of research projects in the past 3 years run jointly with academic and research centers;
- Efficiency in the consumption of materials,
- Energy efficiency;
- % of energy from RES consumed;
- Greenhouse gas emissions;
- Water efficiency;
- % of recycled or reused waste;
- % of raw materials and materials from sustainable sources.

In addition, the priority SDG indicators were determined, consistent with CE objectives, including:

- Resource productivity ratios;
- Domestic material consumption (DMC) per capita;
- Reuse of materials indicator;
- % of renewable energy in final energy consumption;
- Greenhouse gas emission growth rate;

- Corporate investment in innovation to GDP;
- National gross R&D investment to GDP;
- Global innovation (eco-innovation) indicator;
- % of municipal waste intended for specific treatment as a proportion of total waste;
- The number of passenger journeys in urban areas.

3.2. Indicators of Transformation toward a CE—A Breakdown

Table 2 shows some selected indicators of CE transformation in business activity in Poland in the area of sustainable products, along with the preferred directions of change.

Table 2. Proposed CE transformation indicators for business in Poland (product indicators).

Level	Indicator Name/Unit	The Desired Direction of Indicator Change
Main	Resource productivity—DMC/GDP	↓
	Renewable energy in the gross final energy consumption by enterprises (%)	↑
	R&D investment to GDP (%)	↑
Auxiliary	Water consumption in industry to GDP (%)	↓
	The volume of industrial waste produced to GDP (%)	↓
	Secondary raw materials to total production (%)	↑
	Greenhouse gas emissions from industrial activities in CO_2 equivalent (CO_{2e})/year	↓
	Number of e-state services addressed to entrepreneurs (items)	↑
	The number of environmental certificates held (items)	↑
Contextual	Environmental Capex to total investment	↑
	FTEs in CE-related bodies to total employment (%)	↑
	Total number CE public contracts to total public contracts	↑

Some indicators are partially related to the cause-and-effect sequence “action-product-result-effect” resulting from the “Roadmap of Transformation Towards the Circular Economy.” The raw material life cycle and the value creation chain are closely related to business models (at the micro-level) and industry strategies (at the meso-level).

3.2.1. Main Indicators

- Resource productivity—DMC to GDP

Resource productivity is a measure of the total amount of materials directly used by an economy (measured as DMC) in relation to GDP. It provides insights into whether decoupling between the use of natural resources and economic growth is taking place. Resource productivity (GDP/DMC) is the EU sustainable development indicator for policy evaluation.

The resource productivity of the EU is expressed by the amount of GDP generated per unit of domestic material consumption, i.e., GDP/DMC in euros per kg.

DMC is based on the economy-wide material flow accounts (EW-MFA), i.e., on consistent statements of total material inputs entering national economies, changes in the level of material stocks in the economy, and material outflows to other economies or to the environment (Central Statistical Office). However, the level of material consumption alone does not determine the environmental impact of the materials used. It seems wrong to measure the ecological effects by their mass. Still, this solution is more accessible to apply in practice and more meaningful than other indicators, especially those based on value, where changes affect both the time value of money and price changes. Table 3 presents the assessment of the potential applicability of the indicator.

Table 3. Assessment of the potential applicability of the resource productivity indicator.

Benefits	Limitations
Data availability in Poland and Europe.	Not all areas of economic activity are reflected: the indicator reflects only those areas for which market transactions are recorded (due to the specificity of GDP).
Country-level benchmarking.	No import or export data by region available.
High quality of the statistics.	No differentiation of the volume of consumption of materials from primary and secondary sources.
The measurable outcome of the application of the indicator: if GDP is growing faster than DMC, the resource productivity indicator is also going up.	GDP/DMC as an indicator takes a national production perspective, implying that it is insensitive to changes in environmental pressures outside the nation's borders.

DMC measures resources by weight, which impedes the telling of the full story of resource scarcity, economic value, and the environmental impact of their use [40].

- Renewable energy in the gross final energy consumption of enterprises

This is calculated as the share of the total gross final energy consumption from renewable sources in the total gross final energy consumption from all sources. Renewable energy is energy derived from repeating natural processes and generated from renewable, non-fossil energy sources (water, wind, solar radiation, waves, currents, and tides). Geothermal energy, the energy produced from solid biofuels, biogas, and liquid biofuels, and energy from the environment—the natural environment—used by heat pumps are also classified as RES (the Central Statistical Office). Table 4 presents the assessment of the potential applicability of the indicator.

Table 4. Assessment of the potential applicability of renewable energy in the gross final energy consumption by enterprise indicator.

Benefits	Limitations
Consistency with the SDGs and indicators.	Translating indirectly into CE goals, resulting in the increase of resources, e.g., critical resources, metals, etc.
Of critical importance for the implementation of EU strategies and policies as well as the obligations they impose.	Limited benchmarking opportunities—a sector-by-sector presentation recommended.
Of great importance for business—an increasing number of business entities present this type of data in their strategies and other documents.	
Easily measured for individual units of production.	
Directly linked to both the area indicated in the Roadmap (e.g., bio-economy) and National and Regional Smart Specializations.	
Important from the point of view of environmental impact in the Life Cycle Assessment (LCA) methodology.	
Consistency with the CE strategy in Poland—the energy sector is recognized as the key sector in the development of the CE.	

- R&D investment to GDP

This indicator is the product of the sum of internal expenditures on R&D activities made by all the entities of a specific business in the country (irrespective of the source of funds) and the GDP. The indicator is the main parameter used in R&D statistics for measuring the competitiveness and development of a knowledge-based economy. It includes three types of research: basic research, applied research, and development work. R&D differs from other activities in terms of its perceived novelty and the elimination of scientific and/or technological uncertainty. Internal R&D investment is the R&D investment made in the reporting year in the reporting unit, regardless of the source of the funds, i.e., foreign funds (export of R&D works). It includes both current expenditure and investment in R&D-related activity but is not reduced by the depreciation of fixed assets (Central Statistical Office). Table 5 presents an assessment of the potential applicability of the indicator.

Table 5. Assessment of the potential applicability of the R&D investment to GDP indicator.

Benefits	**Limitations**
Availability of data.	Impossibility of measuring dedicated funds invested in delivering CE-related tasks.
The potential for setting out directions for change for the Polish economy.	It is not possible to identify the R&D investment actually made by specific types of enterprises.
Indication of the level of innovation—important in terms of implementing the CE.	Investment in R&D work performed abroad (import of the R&D works) not taken into account.
Possibility of assessing changes in economic development against the EU average.	
Correlation of the indicator with changes in the level of economic development.	

3.2.2. Auxiliary Indicators

- Water consumption in industry to GDP

Water consumption was not included in the CE's analysis and monitoring processes, but the latest research recommends taking it into account. The links between the consumption of raw materials and the water deficit are also indicated in the latest document of the EC, which is a new economic growth strategy for the community. It highlights the fact that half of all greenhouse gas emissions and more than 90% of biodiversity loss and water stress are related to the extraction and processing of resources. The industrial water consumption indicator is calculated as water consumption for the needs of the national economy and population in relation to GDP. Water is one of the basic substances in the economy and the environment, used on a large scale in many production processes (e.g., in metallurgy and the chemical industry). In the production of chemicals and chemical products, water represents as much as 99.9% of the mass of materials used in the process. According to the CE, such significant water consumption proves the need to implement solutions towards "returning" post-process water and wastewater for reuse [41]. A reduction in water consumption indicates an improvement in its efficient consumption, e.g., in the form of graywater, or an improvement in production processes. Table 6 presents an assessment of the potential applicability of the indicator.

- Volume of industrial waste generated to GDP

According to the waste management hierarchy, the volume of waste produced should be minimized. First of all, waste generation should be prevented, but if it continues to be produced, waste should be prepared for reuse, recycling, or other recovery methods, or perhaps for safe disposal. In Poland, waste management objectives have been determined in the National Waste Management Plan [33]. In the plan, the legislative proposals recommended by the European Commission in the CE package, which promote a stronger emphasis on prevention and the limitation of waste generation, were taken into account. Accordingly, the maximum value may be generated from waste by society while adjusting consumption to actual needs; on the other hand, it may maximize entrepreneurs' profits. The product's highest economic value can also be maintained when following the waste management hierarchy [42]. Accordingly, the volume of industrial waste produced indicator was proposed in order to assess the transformation towards a CE. In line with the generally accepted definition of waste in the CE (any substances or items that are being removed, or are intended to be removed, by their possessor or whose possessor has been obligated to remove them), one may embark on a search for innovative technological solutions to generate products instead of waste. Table 7 presents the assessment of the potential applicability of the indicator.

Table 6. Assessment of the potential applicability of water consumption in industry to the GDP indicator.

Benefits	**Limitations**
Readily available and measurable data.	Recycled water not included in the statistics.
Material importance for transformation towards a CE.	Water quality not taken into account in indicators.
Consistency with the SDGs and indicators.	
Compliance with the EU water management legislation (including the Framework Water Directive).	
Country-level benchmarking.	

Table 7. Assessment of the potential applicability of the industrial waste produced to GDP indicator.

Benefits	**Limitations**
Good availability of a variety of data at the level of countries, regions, and businesses.	Difficulties in determining the actual environmental impact of different categories of waste (textiles, mining waste, etc.), types of waste, and assessing the types of impact of waste.
Linking the indicator with the consumption of materials in the economy and the ability to identify the point where waste is generated in the life cycle.	Incomplete coherence of waste codes with the type of production activity.
The potential for imagining the effectiveness and structure of the economy.	Lack of information about the origin of waste, e.g., in the waste recovery process, new waste is generated; the waste is recaptured in the statistics; as a result, the volume of waste is going down, but the volume of waste generated is going up, which is against the goals of the CE and means that there are calls to identify the original source of material in the life cycle.
Rather crucial for minimising the environmental pressure related to waste generation.	Lack of continuity in reporting some data, e.g., mining waste (bi-annual reporting).
	Difficulties in comparing Polish and EU statistics from some countries, e.g., for mining industry waste against mining waste [22].

- Secondary raw materials generated in the total production

Polish and EU law lacks a clear definition of recyclable waste (both the EU and Poland are considering introducing such a definition into legislation in order to stimulate the demand for secondary raw materials). Still, the 2022 Plan indicates that it is important to stimulate the market for recyclable waste and products containing recyclable waste and replace primary waste with recyclable waste. Therefore, effective implementation of a CE and monitoring require the selection and monitoring of recycled material and recyclable waste as materials for reuse in the economy. In this context, it is important to introduce some order into the monitoring procedures by recognizing some substances or materials as side products or raw materials that have lost their waste status. Pursuant to the Waste Act, "a by-product other than waste may be considered an object or substance resulting from a production process that was not originally intended for its production." According to this definition, certain conditions must be met:

1. Reuse of the object or substance is guaranteed;
2. An object or substance is fit for direct reuse rather than reprocessing, apart from where a standard industrial practice is involved;
3. An object or substance is produced as an integral part of the production process;
4. The substance or object meets all important requirements, including legal requirements, in terms of the product, environmental protection, and human life and health, for a pre-defined use, and such use will not lead to some generally negative environmental impact or impact on human life or health.

In addition, the Act clearly describes and specifies the possibility of waste losing its status as waste if, as a consequence of reuse, including recycling, it meets:

1. The below-listed joint requirements:
    - An object or substance is commonly used for specific purposes;
    - A market for such objects or substances, or a demand for such objects or substances, exists;
    - An object or substance meets the technical requirements in terms of their fitness for specific purposes as well as the requirements stipulated in regulations and standards applicable to the product;
    - Application of an object or substance does not lead to any negative consequences for human life, health, or the environment;
2. Requirements arising from the EU laws.

According to the Polish Classification of Goods and Services, potential so-called recyclable material/waste (as it is customarily called), i.e., production waste or recyclable used goods, is recycled or recovered to generate materials (semi-products) for primary or other applications. The Polish Combined Nomenclature of Goods of Foreign Trade, used both by suppliers and clients, is detailed and relatively comprehensive. It allows for the precise specification of the type of recyclable waste. Similarly, the concept of recyclable waste can also be found in the literature. As of 1990, it was believed that recyclable waste represented two types of products: waste (postproduction scrap) generated at various stages of production and used directly on site, and post-depreciation waste (scrap). Another classification is used by the Central Statistical Office in its "Material Economy" publication, where raw materials are divided into:

- Natural materials (minerals, plant, and animal materials);
- Materials resulting from processing (e.g., cement);
- Recyclable material (waste), which, in turn, is divided into postproduction waste generated in the production process and used waste. The latter may be used by another user following its proper preparation, replacing the primary raw material [43].

Ultimately, the indicator could determine the percentage of recyclable waste in the economy, which is already monitored in the green economy by the Central Statistical Office. Table 8 presents an assessment of the potential applicability of the indicator.

Table 8. Assessment of the potential reuse of recyclable waste in total production indicator.

Benefits	**Limitations**
Significant for CE monitoring.	Scarce data.
Very important for environmental protection.	A clear definition of recyclable waste is not available.
Compliance with EU ratios—the CE monitoring framework in the EU includes a set of ten ratios grouped into four stages and aspects of CE.	Low importance for the economy (as in many instances, the share of recyclable waste is relatively low (5–10%), and its share in the production processes satisfies as little as 10% of EU demand).
Recyclable material is commonly used in the CE for the production of new products.	

- Greenhouse gas emissions from industrial activities as a CO_2 equivalent

This indicator presents the total annual emissions of human-produced greenhouse gases, except for emissions from non-ETS sectors (international aviation, international sea transport, agriculture, forestry, and changes in the use of land). As a target, it could apply to the emissions of CO_2 arising from the consumption of groups of resources (biomass, metals, non-metals, power-generating resources, etc.). Table 9 presents an assessment of the potential applicability of the indicator.

Table 9. Assessment of the potential applicability of greenhouse gas emissions from industrial activities as a CO_2 equivalent indicator.

Benefits	**Limitations**
A direct link to the CE.	Limited potential for monitoring at the level of regions.
An opportunity to meet international obligations, including climate neutrality by the 2050 target.	Limited EU country-level benchmarking.
Reference to the regulation on disclosing information on sustainable investment and risk to sustainable development and the regulation on low emissions reference indicators and reference indicators on the positive impact on emissions.	

- Number of services offered to entrepreneurs in the e-state service

This is an indicator measuring access to broadband Internet. Unequal access to the Internet in daily life (study, work, access to information and knowledge) may result in differences in participation in important aspects of social life, i.e., social exclusion. By definition, the indicator refers to the number of enterprises using both the Internet and access to all digital services. It is important to develop the CE business models, e.g., virtualization, causing a considerable reduction in the waste generated and consumed. When used jointly, the CE and digital economy ideas complement each other and, when used jointly, maximize profits and minimize losses.

Ultimately, the index could represent the Polish version of the Digital Economy and Society Index (DESI), which benchmarks EU states in terms of how advanced their information society is. The main index consists of five dimensions, each of which also has the nature of a synthetic index. In 2020, Poland came 25th in the social development ranking of 28 states. Table 10 presents the assessment of the potential applicability of the indicator.

Table 10. Assessing the potential applicability of the number of services offered to entrepreneurs in the e-state service indicator.

Benefits	Limitations
Comparability to other countries.	Limited potential for monitoring at the level of enterprises.
Availability of data for the country and regions.	No data available for enterprises using e-state services.
Link to the institutional development of the country.	High levels of investment required to expand activities to all services offered in the e-state.
A direct link to the CE, including the availability of digital services, e-government as a continuous process of improving the quality of governance and the provision of administrative services by transforming internal and external relations with the Internet and modern means of communication.	Insufficient education on access to digital services.

- Number of environmental certificates awarded

This indicator measures the number of organizations registered in the EMAS or holding environmental certificates such as ISO 14001, ETV, or other certificates recognized as domestic or international certificates. In EMAS, the data is reported by the Central Statistical Office in the green economy indicators. At the end of 2022, in Poland, according to the data presented by the General Directorate for Environmental Protection, 70 organizations were registered in the EMAS register, translating into a growth of 6.5% against 2017. Table 11 presents the assessment of the potential applicability of the indicator.

Table 11. Assessment of the potential applicability of the number of environmental certificates awarded.

Benefits	Limitations
Availability of statistics.	Little interest has been shown by entrepreneurs, including little knowledge and the high costs of the interim audits.
A reference to corporate environmental responsibility.	Few models are used for the effective implementation of the EMAS system.
Impact on the increase of the economic outcomes of operations due to a reduction in the consumption of raw materials, water, and energy; cost efficiencies; a reduction in environmental fees (through the reduction of solid waste, wastewater, and the emission of gases; and an increase in the volume of recycled waste).	Monitoring difficulties because of the consistently low numbers of companies with environmental management systems in place.
	No commercial incentives to introduce eco-management systems.

3.2.3. Contextual Indicators

- Investment in environmental protection to total investment

Spending on environmental protection is the sum of investment expenditures and the current (operating) costs of activities related to environmental protection, reduction of pollution, and/or repair of environmental damage. It considers investment in building individual monitoring subsystems, consisting of building a network of control and measurement stations and test stations at the national, regional, and local levels for the National Monitoring of the Environment, as well as investment in R&D and training. Ultimately, the indicator could apply to CE-oriented spending. Table 12 presents the assessment of the potential applicability of the indicator.

Table 12. Assessment of the potential applicability of the spending indicator for environmental protection.

Benefits	Limitations
Link to economic development and the CE.	Covers only part of the actual environmental costs.
Link to research, technology development, and innovation.	Taking into account all environmental investments, not necessarily directly related to the CE.
Supporting access to information and data quality, as well as communication technologies.	
Supporting the transition to a low-carbon economy in all sectors.	

- FTEs in CE-related bodies to total employment

The number of persons engaged in working in sectors related to circular concepts may indirectly demonstrate the degree to which the CE model has been implemented. However, the model does not require the highest level of production. It only calls for its optimization. That shows the superiority of the indicator measuring FTEs in sectors classified as CE sectors compared with total employment. According to Eurostat, these sectors include recycling, repairs, and reuse of products. Table 13 presents the assessment of the potential applicability of the indicator.

Table 13. Assessing the potential applicability of FTEs in CE-related bodies to the total employment indicator.

Benefits	Limitations
Direct link to CE goals.	Low eligibility for monitoring.
Easy to monitor.	No information available on key sectors directly related to the CE in Poland.
Country-level benchmarking.	
Significant importance for many strategies in Poland.	
Strong synergies with the development of organizational, process, and product eco-innovation.	

- Total CE public contracts to total public contracts

Public contracts represent a significant portion of GDP. Public contracts on the CE, or so-called "green public contracts," which exist in the Polish regulations promoting environmentally-friendly goods, services, and works, may be the factor driving the CE and innovation. The value of CE contracts in total public contracts shows the engagement of the public sector in the implementation of CE. Engagement is particularly important at the initial stage of implementing the CE model. Ultimately, it could be a CE-compliant contract indicator. Table 14 presents the assessment of the potential applicability of the indicator.

The proposed indicators of transformation toward the CE were selected from those already monitored as required by obligations arising from other strategies or politics or from those generally available. In the future, analyses and research may be conducted to develop a more aggregate index that takes into account both the balance of the consumption of material and the consumption of energy and their environmental impacts, e.g., by employing the LCA methodology.

Table 14. Assessment of the potential applicability of total CE public contracts as a total public contracts indicator.

Benefits	Limitations
Linked to environmental, social, and economic potential.	No uniform rules for data monitoring—often the description is in the subject matter of the contract and not in the pricing criteria.
Link to CE growth in Poland.	Low percentage of CE contracts in the total number of public contracts.
EU country-level benchmarking.	

4. Discussion

Currently, the proposed EU indicators create a reference system for the comparison of the progress made by European countries towards a CE, even though there are many discussions concerning the validity of the 10 indicators and the extent to which they manage to measure the correctness of the paths of different countries towards a CE [44].

In recent years, significant progress has been made in assessing the circularity of products [45], companies [46], and regions [47]. CE indicators are an important element of new business models that are systematically improved and introduced to the operations of enterprises. The EC clearly indicates that the transition to the CE model brings economic benefits to bodies involved in the transformation process and the whole economy.

The proposed methodology, based on the example of Poland, assumes the consistency of the indicators, e.g., CE goals and concepts, and their importance in terms of the delivery of national policies. Further to the above, indicators from different strategies and planning documents were analyzed first. Because of their high number, it was challenging to limit their number, so they are mutually complementary and include the broadest scope of CE goals possible. They have been divided into main (strategic objectives), contextual (important for the specific types of raw materials/waste), and auxiliary indicators (evaluating CE supporting measures—R&D investment, certification of an organization). Next, the indicators for which statistics were available were selected, as well as those that directly applied to the expected changes toward a CE.

Despite the simplifications presented above, it is recommended that the transformation towards a CE be monitored to identify outcomes related to resource management methods and to introduce eco-innovative solutions and new business models. Such an approach will speed up the decision-making process and help determine the direction of state intervention. It will undoubtedly result in a better dialogue with entrepreneurs and scientists.

In terms of the CE, indicators monitoring the Europe 2020 strategy objectives are also important and outlined in "Europe 2020: Strategy for Smart, Sustainable and Inclusive Growth," in particular those applying to the effective use of resources.

A set of 30 indicators was proposed, broken down into a three-level structure:

- Headline indicators presenting the productivity of resources.
- Panel indicators for resources such as soil, water, and coal.
- Theme indicators in the following areas: the transformation of the economy (including the transformation of waste into resources); nature and the ecosystem (biodiversity, air, and soil protection); and key areas (food, sustainable construction, and transportation) [48].

In Poland, indicators monitoring activities arising from implementing the Green Growth Strategy of the OECD, adopted in 2011, are also reported. Information on the green economy is published in the reports of the Central Statistical Office entitled "Green Economy Indicators in Poland 2020" [49]. The results are presented in four thematic areas, identified separately to monitor their condition, i.e., natural capital, environmental effects of production, environmental quality of people's lives and economic policies, and consequences. Cohesion with CE goals is evident in the area of environmental effects of production. Sustainable consumption applies to social, political, and ecological practices that allow the delivery of the concepts to individuals or entire collective bodies. The proposed CE business models, including ICT, are important for balancing production and consumption.

Taking into account the goals and tasks of the CE that have been adopted (considering those contained in strategic documents and the areas indicated in the "Roadmap for Transformation Towards a Circular Economy"), it was proposed that in Poland, to monitor the transformation and effects of a CE, separate indexes should be built for transformation towards a CE for sustainable industrial production and sustainable consumption, including both the area of the bio-economy (although the monitoring of different bio-based products is still a challenge [50]) and business models.

Any circular strategies—focusing on reuse or recycling—that do not lead to economic benefits for businesses in the current regulatory environment (and thus are not economically sustainable) are unlikely to be implemented even if they reduce the environmental impact and should therefore be desirable from the point of view of environmental protection [51]. It is important to identify economically viable activities facilitating the transition to a CE, where the starting point may be the use of resource productivity and additionally the calculation of resource productivity in industrial production (excluding services). According to the definition, services correspond to ISIC divisions 50–99, and they include value added in the wholesale and retail trade (including hotels and restaurants), transport, and government, financial, professional, and personal services such as education, health care, and real estate services. The World Bank gives country rankings taking into account value added in the services sector as a percentage of GDP. Thus, the average for 2021 based on 137 countries was 54.35%. The highest value was in Luxembourg: 79.32%, and the lowest was in Sudan: 9.69%. The value for Poland is 55.61%, and it occupies the 65th position on the ranking list [25].

To systematically monitor the transition to a CE, researchers emphasize the importance of developing CE indicators [20,52,53], which quantify the changes taking place [17]—such as, for example, the effects of implementing economic measures. However, studies on the implementation of economic indicators of the CE are still scarce. A number of review studies on CE indicators have been published in recent years, such as [20,54–58]. However, most existing reviews focus on environmental or multivariate CE indicators, while the economic dimension remains under-researched in general [23,57,59]. It is worth noting that, to date, none of the studies have specifically addressed economic indicators that take into account benefits and limitations.

According to the latest Sustainable Development Goals Report 2022, in 2019, the total DMC increased by more than 65% worldwide, reaching 95.1 billion tons. This translates to 12.3 tons per person. The regions that accounted for about 70% of global DMC are East and Southeast Asia, Europe, and North America. During this period, East and Southeast Asia showed the most rapid increase in DMC, from 31% in 2000 to 43% in 2019. The main drivers of this growth are increased population density, industrialization, and the outsourcing of material-intensive production from developed countries to developing countries. Increased dependence on natural resources increases the pressure on vulnerable ecosystems and ultimately affects both human health and the economy.

The main indicators are those that provide information about the CE and illuminate the fulfillment of its basic goals. Due to the economic aspect, they use measures of economic value. The auxiliary indicators give a broader view than the main indicators and give a picture of the CE from different perspectives. Instead, they forgo economic evaluation and focus on physical measures that are easier to interpret and often adapt to meet political or operational goals. They present a more detailed and comprehensive picture of the CE of a given region than the main indicators, but they should not be considered in isolation from them. Contextual indicators provide insight into systemic changes in the structure of the economy but do not have to be directly related to the CE. Therefore, they are only an indirect measure, but they support CE assessment by describing the conditions in which this transformation occurs. Their interpretation calls for a much higher consideration of specific regional characters than before.

On the other hand, indicators at the regional level should be comparable with those adopted for the entire country. Additionally, due to the availability of data, two groups of indicators were proposed, i.e., those currently monitored and those postulated for the future.

5. Conclusions

The transition to CE is both critical and urgent. There is a growing number of companies and governments for whom the transition to CE is an important part of their vision, goals, and strategies; however, they have difficulty defining indicators and monitoring the transition process. CE indicators can contribute to this. They can also help society notice the positive effects of transformation. The development of indicators and their monitoring is necessary both to promote and implement the progress of transformation toward CE.

For indicators to be successful, they must be consistent, widely accepted, and easy to define and understand. It is crucial to identify relevant indicators for individual countries, regions, and sectors, along with their advantages and limitations. In reports, strategies, and documents of international institutions as well as many scientific publications, you can find a number of guidelines for the construction of indicators and models constituting the basis for the assessment of selected activities in the field of implementing CE. Most of them concern the analysis of trends in the use of resources, the management of residual waste, and the creation of new business models, while proposing ways to measure them, but the benefits of their implementation and their limitations have not been individually discussed. An exemplary process of selecting indicators as well as the potential benefits and limitations of using them to assess the degree of transformation of the Polish economy have been identified in the article. The presented process can be used to identify indicators for measuring and monitoring the transformation towards CE in various sectors of the economy.

The CE indicators proposed in the article concern aspects related to sustainable production. The proposed methodology assumed that the indicators should be coherent, both with the goals and assumptions of CE and relevant from the point of view of the implementation of national and EU policies. At the same time, the authors analyzed indicators whose data collection is already monitored in connection with the implementation of obligations arising from other strategies and policies. Indicating the benefits and limitations of using the proposed indicators allows for an appropriate selection in the context of choosing a given sector in which the transformation is taking place. Many indicators have already been developed at the macro- and meso-levels; however, the micro-level indicators still require analysis, evaluation, and consultation. It is the sectors that should choose the indicators adequate to measure the transformation towards CE because, according to research [41], e.g., water consumption will be important in the chemical sector but will not be important for the recycling sector. In the future, analyses and research can be conducted that will allow for the development of a more aggregated index, taking into account both balances of material intensity, energy intensity, and environmental impact, e.g., using the LCA methodology.

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