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Circular economy as assistance for sustainable development in OECD countries

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Abstract

Research background: Circular economy is of great importance, as it plays a vital role in ensuring the reuse of waste created and, therefore, reduces the waste of limited resources, which is the primary goal of the general economic concept. In line with the circular economy, sustainable development gains great attention, as the United Nations announced the sustainable development goals that should be reached by 2030. Hence, the current paper aims at examining whether the circular economy could be treated as an effective assistance tool for sustainable development of OECD countries.
Purpose of the article: The paper aims to investigate whether the circular economy could serve as an assistance tool for sustainable development and, therefore, seeks to determine if the circular economy could directly impact a country's sustainable development.
Methods: First, the countries chosen were prioritised using the Analytic Hierarchy Process (AHP) and the Evaluation Based on Distance from Average Solution (EDAS) methodologies.

AHP method was used for weight assignment to the circular economy indicators that were further used for OECD countries' prioritisation procedure for which multi-criteria decision-making method EDAS was employed. Second, to reveal a link between the circular economy ranking results and sustainable development, a comparative analysis was done. Third, the impact of the country's circular economy on sustainable development was evaluated using the fixed-effect regression model on four years of panel data from 2016 to 2019 for the sample of 32 OECD countries.

Findings & value-added: The comparative analysis of the circular economy's prioritisation results and Sustainable Development Goals Index (SDGI) ranking showed 20 out of 32 matches, assuming a link between the circular economy and sustainable development could be made. The fixed-effect regression equation results demonstrate that the unemployment rate, poverty rate, air pollution exposure, and CO2 emission per capita negatively influence sustainable development. In contrast, indicators such as gross domestic expenditure on R&D, renewable energy, number of passenger cars in use, and households with Internet access positively impact SDGI. The hypothesis that the circular economy is seen as an assistance for sustainable development and directly affects a country's sustainability was approved. The paper contributes to the scientific literature in the field of circular economy and sustainable development interaction and could be seen as an assumption for new research directions, focusing on the linkage between circular economy and sustainable development. Moreover, the obtained results could contribute to a country's policy-makers by highlighting the essential indicators of a circular economy that should be considered while forming the strategy of a country's sustainable development.

Introduction

The circular economy (CE) has gained great attention among scholars. It is a relatively new concept that intends to replace the common linear economy model. Still, the transition to the CE is a complex task (Razminiene, 2019); hence, to make the mentioned transition more smooth and successful, it is vital to understand what factors could help reach the highest level of CE. In line with CE, scholars study sustainable development goals (SDGs) that should be achieved by 2030, according to the United Nations (2015). Even though Millar *et al.* (2019) emphasise that CE could serve as a tool for sustainable development (SD), the linkage between those two concepts has been investigated fragmentally. Therefore, it can be asserted that this current research may be seen as a contribution that fills the gap of literature research on this topic.

It is very important to emphasise that even though the positive relationship between SD and CE is taken for granted most of the time, a deeper analysis reveals some divergent key aspects, such as sharing of responsibilities, beneficiaries, coverage of pivotal dimensions, which represents the differences in basic goals. Therefore, the existence of the negative relationship between SD and CE cannot be ignored. Hence, the current paper seeks to examine if CE could function as assistance for SD and, therefore, determine if CE could directly impact a country's SD.

The paper consists of four parts. The literature review is designed to review the concepts, base the choice of selected indicators and identify the relationship between CE and SD. Based on the literature review, the hypothesis "*The CE is seen as assistance for SD and has a direct impact on a country's sustainability*" was raised. The second part of the paper is dedicated to the methods applied. In order to identify the cohesion of a country's CE and SD, the following methods were employed: a country's CE is expressed by ranking (AHP and EDAS methods) and compared with the country's Sustainable Development Goals Index (SDGI). The impact of the country's CE on SD has been analysed using the regression model on four years of panel data from 2016 to 2019 for the sample of 32 countries (OECD countries). The CE is expressed through the CE areas and is measured by selected indicators. The country's SD is measured according to SDGI. The results are analysed and presented in the third part of the paper. The fourth part of the article covers the discussion and conclusion.

Literature review and hypothesis development

The CE is a systematic approach to economic development created for the benefit of business, society, and the environment. The CE concept can be explained as an economic model with the main aim of resource efficiency through long-term value creation, waste minimisation, and reduction of closed loops products considering environmental protection (Morseletto, 2020).

The CE's primary goal is to replace the outdated take, make and dispose of process and model, which are highly wasteful, with a closed system of make, use, reuse, remake, and recycle that is a more responsible, all-encompassing and abundant resource management process. Typically, the CE could be presented by the five significant loops, determining the CE principles (see Figure 1).

The raw material extraction loop points out the significance of environmental preservation — natural resources should be used in the most efficient way and without depleting the planet's resources. Additionally, it points out that recycled raw materials could be injected back into the economy as secondary raw materials. Besides improving the quantity and quality of secondary raw materials, waste management also needs to be improved (European Commission, 2020c). The product design loop is understood as a critical way to build the CE by creating long-lasting products that are easy to reuse and recycle. It is necessary to consider circularity aspects when designing and developing products. Products must be easily disassembled and separated into different components and materials, facilitate the replacement of defective components, and extend products' service life in various ways (Shahbazi & Jönbrink, 2020). The production and remanufacturing loop aims to turn used, worn, damaged, or obsolete products into functional products with originality (Tjahjono & Ripanti, 2019). In the consumption loop, the significance of customers' behaviour is emphasised. The consumption loop stresses the importance of customers considering the environmental impact and being greener by choosing circular and sustainable products and services that reduce their environmental footprint and support the move towards a stronger CE (European Commission, 2020b). The waste management loop closes the loop in the CE.

Relationship between the CE and sustainability

There is an ongoing debate regarding the cohesion between CE and sustainability. The CE concept provides an immense business opportunity that can bring huge benefits to everyone — society, businesses, and the environment (Bressanelli *et al.*, 2018). Usually, these three elements are described as three pillars that hold up the sustainability concept. Sustainability might be achieved by seeking long-term stability between the economy and the environment. This goal can be achieved under the condition of the integration of economic, environmental and social concerns, environmental protection, equity promotion, and preservation of economic growth and development (Emas, 2015). Therefore, according to Kirchherr *et al.* (2017), the CE could be defined as a system based on business models promoting reducing, reusing, recycling and recovering materials operating at different levels with the intention to achieve SD. The concept offers more sustainable business through activities that retain the value of materials and products already in circulation for longer (Ranta *et al.*, 2021).

The Ellen Macarthur Foundation (2013) emphasises the CE's high contribution to SD by promoting more appropriate use of resources to implement the CE, characterised by a business model and innovative employment opportunities. Korhonen *et al.* (2018) identify the CE as a new business model expected to lead to more SD by separating economic growth from the negative consequences of resource depletion and environmental degradation. Philp and Winickoff (2018) support the idea that moving towards a CE requires that the transition process be managed sustainably. Notwithstanding Geissdoerfer *et al.* (2017), the relationship between the CE and sustainability is not clear and highlights both positive and negative aspects of the relationship.

Thus, both the positive and negative relationships between sustainability and the CE concepts could be explained in various ways. Despite the fact that CE is seen as an assistance tool for SD by many authors, the negative relationship between the CE and sustainability concepts is revealed. Alwood (2014) determine potential costs and technical impossibility as the primary negative relationship. Additionally, the CE impacts the environment and economy dimensions, but does not integrate well the social dimension (Murray *et al*., 2017). These two concepts differ by goals, motivations, beneficiaries, and perception of responsibilities. The main objective of the CE is to close the loop by keeping products as long as possible in the economy and eliminating waste. At the same time, sustainability has a multitude of goals, which shift depending on the agents' interests. The CE's primary motivation is the better use of resources and waste reduction, while the reason for sustainability is past trajectories. Moreover, in the CE concept, the primary beneficiaries are economic actors that implement the system, while in the sustainability concept, it is the environment, economy, and society at large. Furthermore, in the CE, private business and policy-makers are responsible for changes, while in the sustainability concept, responsibilities are shared but not clearly defined (Geissdoerfer *et al*., 2017).

On the other hand, Geissdoerfer *et al.* (2017) distinguish that both concepts emphasise the importance of the commitments motivated by environmental hazards; they highlight the necessity of system change and innovation at the core. Also, the primary ways for industry transformation are considered to be business model innovations and technological solutions. Moreover, both concepts recognise the importance of regulation and incentives as core implementation tools.

First, accepting the criticism but maintaining the importance of CE's contribution to SD, it can be argued that cooperation covering economic and environmental dimensions could be successful. Rashid *et al.* (2013) emphasize the CE as a precondition for sustainability, with higher contributions to the economy and environment.

Second, still supporting the approach that CE could cover all the three SD dimensions, the European Commission (2014) and EEA (2016) consider CE to be a beneficial tool for different sustainability dimensions — the economy, environment, society. The CE highly contributes to improving resource productivity and decreasing import dependency, reducing environmental impact, economic growth and innovation opportunities, and sustainable consumer behaviour and job opportunities.

Even though it is challenging to identify the social aspect directly, Bocken *et al.* (2014) see the CE as one of the sustainability business models, contributing to the core sustainability concepts. Similarly, Kirchherr *et al.* (2017) highlight that the CE's primary goal is to reach and maintain economic prosperity with a high contribution to environmental quality, social equity, and future generations.

In summarising and accepting the criticism, it can be asserted that there are clear arguments of CE having a significant impact on the economy and environment, yet the social dimension is not directly and openly identifiable. Nevertheless, it is clearly revealed as offering society an opportunity to reinvent the economy, making it more sustainable and competitive, ensuring and promoting more innovative and efficient ways of consuming, protecting business against scarcity of resources, boosting economic growth, and creating jobs. Therefore, the hypothesis can be raised:

H_1: *The CE is seen as an assistance for SD and directly impacts the country's sustainability.*

Measuring a country's SD

There are many ways and indices to measure the sustainability and SD of a country; some are more dedicated to the environmental aspect, such as the Ecological Footprint (Wackernagel & Rees, 1996), Environmental Pressure Indicator (Eurostat, 2001), environmental performance index (2002), Environmental Sustainability Index (Esty *et al.*, 2005), and some with more emphases on social aspects, such as the Human Development Index (UNDP, 1990), Human Sustainable Development Index (Bravo, 2014), Human Green Development Index (Li *et al.*, 2014), and some more economical, such as the Genuine Savings Indicator (Hamilton, n.d.), the Total Material Requirement (European Environmnet Agency, n.d.), or there are general indices such as the Barometer of Sustainability (Prescott-Allen, 1995), Sustainable Development Index (Hickel, 2020) or just the National Sustainable Development Indicators (United Nations, 2007).

Many composite indices are constructed by international organisations and used to measure the level of SD. Nevertheless, they have been of very limited use in decision-making since issues inherent to the measurement, weighting and indicator selection have not been appropriately addressed at all levels (Marti & Puertas, 2020). Some indices are criticised for incompleteness to measure sustainability and SD, as they do not integrate well the environmental and ecological aspects (Jin *et al.*, 2020). However, the Sustainable Development Goals Index (SDGI) has received increasing attention due to an effective roadmap to measure and improve sustainability (Weitz *et al.*, 2015). The SDGI is calculated according to the released United Nations 17 sustainable goals (United Nations, 2020), which include no poverty, zero hunger, good health and well-being, quality education, gender equity, clean water and sanitation, affordable and clean energy, decent work and economic growth, industry, innovation and infrastructure, reduced inequalities, sustainable cities and communities, responsible consumption and production, climate action, life below water, life on land, peace, justice and strong institutions, and partnerships for the goals (United Nations, 2020a). In the research, SD will be measured and evaluated according to the SDGI.

Selection of the indicators for the CE

Avdiushchenko and Zaj (2019) state that the CE monitoring framework released by the European Commission is not detailed enough for monitoring the effects of crucial CE areas such as social innovations, eco-innovations, sharing economy initiatives, the level of the greening of the main economic sectors, new business models' implementation, and eco-design. Due to that reason, concluded data, presented in Table 1, are grouped according to the specific areas of the CE, which consist of economic prosperity, zero-waste economy, innovative economy, energy-efficient and renewable energy-based economy, low carbon economy, smart economy, spatially effective economy, bioeconomy, resources and material-efficient economy, and socially orientated economy.

All the specific CE areas presented in Table 1 represent the CE's five loops.

According to the analysed literature and theoretical background, the research will use various CE indicators, which are grouped into the CE-specific areas according to the loops of the circular economy (Table 2).

Due to the lack of information, only energy-efficient and renewable energy-based economy, innovative economy, low carbon economy, economic prosperity, smart economy, and zero-waste economy-specific areas of the circular economy will be included in the research.

Selected indicators will measure each specific CE area.

Research methodology

In order to prioritise the countries and, based on their data, reveal if the CE indicators directly impact SD, several methods were used.

First of all, the weight for each of the analysed indicators is assigned. For that purpose, the questionnaire was prepared for the experts. In order to get reliable research results, the following requirements for the experts were raised:

- to have at least five years of research experience in the field of the CE
- to have a PhD in economics.

The number of experts was established based on Libby and Blashfield (1978), who claim that when starting with three experts, the level of reliability exceeds 75 per cent. Based on this determination, six experts were selected for the current study.

For weight calculation, the Analytic Hierarchy Process (AHP) method proposed by Saaty (1977, 1985) was employed. The essence of the AHP method is that experts compare all the indicators to each other by filling in the priority matrix $A = (a_{ij})_{n\times n}$, where $a_{ij} = {}^{w_i}/_{w_j}, \forall\, i, j = 1, 2, \dots, n$, and $w = (w_1, \dots, w_n)$ is a priority vector.

After the comparison matrices are completed, each element of the matrix is divided by the sum of its column sum to generate a normalised matrix. After this, the consistency of the matrix is assessed. In order to determine the consistency index, the maximum eigenvalue of the pairwise comparison matrix ought to be calculated:

$$\lambda_{max} = \sum_{j=1}^{n} \frac{(A\cdot v)_j}{n\cdot v_j}, \tag{1}$$

where:
λ_{max} – the largest eigenvalue of matrix A,
n – number of independent rows in the matrix,
v_j – eigenvalue of the matrix.

After the value of λ_{max} is computed, the consistency ratio is calculated:

$$CR = \frac{\lambda_{max} - n}{(n-1)\times RI}, \tag{2}$$

where:
CR – consistency ratio,
RI – random index,
λ_{max} – maximum eigenvalue,
n – number of indicators in the comparison matrix.

The random index is one of the most popular and most effectively used decision-making methods developed by Saaty (Shyamprasad & Kousalya, 2020). Random index values are assigned according to Saaty's scale, and in the present case, RI = 1.56.

For experts' pairwise comparison matrices that fulfil the consistency condition (CR < 0.2), the aggregated experts' assessment is calculated.

When the weights are assigned to the indicators, the OECD countries are prioritised by using the Evaluation Based on Distance from Average Solution (EDAS) method. In fact, every method has advantages and disadvantages (Kraujalienė, 2019), but EDAS was chosen due to its pluses. EDAS is a relatively new method compared with the other multi-criteria decision-making methods. This method includes positive and negative distances from the average solutions (Fan *et al.*, 2019). The motivation for employing the EDAS method for the current research is that the obtained results are based on the average solution that represents normalised data that significantly limit the chances of deviation from the best solution, which allows this technique to produce more accurate solutions in problem-solving (Tadić *et al.*, 2019). The methodology of the EDAS is provided below.

First, the decision-making matrix is constructed:

$$X = [X_{ij}]_{m \times n} = \begin{bmatrix} X_{11} & \cdots & X_{1m} \\ \vdots & \ddots & \vdots \\ X_{n1} & \cdots & X_{nm} \end{bmatrix}, \tag{3}$$

where:
X_{ij} – value of *i*-th alternative on *j*-th criterion;
n – number of alternatives;
m – number of criteria.

Second, the average solution is determined:

$$AV_j = \frac{\sum_{i=0}^{n} X_{ij}}{n}, \tag{4}$$

where:
AV_j – the average solution.

Third, the positive distance from the average (PDA_{ij}) and the negative distance from the average (NDA_{ij}) matrices according to the type of criteria (benefit and cost) are calculated:

a. if *j*-th criterion is beneficial:

$$PDA_{ij} = \frac{\max\left(0, \left(W_{ij} - AV_j\right)\right)}{AV_j}, \tag{5}$$

$$NDA_{ij} = \frac{\max(0,(AV_j - X_{ij}))}{AV_j}, \tag{6}$$

b. if *j*-th criterion is cost:

$$PDA_{ij} = \frac{\max(0,(AV_j - X_{ij}))}{AV_j}, \tag{7}$$

$$NDA_{ij} = \frac{\max(0,(X_{ij} - AV_j))}{AV_j}, \tag{8}$$

where:
PDA_{ij} – positive distance from the average,
NDA_{ij} – negative distance from the average.

Fourth, the values of NSP_i and NSN_i are calculated:

$$NSP_i = \frac{\sum_{j=1}^{m} w_j PDA_{ij}}{max_i(SP_i)}, \tag{9}$$

$$NSN_i = 1 - \frac{\sum_{j=1}^{m} w_j NDA_{ij},}{max_i(SN_i)}, \tag{10}$$

where:
NSP_i – normalised value of weighted sum of PDA_{ij},
NSN_i – normalised value of weighted sum of NDA_{ij}.

Fifth, the appraisal score for all alternatives is calculated:

$$AS_i = \frac{1}{2}(NSP_i + NSN_i), \tag{11}$$

where:
AS_i – appraisal score, $0 \leq AS_i \leq 1$.

The last step includes alternatives' ranking according to the decreasing values of AS_i, i.e., the alternative with the highest AS_i is considered to be with the highest CE level.

In order to find out if the CE indicators' influence the SDGI, the regression model is used on four years of panel data from 2016 to 2019 for a sample of 32 countries. The following empirical model is developed for this purpose:

$$\ln SDGI = \beta_0 + \beta_{1t} \ln Unemp_{it} + \beta_2 \ln GDP_{it} + \beta_3 \ln Pov_{it} + \beta_4 \ln DispInc_{it} + \beta_5 \ln RD_{it} + \beta_6 \ln Pat_{it} + \beta_7 \ln RE_{it} + \beta_8 \ln AQ_{it} + \beta_9 \ln CO_{2_{it}} + \beta_{10} \ln NoCar_{it} + \beta_{11} \ln Int_{it} + \beta_{12} \ln Waste_{it} + \beta_{13} \ln EC_{it} + u_i \quad (12)$$

As mentioned before, the selected variables are associated with the CE, and their detailed explanation is presented in Table 2.

In order to determine which meta-regression model — random effect or fixed effect — is more appropriate for the current data, the Hausman test was used. The results showed that p-value was less than 0.0001 (at the significance level 0.01); hence, the appropriateness of the fixed-effects model over the random-effects model was proved. Hence, the fixed-effects model was considered for the representation of the main results of the current research.

Results

The first step of the research was to assign the weight to each of the distinguished CE indicators. All the matrices were tested for consistency, and according to CR, the expert's E5 matrix was inconsistent and, hence, was removed from further calculations. The aggregated matrix and CR are presented in Table 3.

The second step of the study is to evaluate the present situation, i.e. to rank the analysed countries in terms of CE. For that purpose, the EDAS multi-criteria decision-making method was chosen. The prioritisation of the OECD countries is presented in Table 4.

Table 4 shows that Japan has the most significant appraisal score, while Mexico has the lowest. It means that Japan has the most robust CE compared with other OCED countries, while Mexico has the weakest CE among OECD countries. The top 5 countries with the most robust CE in 2019 are Japan, Sweden, Norway, Finland, and Denmark. The weakest CE in 2019 was in Mexico, Australia, Poland, Luxembourg, and Greece. The most crucial thing in the prioritisation procedure is to reveal if there is a link between CE ranking results expressed as EDAS performance scores and SD expressed as SDGI (Table 5).

The comparative analysis was performed based on the condition that a country's position could vary by no more than five places. This condition is based on the fact that not all the CE indicators were used in the ranking, and it is worth noting that comparative analysis includes one-year data. The study showed that there are 20 out of 32 matches (Table 5). Hence, the assumption could be made that the link between the CE ranking results and SDGI exist.

The third step of the research is to perform a fixed-effect regression analysis to develop a CE influence equation on SD. The results are presented in Table 6.

As shown in Table 6, not all of the determining indicators are included in the model. Due to statistical insignificance (p-value > 0.05), the following indicators were removed from the model: GDP, disposable income, patents, municipal waste generated, and electricity consumption. After the indicators were removed, the final fixed-effect regression model was developed, in which $R^2 = 0.769$; consequently, the model explains more than 75 per cent of SDGI variance.

The second column of Table 6 reports the estimation results from the SDGI and influencing indicators equation. First of all, it is worth mentioning that not all of the indicators have the same sign, i.e., four indicators have negative coefficients and four have positive coefficients. The results showed that unemployment negatively affected SD, i.e. the higher the unemployment rate, the lower the SDGI. Ultimately, the result is quite logical because reducing unemployment is one of the overall drivers of decent work, which is another one of the SDG's. The second factor that is negatively associated with SDGI is poverty. In fact, "No poverty" is the first goal of the SDGs. The current results show that the lower the poverty rate, the higher the level of SDGI. The other two indicators with negative signs are CO_2 emission and air quality. These two indicators are related to each other, and both negatively affect SDGI. In fact, SD is associated with managing climate change; the last-mentioned indicators could slow it down. Gross domestic expenditures on R&D have a positive impact on SDGI. In fact, the result is logical and could be explained by the fact that R&D is associated with innovation, and innovations, in turn, positively influence SD. Renewable energy has a positive impact on SD as well.

One of the sustainability pillars covers the environmental issue, and renewable energy has a positive direct relationship with a sustainable environment. The most significant indicator is the number of households with Internet access. The Internet has become one of the most influential information and communication technology (ICT); moreover, it is a platform for the Internet of things (IoT). Both ICT and IoT have a positive influence on sustainability (Roblek *et al*., 2020; Souter, 2012).

The most surprising result is that the number of passenger cars in use positively affects SD, but this just at first glance. As could be seen from Table 5, the most circular is the most economically developed countries. As a rule, in such countries, the number of passenger cars is higher than in, for instance, developing countries. Simultaneously, more sustainable are those countries that are considered to be developed; hence, this relationship and impact are logical from the statistical perspective. From the sustainability perspective, owning a car does not mean using it all the time; hence, the results do not contradict the studies' outcomes investigating the frequency of use of cars.

To sum up the results, the hypothesis that the CE is seen as an effective assistance tool for SD and as directly affecting a country's sustainability, could be accepted.

Discussion

The literature review highlights the discussion on the CE role in the context of SD. Despite different standpoints, there are clear arguments that CE has a significant impact on the economy and the environment; meanwhile, the social dimension is not directly and openly identifiable. However, the role of the social aspect could be clearly revealed by offering society an opportunity to regenerate the economy, ensuring more innovative and efficient ways of consuming, securing and improving resource productivity, creating jobs, and thus making it more sustainable. In this paper, the CE is seen as a contributor to SD by considering all sustainability dimensions of the economy, environment, and society. Based on this, the hypothesis "*The CE is seen as an effective assistance tool for SD and directly impacts the country's sustainability*" was raised and accepted.

The current study is unique because it covers the investigation of the CE impact on SD on a country level, and it contributes to the scientific knowledge on the interface between the CE and SD. The other studies conducted in this area do support the outcomes obtained during this current study. For example, Calicioglu and Bogdanski (2021) claim that the links between CE and SDG have been analysed, but still, "the complete picture on this heterogeneous literature is missing". There are scientists analysing the circular economy in terms of industries and claim that CE could help to promote industries' sustainability strategies by employing new technologies (Ajwani-Ramchandani *et al*., 2021; Liu *et al*., 2021).

Other studies focus on the CE in terms of sustainable food consumption and highlight the linkage between those two concepts (Aiking & de Boer, 2020). Moreover, there are researchers investigating the CE as a technology for fuel recycling (Kumar & Verma, 2021). To sum up, scholars from different fields have researched the CE, but there is a lack of studies investigating the CE of individual countries. In other words, the current paper uses a different approach to the CE and analyses it on a country level and researches not only one country or enterprise, but the OECD countries as a whole. Consequently, the current paper differs from the existing studies and provides new evidence of the circular economy's influence on the sustainable development of a country.

Conclusions

To understand the level of the circular economy and its impact on SDGI, a three-step research process was conducted. The first step covered weight assignment to the determined CE indicators. For that purpose, expert evaluation and AHP methods were employed. The results revealed that the generated municipal waste had the most significant impact on the CE, which corresponds to the new EU Circular Economy Action Plan (European Commission, 2020a) — the initiative promoting sustainable consumption, targeting the entire product's life cycle, starting with the care of resources and a package design, and finishing by recyclability of packaging. The results are distributed by significance as follows: renewable energy, CO_2 emission, patents in environment-related technologies, number of passenger cars in use. Air pollution exposure, gross domestic expenditure on R&D, electricity production, the poverty rate, and households with Internet access had a slightly smaller impact. Household disposable income gross adjusted, gross domestic product, and unemployment rate had the weakest effect on the CE.

The second step of the research was to prioritise the OECD countries in order to find out which one is the most "circular". The results showed that the highest CE level in 2019 was in Japan, Sweden, Norway, Finland, and Denmark. In contrast, Mexico, Australia, Poland, Luxembourg, and Greece had the weakest CE in 2019. It is important to emphasise that the analysed period for the ranking covers 2019, and the results could vary by analysing the average of several years or by choosing another period for the research. Nevertheless, this does not detract from the results; even though the significant disparity between the countries exists, the results are vital for the countries that seek to transit to circular economy, as the strongest CE countries could be treated as a present benchmark. Hence, other, weakest economies could follow suit and pay attention to the CE indicators to be strengthened. The purpose of the ranking was to reveal if there is a link between CE and SD. The comparative analysis showed 20 out of 32 matches, so the assumption could be made that the connection between the CE ranking results (expressed as EDAS performance scores) and SD (expressed as SDGI) exist. Such results already partly contribute to the main research problem and reveal one side of the debate's approval. That provides an assumption for the last part of the research.

The third step of the research was developing a fixed-effect regression equation using 4-year panel data from 32 OECD countries. According to the fixed-effect regression results, GDP, disposable income, patents, municipal waste generated, and electricity consumption are not statistically significant indicators, meaning that they do not impact SD, expressed through SDGI. The unemployment rate, poverty rate, air pollution exposure, and CO_2 emission per capita are statistically significant indicators, and they do have a negative impact on SDGI, while indicators such as gross domestic expenditure on R&D, renewable energy, number of passenger cars in use, and households with Internet access are statistically significant indicators and they do have a positive impact on SDGI. The results are of great importance for policy-makers while revealing other essential areas that need to be addressed to achieve SD. In comparison, the CE is currently focusing most on resources, sustainable product and waste management (OECD, 2019).

To sum up, it could be stated that the CE and SDGI are closely related concepts, and CE could be treated as an effective assistance tool to achieve SDGs. Nevertheless, some limitations of the research also need to be considered. First of all, the period of four years and the number of CE indicators used for the research must be emphasised. For further research, a more extended period of time would be worth evaluating, as well as the inclusion of more CE indicators. Considering that the CE is expressed via indicators but not as an index or individual measure, results ought to be interpreted as an assumption for wider scopes and new research directions. A similar remark could be dedicated to the SD as well, and the replacement of SDGI by another index or a group of several indicators could slightly change the results. Therefore, supplementing the study over a more extended period by selecting more indicators and considering a different SD expression would be very welcome. Noticeable significant disparity between the countries' CE could be the next object of investigation; great attention should especially be paid to differences between developed and developing countries.

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Annex

Table 1. Distribution of CE specific areas and indicators by CE loops

Loop of CE	CE specific area	Indicators
Raw materials extractions	Spatially effective economy	Forest cover indicator, urbanisation rate.
	Bioeconomy	Biofuels, biomass, bio-based products.
	Energy-efficient and renewable energy-based economy	Share of renewable energy sources in total production of electricity, electricity consumption, final energy intensity of GDP, resource intensity of GDP, domestic material consumption.
	Resource and material-efficient economy	Productivity of resource, domestic material consumption, production material reuse rate.
Product design	Innovative economy	Eco-innovations, patents related to recycling sectors, expenditure on research and development in relation to GDP, patents of recycling and secondary materials and others, expenditures on research and development (R&D) in the field of biotechnology, patent applications for 1 million inhabitants.
Production and remanufacturing	Low carbon economy	Emission of particulates, CO_2 emission intensity, pollution treatment.
Consumption	Economic prosperity	GDP, increase in household income, poverty risk indicator, number of persons employed, economic growth.
	Smart economy	Households with Internet access.
	Socially oriented economy	Innovative social enterprises.
Waste management	Zero-waste economy	Municipal waste, food waste, municipal waste recycling rate, market rate of recyclable raw materials, zero waste index, sustainable circular index.

Source: compiled by authors based on Marino and Pariso (2020), Saidani *et al.* (2019), Avdiushchenko and Zaj (2019), European Commission (2014), European Enviromental Agency (2016), Ellen MacArthur (2015), Veleva *et al.* (2017).

Table 2. Selection of CE indicators for the research according to CE loops and specific area

Loop of CE	CE specific area	Indicators (units)	Notation
Raw materials extractions	Energy-efficient and renewable energy-based economy	Air pollution exposure (Exposure to PM2.5 (µg/m³))	*AQ*
		Electricity total production (MWh/1000 capita)	*EC*
		Renewable energy (% of primary energy supply)	*RE*
Product design	Innovative economy	Patents in environment-related technologies (Number)	*Pat*
		Gross domestic expenditure on R&D (% of GDP)	*RD*
Production and remanufacturi ng	Low carbon economy	CO_2 emission intensity (Tonnes/capita)	CO_2
		Number of passenger cars in use (Cars/1000 population)	*NoCar*
Consumption	Economic prosperity	Gross Domestic Product (USD/capita)	*GDP*
		Unemployment rate (Total, % of labour force)	*Unemp*
		Poverty rate (%)	*Pov*
		Household disposable income Gross adjusted (USD/capita)	*DispInc*
	Smart economy	Households with Internet access (%)	*Int*
Waste management	Zero-waste economy	Municipal waste generated (Tonnes/1000 capita)	*Waste*

Table 3. Distribution of weights of CE indicators

Expert	**Gross Domestic Product**	**Unemployment rate**	**Poverty rate**	**Household disposable income Gross adjusted**	**Municipal waste generated**	**Patents in environment-related technologies**	**Gross domestic expenditure on R&D**	**Electricity consumption**	**Renewable energy**	**Capital city air quality**	**CO_2 emission**	**Number of passenger cars in use**	**Households with Internet access**
E1	0.03	0.02	0.17	0.02	0.14	0.20	0.04	0.06	0.16	0.05	0.05	0.04	0.02
E2	0.01	0.01	0.01	0.01	0.12	0.05	0.06	0.12	0.12	0.12	0.12	0.12	0.12
E3	0.01	0.02	0.04	0.04	0.19	0.03	0.04	0.05	0.06	0.11	0.20	0.19	0.02
E4	0.02	0.01	0.02	0.08	0.11	0.11	0.18	0.10	0.11	0.08	0.09	0.03	0.06
E6	0.02	0.03	0.12	0.03	0.11	0.01	0.09	0.10	0.17	0.12	0.16	0.02	0.03
Weights	**0.02**	**0.02**	**0.05**	**0.04**	**0.14**	**0.10**	**0.08**	**0.08**	**0.11**	**0.09**	**0.11**	**0.10**	**0.06**

Table 4. Prioritisation of the level of CE of OECD countries based on 2019 data

Country	AS_i	**Rank**	**Country**	AS_i	**Rank**
Japan	0.77	1	The Netherlands	0.50	17
Sweden	0.67	2	Belgium	0.50	18
Norway	0.62	3	Estonia	0.49	19
Finland	0.61	4	Slovenia	0.49	20
Denmark	0.60	5	Czech Republic	0.48	21
Germany	0.60	6	Chile	0.48	22
Latvia	0.57	7	Slovakia	0.47	23
Austria	0.56	8	Spain	0.47	24
South Korea	0.53	9	Italy	0.46	25
Portugal	0.53	10	Canada	0.44	26
United Kingdom	0.53	11	Turkey	0.44	27
France	0.52	12	Greece	0.44	28
Lithuania	0.51	13	Luxembourg	0.43	29
Ireland	0.50	14	Poland	0.42	30
Hungary	0.50	15	Australia	0.42	31
United States	0.50	16	Mexico	0.39	32

Table 5. Comparative analysis between the CE ranking results and SDGI

Country	**EDAS performance scores**	**Rank**	**SDGI**	**Country**
Japan	0.77	1	85.22	Denmark
Sweden	0.67	2	84.99	Sweden
Norway	0.62	3	82.82	Finland
Finland	0.61	4	81.49	France
Denmark	0.60	5	81.07	Austria
Germany	0.60	6	81.07	Germany
Latvia	0.57	7	80.74	Czech Republic
Austria	0.56	8	80.66	Norway
South Korea	0.53	9	80.38	The Netherlands
Portugal	0.53	10	80.22	Estonia
United Kingdom	0.53	11	79.41	Slovenia
France	0.52	12	79.38	United Kingdom
Lithuania	0.51	13	78.92	Japan
Ireland	0.50	14	78.89	Belgium
Hungary	0.50	15	78.33	South Korea
United States	0.50	16	78.22	Ireland
Netherlands	0.50	17	77.89	Canada
Belgium	0.50	18	77.84	Spain
Estonia	0.49	19	77.13	Latvia

Table 5. Continued

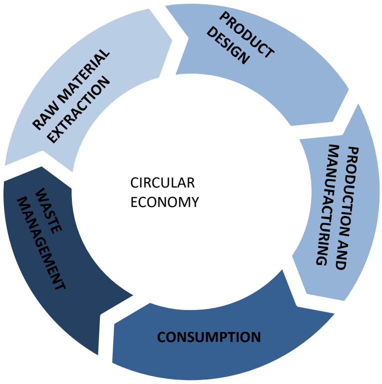
Country	EDAS performance scores	Rank	SDGI	Country
Slovenia	0.49	20	76.89	Hungary
Czech Republic	0.48	21	76.43	Portugal
Chile	0.48	22	76.21	Slovakia
Slovakia	0.47	23	75.93	Poland
Spain	0.47	24	75.79	Italy
Italy	0.46	25	75.61	Chile
Canada	0.44	26	75.10	Lithuania
Turkey	0.44	27	74.78	Luxembourg
Greece	0.44	28	74.52	United States
Luxembourg	0.43	29	73.89	Australia
Poland	0.42	30	71.41	Greece
Australia	0.42	31	68.51	Mexico
Mexico	0.39	32	68.49	Turkey

Table 6. Estimates of fixed-effects regression

Parameter	Estimate	Std. Error	df	95% Confidence Interval		VIF
				Lower Bound	Upper Bound	
Intercept	3.751***	0.149	126.996	3.456	4.045	< 4
ln*Unemp*	-0.033***	0.005	99.913	-0.043	-0.023	< 4
ln*Pov*	-0.039***	0.008	119.465	-0.055	-0.024	< 4
ln*RD*	0.026***	0.006	94.848	0.014	0.037	< 4
ln*RE*	0.014***	0.005	106.827	0.005	0.023	< 4
ln*AQ*	-0.024***	0.007	95.223	-0.039	-0.009	< 4
lnCO_2	-0.034***	0.007	108.867	-0.049	-0.019	< 4
ln*NoCar*	0.031***	0.009	121.995	0.014	0.049	< 4
ln*Int*	0.142***	0.027	126.202	0.088	0.195	< 4

Note: α = 0.10 (*), α = 0.05 (**), α = 0.01 (***)

Figure 1. Circular economy loops



Source: compiled by authors according to Ecologic Institute (2020)