ASSESSING THE IMPLEMENTATION OF THE CIRCULAR ECONOMY IN THE EU COUNTRIES

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ABSTRACT

The circular economy (CE) is generally an economic system which aims to reduce waste and reuse resources. Predetermined by the need for new sources of sustainable development in the current conditions of global environmental issues and qualitative and quantitative limitations of resources, this promising concept has recently fuelled a broad international discussion. The circular economy is now an urgent global priority for policymakers as well, especially in the EU. Given these facts, the benefits and impact of a circular economy with an emphasis on waste and recycling management are being investigated on supranational and national levels (in the EU and its member nations, which are world leaders in terms of its adoption). Systematisation, comparative analysis, benchmarking and generalisation, economic and mathematical modelling (the formation of a model of recycling efficiency in the context of the CE in the EU based on the Eurostat data on the CE in the EU) and statistical methods were the research methods used in the study. It was proven that waste recycling rates have a significant impact on the EU recyclable raw materials trade. The proposed methodology of modelling the CE results can be used for other countries/companies. The research may help to promote effective reformation of global economics by propelling sustainable development.

KEY WORDS

Circular economy, linear economy, sustainable development, waste recycling, reusing, recyclable material.

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Introduction

Nowadays, the global population is growing sharply, which has a great impact on the environment. According to a United Nations report (2019), the population of the world is expected to reach 8.5 billion in 2030, 9.7 billion in 2050 and 10.9 billion in 2100. In addition, this rapid population growth is accompanied by an increase in environmental pollution (Mesagan and Chidi, 2020). Experts estimate that, by 2050, four planets as large as Earth would be needed when taking into consideration the exhaustion of primary resources (McDonald, 2020).

The issue of waste collection and recycling is also becoming urgent due to a steady increase in waste generation and damage to the environment (Ślusarczyk et al., 2016; Kliestikova et al., 2018; Abdel-Shafy and Mansour, 2018; McDonald, 2020; Czikkely et al., 2018). Each country is attempting to boost its economic productivity and competitiveness in the conditions of the fourth industrial revolution (Shpak et al.,

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2019; Rymarczyk, 2020; Sieja and Wach, 2019; Maciejewski and Głodowska, 2020), though not necessarily ensuring long-term sustainability (Islam et al., 2003; Janicke, 2012; Jaki and Siuta-Tokarska, 2019). This is very important given the many problems it can create, in particular the exhaustion of environmental resources and a negative influence on the environment. One should remember that environmental issues have recently become increasingly observable in politics (Dan, 2019; Chovancová and Tej, 2020), and investors treat companies with high environmental performance as more valuable than firms with similar financial results but lower environmental ratings (Filimonova et al., 2020). In order to protect the environment, ensure decent living and working conditions, as well as providing enough resources and sustainable economic development in the years to come, many developed countries (above all European countries such as Germany, the UK, France, the Netherlands, Denmark, and Sweden) have switched from a linear to a circular economic model (Luttenberger, 2020; Michelini et al., 2017; Garcés-Ayerbe, 2019; Mesterházy et al., 2020).

Although various aspects of the circular economy are widely studied in the literature and already applied in practice, we consider it expedient to study systematically and in detail the latest results of CE implementation in countries which are global leaders in this aspect – the nations of the EU. The purpose of this study is to explore the principles and benefits of a circular economy model and assess the implementation of the CE in 28 EU countries, as well as developing a model for the analysis of recycling opportunities in the EU as a tool for evaluating the results of the CE. The conclusions can be the basis for a faster and more efficient transition to circular principles in countries that are less progressive in this area.

The paper is structured as follows: The subsequent section analyses the literature devoted to the CE; this is followed by the methodological part; research results are presented afterwards; and finally, we present the discussion and conclusions.

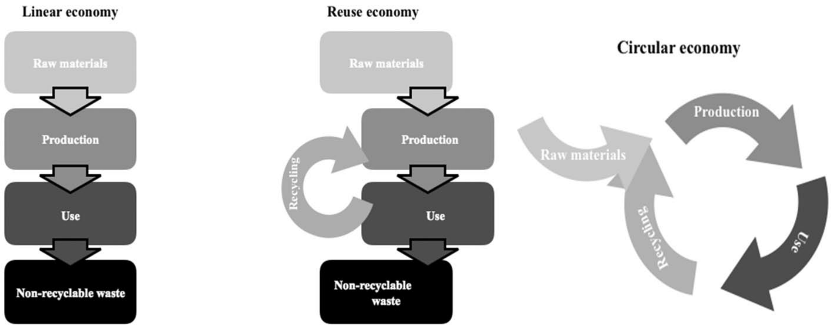
1. Theoretical framework

1.1. Principles and benefits of the circular economy model

For a long time, the traditional economy has been linear, whereby raw materials were used to make products, and afterwards, all waste (e.g. containers, packaging) was thrown away. This was a linear process, optimised towards high volume and low production costs in conditions of wide availability of resources and materials at low cost.

Recently, there has been a shift to a circular economy, where materials are reused, and if new materials are needed, they must be obtained sustainably so that the environment is not damaged. Thus, the aim of a circular economy is to ensure low environmental impact by minimising waste and resource use through re-use, re-manufacture, re-cycle, waste reduction, etc. (Stahel, 2016; Czikkely et al., 2019). One may then state that the concept of the circular economy is crucially different from a traditional linear concept (Figure 1). In general, a circular economy fosters reuse and extends service life through repair. According to the European Commission, "in a circular economy, the value of products and materials is maintained for as long as possible. Waste and resource use are minimised. This brings economic benefits, contributing to innovation, growth and job creation" (Circular Economy, 2020). It "remanufactures, upgrades, retrofits and turns old goods into as-new resources by recycling the materials" (Stahel, 2016).

Figure 1. Transition from a linear to a circular economic model



Source: Government of the Netherlands, 2017.

The CE concept has been gaining popularity since the late 1970s (EMF, 2013) and, as many believe, was first conceptualised by Pearce and Turner (1989). As stated by Geissdoerfer (2017), the model of the circular economy grew out of the sustainable development concept. For example, by conceptualising a loop economy, Stahel and Reday (1976) introduced some characteristics of the circular model, with application to industrial economics. The idea of closed loops was further developed from the perspectives of ecology (Commoner, 1971) and industrial ecology (Graedel and Allenby, 1995).

This topic has recently become an extremely active field of academic research. Ghisellini et al. (2016) provide a literature review to demonstrate the main features, perspectives and implementation at various levels (micro, meso and macro) of the CE on a global scale. Lieder and Rashid (2016) designed a CE framework (describing its environment, resources and economic benefits) and a strategy for a regenerative economy and environment. Bocken et al. (2016) presented a set of strategies on the path from a linear to a circular model. In turn, Kirchherr et al. (2017) critically discussed the various CE conceptualisations, and even stated that varying definitions of the concept may eventually result in its collapse. Furthermore, de Jesus et al. (2017) tried to synthesise the findings at the crossroads of eco-innovation and the circular economy. Kalmykova et al. (2018) presented a literature overview on CE theoretical approaches, strategies and implementation cases, as well as monitoring methods. Shpak et al. (2020) analysed the principles and perspectives of a circular economy model as well as its implementation in Ukraine in the context of European integration. Finally, Avraamidou et al. (2020) highlighted research challenges and opportunities in the analysis and optimisation of CE supply chains. However, despite the wide range of scientific and practical works on this subject, there are many problems in the field that cannot have unambiguous solutions due to rapid economic development, and require further research and improvement (Olah et al., 2019). Among them is analysing the benefits of the CE and the effectiveness of its activities, as well as successful examples of its adoption on national and supranational levels. For our research, the EU and its countries were chosen as subjects, as those leading globally in terms of the adoption of the CE.

A circular economy is an economic model, the basis of which is the reasonable use and recovery of natural resources. This concept is generally based on the 3R approach: reduce, reuse and recycle. The Ellen MacArthur Foundation identifies three main principles of the CE: 1) Designing out waste and pollution. They are not accidents, but the results of decisions at the design stage, where approximately 80% of environmental impacts are established; 2) Keeping products in use. Products and components should be designed so they can be repaired, reused, and remanufactured in the economy; 3) Regenerating natural systems. Natural resources may be increased by returning valuable nutrients to the soil and other ecosystems (EMF, 2020).

Thus, the main advantages of the circular economy model are: 1) optimal waste disposal; 2) innovative and resource efficient methods of production and consumption; 3) energy savings due to a closed production cycle; 4) reducing the negative impact on the environment; 5) protecting the economy from resource scarcity. They also include (Circular Economy, 2020): resource preservation – including those that are scarce or subject to price fluctuation; unlocking new business possibilities; cost savings for industries; building new innovative, resource-efficient businesses; creating local jobs; and facilitating social integration and cohesion.

One should also add that the CE concept is not only a subject of interest to scientists. Recently, it has become a hot topic for policymakers, as well (Geissdoerfer et al., 2017; Becerra-Alonso et al., 2016; Androniceanu, 2019). The European Union and the governments of certain countries, including China, Japan, the United Kingdom, France, Canada, the Netherlands, etc., have developed a number of documents aimed at converting to a circular economy. Germany was first to integrate the CE into its national laws in 1996, with the "Closed Substance Cycle and Waste Management Act", followed by Japan's "Basic Law for Establishing a Recycling-Based Society" in 2002. China's Circular Economy Promotion Law entered into force in 2009. In addition, in 2015 the European Commission adopted the Circular Economy Action Plan (CEAP) (European Commission, 2015a), which as of March 2019, was reported to have been implemented in full. In March 2020, the European Commission adopted a new Circular Economy Action Plan (European Commission 2015b). A circular economy is one of the EU's main policy priorities nowadays, resulting in global leadership in its implementation.

1.2. Review of the indicators of the circular economy

Different indicators are used in scientific papers (George et al., 2015; EMF, 2015; Banaite, 2016; Scheepens et al., 2016; Bocken et al., 2017; Elia et al., 2017; Smol et al., 2017; Avdiushchenko and Zając, 2019) and international ratings to assess the results of the adoption of the CE. For instance, in POLITICO's circular economy index, the following indicators were used: municipal waste and food waste (per person per year), share of traded goods that are recyclable raw materials, municipal recycling rate, material reuse rate, patents related to the CE (since 2000), and investments in CE sectors. According to the 2018 index, Germany, the UK, and France have the most developed circular economies, with strong recycling systems and high levels of innovation in CE sectors (Hervey, 2018).

It should be noted, however, that the countries which top the chart are not necessarily the greenest: POLITICO's ranking varies notably from the 2018 Environmental Performance Index, which is partly prepared by the European Commission's Joint Research Centre and ranks a wider range of environmental policies (Hervey, 2018). This is mainly because some practices that diminish the impact on health and environment are not necessarily circular. For instance, in Nordic countries, burning waste for energy minimises landfilling but does not promote reuse and recycling rates, and thus it is not circular and has not improved the country's ranking. Despite the fact that Denmark, the Netherlands and Sweden score perfectly in terms of recycling, their overall scores are low due to the significant volumes of waste. In the interim, nine Central and Eastern European countries produce the least waste.

According to the Ecopreneur (Circular economy update, 2019), the Netherlands, Slovenia, Scotland, France, Belgium and Finland are leaders in terms of the "circular way". Others (such as Italy and Portugal) have recently made significant progress, while some (e.g. Cyprus, Greece, Malta and Romania) are only at the very beginning. At the same time, some leaders (including the Netherlands) have certain problems, as they generate the largest amounts of waste per person. In turn, Romania is the best (Table 1).

Table 1. Ecopreneur CE ranking of EU Member States in 2019

No.	EU member countries	Eco-innovation index resource efficiency	POLITICO's CE index	Fraction of SMEs minimising waste, %	Per capita municipal waste production, kg	Per capita total waste incineration with energy recovery, kg	Recycling rate -municipal waste, %	Recycling rate –packaging, %	Circular material use rate, %
1	Austria	9*	9	13 *(59)***	22 *(564)*	21 *(405)*	3 *(58)*	12 *(67)*	10 *(9)*
2	Belgium	14	8	5 *(75)*	10 *(419)*	23 *(485)*	4 *(54)*	1 *(82)*	2 *(21)*
3	Bulgaria	27	24	26 *(28)*	8 *(404)*	5 *(65)*	18 *(32)*	17 *(64)*	22 *(4)*
4	Croatia	17	19	10 *(16)*	7 *(403)*	2 *(8)*	24 *(21)*	26 *(55)*	21 *(4)*
5	Cyprus	21	28	29 *(25)*	27 *(640)*	7 *(87)*	25 *(17)*	21 *(59)*	24 *(2)*
6	Czech Republic	25	4	9 *(64)*	3 *(339)*	10 *(98)*	17 *(38)*	3 *(75)*	15 *(7)*
7	Denmark	8	13	19 *(49)*	28 *(783)*	26 *(651)*	9 *(48)*	2 *(79)*	13 *(8)*
8	Estonia	28	17	28 *(9)*	5 *(359)*	20 *(385)*	21 *(28)*	24 *(56)*	6 *(12)*
9	Finland	24	22	16 *(55)*	19 *(504)*	28 *(1037)*	12 *(42)*	16 *(65)*	17 *(5)*
10	France	12	3	2 *(83)*	20 *(514)*	19 *(247)*	13 *(42)*	13 *(66)*	3 *(20)*
11	Germany	10	1	12 *(60)*	26 *(633)*	24 *(529)*	1 *(67)*	5 *(71)*	8 *(11)*
12	Greece	23	26	22 *(37)*	11 *(498)*	3 *(13)*	26 *(17)*	20 *(60)*	28 *(1)*
13	Hungary	18	15	21 *(40)*	6 *(379)*	12 *(105)*	16 *(35)*	27 *(50)*	16 *(6)*
14	Ireland	3	25	1 *(84)*	23 *(581)*	16 *(118)*	14 *(40)*	10 *(67)*	26 *(2)*
15	Italy	2	5	6 *(74)*	17 *(497)*	8 *(91)*	10 *(45)*	11 *(67)*	5 *(17)*
16	Latvia	19	23	23 *(35)*	9 *(410)*	4 *(63)*	22 *(25)*	23 *(58)*	23 *(4)*

17	Lithuania	15	20	27 *(20)*	12 *(444)*	9 *(96)*	8 *(48)*	7 *(70)*	20 *(5)*
18	Luxem-bourg	1	11	14 *(57)*	25 *(609)*	22 *(414)*	7 *(48)*	18 *(62)*	7 *(11)*
19	Malta	4	27	11 *(62)*	24 *(593)*	1 *(0)*	28 *(7)*	28 *(37)*	18 *(5)*
20	The Neth-erlands	11	12	7 *(65)*	21 *(520)*	25 *(622)*	5 *(53)*	4 *(73)*	1 *(29)*
21	Poland	26	6	17 *(55)*	2 *(307)*	18 *(143)*	15 *(35)*	22 *(58)*	9 *(10)*
22	Portugal	13	16	15 *(55)*	15 *(474)*	15 *(113)*	19 *(31)*	19 *(61)*	25 *(2)*
23	Romania	22	18	24 *(31)*	1 *(261)*	17 *(126)*	27 *(13)*	24 *(56)*	27 *(22)*
24	Slovakia	16	21	20 *(44)*	4 *(348)*	11 *(103)*	23 *(23)*	14 *(66)*	19 *(5)*
25	Slovenia	20	7	18 *(51)*	13 *(457)*	13 *(112)*	2 *(58)*	8 *(69)*	11 *(9)*
26	Spain	5	10	8 *(65)*	14 *(443)*	6 *(82)*	20 *(30)*	6 *(70)*	12 *(8)*
27	Sweden	7	14	4 *(76)*	11 *(443)*	27 *(920)*	6 *(49)*	9 *(68)*	14 *(7)*
28	United Kingdom	6	2	3 *(82)*	18 *(483)*	14 *(112)*	11 *(44)*	15 *(65)*	4 *(17)*

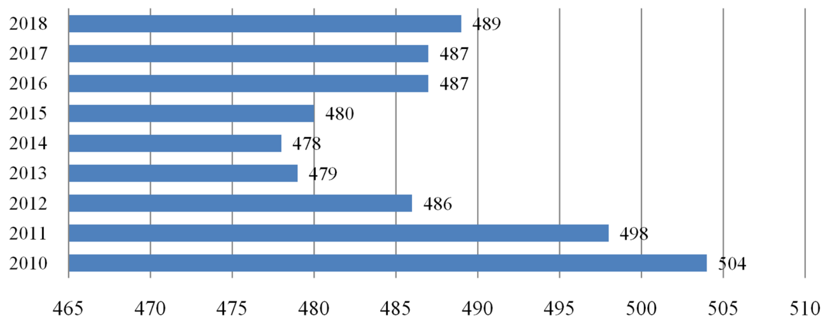
* place in the ranking
** the value of the corresponding indicator (%, kg)

Source: Own elaboration based on Circular Economy Update, 2019.

As can be seen from Table 1, most Ecopreneur CE indicators comprise waste and recycling management.

While the EU is a global leader in the adoption of a circular economy, and some EU member states have been quite successful in minimising their waste, the overall statistics showed a slight growth in municipal waste per capita in the EU in 2014-2018 (Figure 2).

Figure 2. Generation of municipal waste per capita in the EU (2010-2018), kg



Source: European Commission, 2020.

As already mentioned, different types of indicators are used in scientific works in the assessment and modelling of CE performance (George et al., 2015; EMF, 2015; Banaite, 2016; Scheepens et al., 2016; Bocken et al., 2017; Elia et al., 2017; Smol et al., 2017; Avdiushchenko and Zając, 2019). Nonetheless, based on the reasons given, namely the urgency and information availability of different aspects, we chose economic and mathematical modelling of the recycling aspect (which was also researched by Winning et al., 2017; Di Maio and Rem, 2015; Giurco et al., 2014) for further assessment in the CE context.

2. Methods

A number of research methods that made it possible to assess the impact of the CE in the EU countries were used in our study. The systematisation method allowed us to summarise the scientific achievements devoted to the concept of the CE. In turn, statistical methods were the basis for processing the data obtained from open sources. Furthermore, based on a comparative analysis, benchmarking and generalisation, a structural and dynamic assessment of the implementation of the main elements of the CE in different EU countries was conducted. The results thereof became the basis of further CE assessment through the recycling aspect. Lastly, economic and mathematical modelling (using the Data Analysis package in MS Excel) allowed for the formation of a model of waste recycling efficiency in the broad context of the CE in the EU.

The CE recycling model was built based on all available official Eurostat data on the CE in the EU for this period (Table 2).

Table 2. Model input data – main Eurostat CE indicators for the EU (28 countries)

Indicators	2010	2011	2012	2013	2014	2015	2016	2017	2018
Generation of municipal waste per capita – kg per capita, X_1	504.00	498.00	486.00	479.00	478.00	480.00	487.00	487.00	489.00
Recycling rate of e-waste, % (X_2)	27.80	28.70	28.80	29.60	32.20	35.80	41.40	41.40	41.40
Recycling of biowaste, kg per capita (X_3)	67.00	67.00	70.00	72.00	74.00	75.00	80.00	81.00	83.00
Circular material use rate, % of total material use (X_4)	11.10	10.70	11.50	11.60	11.50	11.70	11.90	11.70	11.70
Trade in recyclable raw materials, thousand tonnes (Y)	5959.2	6208.1	5950.6	5918.6	5789.7	5543.5	5488.3	5829.3	5917.3

Source: Own elaboration based on the European Commission, 2020.

3. Research results

The designed CE recycling model of the dependence of trade in recyclable raw materials (thousand tonnes) (Y) is based on such factors as: 1) generation of municipal waste per capita – kg per capita, (X_1), 2) recycling rate of e-waste, % (X_2), 3) recycling of biowaste, kg per capita (X_3), 4) circular material use rate, % of total material use (X_4).

To build a multifactor model, it is necessary to investigate whether all selected factors (X_i) are independent of each other, using the χ^2– criterion. Calculation of the χ^2 criterion:

$$\chi^2 = -\left(n-1-\frac{2m+5}{6}\right)\ln(\det R), \qquad (1)$$

where n is the number of sample values ($n = 9$), $\mathbf{m}$ is the order of the correlation matrix ($m = 4$), and $\mathbf{detR}$ is the determinant of the matrix.

Using the Data Analysis package in MS Excel, the correlation matrix was constructed (Table 3) and its determinant was calculated.

Table 3. Intermediate simulation results (correlation matrix)

Correlation matrix columns and rows	Line 1	Line 2	Line 3	Line 4	Determinant
Line 1	1.000	-0.254	-0.402	-0.675	
Line 2	-0.254	1.000	0.667	0.615	0.137
Line 3	-0.402	0.667	1.000	0.679	
Line 4	-0.675	0.615	0.679	1.000	

Source: Own elaboration.

For a given probability $\boldsymbol{p = 0.95}$ and the number of degrees of freedom $k = \frac{1}{2}m*(m-1)$ =6 the table value of χ^2_{cr} =12.6 was found. Estimated value is $\chi^2 = 11.585$.

The condition $\chi^2 \le \chi^2_{cr}$ is fulfilled, and with the accepted reliability the absence of general multicollinearity is confirmed, which is a condition for constructing an econometric model.

The built-in LINEST function in Microsoft Excel was used for modelling in the form of $\boldsymbol{Y = A_0 + A_1 X_1 + A_2 X_1 + A_3 X_1 + A_4 X_1}$, where A_i are the coefficients of the linear econometric model. Excel is sufficient to build a linear multifactor model, and the built-in LINEST function, which results in determining the coefficient of determination, the F-indicator to evaluate the model according to the Fisher's criterion for the whole general data set, as well as the standards of the coefficients of the model, makes it possible to establish the reliability of each coefficient. The results of modelling are presented in Table 4.

Table 4. Intermediate simulation results of the CE-recycling modelling

A_4	A_3	A_2	A_1	A_0	Model coefficients
-647.1230	96.3936	-83.8771	6.5755	5770.560	
211.3416	31.4358	28.8023	2.2909	2005.015	Standard coefficient errors (Si)
R2 = 0.893	101.8504				
F = 8.354	4.00				
346650.1	41494.01				

Source: Own elaboration.

As a result, the model looks as follows:

$$\boldsymbol{Y = 5570.56 + 6.576\ X_1 - 83.877 X_2 + 96.393 X_3 - 647.123 X_4} \quad (2)$$

The coefficient of determination is 0.893, which indicates a close relationship between the traits of a factor and the result. Fisher's criterion confirms the adequacy of the model with the statistics of the general set, i.e. with a probability P = 0.95 and degrees of freedom k1 = m-1 = 3, k2 = n-m-1 = 4, and the table value of the F-distribution is 6.39. The actual value is F = 8.354, i.e. the actual value is higher than the table value. This is the condition for linking the variables to the entire data set.

The obtained coefficients of the model (1) were checked for statistical significance for the estimation of factors. The value of t-statistics for the degree k = n-m-1 = 4 is t = 2.776 (probability P = 0.95). Then, by the formula: $t_i = \frac{a_i}{S_i}$, where $i = 1.5$; a_i – coefficients of the multivariate model determining the parameters of t-statistics; Si - standard coefficient errors. Accordingly, $t_0 = 2.89$; $t_1 = 2.87$, $t_2 = -2.91$, $t_3 = 3.07$, $t_4 = -3.06$. Comparisons of the obtained value of ti with the table value show that they are larger than the table value, which confirms the statistical significance of the coefficients. Hence, factor coefficients in the model indicate by how many units the resulting trait Y (trade in recyclable raw materials, which is measured in thousand tons) will change if one of them changes by 1 (each in units of measurement).

As can be seen, the generation of municipal waste (*X1*) and recycling of biowaste (*X3*) are positively related to the trade in recyclable raw materials, whereas the recycling rate of e-waste (*X2*) and circular material use rate (*X4*) have a negative impact. As a result of the 1% increase in the *X3* factor (recycling of biowaste), the Y factor (trade in recyclables) will also increase by 96,393 thousand tones. If the factor *X4* (circular material use rate) is increased by 1%, the factor Y (trade in recyclables) will decrease by 647,123 thousand tons. This may be explained by the facts that: 1) recycling biowaste is relatively easy and cost-effective to implement at different levels, and its products (compost and digestate) are in great demand; 2) as circular material use rates increase, more recyclable raw materials are left for domestic use or are not purchased.

Thereby, the effectiveness of the main instruments of a circular economy was proven and motivation for their adoption provided. This demands systematic measures on different levels, starting from the country level. Special legal and economic instruments (e.g. an extended producer responsibility scheme, green tax reforms, and environmental taxation), more sustainable production and consumption patterns, and improved waste management should be implemented. For instance, in the case of EU member states, Ecopreneur's (Circular economy update, 2019) main recommendations are: 1) launching a Green Deal on Circular Procurement, 2) creating circular hubs to support businesses with circular models, 3) creating national circular economy roadmaps, 4) improving the extended producer responsibility (EPR) scheme, 5) introducing low VAT rates for repair services, resold goods and transactions with social reasons, 6) creating a «Green New Deal» to move taxes from labour to resources, 7) shifting investment away from the incineration of municipal waste, etc. However, the detailed features of such activities are a topic for further scientific research.

4. Discussion and conclusions

Nowadays, a friendly approach towards the environment plays an increasingly important role in business. Current living conditions (population growth), economy management (exhaustion of natural resources, greenhouse gas emissions, deforestation, soil erosion, etc.) and the consequences of environmental disasters (e.g. climate change) make it clear that existing methods of resource use and waste management are ineffective and cause irreparable damage to the environment. One of the solutions is a circular economy – a restorative and regenerative concept of recycling, reusing and making profit from what was previously considered unnecessary and thrown away within the framework of a traditional 'linear' economy – 'take – produce – use – throw away'. The model has recently received increasing attention from scientists, policy makers and practitioners on a global scale. Many businesses and countries are already thriving on it.

Given these facts, EU countries, as world leaders in the adoption of a circular economy, were chosen for analysis in this study. One should emphasise that European Union member states are not only intensively developing a legal framework for the transition from a linear to a circular economy, but they are also applying its principles in practice with lesser or greater success, as comparative analysis and benchmarking in this research is testament to. Using different rankings, it was shown that countries such as the Netherlands, Slovenia, Scotland, France, Belgium and Finland are leading in the process, and others (like Italy and Portugal) have just recently made significant progress, while some (e.g. Cyprus, Greece, Malta and Romania) are only at the very beginning. Positive examples from the most effective member states can lead not just other EU member states, but also the rest of Europe and the world, on the path to the CE.

Among the different types of CE performance indicators, based on the popularity, urgency and information availability of different aspects, recycling was chosen for further evaluation of the results of and opportunities for the CE in the EU through economic and mathematical simulation modelling.

The obtained CE-recycling model shows the dependence of trade in recyclable raw materials (thousand tonnes) *(Y)* on several factors, including: 1) generation of municipal waste per capita – kg per capita, % (X_1), 2) recycling rate of e-waste, % (X_2), 3) recycling of biowaste, kg per capita (X_3), 4) circular material use rate, % of total material use (X_4): $\mathbf{Y = 5570.56 + 6.576\ X_1 - 83.877\ X_2 + 96.393\ X_3 - 647.123\ X_4}$. This proved that waste recycling rates have a significant impact on the trade of recyclable raw materials. Thus, the product life cycle is extended, and as a result, the amount of waste is reduced, which proves the efficiency of the CE model.

The research made it possible to analyse the benefits of a circular economy and the effectiveness of its activities in the EU and its countries with an emphasis on waste and recycling management. However, while the European Union has recently shown global leadership in the implementation of the CE, its overall result depends substantially on the initiatives and activities of all EU member states. Hence, their performance was analysed by different indicators, and those connected with the recycling aspect were chosen for further CE modelling. The design model of recycling efficiency in the context of the CE in the EU proved that waste recycling rates have a significant impact on the EU's trade of recyclable raw materials. The methodology of evaluating and modelling the CE results used in the study can be used in the assessment of other countries, subject to the availability of similar statistical information.

There are several contributions made by our paper. Primarily, one should mention its contribution to the theory on the subject. A circular economy model was developed, which can ensure economic growth and increased prosperity without requiring the excessive consumption of natural resources. In addition, it has international coverage, which is larger than a single country (or cross-country analysis). This is an advantage compared to other studies. The application value of the paper should also be underlined. The proposed model is of a universal nature and can be applied by various companies, regardless of their size, including small businesses and the projects of non-profit organisations, etc. Another advantage is that it may help to promote effective reformation of global economics and, as a result, propel countries' sustainable development. Thirdly, given the growing role of the circular economy in modern business, many managers may want to apply this concept (and the guidance proposed) to achieve success in business. We believe that the results of our research may be useful for the formulation of research hypotheses in further surveys.

Our study is beset by certain limitations. Firstly, the model was tested based on a sample of the countries who are leaders in adoption of the circular economy, with their inherent specificity. One does not know whether it could be equally effective in other, less developed countries. Despite this limitation, we believe that our approach was correct. Therefore, further research on the topic is necessary. There is no doubt that in order to promote the CE, special legal and economic instruments, more sustainable production and consumption patterns, as well as improved waste management, should also be used.

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References

Abdel-Shafy, H.I., Mansour, M.S.M. (2018), Solid waste issue: Sources, composition, disposal, recycling, and valorization. Egyptian Journal of Petroleum, 27(4), 1275-1290. https://doi.org/10.1016/j.ejpe.2018.07.003.

Androniceanu, A. (2019), Collaborative digital economy, main attributes, and challenges, in: M. Peters (Ed.), Encyclopedia of educational philosophy and theory, Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-287-532-7.

Avdiushchenko, A., Zając, P. (2019), Circular economy indicators as a supporting tool for European regional development policies, Sustainability, 11, 3025. DOI: 10.3390/su11113025.

Avraamidou, S., Baratsas, S.G., Tian, Y., Pistikopoulos, E.N. (2020), Circular economy – a challenge and an opportunity for process systems engineering, Computers & Chemical Engineering, 133, 106629. https://doi.org/10.1016/j.compchemeng.2019.106629.

Banaitë, D. (2016), Towards circular economy: Analysis of indicators in the context of sustainable development, Social Transformations in Contemporary Society, 4, 142-150.

Becerra-Alonso, D., Androniceanu, A., Georgescu, I. (2016), Sensitivity and vulnerability of European countries in time of crisis based on a new approach to data clustering and curvilinear analysis, Administratie si Management Public, (27), 46-61.

Bocken, N.M., Olivetti, E.A., Cullen, J. M., Potting, J., Lifset, R. (2017), Taking the circularity to the next level: A special issue on the circular economy, Journal of Industrial Ecology, 21, 476-482. https://doi.org/10.1111/jiec.12606.

Bocken, N.M.P., de Pauw, I., Bakker, C., van der Grinten, B. (2016), Product design and business model strategies for a circular economy, Journal of Industrial and Production Engineering, 33, 308--320. https://doi.org/10.1080/21681015.2016.1172124.

Chovancová, J., Tej, J. (2020), Decoupling economic growth from greenhouse gas emissions: the case of the energy sector in V4 countries, Equilibrium. Quarterly Journal of Economics and Economic Policy, 15(2), 235-251. DOI: 10.24136/eq.2020.011

Circular economy (2020), European Commission, retrieved from: https://ec.europa.eu/growth/ industry/sustainability/circular-economy_en. (accessed 7 February 2020)

Circular economy update (2019), Overview of circular economy in Europe 2019. Final report. Ecopreneur.eu, retrieved from: https://circulareconomy.europa.eu/platform/sites/default/files/ecopreneur-circular-economy-update-report-2019.pdf. (accessed 2 February 2020)

Czikkely, M., Oláh, J., Lakner, Z., Fogarassy, C., Popp, J. (2018), Waste water treatment with adsorptions by mushroom compost: The circular economic valuation concept for material cycles, International Journal of Engineering Business Management, 10, 1-12. https://doi.org/10.1177/1847979018809863.

Czikkely, M., Hoang, N.H., Fogarassy, C. (2019), Circular transformation of current business solutions in wastewater management, Polish Journal of Management Studies, 20(2), 196-209. DOI: 10.17512/pjms.2019.20.2.17

Commoner, B. (1971), The closing circle: Nature, man, and technology, New York: Random House.

Dan, H. (2019), Culturally green – an investigation into the cultural determinants of environmental performance, Forum Scientiae Oeconomia, 7(2), 107-126. DOI: 10.23762/FSO_VOL7_NO2_7.

De Jesus, A., Antunes, P., Santos, R., Mendonça, S. (2017), Eco-innovation in the transition to a circular economy: An analytical literature review, Journal of Cleaner Production, 172, 2999-3018. https://doi.org/10.1016/j.jclepro.2017.11.111

Di Maio, F., Rem, P.C. (2015), A robust indicator for promoting circular economy through recycling, Journal of Environmental Protection, 6, 1095-1104. DOI: 10.4236/jep.2015.610096.

Elia, V., Gnoni, G.M., Tornese, F. (2017), Measuring circular economy strategies through index methods: A critical analysis, Journal of Cleaner Production, 142(4), 2741-2751. https://doi.org/10.1016/j.jclepro.2016.10.196.

Ellen MacArthur Foundation (EMF) (2013), Towards the circular economy. 1. Isle of Wight.

Ellen MacArthur Foundation (EMF) (2020), What is the circular economy? retrieved from: https://www.ellenmacarthurfoundation.org/circular-economy/what-is-the-circular-economy (accessed 1 February 2020)

Ellen MacArthur Foundation (EMF) (2015), Circularity indicators – an approach to measure circularity, Methodology & Project Overview, Cowes, UK.

European Commission (2020), Eurostat. Circular Economy, retrieved from: https://ec.europa.eu/eurostat/web/circular-economy/indicators/main-tables (accessed 8 February 2020)

European Commission (2015a), Closing the loop – An EU action plan for the circular economy. The Circular Economy Package Proposal, Brussels, Belgium.

European Commission (2015b), Circular economy action plan. For a cleaner and more competitive Europe, retrieved from: https://ec.europa.eu/environment/circular-economy/pdf/new_circular_economy_action_plan.pdf. (accessed 31 March 2020)

Filimonova, I., Komarova, A., Mishenin, M. (2020), Impact of the global green factor on the capitalization of oil companies in Russia, Oeconomia Copernicana, 11(2), 309-324. DOI: 10.24136/oc.2020.013

Garcés-Ayerbe, C., Rivera-Torres, P., Suárez-Perales, I., Dante, I., Leyva-de la Hiz, D.I. (2019), Is it possible to change from a linear to a circular economy? An overview of opportunities and barriers for European small and medium-sized enterprise companies, International Journal of Environmental Research and Public Health, 16, 851. DOI: 10.3390/ijerph16050851.

Geissdoerfer, M., Savaget, P., Bocken, N.M.P., Hultink, E.J. (2017), The circular economy – a new sustainability paradigm? Journal of Cleaner Production, 143, 757-768. https://doi.org/10.1016/j.jclepro.2016.12.048.

George, D., Lin, B., Chen, Y. (2015), A circular economy model of economic growth. Environmental Modelling and

Software, 73, 60-63. DOI: 10.1016/j.envsoft.2015.06.014.
Ghisellini, P., Cialani, C., Ulgiati, S. (2016), A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems, Journal of Cleaner Production 114, 11-32. https://doi.org/10.1016/j.jclepro.2015.09.007.
Giurco, D., Littleboy, A., Boyle, T., Fyfe, J., White, S. (2014), Circular economy: questions for responsible minerals, additive manufacturing and recycling of metals, Resources, 3, 432-453. DOI: 10.3390/resources3020432
Government of the Netherlands (2017), From a linear to a circular economy, retrieved from: https://www.government.nl/topics/circular-economy (accessed 1 February 2020)
Graedel, T.E., Allenby, B.R. (1995), Industrial ecology, Englewood Cliffs: Prentice Hall.
Hervey G. (2018), Ranking how EU countries do with the circular economy, Politico, retrieved from: https://www.politico.eu/article/ranking-how-eu-countries-do-with-the-circular-economy/. (accessed 1 February 2020)
Islam, S.M.N., Munasinghe, M., Clarke, M. (2003), Making long-term economic growth more sustainable: Evaluating the costs and benefits, Ecological Economics, 47(2-3), 149-166. https://doi.org/10.1016/S0921-8009(03)00162-9.
Jaki, A., Siuta-Tokarska, B. (2019), New imperative of corporate value creation in face of the challenges of sustainable development, Entrepreneurial Business and Economics Review, 7(2), 63-81. https://doi.org/10.15678/EBER.2019.070204
Janicke, M. (2012), "Green growth": From a growing eco-industry to economic sustainability, Energy Policy, 48, 13-21. DOI: 10.1016/j.enpol.2012.04.045.
Kalmykova, Y., Sadagopan, M., Rosado, L. (2018), Circular economy – from review of theories and practices to development of implementation tools, Resources, Conservation and Recycling, 135, 190--201. https://doi.org/10.1016/j.resconrec.2017.10.034.
Kirchherr, J., Reike, D., Hekkert, M. (2017), Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation and Recycling, 127, 221-232. https://doi.org/10.1016/j.resconrec.2017.09.005.
Kliestikova, J., Krizanova, A., Corejova, T., Kral, P., Spuchlakova, E. (2018), Subsidies to increase remote pollution? Science and Engineering Ethics, 24(2), 755-767. https://doi.org/10.1007/s11948-017-9908-0.
Lieder, M., Rashid, A. (2016), Towards circular economy implementation: A comprehensive review in context of manufacturing industry, Journal of Cleaner Production, 115, 36-51. https://doi.org/10.1016/j.jclepro.2015.12.042.
Luttenberger, L.R. (2020), Waste management challenges in transition to circular economy – case of Croatia, Journal of Cleaner Production, 256, 120495. https://doi.org/10.1016/j.jclepro.2020.120495.
Maciejewski, M., Głodowska, A. (2020), Economic development versus growing importance of the financial sector: Global insight, International Entrepreneurship Review, 6(3), 77-90. https://doi.org/10.15678/IER.2020.0603.0
McDonald, Ch. How many Earths do we need? BBC, retrieved from: https://www.bbc.com/news/magazine-33133712. (accessed 30 March 2020)
Mesagan, E.P., Chidi, O.N. (2020), Energy consumption, capital investment and environmental degradation: The African experience, Forum Scientiae Oeconomia, 8(1), 5-16. DOI: 10.23762/FSO_VOL8_NO1_1
Mesterházy, Á., Oláh, J., Popp, J. (2020), Losses in the grain supply chain: Causes and solutions, Sustainability, 12(6), 2342, https://doi.org/10.3390/su12062342.
Michelini, G., Moraes, R.N., Cunha, R.N., Costa, J.M.H., Ometto, A.R. (2017), From linear to circular economy: PSS conducting the transition, Procedia CIRP, 64, 2-6. https://doi.org/10.1016/j.procir.2017.03.012.

Olah, J., Virglerova, Z., Popp, J., Kliestikova, J., Kovacs, S. (2019), The assessment of non-financial risk sources of SMEs in the V4 countries and Serbia, Sustainability, 11(17), 4806. https://doi.org/10.3390/su11174806.

Pearce, D.W., Turner, R.K. (1989), Economics of natural resources and the environment, Harlow: Pearson Education.

Rymarczyk, J. (2020), Technologies, opportunities and challenges of the industrial revolution 4.0: Theoretical considerations, Entrepreneurial Business and Economics Review, 8(1), 185-198. https://doi.org/10.15678/EBER.2020.080110

Scheepens, A.E., Vogtlander, J.G., Brezet, J.C. (2016), Two life cycle assessment (LCA) based methods to analyse and design complex (regional) circular economy systems. Case: Making water tourism more sustainable, Journal of Cleaner Production, 114, 257-268. https://doi.org/10.1016/j.jclepro.2015.05.075.

Shpak, N., Kuzmin, O., Melnyk, O., Ruda, M., Sroka, W. (2020), Implementation of a circular economy in Ukraine: The context of European integration, Resources, 9(8), 96. https://doi.org/10.3390/resources9080096.

Shpak, N., Odrekhivskyi, M., Doroshkevych, K., Sroka, W. (2019), Simulation of innovative systems under industry 4.0 conditions, Social Sciences, 8, 202. DOI: 10.3390/socsci8070202.

Sieja, M., Wach, K. (2019). The use of evolutionary algorithms for optimization in the modern entrepreneurial economy: Interdisciplinary perspective, Entrepreneurial Business and Economics Review, 7(4), 117-130. https://doi.org/10.15678/EBER.2019.070407

Smol, M., Kulczycka, J., Avdiushchenko, A. (2017), Circular economy indicators in relation to eco-innovation in European regions, Clean Technologies and Environmental Policy, 19(3), 669-678. https://doi.org/10.1007/s10098-016-1323-8.

Stahel, W.R. (2016), The circular economy, retrieved from: http://www.nature.com/news/the-circular-economy-1.19594. (accessed 5 February 2020)

Stahel, W., Reday, G. (1976), The potential for substituting manpower for energy, Report to the Commission of the European Communities.

Ślusarczyk, B., Baryń, M., Kot, S. (2016), Tire industry products as an alternative fuel, Polish Journal of Environmental Studies, 25(3), 1263-1270. DOI: 10.15244/pjoes/61543

United Nations, Department of Economic and Social Affairs, Population Division (2019), World population prospects 2019: Highlights. ST/ESA/SER.A/423.

Winning, M., Calzadilla, A., Bleischwitz, R., Nechifor, V. (2017). Towards a circular economy: insights based on the development of the global ENGAGE-materials model and evidence for the iron and steel industry, International Economics and Economic Policy, 14(3), 383-407. https://doi.org/10.1007/s10368-017-0385-3.

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