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TRANSFORMATION TOWARDS CIRCULAR ECONOMY IN COMPARISON WITH ECO-INNOVATION DEVELOPMENT ON THE EXAMPLE OF EU MEMBER STATES

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Abstract: The discussion presented in this paper refers to a broadly understood subject of a circular economy and related issues of eco-innovation, with a particular focus on the two-way relationship between the two. Based on data on EU member states' activities in this area, the aim of this paper is to assess the impact of a circular economy on eco-innovation development. First, the idea of sustainable development from the perspective of a circular economy was presented along with the changes in its perception. Furthermore, the role of the European Commission was highlighted with respect to the legislation of that area for EU member states. A literature review was initiated by the European Commission's forecasts concerning unsustainable production and consumption. In the same section, the definitions of a circular economy and eco-innovation were provided, and a close relationship between these two aspects often highlighted in scientific publications was indicated. Logit models were developed to verify the impact of a circular economy on eco-innovation development. For that purpose, the GRETL econometric package was used. Circular economy indicators and eco-innovation indicators available at the Eurostat and European Commission websites were used as diagnostic variables in the models. In two cases, the logit models indicated a significant relationship between the areas in question, which was also presented as a linear regression function. At the final stage, conclusions were presented, which included research limitations and future research directions.

Key words: circular economy; eco-innovation; logit models.

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Introduction

It should be noted that the challenges and numerous changes facing the environment, economy and society are gradually leading to changes in how the idea of sustainable development is perceived.

Until recently, this concept has been considered in a comprehensive way, with particular emphasis placed on the ways of satisfying the needs of present generations without compromising the ability of future generations to satisfy their needs (Ahmed, 2005; Bajdor, 2012). Nowadays, it is addressed in a much narrower scope. The analyses are more and more concerned with assessing the relationships between the different dimensions of the concept of sustainable development (Kovačič

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Lukman et al., 2021; Vasconcelos and Orion, 2021). In this perspective, new directions of research and analyses are indicated, including those related to resource efficiency (Independent Group of Scientists appointed by the Secretary-General, 2019; Ślusarczyk and Kot, 2018; Rada et al., 2017).

These issues are regularly addressed by manufacturing companies, academic circles, non-governmental organisations, governments and public sector organisations (Androniceanu, 2021; Rodríguez Bolívar et al., 2016; Statistical Office of the European Communities. et al., 2015; Ulewicz and Blaskova, 2018). A key role in this respect has been ascribed to a circular economy, including the propagation of its principles, which has been done in EU member states based on the guidelines developed by the European Commission (Banaitė, 2016; World Health Organizations, 2018; Hanuláková et al., 2021; Antonioli et al., 2022; Serikova et al., 2022). Without a doubt, the pressure to shift from a linear economy, which operates according to the "take-make-dispose" principle and is regarded as unsustainable and leading to waste of resources, intensifies the activities of the above-mentioned entities towards the transition to a circular economy. This mainly involves searching for ways to reuse waste or part of waste as well as generating more energy and striving to increase materials recovery (Blomsma and Brennan, 2017; Oláh et al., 2022; Lis and Nowacki, 2022). In practice, many initiatives and projects are launched, significantly contributing to the transformation of the linear economy. In this context, an important role is played by the change of social attitudes and decoupling of economic growth from the natural environment issues (Mensah, 2019; Tate et al., 2019; Vence and Pereira, 2018; Zhang et al., 2021; Pacana and Ulewicz, 2017; Deja et al. 2021).

As the reports and summaries developed by the European Commission demonstrate, recent years have seen a significant progress towards a circular economy. A particular attention in this area has been paid to eco-innovation, which significantly contributes in practical terms to the delivery of many aspects of a circular economy, including: industrial symbiosis, ecology, "cradle to cradle" designing and new, innovative business models (Androniceanu et al., 2021; Klein et al., 2020).

Since the implementation of innovative technologies accelerates the transformation process towards a circular economy, the main role in the context of facilitating research and innovation is played by political activities, especially in the area of financing these types of projects (European Commission, 2019b; Winans et al., 2017). There is no doubt that the use of eco-innovative solutions determines the broadly understood process of transforming the economy towards a circular economy. However, it should be noted that this relationship also has a reverse direction, i.e. the progress of this transformation translates into eco-innovation development (Cainelli et al., 2020; Demirel and Danisman, 2019; Smol et al., 2017). Thus, one can assume that a circular economy and eco-innovation complement each other. The aim of this paper is to assess the impact of a circular economy on eco-innovation development. Therefore, the relationship between innovation indicators and circular economy indicators was verified. It was followed further in the paper by analyses and conclusions.

Circular Economy and Eco-Innovation– Theoretical Perspective

According to the European Commission's forecasts, by 2050 global consumption will have reached the level of three planets such as Earth, with the global use of biomass, fossil fuels, metals and minerals doubling within the next forty years. The forecasts concerning waste production are not optimistic either. It is assumed that annual waste production will increase by 70% by 2050. Here, one should also mention such problems as excessive extraction and processing of resources, which leads to loss of almost all biodiversity, water supply depletion and massively impacts the overall gas emission (European Commission, 2020). There is no doubt that the factors mentioned above drive systematic conservation attempts with respect to the world economy. Many regulations aimed at achieving sustainable consumption and production worldwide have already been implemented (Avdiushchenko and Zając, 2019; Domenech and Bahn-Walkowiak, 2019; Rajiani et al., 2018; Taranic et al., 2016).

One of them is the strategy for climate-neutral, resource-efficient and competitive economy, which was initiated as part of European Green Deal (European Commission, 2019a), i.e. an action plan that assumes, among other things, transition to a circular economy. It is acknowledged that improved resource efficiency, and consequently increased role of a circular economy, will help to achieve climate neutrality by 2050. Also, economic growth is expected to be de-coupled from the use of resources while preserving the competitiveness of the individual EU countries. Achievement of these goals requires that actions are taken to reduce consumption and double the resource use indicator within the next ten years (European Commission, 2019a, 2020; Smol et al., 2020).

In the literature, one can find a statement that a circular economy is an economy that learns from nature, and thus nothing is wasted. A circular economy should therefore replicate the functioning of natural ecosystems (Ellen MacArthur Foundation, 2020; Zhao et al., 2021, Hlushchenko et al. 2022). It is usually considered as a combination of three main activities, namely: reduction, reuse and recycling (Tate et al., 2019).

The main aim of a circular economy is the development of ecology, which takes place in two complementary dimensions, i.e. industrial and circular, which in practice involves closure of production and consumption cycles. This can be achieved by putting the materials needed for the above-mentioned processes into a closed loop, which should result in minimum exploitation of non-renewable natural resources. A circular economy is an alternative to the traditional linear economy, with the assumption that resources are used as long as possible. What is more, maximum value should be generated from resources during use so that products nearing the end of their life cycle can be further recovered and regenerated. Thanks to closing a loop nothing is wasted. A circular economy also aims to solve the problems of increased amount of waste as well as resource consumption and depletion. It strives to achieve a balance between human beings, planet Earth and economic growth (Naydenov, 2018; Linhartova, 2021).

As is indicated by the European Commission, meeting the goals of a circular economy depends on numerous factors, including, among other things, the stance of governments, the involvement of industry and non-governmental organisations and the participation of the public. Due to increasing demands for environmental protection and irreversible environmental changes, choosing the right direction of action is becoming important. An important role is played here by eco-innovation, which enables a circular economy to reach the expected level of development (European Commission, 2015, 2020).

Eco-innovation is defined as any innovation that contributes to the achievement of the goal of sustainable development. This is done by reducing the environmental impact, improving resilience to environmental pressure or using natural resources more responsibly (European Commission, 2011b).

In the literature, eco-innovations are treated as a subclass of innovations, and their role is to improve both economic and environmental implications for society. Eco-innovations contribute to improved environmental performance and are closely related to economic benefits based on environmental protection. In this case, the environmental goal is considered to be the main dimension defining eco-innovation. In a broad sense, improving the state of the environment requires commitment of resources towards that aim and should not result from investing in intermediate objectives (Miceikienė et al., 2021; Vence and Pereira, 2018).

Although eco-innovation is addressed in numerous scientific studies, its impact on the transition towards a circular economy has still not been explored sufficiently, according to Vence and Pereira. Eco-innovation, which enables such transition, primarily comprises activities focused on transformations in dominant business models. In this context, one should mention changes that include the relationships between products, services and their users, and changes towards the improvement of value systems (Vence and Pereira, 2018; Cioca et al., 2011).

Table 1 presents various types of eco-innovation from the point of view of a circular economy. As was indicated in EIO bi-annual report, they include a wide range of eco-innovations illustrating various dimensions of transformation, i.e. from behavioural changes to implementation of new technologies (Doranova et al., 2016; Mazzoni, 2020).

Table 1. Eco-innovation from the circular economy point of view

Kind of eco-innovation	Description
Product design	Aiming to minimise the environmental impact and reduce material resources used throughout a product's life cycle by implementing various recovery operations (e.g. repair, maintenance, regeneration, recycling, cascading use of materials, etc.).
Process	The production process should be aimed at minimum use of materials and maximum reduction of harmful substance emissions. Risk reduction and reduction of the process costs is also typical. Consequently, the emphasis is put on advanced recovery methods, such as: recovery that includes replacement or repair of faulty units and materials; disassembly and recovery of components and materials; recycling, upcycling and functional recycling.
Organisational	This type of eco-innovation involves reorganisation of management methods and systems in order to close the loop and increase resource efficiency. It is about promoting new business models, e.g. industrial symbiosis, valuable resources recovery schemes.
Marketing	Eco-innovation is related to the process of designing products and services, their distribution, promotion and pricing. Products and services should be designed for their reuse for the same or other purposes. A key role is played here by eco-label.
Social	Focus on conscious consumption, responsible shopping and product reuse, which is closely connected with behavioural and life style changes, i.e. user-implemented innovations. It involves: mutual sharing of products, joint exploitation of the same products, etc.
System	Developing new functionality systems, with emphasis on reduction of the environmental impact and production dematerialisation. It is about modern ways of managing cities, smart cities, permaculture.

Due to the fact that eco-innovation highlights the issue of climate change, resource efficiency and energy shortage, it is commonly regarded as a key factor necessary when developing new business strategies. Also, its role in the context of a circular economy is often highlighted. Current scientific studies indicate that eco-innovation is regarded as the most effective instrument for changing the present model of a linear economy. Moreover, it sets a clear direction for activities aimed at achieving a high level of sustainability of the social, economic and environmental dimensions (Maldonado-Guzmán et al., 2020).

There is no doubt that eco-innovation and a circular economy are interrelated aspects. Since eco-innovation has a positive impact on the environment, it may underlie new business models of a circular economy. Views on the impact of eco-innovation on the economy are firm, and the authors are unanimous on the issue. The

question is: How does eco-innovation make this transformation easier, faster and more effective (Scarpellini et al., 2020).
The relationships between eco-innovation and a circular economy have been discussed in the literature recently. Eco-innovation, including, in particular, organisational and process eco-innovation, is generally indicated as an enabler of the transition to a circular economy (Costa, 2021; Vence and Pereira, 2018).
It should be stressed that the concept of a circular economy is very broad. As was previously mentioned, many scientific publications point to a close relationship between eco-innovation and a circular economy. However, such activities require commitment of many resources, including, in particular, financial ones, the acquisition of which often constitutes the biggest problem for many communities. Policies play a key role here. At this point, one should assume that a more advanced circular economy provides a better capacity for eco-innovation implementation.
The above-mentioned relationship has been confirmed, among other things, by circular economy and eco-innovation indicators for European countries, which show that a high score in circular economy determines the country's dominance in the area of eco-innovation development (Monitoring Framework - Circular Economy - Eurostat; The Eco-Innovation Scoreoboard and the Eco-Innovation Index).
Based on the discussion above, the following hypotheses were formulated with regard to the research problem:
H1: Transformation towards a circular economy significantly impacts eco-innovation development.
H2: Increased waste re-use rate determines eco-innovation development.
The following section presents the relationship between eco-innovation and a circular economy (European Commission, 2011a).

Impact of a Circular Economy on Eco-Innovation Development– Construction of Logit Models

As was stated above, the aim of this paper is to demonstrate a relationship between eco-innovation and a circular economy. At present, transformation towards a circular economy is one of the development priorities of the EU countries. Consequently, most economies are currently under pressure to keep up with the expectations of the countries that lead in that area. However, due to differences in the countries' specific functioning and data discrepancies, it is difficult to indicate the best performing country, i.e. one that should be regarded as a model for the other countries, as well as specific actions that should be implemented and replicated by the other countries. An important issue here is also the need to improve the state of the natural environment, including harmonisation of legal regulations in that area.
In order to assess the above-mentioned relationship, and thus construct an econometric model, the Gretl econometric package was used (Adkins, 2018; Cotrell, 2021; Gretl; Mixon Jr and Smith, 2006; Pelagatti, 2016).
Based on that, at attempt was made to verify the hypotheses formulated in the paper using two main groups of indicators, which are as follows:

-eco-innovation indicators (Indicators - Circular Economy - Eurostat; The Eco-Innovation Action Plan; Smol et al., 2017),
-circular economy indicators (Monitoring Framework - Circular Economy - Eurostat; Moraga et al., 2019).
The indicators from the first main group, i.e. eco-innovation indicators, have been developed by the European Commission as part of Eco-Innovation Action Plan and listed on the eco-innovation scoreboard and the eco-innovation index. The available data cover the period 2012-2021 and show eco-innovation performance across EU member states. Their objective is to show various aspects of eco-innovation by means of sixteen indicators grouped into five dimensions, i.e. eco-innovation inputs, eco-innovation activities, eco-innovation outputs, resource efficiency outcomes and socio-economic outcomes (The Eco-Innovation Scoreboard and the Eco-Innovation Index)
The criteria indicated in the second main group include circular economy indicators available at the Eurostat website. They take into account four basic groups of variables that indicate how much progress has been made towards a circular economy across EU member states (Monitoring Framework - Circular Economy – Eurostat). These are:

- production and consumption,
- waste management,
- secondary raw materials,
- competitiveness and innovation.

In each of the above-presented groups, specific indicators were selected to be used to construct an econometric model. The most current data were available for eco-innovation indicators, where the value of each indicator was provided for the year 2021. With respect to the circular economy indicators, the situation was different. Here, data were provided for the year 2021 only with respect to export and import (secondary raw materials). Waste management indicators are regarded as particularly important from the perspective of the subject addressed in this paper, but the most current values were for the year 2019. Due to the limitations in availability, both in terms of the values and freshness of data, the study was conducted based on selected circular economy indicators presented for the year 2019.
More specifically, fifteen variables were used in the analysis, including five eco-innovation indicators (y1-y5), and fourteen circular economy indicators (x1-x14). Table 2 presents the variables used.

Table 2. Indicators used in the analysis

Eco-innovation indicators	Circular economy	
	group of indicators	**indicators**
eco-innovation inputs (y1) **eco-innovation activities (y2)** **eco-innovation outputs (y3)** **resource efficiency outcomes (y4)** **socio-economic outcomes (y5)**	production and consumption	material footprint (x1) resource productivity (x2) generation of municipal waste (x3) generation of packaging waste (x4) generation of plastic packaging waste (x5)
	waste management	recycling rate of municipal waste (x6) recycling rate of overall packaging waste (x7) recycling rate of plastic packaging waste (x8) recycling of biowaste (x9)
	secondary raw materials	circular material use rate (x10) exports extra (x11) imports extra (x12) imports intra (x13)
	competitiveness and innovation	patents related to recycling and secondary raw materials (x14)

In order to verify the relationship between the selected indicators, it was necessary to perform transformation of the collected variables. For that purpose, normalisation of the variables was carried out so that the previous range could be replaced by the range 0 to 1 (Mohamad and Usman, 2013; Schenatto et al., 2017). The zero unitarization method was used for the process of normalisation of the variables (Kukuła, 2014, 2016; Kukuła and Bogocz, 2014):

Based on the normalised diagnostic variables and using the Gretl statistical package, an econometric model was developed to verify the relationship between the response variable and explanatory variables. For that purpose, the eco-innovation indicators, i.e. indicators y1 to y5, were used as dependent variables, whereas the circular economy indicators, i.e. x1 to x14, were used as independent variables. It should be noted that the procedure of econometric model construction had to be preceded by selection of explanatory variables for the model. Basic statistics were calculated for all the variables. This provided information about the mean, median, maximum and minimum, standard deviation and coefficient of variation. Analysis of the coefficient of variation yielded a high value; therefore, initially, none of the variables was eliminated. At the next stage, correlation coefficient matrix analysis was conducted to assess the relationship between the response variable and explanatory variables and the correlation between explanatory variables. In accordance with the assumption, only those explanatory variables selected for the model were highly correlated with the response variable and were not correlated with the other explanatory variables (Gładysz & Mercik, 2007; Ręklewski et al., 2020). Selection of the explanatory variables based on the analysis of correlation coefficient matrix resulted in a significant reduction of their number. Consequently, the construction of an econometric model in the Gretl package required only comparison of the selected variables without the need to apply the backward stepwise regression method. As a result, the following relationships between the response and explanatory variables were established:

- variable y1 with variables x9 and x14,
- variable y2 showed no relationship with any of the explanatory variables,
- variable y3 with variable x9,
- variable y4 with variable x2,
- variable y5 with variable x1.

The Gretl application allowed for the construction of four econometric models. However, two models were rejected due to a high value of the coefficient of residual variation and a low value of the R-squared coefficient. Interpretation was performed for models where the dependent variables referred to:

- eco-innovation inputs (Table 5),
- resource efficiency outcomes (Table 6).

Table 5. Model 1 – Parameters of the ordered logit model of eco-innovation inputs

Dependent variable: y1					
	coefficient	std. error	t-ratio	p-value	
const.	0.148430	0.0561737	2.642	0.0143	**
x9	0.506866	0.131190	3.864	0.0007	***
x14	0.418183	0.169490	2.467	0.0211	**
Mean dependent var	0.392013		S.D. dependent var	0.248330	
Sum squared resid	0.681060		S.E. of regression	0.168456	
R-squared	0.575230		Adjusted R-squared	0.539832	
F (2, 24)	16.25058		P-value (F)	0.000035	
Log-likelihood	11.36786		Akaike criterion	-16.73573	
Schwarz criterion	-12.84822		Hannan-Quinn	-15.57977	

Analysis of the data contained in model 1 shows that only two variables referring to circular economy have a significant impact on eco-innovation inputs. One of them – recycling of biowaste (kilograms per capita) – is at the significance level $p<0.01$, whereas the other variable – number of patents related to recycling and secondary raw materials – oscillates around the significance level p less than 0.05. It should be noted that these indicators belong to two different groups, namely: waste management and competitiveness and innovation. Verifying the signs of estimation of the explanatory variable parameters indicates that an increase in bio-waste recycling increases eco-innovation inputs. The second variable, i.e. x14, shows the same trend: more patents related to recycling and secondary raw materials generate increased eco-innovation inputs. The coefficient of residual variation (Kurkiewicz and Stonawski, 2005) is 42.97% for model 1, which may indicate poor fitness and suggest that there is no justification for the model's practical application. However, the value of R-squared indicates that the variables have been properly fitted to the model, in which the variability of the dependent variable in 57% was explained by the variability of the independent variables. It should be noted that the closer to 1, the better the model explains the behaviour of the dependent variable. The p value for *the F-test* is less than 0.05, indicating that all the estimated model variables are significant.

Table 6. Model 2 – Parameters of the ordered logit model of resource efficiency outcomes

Dependent variable: y4					
	coefficient	std. error	t-ratio	p-value	
const.	0.168258	0.0498161	3.378	0.0024	***
x2	0.761350	0.121104	6.287	1.41e-06	***

Mean dependent var	0.417656	S.D. dependent var	0.246644
Sum squared resid	0.612829	S.E. of regression	0.156567
R-squared	0.612542	Adjusted R-squared	0.597044
F (1, 25)	39.52320	P-value (F)	1.41e-06
Log-likelihood	12.79299	Akaike criterion	-21.58598
Schwarz criterion	-18.99431	Hannan-Quinn	-20.81534

In model 2, the relationship between the response variable, i.e. resource efficiency outcomes, and one explanatory variable, i.e. resource productivity (euro per kilogram), which belongs to the production and consumption group, was verified. The results indicate high significance of the explanatory variable in the model, i.e. at $p<0.01$. Analysis of the sign of estimation of the resource productivity indicator parameter shows that its increase leads to the improvement of resource efficiency outcomes. In this case, the coefficient of residual variation, which is 37.49%, is the lowest compared to the other functions. It can be thus concluded that this model would be the best in the context of practical application. The value of R-squared indicates that the variable fits well to the model. The variability of the dependent variable was in 61% explained by the variability of the independent variable. The *p*-value for *F*-test is less than 0.05, which also confirms the significance of the fitted variable.

The following section of the discussion is an attempt to evaluate the relationships between the response and explanatory variables from the practical perspective.

Logit Models– Practical Perspective

As was noted in the preceding section of the paper, two independent variables, namely: recycling of biowaste (x9) and number of patents related to recycling and secondary raw materials (x14), showed a significant impact on the dependent variable, i.e. eco-innovation inputs (y1). Eco-innovation inputs means investments (both in financial resources and humans) aimed at the implementation of eco-innovation activities. A decisive role is ascribed here to RandD, including initiatives to protect the environment and energy, as well as scientific and research potential. Ecological investments implemented in this area are focused on waste management systems, and primarily involve waste recycling methods, with particular emphasis on municipal waste (Eco-Innovation Inputs). It should be noted that due to the high value of the municipal waste generation indicator (kilograms per capita), recycling of municipal waste, including biowaste, is regarded as one of the priorities of a circular economy throughout the European Union. The obtained function shows that an increase in recycling of biowaste determines an increase in eco-innovation inputs. One can presume that the countries that propagate the development and upgrading of municipal waste management systems, including biowaste management systems, i.e. those where this indicator is high, increase their spending on eco-innovation. In case of biowaste recycling, they include composting and anaerobic fermentation, which are regarded as the only acceptable solutions in this regard. Biowaste recycling accounts for only 17% of municipal waste recycling (there is a strong relationship between these two indicators), thus it is necessary to search for the most effective ways of biowaste processing to prevent it from being stored with other waste and minimise the negative impact on the natural environment. A similar trend has been observed for the second variable, i.e. number of patents related to recycling and secondary raw materials, whose increase determines an increase in eco-innovation inputs. This indicator reflects a given country's technological progress in a specific sector, including in the area of modern technologies, innovative services and business models. An increase in the number of patents in that area is inextricably connected with the implementation of unconventional methods of collection, transportation, storage and recycling, which on the one hand leads to a country's independence in the sourcing of raw materials, while on the other hand, it improves its competitiveness. It seems, therefore, reasonable to claim that an increase in the number of patents related to recycling and secondary raw materials leads to an increase in eco-innovation inputs, which means financing of patented solutions. The obtained model is described by the following regression function:

$$\mathbf{y1}=0.148+0.507\mathbf{x9}+0.418\mathbf{x14}$$

In the next model, the response variable was resource efficiency outcomes (y4), which was found to be significantly related with the explanatory variable: resource productivity (x2). The resource efficiency outcomes indicator presents a multifaceted approach to eco-innovation in the context of resource productivity improvement. It is assumed that eco-innovation has a positive impact on resource management, on the one hand by increasing the value added, and on the other hand by decreasing the pressure on the natural environment. Thus, the established relationship seems indisputable, especially that the resource productivity indicator is connected with resource efficiency aimed at reducing the pressure and negative impact on the environment. In this case, it is particularly important to decouple the economic issue from the environmental one, however in the context of the indicator in question one can talk about the decoupling when the rate of the increase of the environmental pressure (denoted as DMC – domestic material consumption) is less than the growth rate of a given economic driver (in this case GDP). Increase in the resource productivity indicator, which in practice is the quotient of DMC by GDP, determines an increase in the productivity of the specific indicators within the dependent variable, namely: materials, water, energy and of greenhouse gas emission intensity. The linear form of the regression model is as follows:

$$\mathbf{y4}=0.168+0.761\mathbf{x2}$$

The conclusions constitute the final section of this paper.

Conclusion

There is no doubt that gradual development of a circular economy largely depends on innovation. An important role is ascribed here to the promotion of innovative technologies, the advancement of which is possible through raising awareness and propagating a dialogue and cooperation among the entities involved in eco-innovation development, i.e. companies, RandD institutions, public authorities, etc. There is a growing awareness today that innovations constitute a new form of value delivery. They also demonstrate the impact of the circular economy transformation on the natural environment. Moreover, they contribute to the emergence of new, profitable business models (Grabowska, 2020). Continuous development of a circular economy facilitates the transfer of financial resources for further eco-innovation development. A circular economy provides an impulse for innovation in many sectors of the economy (Delloitte, 2018).

Analysis of the present research shows that eco-innovation development depends on EU member states' performance in terms of a circular economy only in two areas, i.e. those related to inputs and resource efficiency. Here, it is necessary to note the different groups of circular economy indicators, to which the explanatory variables used in the models belong. Although only three explanatory variables showed significance, the above-mentioned relationship refers to specific groups of circular economy indicators, namely: the impact of waste management and competitiveness and innovation on eco-innovation inputs and the impact of production and consumption on resource efficiency outcomes. This is a result of careful selection of data, some of which were rejected already at the stage of selection for the research due to a strong relationship between the response variables. The lack of relationship between the other areas combined with the rejection of two models in the previous section of the paper indicate that no connection exists between a circular economy and eco-innovation in the following areas: eco-innovation activities, eco-innovation outputs, socio-economic outcomes and secondary raw materials. This provides evidence in favour of rejecting hypothesis H2. Moreover, it suggests the necessity of modifying the variables, especially that these indicators should be strongly correlated with each other.

Although the impact of eco-innovation on a circular economy is widely recognised, it should be noted that this is a two-way relationship. There is no doubt that countries with a high score in the circular economy indicator are also leaders in eco-innovation, whereas countries with a low score in the circular economy development perform poorly in eco-innovation. In the vast majority of EU member states, a circular economy is persistently limited to waste management. In practice, it indicates lack of knowledge and experience in the transformation to a circular economy, and consequently inhibits eco-innovation development.

The limitations during the research process mainly concerned the lack of current data on circular economy indicators. It was, therefore, necessary to narrow down the analysis to the year 2019, as it was characterised by the greatest availability of data and in case of many indicators it was also the last of the updated data periods for all EU member states.

The discussion presented in this paper shows that the transformation of national economies towards a circular economy, and more specifically its progress, has a significant impact on eco-innovation progress, and thus there is no evidence in favour of rejecting hypothesis H1.

Authors of numerous scientific publications argue that eco-innovation has a key impact on a circular economy, however the literature does not indicate what directly creates this relationship. Verification of these specific solutions sets the directions of future research.

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TRANSFORMACJA W KIERUNKU GOSPODARKI CYRKULARNEJ NA TLE ROZWOJU EKOINNOWACJI NA PRZYKŁADZIE PAŃSTW CZŁONKOWSKICH UE

Streszczenie: Rozważania przedstawione w niniejszym artykule odnoszą się do szeroko pojętej problematyki gospodarki o obiegu zamkniętym i ściśle z nią związanego – zagadnienia ekoinnowacji, w kontekście których szczególny nacisk położono na występującą pomiędzy nimi dwukierunkową współzależność. Bazując na danych z działalności państw członkowskich UE we wspomnianym obszarze, za cel niniejszego opracowania przyjęto ocenę wpływu gospodarki cyrkulacyjnej na rozwój ekoinnowacji. W pierwszej kolejności nawiązano do idei zrównoważonego rozwoju z perspektywy gospodarki o obiegu zamkniętym, a co za tym idzie zmian w jej postrzeganiu. Ponadto zaakcentowano rolę Komisji Europejskiej w zakresie legislacji tej kwestii dla krajów członkowskich Unii Europejskiej. Przegląd literatury został zainicjowany przez prognozy Komisji Europejskiej dotyczące niezrównoważonej produkcji i konsumpcji. W tym miejscu przybliżono również definicje: gospodarki o obiegu zamkniętym i ekoinnowacji oraz wskazano na ścisły związek pomiędzy tymi dwoma aspektami, często podkreślany w publikacjach naukowych. W celu weryfikacji wpływu gospodarki o obiegu zamkniętym na rozwój ekoinnowacji opracowano modele logitowe. Do tego celu wykorzystano pakiet ekonometryczny - GRETL, w ramach którego zmienne diagnostyczne stanowiły udostępnione na stronach internetowych Eurostatu i Komisji Europejskiej wskaźniki gospodarki o obiegu zamkniętym oraz wskaźniki ekoinnowacji. Otrzymane modele logitowe w dwóch przypadkach wskazały na istotną zależność pomiędzy wybranymi obszarami, co przedstawiono również w postaci liniowej funkcji regresji. Na ostatnim etapie zaprezentowano wnioski, w ramach których nakreślono ograniczenia badawcze i kierunki przyszłych badań.

Słowa kluczowe: gospodarka o obiegu zamkniętym, ekoinnowacje, modele logitowe

以 UE 成员国为例，向循环经济转型与生态创新发展的比较

摘要：**本文提出的**讨论涉及广泛理解的循环经济主题和相关的生态创新问题，特别关注两者之间的双向关系。基于欧盟成员国在这一领域的活动数据，本文旨在评估循环经济对生态创新发展的影响。首先，提出了循环经济视角下的可持续发展理念及其观念的变化。此外，还强调了欧盟委员会在欧盟成员国该领域立法方面的作用。文献综述是由欧盟委员会关于不可持续生产和消费的预测发起的。在同一节中，提供了循环经济和生态创新的定义，并指出了这两个方面之间的密切关系，这在科学出版物中经常被强调。开发了 Logit **模型来**验证循环经济对生态创新发展的影响。为此，使用了 GRETL 计量经济学包。欧盟统计局和欧盟委员会网站上提供的循环经济指标和生态创新指标被用作模型中的诊断变量。在两个案例中，logit **模型**显示了相关区域之间的显着关系，这也以线性回归函数的形式呈现。在最后阶段，提出了结论，其中包括研究局限性和未来的研究方向

关键词：循环经济；生态创新；逻辑模型