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Dynamic panel model in bioeconomy modeling

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Abstract: Currently, technological development is driven by the search for solutions to prevent climate change and environmental degradation, increase energy efficiency, and meet societal needs in relation to avoiding conflict while navigating the implementation of current and future needs. Many of the solutions come from the rapid development of the bioeconomy. The aim of this article is to determine the impact of bioeconomy variables on economic growth in 27 EU countries. The research goal of the paper is based on the estimation of dynamic panel models using the generalized method of moments (GMM). The following set of variables used in the dynamic panel model had a positive impact on economic growth in the EU-27 countries: greenhouse gases by sector: agriculture, circular material use rate, recycling rate of packaging waste by type of packaging – plastic packaging, recycling rate of packaging waste by type of packaging – wooden packaging. Three variables were shown to have a negative impact on economic growth, namely: recycling rate of municipal waste, recycling rate of e-waste, trade-in recyclable raw materials – exports extra-EU.

Keywords: economic growth; generalized method of moments; Malmquist index; Sargan test; Wald test

Empirical studies in the field of economics have almost always focused on looking for and analyzing factors stimulating or limiting the rate of economic growth (Solow 1956; Yin et al. 2003; Mathur 2005; Pyka and Prettner 2018). In recent decades, a further element has however come to have an influence on a new way of perceiving factors in economic development. The attention of a large number of economists was drawn to the drastically changing climate (Dias et al. 2017; Kleinschmit et al. 2017; Ronzon et al. 2020; Sefeedpari et al. 2020). From that moment on, one of the most important goals has come to be to look for those factors, which determine economic growth, but which at the same time limit human impact on the environment. A significant element in the new economic order has come to be the bioeconomy, based on biological resources and waste used in industry and for energy production (European Commission 2015; Bugge et al. 2016). The broad application of management processes based on the bioeconomy had led to new hope not only of slowing damage to the environment but even of improving its current state (Kleinschmit et al. 2017; European Environment Agency 2018).

The many works in this field are testimony to the particular significance of the development of the bioeconomy on a national and global scale (Bedla and Szarek 2020; Kokoszka et al. 2020). This problem was raised by McCormick and Kautto (2013), drawing attention to the identification of factors influencing the development of the bioeconomy as the basis for setting the vision and goals as well as strategies and actions for the transition to the bioeconomy. Bugge et al. (2016) emphasized that one key topic for future studies is the relationship between the bioeconomy and its wider social and economic implications. In their studies, Dias et al. (2017) have shown that the use of biomass to generate bioenergy may be a valuable way of mitigating climate change and may also have economic benefits, though it is important to make sure that energy source does not bring its own environmental costs along with it. This is a challenge, which has been taken up by EU member countries, but also by other countries, such as Ukraine for example, which specializes in biogas production (Havrysh et al. 2020).

To promote the circular use of biological resources and the use of energy from renewable sources, an Updated Bioeconomy Strategy was presented by the European

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Commission (2018). The transformation of the system towards climate neutrality is amongst other things an integral part of the European Green Deal (European Commission 2019), National Energy and Climate Plans (European Commission 2015), and the Framework Strategy for a stable energy union based on a forward-looking climate change policy (European Commission 2015). The bioeconomy sector generated almost 5% of the EU's GDP, occupying 9% of the workforce (Bugge et al. 2016). The crisis caused by the COVID-19 pandemic is probably contributing to the slowing of the development of the bioeconomy. Employment in basic sectors of production fell by slightly over 4% in Q2 of 2020 compared to the same period in 2019, while the total number of hours worked has decreased by 5.6%. By contrast, the gross value added of production sectors rose by 0.1% (European Commission 2020). At this stage, it is not yet possible to define in detail the impact of the ongoing pandemic on the bioeconomy. The epidemiological situation has forced the majority of countries to shut down their economies for a certain time, having an effect on the global food system. One direct effect of this situation will be to lead the strongest economies to increase the competitiveness of their domestic products, and that in turn accelerates the adaptation of circular agriculture to the current nature of the agricultural activity (Solow 1956). The bioeconomy may thus make the agricultural economy in the post-COVID-19 era more resilient by providing farms with nutrients on a cyclical basis and improving soil quality by enriching organic matter and minimizing environmental pollution (Lal et al. 2020).

The development of a global bioeconomy requires appropriate logistical infrastructure to support the trade-in biomass and semi-finished products (Sefeedpari et al. 2020), in turn making it necessary to introduce processes of optimization to minimize the impact on the bioeconomy value chain. The use of biomass requires the environmental and economic effects of inputs to be taken into consideration, along with product lifecycle analysis (Muradin and Kulczycka 2020). Forecasts of development in the field of the bioeconomy in the EU by 2030 and 2050 indicate that bioenergy will become less important, while the position of biomaterials and ecosystem services will improve significantly as a result of efforts to strengthen the competitiveness of the European economy and create new jobs. The importance of biomass used for production is already growing today, as is the use of innovative biomaterials such as bio-based chemicals, lubricants and bioplastics, which offer high added value (Fritsche et al. 2020).

The purpose of the article is to provide answers to two assumed research theses. The first assumption is that there is a process of economic convergence between countries of the EU. The second assumption is that the development of the bioeconomy has a positive effect on economic growth. These research theses were verified based on a constructed dynamic panel model. Another important aspect of the work is to draw attention to emerging possibilities of analyzing and modeling real data describing current trends in the bioeconomy. The work also fills a gap in research in the field of macroeconometric modeling of the bioeconomy sector and estimation of its impact on economic growth.

MATERIAL AND METHODS

Data collection and description of the case study. Measurement of the contribution of the bioeconomy to the general state of countries' economies is certain to become an important indicator of development over the decades to come. Currently, there is no commonly applied method for measuring progress in the achievement of goals set out by policies and strategies in the area of the bioeconomy. In addition, given the differences between the restrictions, possibilities and priorities of individual countries, it is a big challenge to develop a single way of assessing the contribution of the bioeconomy to the national economy (Bracco 2016). The article sets out the construction of a macro-econometric model of growth taking into consideration 19 variables defining the bioeconomy [list provided in Table S1 in electronic supplementary material (ESM); for ESM see the electronic version] and 8 time variables. GDP *per capita* was adopted as the explanatory variable. The descriptive statistics for selected diagnostic variables are presented in Table S2 in ESM (for ESM see the electronic version). Panel data from 27 EU countries were used for the analysis. The adopted time horizon was 2010 to 2017 with annual data frequency. The generalized method of moments (GMM) was used for the construction of dynamic panel models. GMM was used for the construction of dynamic panel models. The model, written in the first-difference form:

$$\Delta y_{it} = \left(1-\beta\right)\Delta\left(y_{i,t-1}\right) + \Delta x_{it}\delta + \Delta v_t + \Delta u_{it} \tag{1}$$

where: $\Delta x_{it} = x_{it} - x_{i,t-1}$; v_t – a random variable symmetric with respect to 0, understood as a random disturbance; u_{it} – non-negative random components with expected value greater than 0, showing ineffectiveness; δ – constant

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$$Z_i^L = \begin{bmatrix} \Delta y_{i2} & \Delta x_{i2} & \Delta x_{i3} & 0 & 0 & 0 & \dots & 0 & 0 & 0 \\ 0 & 0 & 0 & \Delta y_{i3} & \Delta x_{i3} & \Delta x_{i4} & \dots & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 & 0 & \dots & \Delta y_{i,T-1} & \Delta x_{i,T-1} & \Delta x_{iT} \end{bmatrix} \begin{matrix} t=3 \\ t=4 \\ \vdots \\ t=T \end{matrix} \quad (2)$$

$$Z_i^L = \begin{bmatrix} \Delta y_{i2} & \Delta x_{i2} & 0 & 0 & \dots & 0 & 0 \\ 0 & 0 & \Delta y_{i3} & \Delta x_{i3} & \dots & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & & \vdots & \vdots \\ 0 & 0 & 0 & 0 & \dots & \Delta y_{i,T-1} & \Delta x_{i,T-1} \end{bmatrix} \begin{matrix} t=3 \\ t=4 \\ \vdots \\ t=T \end{matrix} \quad (3)$$

The system GMM estimator is a much better tool for avoiding bias. The basic assumption of the system estimator is the calculation of the (t – 2) system of the first-difference model, as well as the (t – 2) of equations, for which undifferentiated levels of variables have been defined. However, it is still no less obligatory to take additional conditions into account, due to the individual effects that exist in the model for equations in levels.

In the event that the additional explanatory variable is a strictly exogenous variable or a predetermined variable, the matrix of instruments for the i^{th} observation takes the form of Equation (2).

If the additional explanatory variable is an endogenous variable, the matrix of instruments for the i^{th} observation is as in Equation (3).

The instruments matrix in levels, as well as in first differences, is presented in Equation (4).

$$Z_i^S = \begin{bmatrix} Z_i^D & 0 \\ 0 & Z_i^L \end{bmatrix} \quad (4)$$

As a result, the system GMM estimator takes the form:

$$\hat{\alpha}_D = \left(\tilde{X}_s{}' Z^S W_N Z^{S'} \tilde{X}_s \right)^{-1} \tilde{X}_s{}' Z^S W_N Z^{S'} \tilde{y} \quad (5)$$

where: W_N – weight matrix [Equation (6)]

The weight matrix for the initial two-step GMM estimator was determined as in Equation (6):

$$W_N = \left(\frac{1}{N} \sum_{i=1}^{N} Z_i^S{}' H_S Z_i^S \right)^{-1} \quad (6)$$

The covariance matrix for the analyzed estimator is estimated using the Equation (7).

Verification of significance of the model. The significance of the estimated model was assessed based on Arellano-Bond tests for autocorrelation of 1st $AR(1)$ and 2nd order $AR(2)$, the Sargan test and the Wald test. The Arellano-Bond test for autocorrelation (Arellano and Bond 1991) is used to verify the null hypothesis that supposes the absence of 2nd order autocorrelation of the random component in the first-difference model.

Assuming that the random components are homoskedastic, though still correlated in a specific way, it means that they create an autoregressive first-order process:

$$\varepsilon_t = \rho_1 \varepsilon_{t-1} + u_t \quad (8)$$

where ε_t – white noise; ρ_1 – first-order autocorrelation coefficient, $|\rho_1| < 1$

In the case where the random components create a first-order autoregressive process, the autoregressive coefficient of each successive, arbitrary order τ takes the form:

$$\rho_t = \frac{\operatorname{cov}\left(\varepsilon_t, \varepsilon_{t-\tau}\right)}{\sigma^2} = \rho_t^{\tau} \quad (9)$$

In the results for the estimated model, the occurrence of 1st order autocorrelation should be expected, due to the fact that because ε_{it} (random component) are independent, the first differences ε_{it} show 1st order autocorrelation. The appearance in the model of autocorrelation of an order higher than 1 would mean that the moment conditions are not met, which can only mean the wrong instruments were selected during the GMM estimation. For this reason, it is necessary

$$\hat{\Sigma}_{\hat{\alpha}} = N\left(\tilde{X}' Z W_N Z' \tilde{X}\right)^{-1} \tilde{X} Z W_N \left(\sum_{i=1}^{N} Z_i' \Delta\hat{u}_i \Delta\hat{u}_i' \right) W_N Z' \tilde{X} \left(\tilde{X}' Z W_N Z' \tilde{X}\right)^{-1} \quad (7)$$

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to reject the null hypothesis about the absence of autocorrelation of random components of the order $AR(1)$ (Baltagi 1995). An alternative way of assessing the quality of the model is the Sargan test for the over-identification of restrictions and their corresponding degrees of freedom. In that case, all instruments in the model are exogenous, and so not correlated with the random component of the model ε_{it}.

As a result, an estimation of an additional model is performed, in which the rest of the model is made up of dependent variables, and all instruments are explanatory variables. In summary, in the Sargan test, the null hypothesis says that the choice of instruments was appropriate, and the alternative hypothesis assumes an incorrect choice of instruments (Arellano and Bond 1991). Furthermore, if the null hypothesis is true, then there is no correlation of instruments with random errors. The Wald test is a test for general significance and the corresponding degrees of freedom. It offers the possibility of testing the overall significance of variables, for both determinants and time variables (Ronzon et al. 2020). The null hypothesis assumes that all variables tested are insignificant overall. The alternative hypothesis says that the tested set of variables is significant overall. The overall significance of the tested variable is checked by means of the F-statistic, which takes the form:

$$F=\left[\left(Rb-q\right)'\left(RV\left(b\right)R'\right)^{-1}\right]\left(Rb-q\right) \quad (10)$$

where: R – zero-one matrix of known elements with dimensions J by n (n – number of parameters; J – number of linear restrictions planed on n parameters); q – vector; b – matrix of assessment of parameters of the model, $V(b)$ – covariance matrix.

If $F < w$, then there are no grounds to reject H_0, but where $F > w$ H_0 is rejected in favor of H_1 (where: w – critical value, with the distribution χ^2 with J degrees of freedom).

The time series are stationary, which was confirmed during the Dickey-Fuller test using the akaike information criterion (AIC).

RESULTS AND DISCUSSION

Dynamic panel model. Based on panel data collected from 27 member states of the EU concerning 19 explanatory variables, a dependent variable and 7 time variables, a dynamic panel model was constructed, the parameters of which are shown in Table 1.

Based on the results obtained from the dynamic panel model estimation, there was found to be a process of economic convergence occurring between the 27 EU countries, which is shown by the value of the dependent variable $Y(-1)$ equal to 1.9411. This result means that countries with a lower level of wealth in the initial period were characterized by a faster rate of economic growth compared to countries, which were more wealthy at the outset. The results obtained indicate differences in the response of individual economies of the EU to the consequences of the global financial crisis of 2008. Less developed member states, especially those located in Central Europe, coped with the economic recession a little more easily and, over the course of the second decade of the 21st century, systematically made up for the distance between them and the most developed countries of the grouping. It is however worth emphasizing that the changes which took place over the analyzed period of time, despite spatial differences, had a negative impact on economic growth for the EU as a whole.

One of the determinants of economic growth which certainly contributed to an increase in the rate of convergence between economies of the EU was the development of the bioeconomy in European countries. This is indicated by the results obtained when constructing the dynamic panel model using the two-step GMM taking into consideration variables reflecting the degree of advancement of the bioeconomy and time variables with the dependent variable GDP *per capita* (Table 1). Of all the variables, used to construct the model, describing the impact of the bioeconomy on the dependent variable (GDP *per capita*), the following had a positive impact: greenhouse gases by sector: agriculture, circular material use rate, recycling rate of packaging waste by type of packaging – plastic packaging, recycling rate of packaging waste by type of packaging – wooden packaging.

In turn, the following variables had a negative impact on economic growth: recycling rate of municipal waste, recycling rate of e-waste, trade-in recyclable raw materials – exports extra-EU. A further reduction in insignificant variables led to a worsening in the parameters of the model. Explanations of results can be linked with the results of mutual correlation between these variables and GDP *per capita* (Table 2).

Assessment of significance of the model. The significance of the estimated model was assessed based on Arellano-Bond tests for autocorrelation of 1st $AR(1)$ and 2nd order $AR(2)$, the Sargan test and the Wald test.

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Table 1. Results of the dynamic panel model estimation using the two-step GMM taking into consideration time variables with the dependent variable GDP *per capita*

Variable	Coefficient	SE	z	P-value	Significance
$Y(-1)$	1.9411	0.5222	3.7170	0.0002	***
$X1$	0.0129	0.0467	0.2759	0.7826	–
$X2$	−0.01165	0.0510	−0.2286	0.8192	–
$X3$	−0.0200	0.0242	−0.8276	0.4079	–
$X4$	0.0931	0.0536	1.7390	0.0820	*
$X5$	0.0507	0.0850	0.5962	0.5510	–
$X6$	0.0976	0.0721	1.3550	0.1756	–
$X7$	0.0254	0.0316	0.8036	0.4217	–
$X8$	−0.0179	0.0114	−1.5730	0.1157	–
$X9$	−0.1481	0.1114	−1.3290	0.1838	–
$X10$	0.0433	0.1381	0.3138	0.7537	–
$X11$	−0.3285	0.1869	−1.7580	0.0788	*
$X12$	1.1957	0.7597	1.5740	0.1155	–
$X13$	0.1950	0.1120	1.7410	0.0816	*
$X14$	0.7021	0.3924	1.7890	0.0736	*
$X15$	0.1167	0.0649	1.7980	0.0721	*
$X16$	−0.0515	0.0362	−1.4230	0.1547	–
$X17$	−0.1544	0.0937	−1.6470	0.0995	*
$X18$	−0.0339	0.0187	−1.8090	0.0704	*
$X19$	−0.0039	0.0082	−0.4724	0.6366	–
$T2$	−18.4953	10.7008	−1.7280	0.0839	*
$T3$	−18.4914	10.6816	−1.7310	0.0834	*
$T4$	−18.4730	10.6699	−1.7310	0.0834	*
$T5$	−18.5039	10.6903	−1.7310	0.0835	*
$T6$	−18.4958	10.6892	−1.7300	0.0836	*
$T7$	−18.5500	10.7104	−1.7320	0.0833	*
$T8$	−18.5479	10.7201	−1.7300	0.0836	*

***High significance; *lower significance; z – estimated parameter; GMM – generalized method of moments
Source: Author's calculation based on Eurostat (2021)

Table 2. Linear correlation coefficients for sample observations

GDP *per capita*	$X4$	$X13$	$X14$	$X15$	
1.0000	0.1272	−0.0011	−0.2279	−0.1036	GDP *per capita*
–	1.0000	0.2264	0.0179	0.4718	$X4$
–	–	1.0000	−0.0764	0.1474	$X13$
–	–	–	1.0000	0.0700	$X14$
–	–	–	–	1.0000	$X15$

Critical value (for two-sided 5% critical area) = 0.1335 for n = 216
Source: Author's calculation based on Eurostat (2021)

The results of verification of the signification of the constructed model are presented in Table 3.

The result of the $AR(1)$ test for error z = −2.3297 (P-value = 0.0198) means the conditions of moments are met, and thus that the choice of instruments when estimating the model was correct. First differences ε_{it} show a 1st order autocorrelation, while at the same time there is 2nd order autocorrelation of the random com-

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Table 3. Results of the assessment of the significance of the estimated model

Test	Result
Sum of squared residuals	20.5269
Residual standard error	0.3560
Number of instruments	53
Test $AR(1)$ for error	$z = -2.3297$ (0.0198)
Test $AR(2)$ for error	$z = -0.2192$ (0.8265)
Sargan test – over-identification	$\chi^2 = 1.5102\text{e}{-010}$ (1.0000)
Wald test (joint)	$\chi^2 = 3\,271.7200$ (0.0000)

Source: Author's calculation based on Eurostat (2021)

ponent in the first-difference model [$AR(2)$ test for error: $z = -0.2192$ (P-value = 0.8265)].

Studies of the appropriateness of the model were also performed based on the Sargan test, which offers the possibility of checking if the instruments are not correlated with the random components, which is equivalent to confirming the correct choice of these instruments. The null hypothesis assumed that the instruments were chosen appropriately, while the alternative hypothesis assumed that the instruments were chosen in an incorrect manner. The result of the Sargan test $\chi^2 = 1.5102\text{e}{-010}$ indicates that there are no grounds to reject the null hypothesis, which is also evidence that the choice of instruments was appropriate. Based on the Wald test (joint), the significance of the dependent variable was confirmed.

Economic convergence in countries of the EU. The results of the studies conducted confirm an ongoing process of economic convergence, estimated on the basis of the dependent variable GDP *per capita*, between member states of the EU over the time interval adopted for the analysis. The less developed countries of Central Europe, affected to a lesser degree by the effects of the 2008 crisis achieved a significantly faster rate of economic growth over the period from 2010 to 2017 compared to countries with a higher level of wealth in the initial period. Nevertheless, the rate of economic growth over the analyzed period, for the entire grouping, was low. The consequences of the global financial crisis, which started in 2008 in the US, before spreading worldwide, limited economic growth to a greater degree in the most wealthy countries, and thereby accelerated convergence within the grouping as a whole, with the deployment of the bioeconomy being a stimulant of economic growth. A rise in the rate of economic growth leads to an acceleration of the process of economic convergence in the EU, while the bioeconomy is an important element of the growing convergence in all economies of the grouping – especially in the countries of Central Europe.

CONCLUSION

The changes in climate being experienced by global society prompted the world of science to look for alternatives to development based on conventional energy sources. It soon turned out that a significant element in the new approach to economic growth may be its stronger linkage with biological resources, which can offer an important alternative to solid fossil fuels. The bioeconomy has thus become an important element in the initiated processes of adaptation (Bracco et al. 2018). The impact of production processes, which are elements of the bioeconomy is increasingly frequently treated as an important element in economic growth, which on the one hand contributes to an increase in efficiency, while on the other hand not only halts damage to the environment but actually improves its current state. In the scientific literature, components related to the bioeconomy are increasingly frequently connected with determinants of economic growth. Its positive effects in the area of increasing employment and gross value added are also emphasized. Based on innovative knowledge and modern technologies, the bioeconomy, therefore, means growing investments and economic development and is a key element in stimulating employment and the capacity to generate income by building potential and increasing the efficacy of new investments (Pyka and Prettner 2018). The role of the bioeconomy in creating economic growth in low- and middle-income countries, for which it represents an opportunity to make efficient use of available biomass resources, is also emphasized. It can be seen today that, in such a situation, the bioeconomy can open up new opportunities for economic development and industrialization and provide support in achieving economic and social goals such as reducing unemployment and ensuring access to energy from renewable sources (FAO 2018).

The following set of variables used in the model had a positive impact on economic growth in the EU-27 countries: greenhouse gases by sector: agriculture, circular material use rate, recycling rate of packaging waste by type of packaging – plastic packaging, recycling rate of packaging waste by type of packaging – wooden packaging. For several years, a trend has been observed in looking for mainly technological solutions in the field of bioeconomy and the development of the circular economy. Beneficial changes in economic growth, brought about by the growing use of materials in a closed loop, as well as the recycling of plastic packaging and wooden packaging, result from the benefits of re-using waste. There are also positive changes related to the creation of new jobs and the impact of demand factors on the acceleration of the rate of economic growth, increasing technological innovation and development of the R&D sector. In addition, it is worth emphasizing that the deployment of a circular economy is now becoming a necessity in every country of the EU, due to the strategic directions of development of the grouping and the implemented policies.

Three variables were shown to have a negative impact on economic growth, namely: recycling rate of municipal waste, recycling rate of e-waste, trade-in recyclable raw materials – exports extra-EU. Greenhouse gases by sector: agriculture: greenhouse gases (GHG) emissions in agriculture and GDP growth interact and to some extent reinforce each other. This can be presented through the process of increasing society's wealth and greater expenditure, for example, on animal products, which drives the increase in GHG production and emissions, and these changes have been included in the model on the basis of feedback. Circular material use rate, recycling rate of packaging plastic packaging and wooden packaging: these new areas of economic development and the ongoing transformation from an economy based on non-renewable resources towards circular material use are slowly becoming the driving force of many European economies, leading to their greater competitiveness and dynamic development. Recycling rate of municipal waste, recycling rate of e-waste: on the other hand, the recycling rates (in particular the municipality waste and e-waste) are so low that the demand for recycling of these products is much higher than the current level of response in this area, which generates high costs and negatively affects the economic development. The solution is to introduce municipality waste and e-waste processing on a much larger scale. A similar situation is noticeable in international trade, especially in the export of materials that can be recycled, which again generates high costs and creates a moral dilemma.

This is a result of the relatively low level of these indicators in individual countries of the EU. Although numerous studies are constantly being carried out on the use of municipal waste, the degree of deployment of these solutions is still insufficient, and, due to the small scale of their deployment, the costs are very high. A similar situation can be seen in the case of recycling e-waste. It is estimated that only one third of all e-waste is recycled in the EU. The low level of re-use of waste of this type is a sign of inefficiency and has an unfavorable impact on the economy. Trade-in raw materials for recycling, and especially exports, is not highly advanced. Every country produces huge amounts of raw material of its own (waste), that can be re-used, thus making it difficult to find a consignee. Moreover, highly developed economies pay to be able to export and dispose of e-waste. On the basis of the studies conducted, the stated research theses were positively verified. When analyzing the results of an estimation obtained by employing a dynamic panel model using the two-stage GMM taking into consideration time variables with the dependent variable GDP *per capita*, it was shown that in the years following the global financial crisis, there was a process of economic convergence between EU countries, in which factors related to the dynamic development of the bioeconomy became an important element. The work also points to the significant impact of determinants resulting directly from the deployment of the bioeconomy on economic growth and the economic structure of the analyzed area of countries of the EU.

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