

Article

Sustainability of Circular Economy Indicators and Their Impact on Economic Growth of the European Union

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Abstract: In this paper, we develop a methodology for studying the sustainability of the circular economy model, based on environmental indicators, and its impact on European Union (EU) economic growth. In open-end systems, waste is converted back to materials and objects through recycling; hence, a linear economy is transformed into a circular economy (CE). Environmental factors support the argument for the sustainable implementation of a circular economy. The main objective of this paper is to analyze the sustainability of the CE indicators and to elaborate a multilinear regression model with panel data for determining the dependency of the main CE factors on EU economic growth. Starting with the model of economic growth based on circular material use rate, recycling rate of municipal waste (RRMW), trade in recycling materials, labor productivity, environmental taxes, and resource productivity as independent variables, six statistical hypotheses were validated through a multiple regression model with the use of the statistical software EViews 11. The research study was conducted for 27 EU countries, and the data was collected from the European Union Statistical Office (EUROSTAT), during the time frame 2010 to 2017. Based on econometric modeling, the paper highlights that circular economy generates sustainable economic growth across the EU.

Keywords: circular economy; sustainability; environmental indicators; economic growth; panel data

1. Introduction

Anthropological evolutionary studies have highlighted the risk factors facing society as a whole. Population growth cannot be sustained worldwide at the same rate as the finite natural resources. Industrial development and its impact on climate change as a result of the environmental pollution represent another major harm affecting the ecosystem. In this regard, the European Commission (EC) has proposed a strategy in the field of circular economy (CE) [1], which identifies the risks generated by geopolitics and recommends a list of objectives to be achieved, including adaptation to climate change, reducing dependence on finite resources and its effects, food security, and job growth in rural areas.

In order to achieve these goals, as set by the EC, the transition to the circular economy implies the knowledge and awareness of the way a CE model functions—respectively, information about the recycling systems, economic goals, and governmental policy—in order to determine the stage of the transition process. The next step is economic modelling, to achieve the expectations of the decision makers. Economic studies applied in the CE field will be those that will contribute significantly to the expertise in the field of recycling and biomass reuse by means of biotechnology.

There are plenty of CE models in the economic literature. Rick Bosman and Jan Rotmans compared the two sustainability models of the transition to the circular economy in Finland and Netherlands.

Their research paper [2] contains a series of guidelines adapted to the economic conditions of the two states. Out of these, we note the authors' suggestion for the development of partnerships between public and private, whereby both private environment and public decision-makers work together and find the best solutions to solve issues in the transition from linear to circular economy. Inevitably, demographic development and consumer preferences are considered as the main determinants of the sustainability of the circular economy [3].

A management system for the development of the circular economy should know what the provisions are for converting a linear economy into a circular economy. The sustainability of the transition models was analyzed by a recent paper [4]. The modeling of sectoral inter-dependencies requires both qualitative and quantitative analysis. For this reason, there is no perfect integrative management model that in aggregate captures all the exogenous variables, for reasons that, as can be seen, are related to the permanent evolution of the dependencies and the multitude of the indicators.

In order to make valuable economic analyses, it is necessary to adapt to the economic situation of each country, adjusted according to the member state policy and the demand from the private environment for the products obtained from recyclable materials and for bioenergy [5]. This specific context is useful in the process of decision-making, for developing a technology suitable for recyclable materials, and for evaluating the contributions of these sectors in producing positive externalities on the production and competition recorded in other complementary sectors, such as in the chemical or in the biofuel industry. Nowicki et al. [6] performed a thoroughly economic study at the level of economic subsectors; thus, the analysis was performed for products that might have bio-ingredients.

From the economic models perspective, a classification of research works could be done into general equilibrium models for the analysis of multi-sectoral interdependencies; those done at the macro level, developed by some researchers [7,8]; equilibrium economic models, applicable to certain economic sectors [9]; and those defined as partial models and bottom-up models [10], which answer circumstantial questions related to procedural, technological, or behavioral evolution, studying developmental aspects of recyclable sources, and the ecological and economic effects resulting from these operations.

Research analyses at the EU level have common landmarks that are crucial for a contextual analysis. This is mainly due to the common features of the two projects launched at EU level by the EC, underpinning the framework for assessing the transition to a sustainable circular economy. The first study was released in 2012, and it relates to the set of analytical tools to respond to the EU Strategy on the Circular Economy within the EU Seventh Framework Programme. This research takes an inventory of industries with the potential of generating products from recyclable materials, and describes the barriers in the progress of the new industry. The second study was released by the EC in 2013, and its objective was to integrate the data collected from the first study and conceptualize them in an artificial intelligence system. The model illustrates the connection between environmental factors and society. The system of management is described by human use, consumerism, technological progress and innovation, limited resources, and not least by government programs.

From the perspective of the transition to a sustainable circular economy with significant impact on economic growth, in the EU countries, the potential of the production of recyclable materials, such as in the zootechnic, bioindustry, fish farming, pharmaceutical, and chemical industries, can be relevant. Economic reforms, as well as adopted environmental and research policies, that set organizational forms are necessary elements to turn negative effects into benefits for the circular economy.

The objective of the present paper is to develop an assessment model of the interdependencies of the economic sectors, taking into account the independent variables, such as the circular material use rate, the recycling rate of municipal waste (RRMW), trade in recycling materials, real labor productivity, environmental taxes, and resource productivity.

According to Yamamoto and Hosoda [11], CE refers to the recycling-based economy of 3R (reduce, reuse and recycle), comparing to the linear model of production, consumption, and disposal. In order to vitalize this sector and contribute to a CE, an EU waste policy was created to manage the necessary

framework to implement waste management strategies. Nowadays, legal regulations, such extended producer responsibility (EPR) standards, add to the sustainability requirements in the business sectors, as they impose on manufacturers to organize and reimburse for the treatment and reintegration of their products at the end of the life cycle, which is acknowledged as being effective for contributing to a CE [12]. Recycling is a key factor in the CE in terms of waste management procedures, which implies biological treatment or material recycling, namely anaerobic digestion and composting, according to Lakatos et al. [13].

This paper has the following structure. Firstly, we make a statistical description of the independent variables used in the paper. Then, the multiple regression model is estimated. Finally, the research hypotheses are validated. Further research, limitations of the study, and conclusions are summarized in the last section of the article.

2. Materials and Methods

2.1. Research Methodology

The impact of circular economy indicators on economic growth has been investigated by many researchers. It has been proven that a CE has a significant impact on economic growth [14–16]. Other researchers [17–19] have concluded that circular material use rate and productivity of the resources are strongly correlated with economic growth.

Furthermore, while some authors [20,21] argue that the RRMW has a significant impact on economic growth, other researchers [22–24] emphasize that real labor productivity and environmental taxes are strongly correlated with economic growth. Moreover, other economists [25,26] underline that circular material use rate and trade in recycling materials are strongly correlated with economic growth.

We formulate our research question based on the empirical results stated above: “What is the CE’s impact on economic growth at the EU level?”. Our goal is to make an estimation of the six explanatory variables used in our research—namely, the RRMW, circular material use (CMU) rate, trade in recycling materials, real labor productivity, environmental taxes, and resource productivity—and their impact on economic growth. Following the empirical studies mentioned above, these explanatory factors are some of the most important indicators of the CE.

We start our analysis with formulating statistical hypotheses (see Table 1).

Table 1. Hypotheses of the research study.

Hypothesis Number	Hypothesis
H ₁	Circular material use (CMU) rate has is strongly correlated with economic growth
H ₂	The impact of the recycling rate of municipal waste (RRMW) on economic growth is positive and significant
H ₃	Trade in recycling materials are strongly correlated with economic growth
H ₄	Real labor productivity is highly correlated with economic growth
H ₅	The impact of environmental taxes on economic growth is significant
H ₆	Resource productivity is a significant factor of economic growth

To validate all six hypotheses described in Table 1, we will use a panel data regression model, which will be presented in Section 3.

2.2. Circular Economy Indicators in European Union Countries

As opposed to the traditional economy, CE is developing economic models to better use the resources. In our study, six macroeconomic factors to describe CE were used, and their impact on economic growth was analyzed. In our model, the six indicators will be the independent factors of the regression model.

A description of the dependent variable in the model (Y) and the six independent variables (X_1 – X_6) can be seen in Table 2.

Table 2. Descriptive statistics of variables in the model.

Variable	Name	Definition	Unit
(Y)	GDP per capita growth	Gross domestic product increases per capita in EU member states	Percentage (%)
(X_1)	CMU rate	The ratio of the circular use of materials to the overall material use	Percentage (%)
(X_2)	RRMW	Measures the tonnage recycled from municipal waste divided by the total municipal waste arising	Tons
(X_3)	Trade in recycling materials	The trade in recyclable raw materials (tons) in the EU countries	Tons
(X_4)	Real labor productivity	The productivity per person employed in relation to EU average	Percentage (%)
(X_5)	Environmental taxes	A tax whose base is a physical unit of something that has a proven, specific negative impact on the environment	Euro
(X_6)	Resource productivity	Gross domestic product divided by domestic material consumption	Euro/kg

2.3. Research Methodology

Figures 1–6 represent the evolution of the CE indicators at the EU level from 2010 to 2017. The first analyzed indicator is the “circular material use rate” [27]. The CMU rate is calculated as the quotient between the circular use of materials and the total material used. The evolution of this indicator in EU member states, from 2010 to 2017, can be seen in Figure 1.

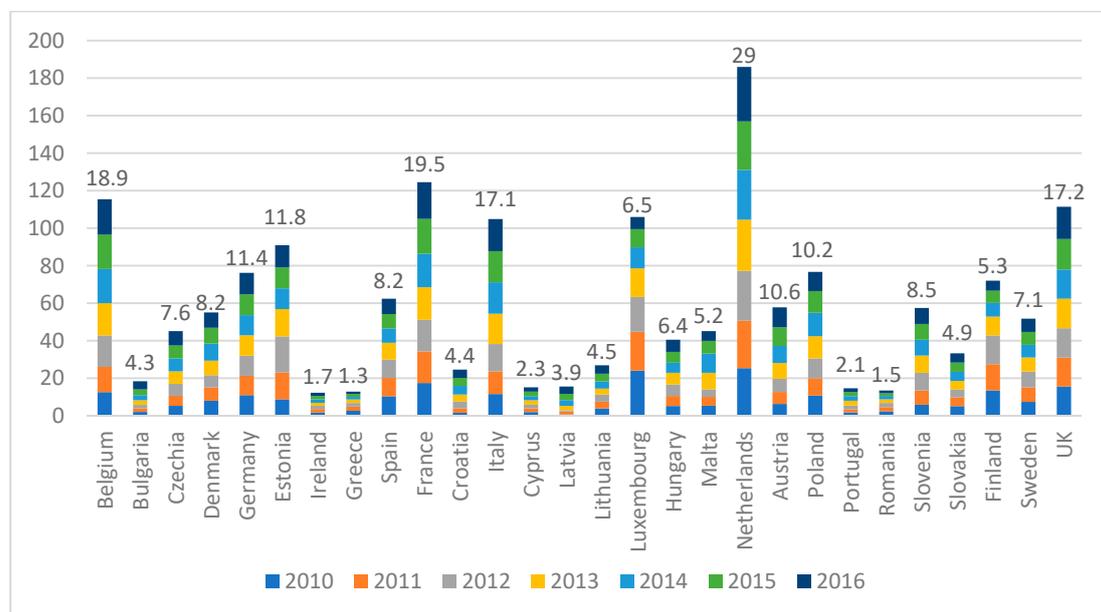


Figure 1. Circular material use (CMU) rate (%). Source: Eurostat, 2019.

From Figure 1, we can observe that on the top rankings of CMU are the Netherlands (29%), France (19.5%), and Belgium (18.9%), while in last place are Ireland (1.7%), Romania (1.5%), and Greece (1.3%).

Another analyzed macroeconomic factor is RRMW [28]. RRMW is defined as municipal waste recycled from total municipal waste generated. The evolution of this indicator in EU countries between 2010 and 2017 can be seen in Figure 2.

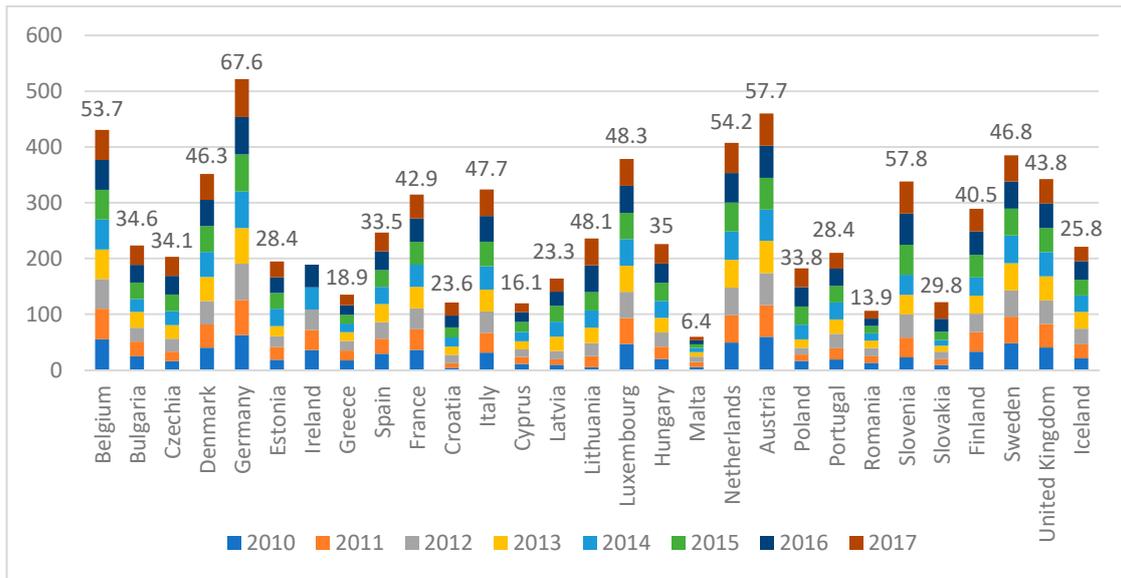


Figure 2. RRMW (%) in European Union (EU) countries between 2010 and 2017. Source: Eurostat, 2019.

Thus, it can be seen that in 2017, the EU member states with the highest rates of RRMW were Germany (67.6%), Slovenia (57.8%), and Austria (57.7%), while the countries with the lowest rates of recycling municipal waste were Cyprus (16.1%), Romania (13.9%), and Malta (6.4%).

Furthermore, Figure 3 reveals the status of trade in recyclable raw materials (tons) in the EU countries between 2010 and 2017.

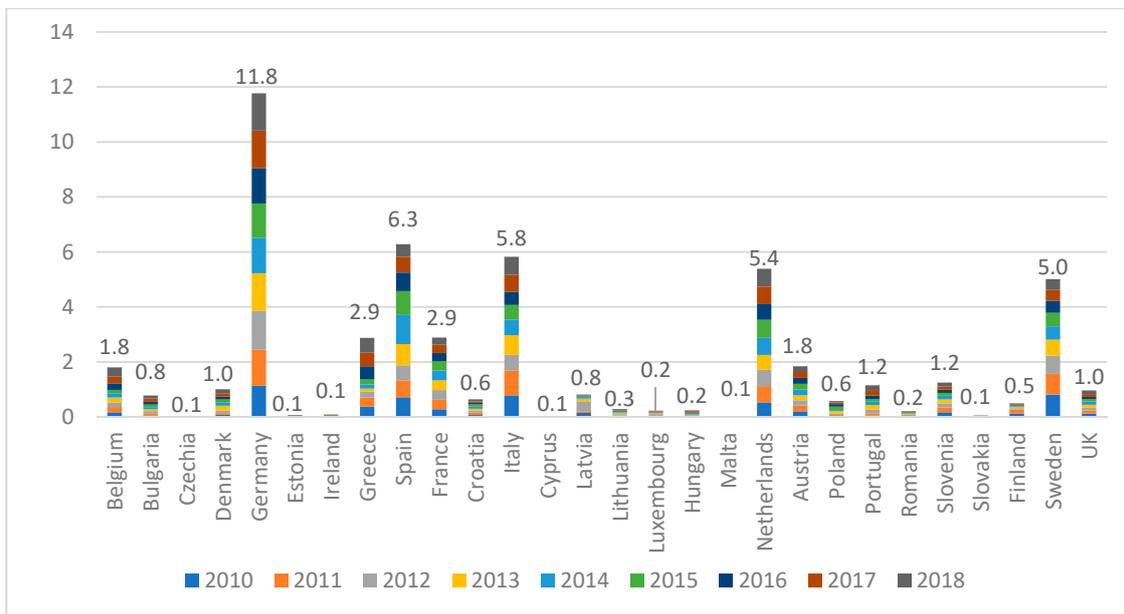


Figure 3. Trade in recyclable raw materials (million tons) in EU member states. Source: Eurostat, 2019.

From Figure 3, we can observe that the EU country with the highest amounts of trade in recyclable raw materials is Germany, followed by Spain and Italy, while on the last places we can see the Czech Republic, Spain, and Italy.

Figure 4 illustrates the real labor productivity per person in the EU member states, in 2018.

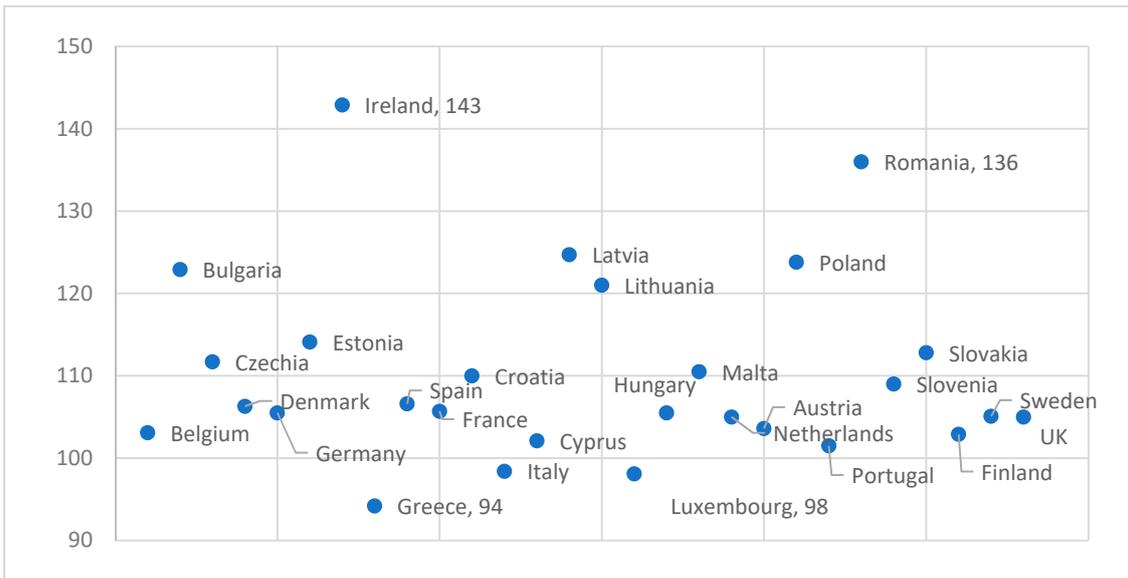


Figure 4. Real labor productivity per person in the EU countries in 2018 (base year 2010 = 100%). Source: based on processed data provided by Eurostat, 2019.

In Figure 4, it can be seen that in 2018, Ireland ranks first (143%) in the real labor productivity per person index, followed by Romania (136%). At the same time, Luxembourg (98%) and Greece (94%) were on the last places in this ranking.

Figure 5 gives a description of the evolution of the environmental taxes (revenues in billion euro) in EU countries, between 2008 and 2017.

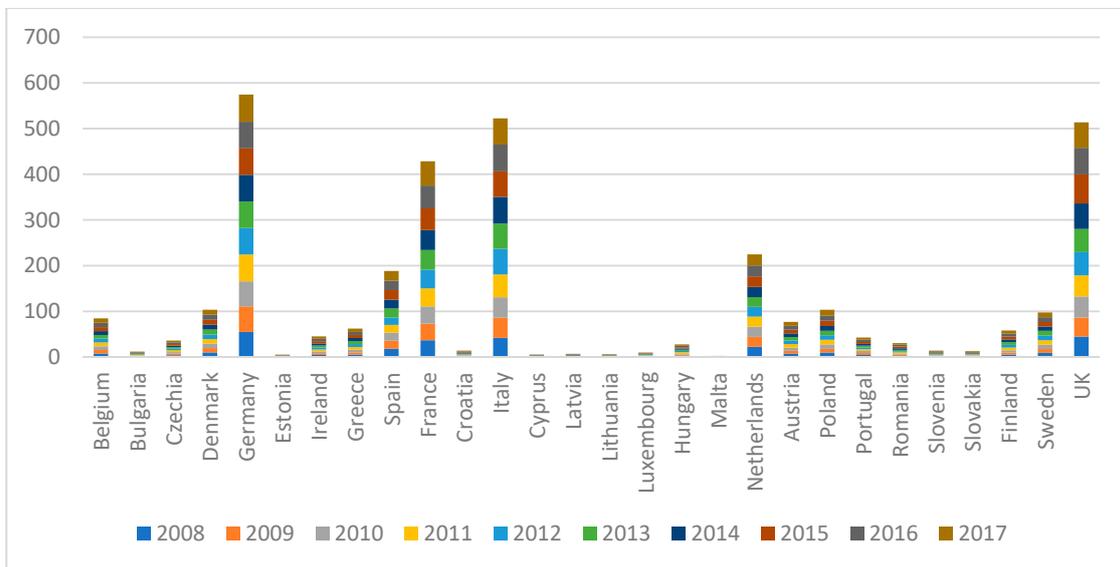


Figure 5. Environmental taxes (revenues in billion euro) at EU level, between 2010 and 2017. Source: Eurostat, 2019.

From this graph, we could see that the EU states with the highest values of environmental taxes were Germany, Italy, and the United Kingdom, while the countries with the lowest values of environmental taxes collections were the Baltic countries: Lithuania, Latvia, and Estonia.

The productivity of resources is one of the most important circular economy indicators. In Figure 6, we could see the evolution of this indicator at the EU level, between 2010 and 2018.

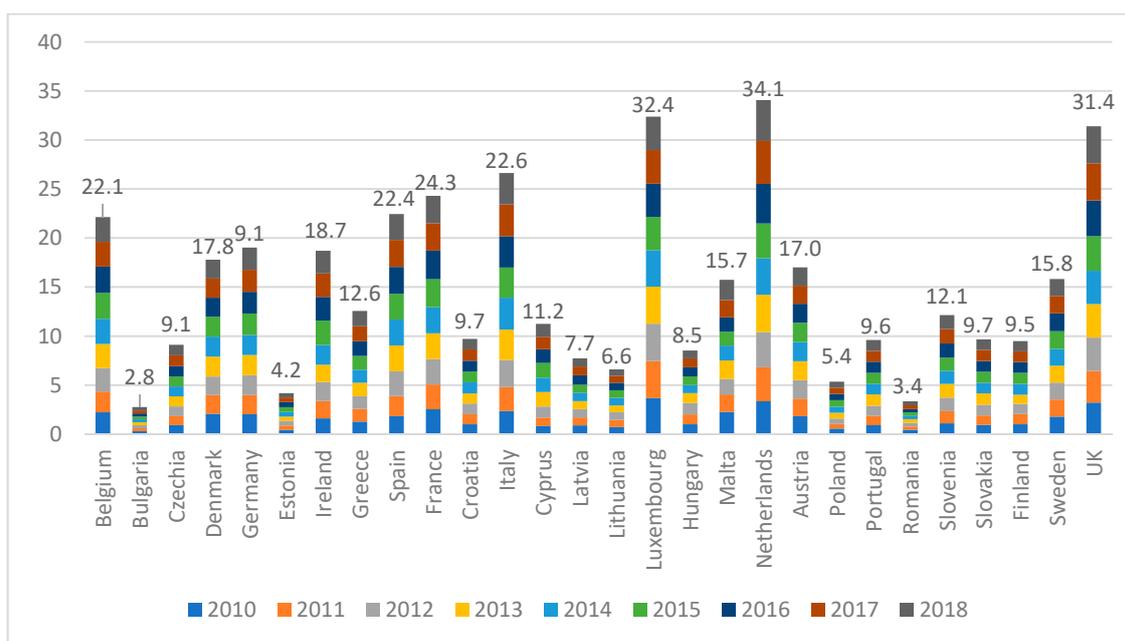


Figure 6. Resource productivity (euro/kg) in EU countries between 2010–2018. Source: Eurostat, 2019.

From the above figure, we could see that real labor productivity and domestic material consumption in 2018 was highest in the Netherlands (4.2 euro/kg), followed by the United Kingdom (3.8 euro/kg) and Luxembourg (3.4 euro/kg). In the same time, in the last places were Estonia (0.4 euro/kg), Romania (0.4 euro/kg), and Bulgaria (0.3 euro/kg).

3. Results

A statistical description of the indicators used in the regression model—i.e., minimum, maximum, median, mean, and standard deviation—can be seen in Table 3. The values of the median and the mean of the variables of the model from Table 3 reveal how close the data is to normal distribution. If the mean and median values are close to one other, then we could say that the data follows a normal distribution [29]. In Table 3, we could see that these values are approximately equal to one other, so we can assume that the variables used in our model are normally distributed.

Table 3. Descriptive statistics.

Variable	Min	Mean	Median	Max	St. dev.	N
Y	6.981	30.612	29.084	118.299	2.229	27
X ₁	1.300	8.557	7.800	29	6.580	27
X ₂	6.400	37.178	34.800	67.600	14.882	27
X ₃	0.001	0.211	0.187	1.350	0.299	27
X ₄	94.200	110.286	106.000	143.000	11.282	27
X ₅	0.303	8.171	7.095	59.259	18.930	27
X ₆	0.332	1.731	1.492	4.173	1.060	27

Source: own calculations, with the use of EViews 11.0.

Pearson correlation analysis was performed to test multicollinearity between the explanatory variables of the regression model. As we could see in Table 2, the correlation coefficients between the independent variables in Table 4 are smaller than ± 0.30 , we could conclude that there are no multicollinearity issues between the selected variables [30].

Table 4. Pearson correlation matrix between explanatory variables.

Variable	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆
X ₁	1	0.134	0.128	0.212	0.289	0.283
X ₂	0.134	1	0.148	0.207	0.258	0.198
X ₃	0.128	0.148	1	0.149	0.081	0.246
X ₄	0.212	0.207	0.149	1	0.102	0.269
X ₅	0.289	0.258	0.081	0.102	1	0.174
X ₆	0.283	0.198	0.246	0.269	0.174	1

Source: own calculations, with the use of EViews 11.0.

A Lagrange multiplier (LM) Breusch–Pagan test and *F*-test were performed to analyze whether our method has random effects, fixed effects, or pooled data.

The LM Breusch–Pagan Test was used to choose between random models and the pooled method [31]. The null (H_0) and the alternative (H_1) hypotheses are the following:

$$H_0: \sigma_u^2 = 0; H_1: \sigma_u^2 \neq 0;$$

If we accept the null hypothesis that the variance of the unit effects is zero, it would indicate that the regression model will be tested with the LM Breusch–Pagan Test. The results of the Pooled Model Test could be seen in Table 5.

Table 5. Random effect test.

	Cross Section	Time	Both
Coefficient	18.73	49.132	79.45
Probability	0.091	0.603	0.047

In Table 5, we could see that the *p*-value (probability = 0.091) is greater than 0.05, so the null hypothesis H_0 was accepted. In this case, we could state that the random effect model is not appropriate for our analysis, so pooling is suitable for our analysis.

Now we need to choose between the pooled and fixed effect models. For this, an *F*-test was performed [32,33].

The restricted model is as follows:

$$Y_i = X\beta + u_i, i = \overline{1, N} \quad (1)$$

Unrestricted model: $Y_i = X_i\beta_i + u; H_0 : \beta_i = \beta; H_1 : \beta_i \neq \beta$.

If the Hypothesis H_1 is accepted, then $\beta_i \neq \beta$ and the restricted model would be accepted, in which case the pooled data technique would be used to analyze our model. Otherwise, the fixed effect model would be validated.

Table 6 gives us the results of the *F*-test. The hypothesis H_1 is rejected, since the *p*-value (probability (*F*-statistic) = 0.316) is greater than the 0.05 threshold. Hence, we conclude that the fixed effect model will not be used in our model.

Table 6. Fixed effect test.

Test	Value
<i>F</i> -statistic	4.36
Probability (<i>F</i> -statistic)	0.316

Therefore, the pooled least square (PLS) Method was performed to test the six statistical hypotheses. This method was used to estimate the impact of the CE indicators on economic growth in EU countries between 2010 and 2017.

For the multiple linear regression, the endogenous variable (Y) is economic growth, determined by a set of six exogenous indicators, i.e., circular material use rate (X_1), RRMW (X_2), trade in recycling materials (X_3), real labor productivity (X_4), environmental taxes (X_5), and resource productivity (X_6) as independent variables. For economic growth, we have used a proxy variable: GDP per capita growth.

To analyze the economic growth between EU member states between 2010 and 2017, according to the explanatory variables, the output of the regression model is revealed in Table 7. For the analysis, the data was collected for all EU countries except Croatia, who joined the EU in 2013.

Table 7. Impact of the CMU rate, RRMW, trade in recycling materials, real labor productivity, environmental taxes, and resource productivity on GDP per capita growth in EU countries.

Dependent Variable: GDP_CAPITA_GROWTH				
Method: pooled least squares				
Sample: 2010–2017				
Total panel observations: 216				
GDP_CAPITA_GROWTH = C(1) + C(2) × CIRCULAR_MATERIAL + C(3) × MUNICIPAL_WASTE + C(4) × TRADE_MATERIALS + C(5) × LABOR_PROD + C(6) × ENVIRON_TAXES + C(7) × RESOURCE_PROD				
	Coefficient	Standard Error	t-Statistic	Probability
C	−12.9335	1.245	2.875409	0.0284
CIRCULAR_MATERIAL	0.107652	0.930	3.765092	0.0073
MUNICIPAL_WASTE	0.118950	0.848	2.987650	0.0053
TRADE_MATERIALS	0.108709	0.872	3.679802	0.0027
LABOR_PROD	0.203765	0.459	2.897695	0.0231
ENVIRON_TAXES	0.097522	0.073	3.098783	0.0089
RESOURCE_PROD	0.178292	0.109		
R-squared	0.776552	Mean dependent var		4.8762
Adjusted R-squared	0.687378	SD dependent var		0.8954
Standard error (SE) of regression	2.195433	Akaike info criterion		1.9034
Sum squared residual	14.45673	Schwarz criterion		1.9835
Log likelihood	82.38760	Hannan-Quinn criterion		1.6902
Durbin-Watson statistic	2.187454			

According to the above table, the regression equation is:

$$Y = -12.933 + 0.107X_1 + 0.118X_2 + 0.108X_3 + 0.203X_4 + 0.097X_5 + 0.178X_6, \quad (2)$$

where Y is the GDP per capita growth, X_1 is the circular material use rate, X_2 is the recycling rate of municipal waste, X_3 is the trade in recycling materials, X_4 is real labor productivity, X_5 represents environmental taxes, and X_6 refers to resource productivity.

Hence, as we can see in Table 8, all six hypotheses are validated.

Table 8. Statistical hypotheses.

Hypothesis	Valid (Yes/No)
Hypothesis 1	Yes
Hypothesis 2	Yes
Hypothesis 3	Yes
Hypothesis 4	Yes
Hypothesis 5	Yes
Hypothesis 6	Yes

As we could see in the above table, all six hypotheses were validated by the regression model. A description of the regression variables can be observed in Table 2.

4. Discussion of the Results

The present study connects with the economic literature regarding the impact on economic growth of the CE indicators. The multiple linear regression coefficients used in the regression model were estimated by the PLS model, and the regression computations were performed by EViews 11.0 software.

The study was focused on the development of a multilinear regression model with panel data between the economic growth, as a dependent variable, and six other explanatory factors: CMU rate, RRMW, trade in recycling materials, real labor productivity, environmental taxes, and resource productivity. As we can see from the results, the greatest impact on economic growth was that of real labor productivity (coefficient = 0.203765), followed by resource productivity (coefficient = 0.178292) and RRMW (coefficient = 0.118950).

Analyzing the economic growth in the selected EU countries in our study between 2010 and 2017, using the explanatory factors, the following equation was obtained through analysis of the multiple linear regression (see Table 6): $Y = -12.933 + 0.107X_1 + 0.118X_2 + 0.108X_3 + 0.203X_4 + 0.097X_5 + 0.178X_6$, with standard error coefficients 0.930, 0.848, 0.872, 0.459, 0.073, and 0.109.

Since the value of *R*-squared is 0.7765, we emphasize that 77.65% of the variability of the endogenous variable is determined by the exogenous factors of the model, and conclude that 22.35% of the dependent variable's variability is still explained by other indicators that are not included in the analysis. Additionally, the value of the Durbin–Watson (DW) statistical test is $DW = 2.18$, close to 2, we conclude that there are no collinearity issues with the residuals in the regression model, which leads to the conclusion that the errors are not autocorrelated.

As we can see in Table 7, the results of the estimated model are significant at the 95% confidence level for all six explanatory factors in the analysis. The conclusions of the study are in line with the work of Puigcerver-Peñalver [34], who analyzed a multiple linear regression model in which the economic growth was explained by several CE environmental macroeconomic indicators.

Analyzing the results of the regression model, we can state that the model was correctly specified and the selected CE indicators were all significant, with positive impacts on EU economic growth in EU member states; the coefficients estimated by the panel data regression model were all significant, and most of the economic growth's variation was determined by the model. The results of the paper are consistent with another recent study [35], in which the authors developed a regression model to explain the economic growth explained by resource and labor productivity in EU member states. The results could be also linked with two other studies [36,37], which argue that sustainability and the circular economy impact on economic growth is not increased by a simple shift to renewable resources or materials. The authors highlight that recycling rates and environmental innovation are also significant factors of sustainable development and economic growth. Nevertheless, other studies [38,39] confirm our results that the CMU rate and trade in recycling materials have positive and significant impacts on economic growth, while [40] arguing that environmental taxes are one of the most important drivers for that economic growth. Last but not least, the results of our paper confirm the work of Aid et al. [41], who analyzed the barriers for inter-organizational resource management, and in turn uncovered some potential opportunities and risks of novel offerings from the waste management sector in Sweden. The results of the paper validate the conclusions of the research [42,43], underlining the significant impact of innovation in the recycling sector on the economic growth.

Eventually, not all EU countries will have the same level of implementation of CE indicators. While Nordic and Western countries have outstanding results and are on top of the CE rankings, Eastern European countries still need to improve their CE macroeconomic indicators. Sweden, Denmark, and Finland are the top-ranking countries in a composite score with eco-innovation inputs [44].

The novelty of this research comes from the panel data econometric analysis of the 27 EU member states, in order to determine the interrelationship between the CE and economic growth.

Multiple linear regression analysis was based on the data of the macroeconomic indicators over a period of eight years, and therefore, the main limitation of this research is associated with the time

length period used in the econometric research. Thus, future research could encompass longer time periods and may reveal a better picture of the econometric model to analyze CE at the EU level.

5. Conclusions

Studies conducted on advanced economies have revealed multiple assets of the civil society in the spirit of environmental protection, in parallel with the investments in recycling infrastructure. The positive effects of the CE model can be offset by increasing the level of municipalities' income, the labor force employed, and the profit obtained by the contractors providing the environmental infrastructure. The econometric analysis performed highlights the impact of exogenous indicators, determining factors of the CE in the economic growth.

Economic growth and environmental performance must go hand in hand. The natural environment is based on economic activity and growth, providing the main resources we need to produce services and goods, and processing and absorbing unwanted by-products in the form of waste and pollution. Circular economy and environmental assets contribute to economic growth and social activity, helping to regulate flood risks, regulating the local climate (both temperature and air quality), and maintaining the supply of clean water and other resources. Correspondingly, economic growth contributes to the investment and dynamism needed to deploy and develop new technology, which is foundational to both managing environmental assets and productivity growth.

Perhaps the most important benefit is the one felt at the individual level. By making an analogy between the product life through reuse, which translates into life prolongation and the benefits of this natural process on the biological human life, and given that the basic resource is biomass, we can observe how the quality of the environmental factors is implicitly propagated, positively impacting the quality of the human life. The analysis can be further developed using other macroeconomic indicators commensurate the attributes of the CE and environmental challenges, shedding light on the latest EC developments in the field in order to implement the circular economy in day-to-day activities. Future research could be developed for a longer period of time and use other economic indicators or econometric models.

Author Contributions: M.B. drafted the initial manuscript and revised the final manuscript. M.B. contributed the data acquisition and estimated the model; C.L.T. contributed with conclusions and recommendations, as well as the limitations of the study and further research; C.L.T. contributed the literature review; M.B. was responsible for the overall writing process.

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Abbreviations

EU	European Union
EC	European Commission
OLS	ordinary least squares
PLS	Pooled least square
GDP	gross domestic product
PPS	purchasing power standard
CE	circular economy
RRMW	recycling rate of municipal waste
EPR	extended producer responsibility
CMU	circular material use
DMC	domestic material consumption

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