Circular Economy Innovation and Environmental Sustainability Impact on Economic Growth: An Integrated Model for Sustainable Development

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Abstract: This study examines the link between selected indicators of a circular economy, including essential components of environmental and economic growth. Developed economies are continuously innovating to promote growth and giving governmental support to the producers to move from linear economies to circular ones. Hence, waste materials in industrial systems are recycled or re-used, improving the efficiency of using finite resources with the no-waste approach. The aim of this paper is the following: (1) to identify the main components of a circular economy, which are also supportive of sustainability and development; (2) to check the impact of these variables in the economic growth of European Union countries; (3) to find out if the three components of sustainable development adopted to circular economy (CE) indicators (environmental–social–economic) are significant to economic growth. We used a fixed effect panel data analysis to identify the circular economy’s impact on the economic growth of European countries. Additionally, to support the results of the regression analysis, we employed a second method—generalized methods of moments—computing the Arellano–Bond dynamic panel data estimation method. The model included five independent variables, such as environmental tax rate, a recycling rate of waste, private investment and jobs in a circular economy, patents related to recycling, and trade of recyclable raw materials. The identification of each variable was made based on a deep search through literature. The results of both econometric models showed a strong and positive correlation between a circular economy to economic growth, highlighting the crucial role of sustainability, innovation, and investment in no-waste initiatives to promote wealth.

Keywords: circular economy; sustainability; innovation; environmental dimension; economic growth; panel data

1. Introduction

The circular economy (CE) is perceived as a crucial model for industrial economics to pursue sustainable development [1–5]. CE is acknowledged “as a solution for harmonizing ambitions for economic growth and environmental protection” towards the constraints of the take–make–use–dispose linear economy [6] (p. 37). In [7], it is claimed that “CE provides a reliable framework towards radically improving the present business model towards preventive and regenerative eco-industrial development as well as increased wellbeing based on recovered environmental integrity” (p. 27), despite the fact that CE global pursuit needs further engagement.

Transitioning an economic model from production–consumption–waste to production–consumption–reuse requires the involvement and commitment of several stakeholders, such as producers, consumers,
and policymakers [8]. Value co-creation among these actors is a critical part of the viability of this economic model, which is expected to have a positive impact on the community’s social life, the economy’s sufficiency, and the natural environment [9]. The CE approach has been guided by the [10] study, where the earth is depicted as a circular, closed system with limited resources, in which the economy and environment should exist side by side.

Due to its importance and the expected impact on sustainability, CE has received a lot of attention from researchers, policymakers, and entrepreneurs [11]. The European Circular Economy package [12] is an indication of the EU commitment towards a CE. On the other hand, entrepreneurs are becoming conscious of the business model opportunities raised by the CE [3]. Concurrently, [13] point out the “need to encourage a larger contribution of scholars from the Business and Economics area to explore the viability and profitability of CE strategies and related managerial practices to overcome related issues” (p. 1652).

In their systematic literature study, [14] found that the CE “is viewed as a condition for sustainability, a beneficial relation, or a trade-off” (p. 767). The authors define CE as a “regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops,” and refer to sustainability “as the balanced integration of economic performance, social inclusiveness, and environmental resilience, to the benefit of current and future generations” [14] (p. 766).

Some authors have been centered on evaluating the impact of a CE on the natural environment progress [1,3,4]. Other scholars have been focused on analyzing the CE on an integrated view of sustainability, including not only the environmental impact, but also the social and economic [15,16]. Some researchers refer to increased job opportunities when evaluating the community’s social life improvement [7,17,18]. Other authors have built up other aspects of the CE’s impact on social life, such as an efficient tax system or consumer behavior change [5].

Besides analyzing the CE’s impact on society, the economy, and the environment, raising awareness of the community’s consumers and promoting the development of circular innovative business models and governmental policies to support them have been discussed and researched by many scholars [7,17,19].

In this research, aside from business model innovation and responsible consumers, we present collaboration through the quadruple helix as another enabler of CE. The novelty of this study lies in the proposed conceptual framework of the integrated circular economy (Figure 1), which is a theoretical framework composed of two complementary structures. The first structure is devoted to the necessity of a quadruple helix model in support of CE. This has been derived and strongly supported by the literature findings, and not considered to be measured in this paper, whereas the second structure comprises the three-based scheme of sustainable development—social–environmental–economic—with innovation in the center as a key driver to CE.

In addition to the proposed framework of an integrated circular economy, the novelty of this paper is the association of the CE variables with each of the sustainable development aspects: the social–environmental–economic. Although there are some limited studies using panel data to measure the impact of CE in GDP, such as [20,21], none of them has considered the CE variables to be associated with the three dimensions of sustainable development.

Lastly, this study uses two different methods—the fixed effect method and generalized methods of moments (GMM)—to cross-check the results and strengthen the findings. If the fixed effect method is a widely used method, but sometimes criticized [22], the GMM, using the Arellano–Bond conditions, represent a robust method instead [23].
Specifically, in this paper, we aim to identify the main components of the CE supportive to sustainability with an impact on economic growth (EG). Referring to this objective, we pursue our analysis on the following research questions (RQs) and hypotheses (H):

RQ1: Are CE components supportive of sustainability?
RQ2: To what extent do the CE components impact GDP?
H1a: The CE “environment” aspect has a positive impact on GDP.
H1b: The CE “social” aspect has a positive impact on GDP.
H1c: The CE “economic” aspect has a positive impact on GDP.

Considering what we said before, this study targets both theoretical and empirical contributions to the literature. Its theoretical contribution is related to the proposed framework on the integrated CE, which, on the one hand, is supported from the quadruple helix model, and on the other hand, positions the CE factors in line with the sustainable development triangle. Regarding the empirical contribution, this paper explores and cross-checks the results from two models, exhibiting stronger evidence on the findings.

This paper has the following structure: firstly, we present a literature review supporting the proposed framework of an integrated circular economy. Then, we make a theoretical and statistical description of the independent variables used in the paper. Next, the two methods of panel data are applied and checked for compatibility and validation. Finally, the last session is devoted to further research, limitations of the study, conclusions, and discussions.

2. Literature Review on Circular Economy

2.1. From a Linear to a Circular Economy

The CE approach had achieved attention by the second half of the 1970s [3]. It conceptualizes a new economic system of change in business model innovation on one hand, and consumer behavior on the other, in which, both producers and consumers focus on reprocessing, restoring, renovating, and recycling previously used materials and products. Since its very beginning, the CE presented itself as an alternative model to the neoclassical economy both from a theoretical and practical point of view, as it acknowledges the fundamental role of the environment, as well as its functions and the interplay between the environment and the economic system [7] (p. 24). The challenge of environmental pollution, as well as the challenge of global resource scarcity, are addressed in this structure [6]. Through this system, it is intended to pass from production–consumption–waste economic behavior to a production–consumption–reuse one, aiming not only for sustainable development through economic
sufficiency, but also environmental and social life sustainability. In [7] it is emphasized that “the transition towards CE comes from the involvement of all actors of the society and their capacity to link and create sustainable collaboration and exchange patterns” (p. 11). This can be achieved through sustainable resource management, societal behavior change, and business operation models. By promoting the adoption of closing the loop production patterns within an economic system, CE aims to increase the efficiency of resource use, with a special focus on urban and industrial waste to achieve a better balance and harmony between the economy, environment, and society [7] (p. 11).

2.2. From Circularity to Sustainability

The systematic literature network analysis of 1558 papers conducted by [13] define “four common factors driving research about CE, namely: (i) the active debate about CE’s role to reach sustainability, (ii) the interdisciplinary background of scholars, (iii) the development agendas underpinned by CE established by either Chinese or European governments; (iv) the importance of financial support” (p. 1643).

Different definitions of CE are provided in the literature. Some of them have a holistic perspective and some of them a partial one focusing more on the environmental impact of circularity. In [24], CE is defined as recuperative, which disposes of waste through designing innovative business models that empower enhanced material, product, and system design usage. In [25], it is suggested that CE is defined as “an economic model in wherein planning, resourcing, procurement, production and reprocessing are designed and managed, as both process and output, to maximise ecosystem functioning and human well-being” (p. 369). The main aim of a circular economy is considered to be economic prosperity, followed by environmental quality; its impact on social equity and future generations is barely mentioned [19] (p. 221). The majority of the research on CE development focuses on “resource scarcity and environmental impact perspective leaving economic benefits of industrial actors in general and specifically on individual level missing” [6] (p. 46). On the other hand, [7] see the consumer’s responsibility, along with substantial policies, as crucial for CE. They define CE as “the adoption of cleaner production patterns at a company level, an increase of producers and consumers responsibility and awareness, the use of renewable technologies and materials (wherever possible) as well as the adoption of suitable, clear and stable policies and tools” [7] (p. 11).

Although sustainable development lays out the triple bottom line system, focusing on the environmental, economic, and societal benefits as a whole, CE prioritizes the economic system, where the main beneficiaries are the economy and environment, while societal benefits arise from environmental improvements, manual labor, or fairer taxation [14]. Meanwhile, there are many similarities between CE and sustainability concepts identified by [14] as (i) non-economic aspect integration into development; (ii) different stakeholder cooperation necessity; (iii) regulation and incentives as core implementation tools; (iv) business model innovation for industry transformation.

To satisfy the concept of sustainable development, the best possible use of all available economic resources should be studied for the production of the maximum possible output of goods and services that are needed for the community now and in the future, and the just distribution of this output [26] (p. 97). While describing the attributes of a sustainable economic system, [27] mentioned it: (i) boosts consumption reduction; (ii) contributes to social and environmental improvements; (iii) is closed-loop, zero-waste allowance; (iv) focuses on process and experience transmission; (v) awards talents, and (vi) is raised on cooperation and sharing. On the same line, [2] developed eight archetypes to support business model innovation for sustainability, such as: “(i) maximise material and energy efficiency; (ii) create value from “waste”; (iii) substitute with renewables and natural processes; (iv) deliver functionality, rather than ownership; (v) adopt a stewardship role; (vi) encourage sufficiency; (vii) re-purpose the business for society/environment; (viii) develop scale-up solutions” [2] (p. 55). Among the eight options, circularity is also viewed as a means towards sustainability. In their research, [14] found that CE “is viewed as a condition for sustainability, a beneficial relation, or a trade-off in literature” (p. 767).
On the other hand, [18] included sustainability as an aim to be accomplished by the CE. They defined CE "an economic system that replaces the "end-of-life" concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, [...], with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations" [19] (p. 229). Responsible consumers and business model innovation stay at the core of enabling CE, where collaborative consumption models are perceived among the most advantageous models for consumers to move to a CE [19]. Collaborative platforms being positioned on multiple ownerships between consumers are continuously evolving their purchasing behavior and approaches. Inspired by the principles of sustainable consumption, its starting point is the idea that every underutilized resource is a wasted resource [28] (p. 1797). In [29], it is argued that these collaborative platforms of consumption stay at the ground of CE accomplishment through an increase of employment and resource efficiency.

In this research, we adopted the definition of [19] on the CE as an economic system operating at micro-meso-macro levels, focusing on the 4R of reducing, reusing, recycling, and recovering materials in production–consumption activities and aiming to achieve sustainable development. Related to the issue of CE enablers beside business model innovation and responsible consumers, we added collaboration through the quadruple helix, too. In [30], it is argued that to achieve open innovation micro- and macro-dynamics, a quadruple helix model is needed for social, environmental, economic, cultural, policy, and knowledge sustainability. The quadruple helix is an extension of the [31] triple helix spiral collaboration model of innovation between university–industry–government, which were referred by them as a "laboratory for knowledge-based economic development." In the quadruple helix model, [32] recognized "media-based and the culture-based public" as a fourth helix of collaboration by emphasizing that ‘culture and values, on the one hand, and the way how ‘public reality’ is being constructed and communicated by the media, on the other hand, influence every national innovation system” (p. 206). With an open platform, technological advancement, the mobility of highly educated people, and societal engagement, companies can absorb knowledge resources efficiently [30] (p. 2).

Figure 1 below provides our “integrated circular economy” framework, where a sustainable circular economy impacting social, environmental, and economic aspects can be achieved through the support of the quadruple helix model of innovation, as explained above.

We based our proposal of this theoretical framework on the literature background, which supports the need for a quadruple helix model to develop a sustainable circular economy. In the next section, we will consider the details of Figure 1 (second part) devoted to the CE and the triangle of sustainability, from which we constructed our empirical analysis.

3. Materials and Methods

3.1. Circular Economy Indicators

The concept of the circular economy has been a deliberate topic since the late 1970s [3]. In addition to that, the impact of the circular economy on economic growth has been studied by many researchers [20]. As such, the study of [14] argued that there is a direct connection between CE and economic growth. The authors made detailed research on the papers published from 1950 to January, 2016 with the topics on “sustainability,” “circular economy,” and “circular economy and sustainability.” The findings showed that there were 59,464 papers on sustainability, 295 papers on the circular economy, and 67 papers on circular economy and sustainability.

Furthermore, the CE was analyzed on both a micro-level [33–36] and macro-level [37–39]. On the macro-level, [40] proposes some indicators to measure the CE progress throughout the EU member countries. Referring to priority areas of the CE Action Plan in Europe [12], the monitoring framework indicators are segregated into four group areas: (1) production and consumption, (2) waste management, (3) secondary raw materials, and (4) competitiveness and innovation. Exploring the effects of the CE progress on the economic growth and sustainability of the countries, especially in the European
Union [41], has been a prime concern of many scholars in the last few years. In their study, [42] developed a “Circular Economy Composite indicator to benchmark EU countries performance” (p. 618). Through this index, it aims to provide policymakers with a tool for defining the country-level strengths and weaknesses of circular economy performance [42].

In [7], 155 papers covering circular economy are classified according to two conceptual groups (CE models and CE principles) and according to micro-, meso-, and macro-level studies. As seen from the results, the aggregate of all these papers implies and targets sustainable development. In the same line, this study supports the sustainable development in the framework of the circular economy (Figure 1, second part) considered in the macro-level analysis. In addition, it is important to mention that sustainability and the circular economy’s impact on economic growth is not increased by a simple shift to renewable resources or materials [6,43]. Specifically, it considers five important variables retrieved from the Eurostat database. The definitions and specifics of each variable of our model were consulted from the same source (see Appendix A) and listed below as such:

- Environment Tax Revenues (defined as var1)
- Recycling Rate of Municipal Waste (defined as var2)
- Private Investment, Jobs, Gross Value Added related to CE (defined as var3)
- Patents related to Recycling (defined as var4)
- Trade-in Recyclable Raw Materials (defined as var5)

The internal market factors are crucial to be considered. Thus, the variables above included the waste management within a country, the taxation collections from producers and consumers, the private investments and jobs related to CE, and the innovation side of CE, which is connected to patents and open economy as well. Sustainable economic growth should be supported by different pillars of the economy and the integration among them. The economic criteria are based on the well-functioning and the operation of the economy in the European market [44]; thus, the integration of all actors would bring the best outcome to the market. The circular economy covers a large range of society, defining it as both consumers and producers. As important and vital pillars are to this support, we proposed the environmental aspect, the social aspect, and the economic aspect (the triangle of sustainable development). Referring to Figure 2, we categorized var1 and var2 as indicators that have an impact on environment dimension; var1, var3, and var4 as indicators that have an impact on a social dimension; and var1, var3, var4, and var5 as indicators that have an impact on the economic dimension.

**Sustainable Economic Growth in Circular Economy**

| Environmental Impact | Environment tax revenues |
|-----------------------|--------------------------|
|                       | Recycling rate of municipal waste |

| Social Impact          | Environment tax revenues |
|------------------------|--------------------------|
|                       | Private investment, jobs, gross value added related to CE |
|                       | Patents related to recycling |

| Economic Impact        | Environment tax revenues |
|------------------------|--------------------------|
|                       | Private investment, jobs, gross value added related to CE |
|                       | Patents related to recycling |
|                       | Trade-in Recyclable Raw Materials |

**Figure 2.** Modelling circular economy in the context of sustainable growth.
3.2. Data

Overall, we extracted five major proxies to measure the effect of circular economy innovation on economic growth, such as environmental tax revenues, the recycling rate of raw materials, private investment, jobs/gross value added, patents related to recycling, and trade-in recycling raw materials. The choice of the variable selection is based on two strategies. First, it is decided that these indicators have a strong reflection of circular economy innovation, which is based on a literature survey. Second, it is also ensuring that these five major proxies-related data must be available across EU28 countries. Regarding the source of the data, we extracted these variables from the Eurostat for EU28 countries. Concerning the economic growth, we used GDP per capita. GDP per capita measures economic growth more efficiently than simply using the total national output (GDP). In order to examine the link between economic growth and the main components defining circular economy, we used panel data analysis. The regression equation was performed for EU28 by considering the panel data from 2000 to 2017. Data for the dependent variable, GDP growth (GDP per capita), were retrieved from World Development Indicators, whereas the data for all other independent variables were retrieved from Eurostat.

The independent variable selection was also based on literature. For example, a study [45] argues that the environmental taxes are important drivers of economic growth. Other studies, such as [6,43], confirm the importance of recycling rates and environmental innovation in sustainable development and economic growth. The other variable, trade, is found to have positive effects on economic growth and sustainable development [25,46].

Based on Figure 2, we extracted three variables to estimate the effect of the circular economy on economic growth. These variables were environmental, social, and economic impacts and they were interrelated with each other (overlapping). More precisely, to measure the environmental impact on growth, we used two proxies, such as environmental tax revenues and the recycling rate of municipal wastage. In order to investigate the social impact on growth, we added two additional indicators: “patents-related recycling” and “private investment gross value added.” Lastly, to measure the economic impact, trade-in recycled raw materials were included combined with environmental and social impacts. In summary, Figure 2 shows that environmental, social, and economic factors are the key proxies of the circular economy.

In addition, we introduced a new variable labelled as the innovation, which was the multiplication of two variables: that of “private investment, jobs, gross value added related to CE” and “patents related to recycling.” As argued by the study of [47], there is a direct link between labor force, investment, employability, and innovation. In addition, most researchers have achieved agreement on the necessary function of the patent system in promoting innovation [48]. Lastly, [49,50] confirm that innovation in the recycling sector is crucial for GDP growth. Hence, based on the literature and as we proposed in the conceptual framework of integrated circular economy (Figure 1), the sustainable development triangle has to be supported by innovation. Table 1 shows the summary statistics of all variables before the regression analysis. If we compare the median and mean per each component, we reveal that the values are close to each other. This supports the fact that the selected data for our model followed a normal distribution [51].

For some additional information on the dataset, we have included the full data in the boxplot (Figure 3). The variable of innovation did not show outliers in its dataset. In the meantime, the dataset on taxes, recycling, and trade had a few outliers that were not problematic for our sample. However, considering GDP, the dataset included some outliers from both sides, which might be the effect of not taking its logarithmic values. As stated above, all these variables were normally distributed.
Table 1. Descriptive statistics.

| Variable | Variable Definition * | Observ. | St. Dev. | Min     | Max     | Mean    | Median |
|----------|------------------------|---------|----------|---------|---------|---------|--------|
| Gdp      | GDP per cap. growth (annual %) | 504     | 3.710    | −14.560 | 23.985  | 2.219   | 2.0981 |
| log_tax  | Log (Proportion of env. tax revenues in GDP) | 502     | 0.221    | 0.457   | 1.6094  | 0.941   | 0.9321 |
| log_rec  | Log (Recycling Rate of Municipal Waste) | 487     | 1.028    | −1.609  | 4.214   | 2.973   | 3.2847 |
| log_innov | Lvg (Priv. Inv., Jobs, Gross Val. Add. x Patents related to Recycling) | 145     | 2.817    | 1.784   | 14.818  | 9.634   | 9.6001 |
| log_trade | Log (Trade in Recycl. Raw Mat.) | 392     | 2.407    | 0.693   | 14.493  | 10.864  | 11.3897 |

* Details are found in Appendix A

Figure 3. Visualized summary statistics with boxplot.

Figure 4 shows the scatterplot of GDP with each variable. As observed, there were concentrated datasets for recycling and trade. As per the other two variables, tax and innovation, the correlation with the GDP seems to be the horizontal line, which is slightly positive.

As a second step, we found the results shown from the correlation matrix for testing the multicollinearity. The Pearson correlation matrix helped us to identify whether there were highly correlated variables among them. According to [52], the presence of high correlation—generally accepted 0.90 and higher—is the first indication of substantial collinearity. As found for our results, we did not have high correlations; thus, we concluded that we did not have multicollinearity problems within our variables. In order to examine the effect of circular economy innovation on economic growth, we used two models: i.e., the fixed effect model and the system GMM [23]. In the fixed model, we investigated the impact of circular economy proxies on economic growth without addressing the endogeneity problem. However, this strategy allowed us to check the strength (coefficients) and the direction (positive/negative) of each proxy on economic growth. To remove the endogeneity problem, system generalized methods of moments (GMM) provided more efficient coefficients than simply using an ordinary least square (OLS). Through this estimation, the model used an instrumental variable (lagged one period) of the dependent variable (GDP per capita). In other words, the motivation to use system GMM was based on three reasons: first, system GMM somewhat addresses the causality due to the link between circular economy indicators and the GDP growth. Second, the fixed effect—e.g., demographic characteristics (size and growth) of each EU country might have a correlation with the
unobserved factor. Third, system GMM works even with a small sample size (N = 100, 50, 35) and produced efficient coefficients [53].

Figure 4. Scatterplot of GDP and other variables.

4. Results

A preliminary test to our model should be the Hausman test. This test shows us which model should be selected: the random effect model or the fixed one. As such, we set up the null and the alternative hypothesis, respectively. The null hypothesis, H0, indicated that the model was with random effects, and the alternative one, H1, stated the rejection of random effects, thus, showing that the fixed effect is the appropriate model for our case.

As we ran the Hausman test, we found out that Prob. > Chi2 = 0.0001, meaning that we rejected the null hypothesis in favor of the alternative one. Consequently, a fixed effect (FE) method was appropriate for our analysis.

Based on the Hausman test value, Equation (1) shows the equation for our panel data analysis. We used the logarithmic values for our variables to have compatible numbers with the regression process. Our FE analysis has the following form:

\[ gdp_{i,t} = \alpha_0 + \alpha_1 \log{tax}_{i,t} + \alpha_2 \log{rec}_{i,t} + \alpha_3 \log{innov}_{i,t} + \alpha_4 \log{trade}_{i,t} + \alpha_i + \epsilon \]  

(1)

where:
- \( i \) = used for number of countries
- \( t \) = used for time (of panel data time period)
- \( \alpha_0 \) = used for the interception of the regression
- \( \alpha_i \) = used for individual specific effect
- \( \epsilon \) = used for the error term
log\text{tax} = \text{used for environment tax revenues}

log\text{rec} = \text{used for recycling rate of municipal waste}

log\text{innov} = \text{used for private investment, jobs, gross value added related to CE * patents related to recycling}

log\text{trade} = \text{used for trade in recyclable raw materials}

Table 2 reports the details of the fixed effect estimation method and the significance of the variables. All the independent variables positively affected the GDP growth per capita of the EU countries. Three of the variables were found to be significant. Specifically, environmental tax revenues and the recycling rate of municipal waste were significant at the significance level of 0.01. The other variable, defined as innovation, had a significance level of 0.1. Meanwhile, trade in recyclable raw materials was found to be insignificant.

Table 2. Fixed effect panel data method.

| Economic Growth ([GDP Per Capita]) | EU Countries |
|-----------------------------------|--------------|
| Environmental Tax Revenues [L1.log\_tax] | 11.6908 *** (4.0962) |
| Recycling Rate of Municip. Waste [L1.log\_rec] | 2.4378 *** (0.7476) |
| Innovation (Priv. Invest, Jobs in CE * Patents related Recycling) [L1.log\_innov] | 0.6854 * (0.4235) |
| Trade in Recyclable Raw Mat. [L1.log\_trade] | 0.0863 (0.5874) |
| R-sq. (overall) | 0.0029 |
| F-Stat | 10.80 *** |
| Rho | 0.7460 |
| Observations | 135 |
| Nb. of Groups | 23 |

*** p < 0.01; * p < 0.1. Robust standard errors are in parentheses ( ).

As we previously stated, the panel data used were conducted for 28 countries of the EU but because of some missing data, the number of countries was reduced to 23 (refer to Table 1, number of groups). The F-Stat was found to be significant, supporting the overall model significance, too.

Specifically, according to the results, environmental tax revenues were found to have a positive effect on the model. With one unit increase in environmental tax revenues, the GDP growth is likely to increase by 11.69 units (EU28). In other words, environmental tax revenues are an important indicator that have a positive and significant association with economic growth. The recycling rate of municipal waste was found to be significant for EU28 and positively impacted the GDP per capita. It should be mentioned that the significance level was within 1%. This variable was categorized as waste management, which is directly related to the municipality. For each unit increase in the recycling rate of municipal waste, we expected an increase of 2.43 units in the GDP per capita for the European countries. This result showed that municipality management is being considered as a crucial factor in economic growth.

On the other hand, the variable indicating the innovation capacities of EU countries, composed by two subcategories—that of “private investment, jobs, and gross value added related to CE” and “patents related to a circular economy”—was positively and significantly (at a significance level of 10%) associated with the GDP per capita of European countries. Thus, for one unit increase in innovation, GDP per capita increased by 0.68 units (EU28). This variable was selected as an indicator of both social and economic impact. Hence, we confirmed that both the social aspect and economic aspect of the circular economy were roughly significant and highly important dimensions for economic growth.

Surprisingly, even though the trade in recyclable raw materials is positively associated with GDP per capita, the model could not confirm it due to its insignificance. This was a surprising result given
that trade in recyclable raw materials is considered one of the most important dimensions in economic growth. Consulting the definition of Eurostat of this variable, “trade-in recyclable raw materials” measures the intra-EU and extra-EU imports and exports. Thus, based on the results, it seems that the existent trade volume does not have significant capacities to influence EU economic growth, even though, based on the Gravity model, it is expected that the volume of trade among EU countries will be highly extensive [34]. We can support this result by highlighting the waste management within countries itself, rather than trading them to other countries.

In the meantime, the estimation method used in this study, fixed effect, is criticized by the general literature. For example, [22] have presented twelve limitations and misapplications of fixed effect models. Hence, even though the sample size might be large enough, the fixed effect method can be biased and usually downward. Therefore, in order to better consider the effects of the independent variables to the dependent one in our model, we used the GMM, using the Arellano–Bond conditions, which at the same time was the most robust one [23]. The GMM estimation method is used to estimate dynamic panel data models, based on a model in first differences. This method is used to solve the endogeneity, heteroscedasticity, and serial correlation problems. Our GMM, using the Arellano–Bond, has the following form:

\[
\Delta \text{gdp}_{it} = \Delta \text{gdp}_{i,t-1} + \alpha_1 \Delta \text{log}_{\text{tax},it} + \alpha_2 \Delta \text{log}_{\text{rec},it} + \alpha_3 \Delta \text{log}_{\text{innov},it} + \alpha_4 \Delta \text{log}_{\text{trade},it} + \Delta \epsilon_{i,t} \tag{2}
\]

where:
- \(i\) = used for a number of countries
- \(t\) = used for time (of panel data time period)
- \(\epsilon\) = used for the error term
- \(\Delta \text{gdp}\) = used for gross domestic product
- \(\Delta \text{log}_{\text{tax}}\) = used for environment tax revenues
- \(\Delta \text{log}_{\text{rec}}\) = used for recycling rate of municipal waste
- \(\Delta \text{log}_{\text{innov}}\) = used for private investment, jobs, gross value added related to CE * patents related to recycling
- \(\Delta \text{log}_{\text{trade}}\) = used for trade-in recyclable raw materials

Thus, when computing the Arellano–Bond dynamic panel data estimation method (refer to Table 3), we found similar results with the FE method. In both of the models, we used lag1, assuming that the selected variables would show their effect on economic growth at least one year later. The environment tax revenues and recycling rate of municipality waste were found to be significant at a 1% significance level, and positively affected the GDP growth. On the other hand, the variable of innovation was found to be within some limits of significance (a significance level of around 20%), but, again, it could be accepted as significant and positively contributing to economic growth. Lastly, consistent with the results of the FE method, we could not support the impact of the trade factor, even though it is a positive one.

In addition, the overall model was found to be significant as well (Prob > chi2). Being a robust method, GMM supported our results and confirmed once again all the circular economic factors we included in the model to explain the sustainable economic growth of EU countries.
5. Discussion and Conclusions

Through this research, we aimed to identify the CE components supportive of sustainability with a positive impact on economic growth. We defined CE as an economic system operating at micro-meso-macro levels, focusing on the 4R of reducing, reusing, recycling, and recovering materials in production-consumption activities, aiming to achieve sustainable development, enabled by business model innovation and responsible consumers, and supported by the quadruple helix collaboration.

Analyzing the results of both the fixed effect panel data method and the Arellano–Bond dynamic panel data estimation method, we can state that the results match with each other and all the selected indicators positively impact EU economic growth in the EU member states. As such, all the variables are significant except for the trade factor. The results of the paper are consistent with some other recent studies [21,29], in which the authors developed regression models to explain the economic growth explained by similar variables related to CE for EU member states. In the first study, that of [21], circular material, municipal waste, the trade of circular materials, labor productivity, environment tax, and resource productivity were all significant and positive to economic growth. The second study [20], resource productivity, recycling rate, environmental employment, and environmental innovation were all important to the GDP growth of EU countries. The novelty of our study is the categorization of variables based on the sustainable economic development triangle adopted for the circular economy (environmental—social—economic) and the examination of their effect of economic growth. To sum up, the study strongly confirmed the importance of the three components of the circular economy to economic growth for the case of EU28.

The results of both models used to determine the linkage between CE and EG highlight important results. The outcomes could be linked to other studies, which argue that environmental taxes are important drivers of economic growth [45]. Other studies confirm that the importance of recycling rates and environmental innovation are also significant factors of sustainable development and economic growth [6,43]. The significance of innovation in the recycling sector is supported by other studies that validate it as an essential factor in GDP growth [49,50]. Similarly to [25] and [46], our results concluded that the trade of recyclable raw materials has a positive impact on economic growth and sustainable development; however, contradictory to these studies, in our models, we could not confirm its significance.
This study strongly endorses the fact that the circular economy should be supported by the main actors of sustainable economy supports—the quadruple helix model of innovation—academia, government, business, and civil society. We use the term innovation because the circular economy itself is based on the fundamentals of innovation that make the sustainability triangle essential to economic growth. Moreover, the validation of all our hypotheses revealed the relationship between the circular economy factors and the need for collaboration among the quadruple helix model to support that the improvement of economic indicators is important to implement and advance circularity, which significantly contributes to economic growth.

Briefly, we can conclude that:

1. all CE indicators considered in this study are found to positively affect economic growth;
2. if the CE indicators are associated with the sustainable economic development triangle adopted for the circular economy (environmental–social–economic), the findings show that they have a positive effect on economic growth as well;
3. theoretically and empirically based, the study underpins the necessity of innovation in the core of CE;
4. this study emphasizes and strongly supports the stipulation of the collaboration among academia, government, business, and civil society.

The results of this study could be useful to policymakers and authorities that are engaged with the growth and development policies and implementation of the right structures and targets of relevant innovation. However, the used regression analysis could be further improved by adding other control variables and adding a longer time period. Another suggestion for future research could be the implementation of such models in a larger number of countries and making some comparisons among EU and non-EU countries.

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Appendix A

_Environment Tax Revenues_: The indicator is presented as the proportion of environmental tax revenues in gross domestic product (GDP). It is considered as a market internal factor which includes the contribution of all actors, such as consumers and producers, to the circular economy.

_Municipality (Waste Management)_

Recycling Rate of Municipal Waste: The indicator measures the share of recycled municipal waste in the total municipal waste generation. Recycling includes material recycling, composting, and anaerobic digestion.

_Innovation_

Private Investment, Jobs, Gross Value Added related to CE: The indicator includes: the gross investment in tangible goods, the number of persons employed, and the value-added at factor costs in the following three sectors: the recycling sector, the repair and reuse sector, and the rental and leasing sector.

Patents related to Recycling: The indicator measures the number of patents related to recycling and secondary raw materials. The term ‘patents’ refers to patent families, which include all documents relevant to a distinct invention (e.g., applications to multiple authorities), thus, preventing multiple counting. A fraction of the family is allocated to each applicant and relevant technology.
Open Economy

Trade-in Recyclable Raw Materials: The indicator measures the quantities of selected waste categories and by-products that are shipped between the EU member states (intra-EU) and across the EU borders (extra-EU). The indicator includes the following variables: “intra-EU trade of recyclable raw materials (measured as the Imports from EU countries),” “imports from non-EU countries and exports to non-EU countries of recyclable raw materials (as regards extra-EU trade).

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