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The Role of the Circular Economy in Economic Development: An Empirical Investigation for Panel of Some Selected European Economies

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Abstract

This study examines the relationship between the circular economy and economic development in 14 EU countries for the period 2000–2020.
Compared to previous work, we emphasize the importance of taking into account cross-dependencies and heterogeneity between the countries making up the Panel. Furthermore, the cointegration relationship employed in this work considers structural shocks and cross-dependencies using the test of Westerlund and Edgerton. This last test made it possible to validate the long-term relationship in the model. This study used the augmentedmean group technique to overcome some economic problems. Using Kónya's bootstrap panel causality test, we found that the causal relationship is only found in a few countries.
According to the empirical analysis conducted in this work, our findings indicate that economic growth, research and development and the generation of municipal waste favor the recycling and composting of municipal waste. In the same way, the recycling of municipal waste, research and development expenditure and the Generation of municipal waste increase positively the economic growth rate.
Our empirical results provide important policy implications for 14 EU countries that need to take adequate measures to improve the recycling rate through environmentally friendly technology to achieve a level of sustainable growth and development. Compared to previous studies, this work attempts to fill a gap in current research and enrich the existing literature between the circular economy and economic development in Europe.

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Introduction

The circular economy has become one of the themes that have received so much theoretical and empirical interest in recent years. This concept has developed to constitute a model to follow and replace the old paradigm of the so-called linear economy, by limiting the waste of resources and its effect on the environment through recycling but also by product design, thanks to eco-design, to develop objects or services designed to limit waste (Kampelmann 2016). The linear economy is considered to be a process of wealth creation based on the conversion of natural resources into waste through production (Bourdin and Maillefert 2020). This economic model is based on approach on the "take-make-dispose" and not able to maintain the balance between supply and demand in the consumption of natural resources (Ghisellini, Ripa, and Ulgiati 2018; Goyal, Esposito, and Kapoor 2018). In this sense, Andrews (2015) explains the limitations of the traditional linear economy and how the circular economy offers a more sustainable and efficient alternative. His study explores the role of designers in promoting the circular economy and highlights how design thinking can be used to create innovative solutions that support this economic model. As a result, current policies at the international level have changed direction in favor of growth models that face pollution growth by overcoming the old models based on the continuity of production and waste at all levels (Ghisellini, Cialani, and Ulgiati 2016). Sehnem et al. (2019) consider that the circular economy assumes that resources are unlimited and always available at low cost. This assumption seems unacceptable in the real world and cannot determine the long-term growth pattern.

A circular economy (CE) therefore includes, as a whole, all forms of the economy (Blomsma and Brennan 2017) built around circularity, in which materials, resources, waste, and energy are reused as much as possible to avoid waste. The idea of circular economy has two long parts, the first dealing with the movements of materials in an economy and the second involving thinking about the economic conditions that can lead to such movements (Ekins et al. 2019). The idea of reconciling economic development and ecological development dates back to the 1970s during the Stockholm conference in 1972 under the theme of eco- development. In Morocco, the circular economy is part of the strategic plan for the new development model at local, national, and global levels (Benmahane 2018). It can provide an impetus to face environmental challenges and meet the most pressing needs in the short and long term. It is supposed to be a necessary step for the achievement of the objectives of the new development model and an essential long-term milestone for sustainable development. To do this, various programs and plans have been launched to achieve the expected objectives of sustainable development. The implementation of an energy strategy (ENR) aims to exploit new sources of energy such as the transformation of waste and it also aims to use renewable energies as much as possible. This strategy makes it possible the countries to produce energy from renewable sources in the world. As Brundtland report (*Report of the World Commission…*, 1987) has pointed out this development model must meet the needs of the present, without undermining the ability of future generations to meet theirs. Furthermore, according to Kirchherr, Reike, and Hekkert (2017), CE is considered an economic system that seeks to reduce, reuse, recycle, and recover resources (Kristensen and Mosgaard 2020) through sustainable business models. In this way, CE represents a significant opportunity for companies by forcing them to go beyond their environmental and energy efficiency objectives (Leitão 2015). In this perspective, through a certain industrial symbiosis, the collaboration between companies in the same sector or different sectors could optimize the use of resources. This may involve the exchange of by-products, the reuse of waste from one company as raw material for another, or even the pooling of infrastructures. In addition, companies can also in a continuous cycle (The value loop) design products in such a way that they can be easily repaired, remanufactured, recycled, or reused, to maximize value throughout their life cycle (Bjørnbet et al. 2021). The circular economy is often seen as an opportunity for companies to extend the economic life of goods (Gregson et al. 2015), join efforts along the supply chain and also involve consumers, seeking to recover the value of these products throughout their life cycle.

A certain industrial ecology can be developed through this interaction between companies in a given region to optimize the flow of materials and energy between economic players in the same territory, thus promoting the circular economy at the local level. By doing so, they can make significant profits and create more employment in the market. Moreover, Tonelli and Cristoni (2018) indicate that most companies consider the circular economy as a risky and expensive system rather than a source of revenue generation. As the World Economic Forum (2014) report points out, if companies set up circular supply chains to increase recycling, reuse, and remanufacturing, one billion dollars and 100,000 new jobs could be created by 2025 (Kalmykova, Sadagopan, and Rosado 2018). According to the same report, this eco-design, waste prevention and reuse can bring an estimated net savings of up to Euros 600 billion to EU businesses, while reducing greenhouse gas emissions. In addition, other measures to increase resource productivity by 30% by 2030 could increase GDP by nearly 1% and also create an additional 2 million jobs (European Commission 2014a; 2014b). Mazur-Wierzbicka (2021) points out that in the case of European countries, CE is seen as a priority for development and an important element of industrial strategy. According to this last author, his analysis of 28 European countries shows that the most advanced countries begin to feel the problems of waste generation, exhaustion of resources, environmental pollution, increasing consumerism, or unbalanced consumption earlier than the less advanced countries. The latter, for lack of infrastructure, cannot get involved in the implementation of the EC.

The remainder of the study is organized as follows. Section 2 provides a literature review on the relationship between the circular economy and economic development. Section 3 presents econometric analysis, including the selection and analysis of the sample and model specifications, different tests of cross-sectional dependencies, cointegration, and causality with cross-sectional dependencies and heterogeneity. Finally, section 4 contains the most relevant conclusions and the most significant contributions of the study and policy implications.

Literature review

From the theoretical background, we can consider that the circular economy is a new production paradigm that can drive the economy toward long-term growth and maintain sustainable development (Korhonen et al. 2018; Arruda et al. 2021). A circular economy includes activities to reduce, reuse and recycle materials along the production chain, thereby reducing the harmful impact of economic activities on the environment (Ormazabal et al. 2018). Economic growth must be independent of environmental pressures to keep ecosystems resilient and prevent the effect on human well-being. The goal of CE is to change the status quo and inspire new business visions, and innovations that improve efficiency and competitiveness (De Jesus and Mendonça 2018). The circular economy offers potential environmental benefits, including reduced greenhouse gas emissions, energy savings, and conservation of natural resources (European Commission 2015).

Empirical investigations could assess the environmental impacts of circular economy practices and their relationship to economic development. This could involve analyzing indicators such as carbon footprints, resource productivity, and environmental certifications.

In international scientific research, there is a lot of discussion about the economy but very little attention is given to the existing link between the circular economy and economic growth (Kaivo-oja, Vehmas, and Luukkanen 2022). Dinda (2020) investigates the circular economy approach for sustainable economic development and finds that the circular economy model emphasizes the reuse of resources without degrading the environment, which is crucial for the future of our world. Using quantile regression, Horbach and Rammer (2019) find a positive relationship between CE innovation experienced by a panel of German firms in 2012 and 2014, and sales and employment growth in the case of German firms during the period 2014–2016. Simionescu (2020) used a macroeconomic approach based on panel data models (panel ARDL) from European countries (Cyprus, Latvia, Lithuania, Hungary, Poland, Romania, Slovenia, and Slovakia) and Bayesian random linear regression models analysis over the period 2008 to 2020. The results show that gross investment in material goods and more people employed in circular economy sectors are long-run factors to sustain economic development in these countries. By estimating two fixed effects models in the case of a panel of countries composed of 23 European countries, Ferrante and Germani (2020) found that the circular economy has a significant effect on employment and poverty reduction and that there is unidirectional causality between the circular economy and employment. Škrinjarić (2020) empirically assessed CE achievements of selected European countries by applying gray relational analysis (GRA), with a robustness check via MCDM (Multiple Criteria Decision) approach over the period 2010–2016. The results indicate regional differences between European countries in terms of their involvement in the circular economy. It was noted that the countries with higher GDP per capita, good infrastructure, education, and the development of R&D (research and development) such as Germany, Netherlands, Denmark, France, and Italy perform better than less developed countries such as Romania, Greece, Cyprus, Slovakia and Bulgaria. The last countries are lower ranked concerning the indices of corruption and organizational efficiency. These results seem to be confirmed by the work of Mazur-Wierzbicka (2021). Ghazi Alajmi (2016) examines whether municipal solid waste is influenced by economic activity or not, and the Environmental Kuznets Curve (EKC) hypothesis between economic growth and MSW in Saudi Arabia lasted from 1980–2012. The results show that this EKC hypothesis is not validated over the study period using a VECM model. The study conducted by Vuţă et al. (2018) assessed the effect of the circular economy on the economic growth of EU–28 countries over the period 2005–2016. The authors conclude that a circular economy is an excellent tool to move towards more sustainability in Europe. More recently, Georgescu, Kinnunen, and Androniceanu (2022) assess the relationship between the recycling of R&D expenditure, generation of municipal waste per capita, and the recycling rate of municipal waste influence the GDP per capita in a panel of 25 European countries during the period 2000–2018. In the first equation, the authors try to test the impact of R&D expenditure, generation of municipal waste per capita and the recycling rate of municipal waste influence the GDP per capita. In a second equation, they attempt to test whether these variables affect GDP per capita. To do this, the authors use two estimation methods (a fixed effects model and a Tobit model). Their results show that the recycling rate has a positive effect on economic development and vice versa. In this study, given the positive relationship between waste generation and GDP per capita, innovative measures need to be implemented by these countries to reduce waste generation and achieve sustainable development. Gardiner and Hajek (2020) investigate the relationships between municipal waste generation, R&D intensity, and economic growth in EU regions (old and new EU regions) between 2000–2018. This study shows that there is a long-term relationship between municipal waste production and economic growth. Furthermore, this work showed a positive two-way causality between municipal waste generation and GDP was observed for regions of old EU member states, while only a long-term one-way effect from GDP to the generation of municipal waste has been observed for the regions of the new EU Member States. In the short term, these results indicate bidirectional causality for the two categories of regions. Bianchi and Cordella (2023) examine a panel covering 28 European countries over the period 2010–2019. Their findings confirm that promoting a shift to more circular economic systems can reduce primary resource extraction. More recently, the empirical work of Feiferytė-Skirienė and Stasiškienė (2023) show the importance of structural shocks such as the global financial crisis of 2008–2009 on the durable transition. The results show that there is a short-term positive impact on environmental degradation and that economic interests prevail over environmental objectives and that following the Covid–19 crisis and the war between Russia and Ukraine, industrial behavior has shifted from sustainable to linear. The authors argue that, so far, countries' actions on sustainable transitions are insufficient and require drastic decisions and economic changes focused not only on short-term but also long-term solutions. From what has been cited above, it seems to us that the empirical work dealing with the relationship between the circular economy and economic development shows serious problems in the empirical analysis. Firstly, in the case of the panel, taking into account the dependencies between the individuals of the panel and secondly the importance of structural shocks is completely ignored. These last hypotheses can lead to a statistical bias and lead to retaining the wrong model in the analysis. To fill the gap in the literature, this paper aims to take into account all of these empirical considerations, in particular the impact of structural shocks and the hypothesis of dependencies that may exist between the countries analyzed in the panel context.

Econometric analysis

Data and models specification

This section will be devoted to the econometric examination of the relationship between the circular economy and economic development in a panel of 14 European countries (France, Germany, Spain, Netherlands, Belgium, Finland, Portugal, Czech Republic, Estonia, Cyprus, Hungary, Poland, Slovenia, and Slovakia). Our Datasets were collected from Eurostat and World Bank. This panel analysis will be based on a sample depending on the availability of data for the period 2000–2020. According to the seminal work of Georgescu, Kinnunen, and Androniceanu (2022), we will test the following two models:

The first-panel data model to be estimated has the form:

$$\ln RMU_{it} = \alpha_i + \beta_{1i} \ln GDPC + \beta_{2i} \ln RD + \beta_{3i} \ln GMW + \varepsilon_{it}. \quad (1)$$

The second-panel data model is:

The second-panel data model is:

$$\ln GDPC_{it} = \alpha_i + \varphi_{1i}\ln RMU + \varphi_{2i}\ln RD + \varphi_{3i}\ln GMW + \varepsilon_{it}, \tag{2}$$

where *RMU*, *GDPC*, *RD*, and *GMW* are respectively Recycling rate of municipal waste (% of total waste generated), GDP per capita (constant, USD 2015), Research and development expenditure (% of GDP), and Generation of municipal waste per capita (kg per capita). *t*: is the period term (2000–2020) and ε_{it}: The error term.

Unlike previous studies, in this work, we will try to test these two models by testing the presence of heterogeneity and independence for this panel composed of 14 EU. The long-term or cointegration relationship will be tested by taking into account the dependence between the individuals in the panel and the structural breaks, in particular the impact of the 2008 subprime crisis and the covid–19 crisis. According to the literature already mentioned, structural shocks can play an important role in the circular economy.

Estimation strategy

Before proceeding to the estimation of the two proposed models, we will first, test the hypothesis of independence between the countries by applying the Pesaran test (2004) and the heterogeneity hypothesis between countries (Pesaran and Yamagata 2008) will be applied. Second, we apply panel unit root and cointegration tests with dependencies and structural breaks. Finally, two tests of causality between the variables of the models will be done.

Panel independence and heterogeneity test

The test of the two hypotheses of cross-sectional dependencies and the homogeneity between the variables are important in econometric analysis. Depending on these latter assumptions, the choice of tests used in the empirical analysis, such as panel unit root tests and cointegration tests will be made. The following two tables (Tables 1 and 2) show respectively the cross-sectional dependence test and the homogeneity test in the data.

Table 1. CSD outcomes

	Eq.1	Eq.2
Breusch–Pagan LM	593.48*** (0.000)	403.85*** (0.000)
Pesaran-scaled LM	37.24*** (0.000)	23.19*** (0.000)
Pesaran CD	9.91*** (0.000)	3.74*** (0.000)

Note: (***) indicate the rejection of the null hypothesis (cross-sectional independance) at 1% level.
Source: authors' calculations.

The results of Pesaran, Ullah, and Yamagata (2008) showed that the p-value was 0.000 and therefore the null hypothesis – there is cross-sectional independence – is rejected at a significance level of 1%. We can conclude that there is a cross-sectional dependence between the series. It is worth noting here that ignoring cross-sectional dependencies introduces significant bias and scale bias (Pesaran 2006), suggesting that examining cross-sectional dependencies is a critical step in analyzing panel data. For the homogeneity test, it was analyzed using the delta tilde test and the adjusted delta tilde provided by Pesaran and Yamagata (2008). According to this test, the null hypothesis tested is the existence or not of heterogeneity in the panel. The results given in Table 2 show that the panel studied is heterogeneous because the hypothesis of homogeneity is rejected since the p-value is zero for the two types of underlying tests.

Table 2. Results of slope heterogeneity test

Eq.1	*Statistic*	*p-Value*
Δ^	7.092***	0.000
Δ^adj	7.882***	0.000
Eq.2	***Statistic***	***p-Value***
Δ^	19.143***	0.000
Δ^adj	21.276***	0.000

Note: (***) indicate the rejection of the null hypothesis (homogenous panel) at 1% level.
Source: authors' calculations.

In light of these test results, the panel unit root test and cointegration test regarding the cross-sectional dependence, accordingly, will be conducted.

Panel unit root test

Before any panel empirical estimation, it is important to test the order of integration of the series studied. In this work, we tried to use three types of test generations Breitung (2000), Choi (2002), Im, Pesaran, and Shin (2002), Levin, Lin, and Chu (2002), and Hadri test of Carrion-i-Silvestre, del Barrio-Castro, and Lopez-Bazo (2005). The results of these different tests are given in the following table (Table 3).

Table 3. Panel unit root tests

Variables	Breitung (2000) t-stat	Levin, Lin, and Chu (2002) t*-stat	Im, Pesaran, and Shin (2002) W-test	Choi (2002) Pm test	Carrion-I-Silvestre, del Barrio-Castro, and Lopez-Bazo (2005) LM(λ)-test Hadri test Homogenous Panel Heterogeneous Panel	
					Homogenous Panel	Heterogeneous Panel
ln*RMU*	1.30 (0.90)	**– 2.46***** (0.006)	– 0.40 (0.34)	– 0.17 (0.57)	– 1.85 (0.97) **[11.34]**	5.06 (0.000) **[37.90]**
Δ(ln*RMU*)	– 3.54** (0.000)	–	**– 8.91***** (0.000)	**21.44***** (0.000)	–	–
ln*GDPC*	4.05 (1.00)	– 0.67 (0.25)	– 1.19 (0.12)	**3.16***** (0.000)	0.932 (0.17) **[16.83]**	2.097 (0.018) **[41.01]**
Δ(ln*GDPC*)	5.24 (1.00)	– 0.13 (0.45)	**– 1.87**** (0.03)	–	–	–
ln*RD*	0.55 (0.71)	**– 2.29***** (0.01)	– 0.92 (0.18)	– 1.66 (0.95)	2.537 (0.006) **[13.07]**	20.751 (0.000) **[32.65]**
Δ(ln*RD*)	– 0.27 (0.39)	–	– 0.56 (0.28)	**14.73***** (0.000)	–	–
ln*GMW*	2.84 (0.99)	2.33 (0.99)	2.06 (0.98)	**1.58*** (0.06)	2.65 (0.004) **[12.569]**	17.553 (0.000) **[32.152]**
Δ(ln*GMW*)	0.76 (0.77)	**– 1.83**** (0.03)	– 0.93 (0.17)	**20.15***** (0.000)	–	–

Notes: For the test of Carrion-i-Silvestre, del Barrio-Castro, and Lopez-Bazo (2005), the number of breaks points has been estimated using LWZ information criteria allowing for a maximum m^{max} = 5 structural breaks. The long variance is estimated using the Bartlett kernel with automatic spectral window bandwidth selection as in Andrew (1991). The p-values and bootstrapped critical values are respectively in the brackets. (*), (**), (***) indicate the rejection of the null hypothesis (Unit root) respectively at 10%, 5% level and 1%.
Source: authors' calculations.

Before estimating the long-term relationship for the two models (1) and (2), we examine the stationarity of the variables. Overall, the first and second-generation tests provided respectively by Levin, Lin, and Chu (2002) and Im, Pesaran, and Shin (2003) give mixed results. Moreover, when we consider the assumption of cross-sectional dependence and the heterogeneity of our panel, the series exhibit their stationarities. As Hurlin and Mignon (2005) noted, the panel is no longer a mere collection of independent individuals, but a structure that can be subject, for example, to the influence of observable or unobservable common factors. Failure to take into account these cross-sectional dependencies can easily lead to a statistical bias. After showing the stationarity of the variables, the next step will be dedicated to examining the long-term relationship for the two models in question.

Panel cointegration test

The long-term analysis is carried out by the cointegration test with cross-sectional dependencies developed by Westerlund (2008) (Cointegration test of Westerlund-Durbin-Hausman 2008) and the test with transversal dependencies and structural breaks (Cointegration tests of Westerlund and Edgerton 2008). The last test takes into account the structural shocks already mentioned previously. These shocks can have an impact on the emission of waste and therefore on the circular economy. Taking them into consideration seems important to us to verify the long- term relationship given the period of analysis which spans between 2000 and 2020 and which is made up of several shocks, in particular the subprime crisis in 2008 and the COVID–19 period. Tables 4 and 5 show the results of the two cointegration tests.

Table 4. Westerlund (2008) Durbin-Hausman Cointegration Test

	*DH*g group statistics	*DHp* panel statistics
Eq.1	22.850 ***	5.359***
Results	**There's co-integration**	**There's co-integration**
Eq.2	6.501***	4.946***
Results	**There's co-integration**	**There's co-integration**
Critical values		
%1	2.33	2.33
%5	1.645	1.645
%10	1.28	1.28
For group statistics		For panel statistics
H0: No cointegration		H0: No cointegration
H1: Cointegration for all panel		H1: Cointegration for some countries

Note: (***) indicate the significance level at 1% for *DH*g and *DHp tests*.
Source: authors' calculations.

The statistics given for the Durbin Hausman group and the Durbin Hausman panel statistics reported in Table 4 show that the null hypothesis of no cointegration is rejected. We, therefore, conclude that the long-term relationship holds for both equations. Now we conduct the second cointegration test taking into account structural breaks and cross-dependencies. Table 5 gives the results of Westerlund and Edgerton (2008).

Table 5. Westerlund and Edgerton (2008) cointegration tests

	Zτ (N)		*Zφ (N)*	
	Value	*P-Value*	*Value*	*P-Value*
Equation 1 (with RMU)				
No break	0.223	0.558	– 1.091	0.138
Level break	– 10.644**	0.000	– 7.204**	0.000
Regime shift	– 6.269**	0.000	– 4.109**	0.000
Equation 2 (with GDPC)				
No break	0.323	0.373	– 1.236	0.108
Level break	– 3.723***	0.000	– 1.369***	0.000
Regime shift	– 7.901***	0.000	– 10.163***	0.000

Notes: The test is implemented using the Campbell and Perron (1991) automatic procedure to select the lag length. We use three breaks, which are determined by grid search at the minimum of the sum of squared residuals. The P-values are for a one-sided test based on the normal distribution. The null hypothesis of Westerlund and Edgerton test is non-Cointegration and (*), (**), (***) indicate the rejection of the null hypothesis respectively at 10%, 5% level and 1%.
Source: authors' calculations.

Westerlund and Edgerton (2008) tests clearly show the acceptance of cointegration with cross-sectional dependencies and structural breaks. Moreover, the non-cointegration is not accepted if we consider the two models without structural breaks. This test presents reliability much more than that provided by the first-generation tests which are based for the most part on critical values according to the normal law (Jabri and Brahim 2015).

The two methods of cointegration with dependencies and with dependencies and structural breaks indicate the existence of a long-term relationship between the variables. Therefore, long-term coefficients must also be obtained with the estimation of the parameters.

Estimation of the long-term relationship of the parameters

As the long-term relationship is verified, we will try to estimate the parameters of the models. For this proposal, we will estimate the two equations (1) and (2) by the AMG (Augmented Mean Group), FMLOS (Fully Modified Ordinary Least Squares), DOLS (Dynamic Ordinary Least Squares), and OLS (Ordinary Least Squares with fixed effect). We recall that the AMG method makes estimates by taking into consideration the two hypotheses the cross-sectional dependence and slope homogeneity in the panel.

Table 6. Panel long-run estimators

	AMG	FMOLS	DOLS	OLS-EGLS (fixed effects)
Equation 1 (with RMU)				
lnGDPC	2.69*** (0.000)	1.07*** (0.000)	1.05*** (0.01)	1.01*** (0.000)
lnRD	0.86*** (0.000)	0.34** (0.04)	– 1.87** (0.04)	0.26*** (0.000)
lnGMW	0.26* (0.08)	2.61*** (0.000)	2.56*** (0.002)	2.71*** (0.000)
Common Dynamic Process	0.93*** (0.000)			
Constant	– 26.67*** (0.000)			– 26.08*** (0.000)
Hausman test: p-value				19.60*** (0.000)
Equation 2 (with GDPC)				
lnRMU	0.06*** (0.000)	0.16** (0.02)	0.29*** (0.002)	0.21*** (0.000)
lnRD	0.10*** (0.000)	0.14*** (0.002)	0.15*** (0.007)	0.14*** (0.000)
lnGMW	0.18*** (0.000)	0.10*** (0.000)	0.08*** (0.000)	0.10*** (0.000)
Common Dynamic Process	1.06*** (0.00)			
Constant	9.14*** (0.000)			8.36*** (0.000)
Hausman test: p-value				(103.08)*** 0.000

Notes: Probability values are in brackets. (*), (**), (***) indicate the significance level at 10%, 5% level and 1%.
Source: authors' calculations.

The outcomes of the different estimation methods are presented in table 6. It turns out that the coefficients appear of the same sign for all the estimation techniques. Since our panel is characterized by a cross-sectional dependence and a heterogeneous panel, according to the AMG estimation method, we find that all the coefficients are statistically significant and with their expected signs. Our findings indicate that Economic growth, research and development, and the generation of municipal waste favor the recycling and composting of municipal waste. The recycling of municipal waste has a positive effect on the level of economic growth. If the recycling rate of municipal waste were to increase by 1%, GDP per capita would increase by 0.06%, and when Research and development expenditure were to increase by 1%, GDP per capita would increase by 0.10%. Regarding the Generation of municipal waste per capita (GMW), if it increases by 1%, the economic growth rate increases by 0.18% confirming previous work such as that of Razzaq et al. (2021) which highlighted that the recycling of solid waste municipalities stimulates economic growth. All of these results show that 14-EU countries must pursue their waste recycling policies to achieve economic growth and achieve a level of sustainable development. The last step of the estimation strategy consists in verifying the direction of causality between the variables. To do this, we will perform two causality tests. The first causality test is that of Dumitrescu-Hurlin (2012) between the variables for the whole panel and the second test is that of Kónya (2006) Bootstrap Panel Causality test. The Dumitrescu-Hurlin (2012) test is performed to test Granger causality for heterogeneous panel while the second Kónya (2006) test is applied to take cross-sectional dependence by country and slope heterogeneity features into account.

Panel Causality analysis

The cointegration relationship showed that there is really a long-term relationship between the variables, which also shows the possibility of the existence of a causal relationship between these variables. In this study, we will perform two causality tests: The Dumitrescu-Hurlin (2012) causality test whose null hypothesis to be tested is that of the non-causal relationship against the alternative hypothesis is that of causality between the variables. The Kónya (2006) Bootstrap Panel Causality tests consist in testing cross-section dependence and heterogeneity of the panel countries. The results are indicated respectively in the following Tables 7 and 8.

According to the results of Dumitrescu-Hurlin (2012), we find that there is a bidirectional causal relationship between the recycling rate to level to economic development and between the generation of municipal waste to recycling rate. Contrary to the work of Georgescu, Kinnunen, and Androniceanu (2022), a two-way causality is found from research and development to the recycling rate. Contrary to the work of Georgescu, Kinnunen, and Androniceanu (2022) a double causality is found from research and economic development to the recycling rate. In addition, a one-way causality from economic development to municipal waste generation and from the level of economic development to research and development.

Table 7. Summary of the Dumitrescu-Hurlin panel causality test

Null hypothesis	Causality	W-stat	Zbar-stat	P-Value
lnRMU > lnGDPC	lnRMU > lnGDPC	1.65	1.06	0.28
lnRMU > lnRD	lnRMU >> lnRD	6.73	2.92	0.003
lnRMU > lnGMW	lnRMU >> lnGMW	2.23	2.3	0.02
lnGDPC > lnRMU	lnGDPC >> lnRMU	2.27	2.39	0.02
lnGDPC > lnRD	lnGDPC >> lnRD	10.34	6.37	0.00
lnGDPC > lnGMW	lnGDPC >> lnGMW	2.08	2.00	0.04
lnGMW > lnRMU	lnGMW >> lnRMU	1.91	1.64	0.10
lnGMW > lnGDPC	lnGMW > lnGPDC	0.57	– 1.17	0.24
lnGMW > lnRD	lnGMW >> lnRD	2.23	2.31	0.02
lnRD > lnRMU	lnRD >> lnRMU	6.20	2.42	0.01
lnRD > lnGMW	lnRD >> lnGMW	3.74	5.45	0.00
lnRD > lnGPDC	lnRD > lnGPDC	2.48	– 1.28	0.26

Notes: The null hypothesis of Dumitrescu-Hurlin test is non-Causality. Probability values are in brackets. (*), (**), (***) indicate the rejection of the null hypothesis respectively at 10%, 5% level and 1%. >: No Causality and >>: Causality).
Source: authors' calculations.

These last results can be interpreted as follows. The more economic activity there is, the more municipal waste will be generated. In turn, the level of economic development favors research and development in these countries taken as a whole. We are now trying to verify these results by country by running the Kónya test (2006). The results are reported in Table 8.

Table 8. Kónya (2006) Bootstrap Panel Causality test

Country	RMU→DPC	RMU→RD	RMU→GMW	GDPC→RMU	GDPC→RD	GDPC→GMW
France	1.22 (0.30)	2.47 (0.59)	1.20 (0.28)	2.64 (0.11)	0.67 (0.41)	0.0005 (0.98)
Germany	2.74 (0.20)	0.66 (0.46)	0.008 (0.92)	2.61 (0.13)	1.20 (0.27)	0.42 (0.52)
Spain	6.74 (0.000)	0.25 (0.59)	0.25 (0.64)	0.08 (0.77)	0.89 (0.34)	0.08 (0.77)

Country	RMU→DPC	RMU→RD	RMU→GMW	GDPC→RMU	GDPC→RD	GDPC→GMW
Nether-lands	0.04 (0.80)	0.92 (0.38)	**4.78**** (0.04)	1.80 (0.19)	1.12 (0.29)	0.85 (0.36
Belgium	1.22 (0.20)	2.37 (0.16)	0.57 (0.47)	1.68 (0.19)	0.56 (0.45)	0.68 (0.41)
Finland	0.40 (0.60)	**6.32**** (0.02)	0.86 (0.77)	1.25 (0.27)	1.12 (0.29)	1.04 (0.30)
Portugal	0.16 (0.50)	0.98 (0.48)	0.04 (0.84)	1.35 (0.25)	0.05 (0.87)	0.53 (0.47)
Czech Rep.	1.42 (0.50)	0.28 (0.66)	0.01 (0.91)	2.22 (0.16)	0.38 (0.53)	0.20 (0.65)
Estonia	**2.76*** (0.10)	0.25 (0.63)	0.03 (0.96)	0.73 (0.40)	0.004 (0.94)	0.03 (0.85)
Cyprus	2.86 (0.10)	2.65 (0.11)	**7.90**** (0.006)	0.27 (0.62)	0.002 (0.96)	1.14 (0.28)
Hungary	0.03 (0.80)	2.65 (0.27)	0.001 (0.99)	0.06 (0.80)	1.40 (0.24)	2.22 (0.14
Poland	5.70 (0.10)	**3.65*** (0.06)	0.03 (0.86)	**4.47**** (0.04)	**4.19**** (0.04)	0.35 (0.55
Slovenia	1.18 (0.50)	1.77 (0.24)	0.82 (0.42)	1.62 (0.63)	0.43 (0.51)	0.004 (0.94)
Slovakia	5.27 (0.40)	1.19 (0.30)	**11.05**** (0.02)	2.08 (0.16)	0.17 (0.68)	0.48 (0.49)

Note: (*), (**), (***) indicate the rejection of the null hypothesis (non-Causality) respectively at 10%, 5% level and 1%. →: Direction of causality.
Source: authors' calculations.

Table 8. Kónya (2006) Bootstrap Panel Causality Test Result (continued)

Country	RD→RMU	RD→GDPC	RD→GMW	GMW→RMU	GMW→GDPC	GMW→RD
France	**2.86*** (0.09)	**4.47**** (0.03)	1.80 (0.18)	0.62 (0.43)	1.03 (0.31)	0.13 (0.72)
Germany	**3.58*** (0.06)	**11.93***** (0.000)	0.03 (0.85)	2.16 (0.14)	**3.96**** (0.05)	4.34 (0.04)
Spain	**9.37**** (0.002)	**22.86***** (0.000)	1.51 (0.22)	0.19 (0.66)	0.08 (0.77)	**14.49***** (0.000)
Netherlands	2.47 (0.11)	1.30 (0.25)	**12.98***** (0.000)	0.04 (0.84)	0.21 (0.65)	0.94 (0.33)
Belgium	**6.35**** (0.01)	**9.08**** (0.002)	0.29 (0.58)	0.32 (0.57)	0.66 (0.41)	16.44 (5.03)
Finland	1.62 (0.20)	0.69 (0.41)	1.03 (0.31)	**4.29**** (0.04)	**3.53*** (0.06)	**3.03*** (0.08)

Country	RD→RMU	RD→GDPC	RD→GMW	GMW→RMU	GMW→GDPC	GMW→RD
Portugal	0.61 (0.44)	**6.45*** (0.01)	1.32 (0.25)	0.96 (0.33)	6.41 (0.01)	0.03 (0.86)
Czech Rep.	**3.08*** (0.08)	1.70 (0.92)	0.82 (0.36)	**4.83**** (0.03)	**7.80***** (0.005)	2.14 (0.14)
Estonia	0.96 (0.33)	0.48 (0.49)	1.50 (0.22)	0.008 (0.93)	0.03 (0.87)	1.34 (0.25)
Cyprus	0.03 (0.87)	0.70 (0.40)	0.15 (0.70)	7.77 (0.005)	0.66 (0.42)	**5.39**** (0.02)
Hungary	1.63 (0.20)	1.48 (0.22)	2.27 (0.13)	2.57 (0.11)	0.04 (0.84)	1.25 (0.26)
Poland	**5.36**** (0.02)	**19.39***** (0.000)	1.17 (0.28)	4.98 (0.02)	**3.85**** (0.05)	1.02 (0.31)
Slovenia	0.47 (0.49)	2.67 (0.10)	**4.12**** (0.04)	1.64 (1.20)	0.67 (0.41)	1.53 (0.22
Slovakia	**2.82*** (0.09)	**3.60*** (0.06)	2.22 (0.14)	0.76 (0.38)	0.20 (0.65)	0.28 (0.60)

Note: (*), (**), (***) indicate the rejection of the null hypothesis (non-Causality) respectively at 10%, 5% level and 1%.

→: Direction of causality.
Source: authors' calculations.

According to the findings presented in Table 8, the null hypothesis of non-causality from the RMU to GDPC is rejected in one country (Estonia) of the 14 EU countries in the panel. This result may suggest that the other European countries in the panel should promote the recycling rate to achieve development sustainability. When the causality is analyzed from the RMU to RD and from the RMU to GMW, the non-causality is only found in 2 and 3 countries respectively. Moreover, the causality from GDPC to RD is found in the Poland case. Furthermore, there is causality from RD to RMU in France, Germany, Czech Republic, and Slovakia at a 99% significance level and in Spain, Belgium, and Poland at a 95% significance level. This explains that spending on research and development can play an important role in improving the recycling rate in these countries. The non-causality from RD to GDPC is rejected in 7 EU and from RD to GMW is causal relationship is accepted only in 2 EU countries. Concerning the causality from GMW to RMU, it is accepted in 2 EU, and from GMW to GDPC this causality is accepted only in 4 EU countries. Finally, the non-causality from GMW to RD is rejected in 3 EU countries.

Conclusion

This study examines the relationship between the circular economy and economic development in a panel of 14 European countries over the period 2000–2020. To do this, we have tried to emphasize the importance of taking into account the features of the panel, in particular cross-sectional dependence and heterogeneity. To the authors' knowledge, this is the first research study on the relationship between the circular economy and economic development by considering these two crucial assumptions in the panel analysis. Furthermore, previous studies investigating the relationship between circular economy and economic development overlook these two important assumptions which, according to Pesaran (2006), lead to significant biases and distortions. Similarly, we have tried to consider the structural shocks that play an important role in the implementation of the circular economy in the service of economic development. According to the cointegration methods of Westerlund (2008) and Westerlund and Edgerton (2008), we have shown that there is a long-term relationship in the two models. For the entire panel and considering only the heterogeneity of the panel (Dumitrescu-Hurlin 2012), the results indicate causal relationships between the variables. Moreover, by using the causality test with cross-sectional dependencies and heterogeneity (Kónya 2006), the causal relationship between the variables is not verified for some countries. This can allow us to assume that these countries should take adequate measures to improve the rate of recycling by improving clean technologies, creating economic growth, and achieving sustainable development respectful of the environment. Using AMG estimation which takes into account cross-sectional dependence and panel heterogeneity, we found that all parameters have their expected signs. Several reasons can explain these different cross-correlations such as the omission of common factors, spatial spillovers, and interactions within socio-economic networks (Pesaran and Tosetti 2011). In comparison with the other estimation methods (FMOLS, DOLS and OLS-EGLS with fixed effects) the parameters emerge with the same expected signs. From the first equation, we find that the level of development, R&D expenditures as well as municipal waste, have a positive effect on the recycling rate. In the second equation, the rate of recycling, R&D expenditures as well as municipal waste have a positive effect on the level of economic development. From these results, it appears that technological development promotes economic growth but not the quality of the environment. As a result, the countries studied must therefore take adequate measures to accelerate the rate of waste recycling by introducing environmentally friendly technologies. The use of these technologies can reduce the generation of waste and therefore a positive effect on sustainable development.

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Rola gospodarki o obiegu zamkniętym w rozwoju gospodarczym: badanie empiryczne dla panelu wybranych gospodarek europejskich

W artykule przeanalizowano związek między gospodarką o obiegu zamkniętym a rozwojem gospodarczym w 14 krajach UE w latach 2000–2020.
W porównaniu z poprzednimi pracami autorzy podkreślają znaczenie uwzględnienia wzajemnych zależności i niejednorodności pomiędzy krajami wchodzącymi w skład panelu. Co więcej, relacja kointegracji zastosowana w tej pracy uwzględnia wstrząsy strukturalne i wzajemne zależności dzięki zastosowaniu testu Westerlunda i Edgertona. Test ten pozwolił na walidację długoterminowej zależności w modelu. W badaniu wykorzystano technikę rozszerzonej grupy średniej w celu przezwyciężenia niektórych problemów ekonomicznych. Wykorzystanie bootstrapowej panelowej analizy przyczynowości Kónya pozwoliło na stwierdzenie, że związek przyczynowo-skutkowy występuje tylko w kilku krajach.
Przeprowadzona analiza empiryczna wskazuje, że wzrost gospodarczy, badania i rozwój oraz wytwarzanie odpadów komunalnych sprzyjają recyklingowi i kompostowaniu odpadów komunalnych. W ten sam sposób recykling odpadów komunalnych, wydatki na badania i rozwój oraz wytwarzanie odpadów komunalnych pozytywnie wpływają na tempo wzrostu gospodarczego.
Uzyskane wyniki badań empirycznych mają istotne implikacje dla 14 krajów UE, które muszą podjąć odpowiednie działania w celu zwiększenia poziomu recyklingu za pomocą technologii przyjaznych dla środowiska, aby osiągnąć poziom zrównoważonego wzrostu i rozwoju.
W porównaniu z poprzednimi badaniami niniejszy artykuł ma na celu wypełnienie luki w dotychczasowych badaniach i wzbogacenie istniejącej literatury na temat gospodarki o obiegu zamkniętym i jej związku z rozwojem gospodarczym w Europie.

Słowa kluczowe: gospodarka o obiegu zamkniętym, rozwój gospodarczy, zależności przekrojowe i niejednorodność, analiza panelowa kointegracji, rozszerzona grupa średnia, analiza panelowa przyczynowości