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Published in:
Journal of Business Economics and Management

DOI:
10.3846/jbem.2022.16050

Published: 01/01/2022

Journal of Business Economics and Management
ISSN 1611-1699 / eISSN 2029-4433
2022 Volume 23 Issue 1: 199–217
https://doi.org/10.3846/jbem.2022.16050

EMPIRICAL EVIDENCE ON CIRCULAR ECONOMY AND ECONOMIC DEVELOPMENT IN EUROPE: A PANEL APPROACH

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Received 07 June 2021; accepted 18 October 2021

Abstract. Sustainable economic growth is desired to be achieved by governments targeting economic, social, and environmental benefits. The idea of circular economy model is to consider feedback effects from proper waste management instead of one-way effects typical with the classical linear model. Several sectors of society contribute to circular economy and its monetary and environmental outputs in a sustainable way. The aim of this paper is to analyze the dependencies and causalities of circular economy and economic developments in the EU. The research objectives include testing (i) whether research and development (R&D) expenditure, GDP per capita and generation of municipal waste per capita influence the recycling rate of municipal waste, and (ii) whether R&D expenditure, generation of municipal waste per capita and the recycling rate of municipal waste influence the GDP per capita. The relevant indicators are obtained from Eurostat. The research methods of fixed effects and Tobit approach are used to study the statistical relevance of the two models. The pairwise causality of variables is tested by Dumitrescu–Hurlin causality test. One result of the study is that technology development, by a decreasing life of products, leads to an increase of waste generation. Therefore, environmentally friendly technologies should be produced.

Keywords: circular economy, economic development, competitiveness, fixed effects model, Tobit model, Granger causality.

JEL Classification: C51, O11, Q56.

Introduction

In a world facing huge challenges, fast economic, environmental and technological changes occur. These fast transformations require a change in the economic model of development. Thinking in the terms of linear economy is justifiably challenged by a practical model to

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utilize reusable by-products of economic growth, which have been neglected by the linear model, which typically builds on the using scarce resources to maximal production without accounting for degradation of the natural environment.

Circular economy is about efficient production of economic value-added while mitigating the amount of waste by-produced by the economic and social environment (Ellen MacArthur Foundation, 2013). Full product and service life cycles must be considered. The linear model says that the products are usually thrown away or stored when a life cycle ends. A new three-step approach is proposed by the circular economy model: reduction-reuse-recycling. Therefore, the long-term development needs of humanity should be put in harmony and resources should efficiently recirculate through adaptation of populations and infrastructure to limit the produced waste from the economic process, while not reducing well-being of people through the transition.

The circular model is promoted by the EU governance and implemented on national level to replace the linear economic model. This requires a coordination to redesign production schemes and business models. UK, Germany, Netherlands and Nordic countries, for instance, have adopted some forms of circular economy with expenditures directed for the purpose. The transition towards circular economy reduces environmental degradation, improves the effectiveness and security of raw materials supply, while innovation and economic growth is stimulated, which leads to to better competitiveness and more jobs. Consumers are expected to benefit from innovative solutions for sustainable broad R&D applications by enhancing the quality of life in a monetarily effective way (Morgan, 2020; Geissdoerfer et al., 2017).

In this paper, we analyze the impacts and causalities that the transition stage towards the circular economy has had on economic development in EU countries and vice versa (cf. Connolly-Barker et al., 2020), continuing the paper by Androniceanu et al. (2021). This research includes 25 EU countries focusing on sustainable economic growth (Dobson-Lohman, 2020; Kot & Brzezinski, 2015). The research is conducted on the panel data of the time-series of the selected indicators (Moraga et al., 2019). By means of correlative and causal analysis, two research questions can be specified: (i) Do research and development expenditure (R&D), GDP per capita and generation of municipal waste per capita influence the recycling rate of municipal waste in a statistically significant way? (ii) Do R&D expenditure, generation of municipal waste per capita and the recycling rate of municipal waste influence the GDP per capita in a statistically significant way?

The results show strong relationships implying that the more advanced circular economy, the greater the impact on the sustainable economic growth in the EU countries under study. Thus, circular economic model is feasible, sustainable as well as value-adding strategy to implement for the economies of EU member states (Monni et al., 2017; Androniceanu, 2020).

In the first section, the theoretical background is discussed with respect to literature. In Section 2 the data, hypotheses and methodology are presented. The analysis is conducted in Section 3 and discussed with policy implications in Section 4. Finally, the paper is concluded with some future research suggestions.

1. Theoretical background

The generic term *circular economy* refers to an industrial economy with a technical/industrial production using resources efficiently so that the resources are recycled or returned to environment without negative environmental externalities. Circular economy concept has been under study, but the fast-developing field has still serious research gaps to be identified and solved by research. Boulding (1966) discussed an economic model with circular flows of material, but the term circular economy was first used by Pearce and Turner (1990) in their critique of the linear economic model for its negative environmental implications. Steffen et al. (2015) noted that the linear model lacks sustainability specifically as natural resources have restrictions for their availability and accessibility. In the world of diminishing resources and increasing pollution, life is endangered making the linear model obsolete (Nassar & Tvaronavičienė, 2021; Andryeyeva et al., 2021; Marino & Pariso, 2021; Androniceanu, 2019).

The Circular Economy is a reduction, reuse and recycling-based system since waste is a valuable resource (Kirchherr et al. 2017; Murray et al., 2017; Rizos et al., 2017). Used or defective products can be repaired and used again, other products can be reused directly, others can be recycled. The implementation of the circular economy will implicitly lead to: reducing the amount of generated waste; increasing the productivity of the resources used; consideration of waste as a valuable product; encouraging the recycling of valuable materials; decreasing the destructive impact that production and consumption processes have on the environment (Liu et al., 2009; Geng et al., 2013).

In the circular economy model, economic growth can be achieved by decreasing the use of natural resources through re-cycling the materials, already within the system and the lower use of natural resources (Esposito et al., 2015). Thus, circular economy contributes effectively to sustainable economic development (Geng et al., 2012; A.-M. Androniceanu, et al., 2020). Banaitė (2016) demonstrated that circular economy decreased the use of natural resources, while the consumption of energy rose, leading to increasing pollution (Ionescu, 2020; Nekmahmud et al., 2020). Beneficially, circular economy has shown to maintain the value of recycled materials, while the generation of waste has been minimized (Bayar et al., 2020; Borocki et al., 2019; Çera et al., 2020; Grondys et al., 2021). To continue as before, the exploitation-production-disposal economy should consume the resources of three planets Earth by 2050 (Stott et al., 2010). Moreover, half of greenhouse gas emissions and over 90% of biodiversity loss are generated by the production and use of new materials. These are the reasons why the transition to a use-reuse-regeneration economy is extremely important for protecting the environment and building a sustainable future.

The EU produces over 2.5 billion tonnes of waste annually and it has updated the legislation on waste management with the purpose to promote a more sustainable circular economic model. An estimated 95% of the plastic packaging value waste due to the lack of recycling creates economic and environmental losses in the EU (Ohanyan & Androniceanu, 2017; Meyer et al., 2017).

Even if the circular economy concept may be motivated by environmental reasons, most reports and research supporting the legislative package approved by the EU in 2015 bring out several motivations and deeper implications for medium and long-term economic developments. The EU has set specific targets, e.g. to the collect 90% of water bottles by 2029, to recycle 25% of plastic bottles by 2025 and 30% of all plastic products by 2030. The EU is creating legislative incentives for the EU states and promoting industrial cooperation to circulate material from one industrial sector to another. Circular economy is presented as an emerging sustainable development strategy for the EU (Siekelova et al. 2020; Tamulevičienė & Androniceanu, 2020; Mazzoni, 2020; Nikanorova & Stankevičienė, 2020; Stankevičius et al., 2020).

Some studies show that the European Union has diverse results regarding the transition to the circular economy. For example, Italy and Spain have demonstrated transitional circular developments while, many countries are still lacking a national circular economy strategy. 300 corporate executives were surveyed on the actions taken in European companies (Haller, 2020): almost 95% considered circular economy as a strategic option to create competitive advantage through diversification and cost reductions with increasing market share; however, creation of value was seen uncertain and with the lack of skills this could hinder the adoption of the circular model in Europe.

In this paper, 25 countries of the European Union for which data is available, are studied using time series for the period 2000–2018 based on key indicators that reflect the changes corresponding to the three dimensions of this research: circular economy, economic development, and environment. The research methodology presented in section 2 and applied in section 3 reflects the transformations which occur in the European system and reveals their causality, impact, and effects.

The results imply that there is a great potential to develop and be competitive through implementation of the circular economy model. The paper is a continuation of Androniceanu et al. (2021), where the circular economy model is studied by cross-country approach applying Principal Component Analysis for EU countries in 2019. The contribution of this paper consists in evaluating the correlation between circular economy indicators and economic development by extending the previous research of the authors, using a fixed effects model (FEM) and a Tobit model. GDP per capita and recycling rate of municipal waste, respectively, are considered as the dependent variables. The findings show that economic development is strongly associated with recycling waste rate and generation of municipal waste per capita. In the context of demographic growth, waste generation is related to consumer behavior. As income increases, waste generation increases too. Granger causality test for panel data proposed by Dumitrescu and Hurlin (2012) is applied and the results indicate a bidirectional causality between GDP per capita and recycling rate of municipal waste.

The circular economy model recycling is an essential element in the policies of waste management. The disposed production waste is recycled and used continually, made into new products in a circular way. Since more waste is generated, of great importance are the policies which reduce the negative effects for environment, climate, planet in general. The recycling efficiency is measured by the recycling rate of municipal waste, computed as the tonnage recycled from the municipal waste divided by the total municipal waste. Several papers study the correlation between the recycling efficiency and economic growth. Tantau et al. (2018) use a panel model consisting of 28 EU members and period 2010-2014 and by means of the Durbin-Wu-Hausman test decide that the random effects model is valid. The conclusion of the paper by Tantau et al. (2018) is that the domestic material consumption and resource productivity are in a significant correlation with the recycling rate of municipal waste. Rincón-Moreno et al. (2021) summarize a set of circular economy indicators proposed by European Commission with the purpose of helping companies propose and apply their own strategies in circular economy. Busu and Trica (2019) find that the circular economy indicators have a strong influence on economic growth. The model validation is done by the pooled least square (PLS) method, which showed that the greatest impact on economic growth belongs to real labor productivity, followed by resource productivity and recycling rate of municipal waste. A similar analysis was done by Busu (2019), Trica et al. (2019) applying the same PLS model and concluding that the environmental circular economy variables correlate significantly with economic growth. Ferrante and Germani (2020) estimate two fixed-effects regressions with robust standard errors, showing that employment in circular economy is strongly correlated with socio-economic and development indicators (Kosach et al., 2020; Androniceanu, 2021). A uni-directional causality from circular economy to employment is also revealed. Gardiner and Hajek (2020) find a short and long run bidirectional causality between waste generation and economic growth in EU using a panel vector error correction model. Ghazi Alajmi (2016) applied a vector error correction model and Granger causality test and found that a high rate of economic growth leads to an increase of municipal solid waste in Saudi Arabia. Magazzino et al. (2020) explore the connection between the municipal waste generation and GDP in Switzerland during 1990–2017 using causality and machine learning techniques. The relationship between generation of municipal waste per capita and GDP has been examined several times by means of EKC (Environmental Kuznets Curve) hypothesis (Kuznets, 1955). EKC is an inverted U-shape curve depicting the relation between environmental degradation and GDP per capita. So, municipal waste per capita increases, then decreases, when GDP per capita increases., according to EKC. Jaligot and Chenal (2018) study if the EKC (Environmental Kuznets Curve) hypothesis is verified for environmental and socio-economic development indicators. For Switzerland, one of the top producers of municipal solid waste per capita, Jaligot and Chenal (2018) prove that by verifying the ECK curve, waste generation becomes stable as income increases. Razzaq et al. (2021) estimate by an ARDL model that municipal solid waste recycling stimulates economic growth in the long-run and in the short-run as well. According to the group coordinated by Ghisellini (Ghisellini et al., 2014), there are three principles of the circular economy: eco-design, reuse of products and materials and the transformation of industrial waste into valuable nutrients. Through eco-design, biological nutrients can simply be composted. Technical materials – polymers, alloys and other man-made/processed materials can be designed in such a way that they can be reused/taken over in a new field – recycling with higher value, minimizing energy consumption. Products must be designed so that they can be reused, repaired and reproduced. Regeneration of resources by natural ecosystems by returning valuable nutrients to the soil and natural ecosystems can enrich the planet's resources (Greyson, 2007).

Over time, the cross-country approach in the study of environmental degradation and economic development was used by Dasgupta et al. (2001), Shi (2003), etc. The panel data approach was preferred to the cross-section and time series approaches because economic development varies over time and over country (Arbulú et al., 2015; Jaligot & Chenal, 2018).

Jaligot and Chenal (2018) emphasize a few advantages of panel data approach to cross-section and time series approaches: the model parameters can be estimated with a better accuracy due to the more degrees of freedom of panel data models; the dynamics of the social and economic determinants is better reflected by such models; the heterogeneity taken into account by panel data approach is more realistic unlike the homogeneity contained in cross-sectional data.

2. Data and methodology

The fixed effects model for panel data for 25 EU countries for 2000–2018 is applied, with the study of the determinants of GDP per capita and recycling rate of municipal waste, respectively, in the context of circular economy. At the same time, applying the Tobit model for the same cases, similar results are obtained here. The advantage of using fixed-effects approach is advantageous due to varying amount of waste generated, recycling waste rate and economic development over time.

Table 1. The definitions of variables

Variable	Description
GDP	GDP per Capita (PPP, USD 2010)
RMU	Recycling rate of municipal waste (% of total waste generated)
R&DEXP	Research and development expenditure (% of GDP)
GMW	Generation of municipal waste per capita (kg per capita)

Five proposed hypotheses have been validated by both fixed effects model and Tobit model, so that the correlations between variables are in accordance with economic theory. The aim is to study the relationship between economic growth, recycling rate of municipal waste, research and development expenditure and generation of municipal waste per capita in several European countries for which there is available data. The relationship between the three variables is determined by fixed and random effects modes. The 25 European countries under analysis are Belgium, Bulgaria, Czech Republic, Denmark, Germany, Estonia, Ireland, Greece, Spain, France, Italy, Cyprus, Latvia, Lithuania, Luxembourg, Hungary, Netherlands, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Finland, and Sweden. Datasets were collected from Eurostat and World Bank. In Table 1, the definitions of variables are presented.

To quantify the impact of circular economy indicators and economic development, five statistical hypotheses are formulated:

Hypothesis 1: Recycling rate of municipal waste (RMU) has a positive effect on economic development (GDP) and conversely.

Hypothesis 2: Research and development expenditure (R&DEXP) has positive effects on recycling rate of municipal waste (RMU).

Hypothesis 3: Research and development expenditure (R&DEXP) has a positive effect on economic development (GDP).

Hypothesis 4: Generation of municipal waste per capita (GMW) has s positive effect on recycling rate of municipal waste (RMU).

Hypothesis 5: Generation of municipal waste per capita (GMW) has a positive effect on economic development (GDP).

These five statistical hypotheses will be tested with multiple linear time series regression.

The panel dataset consists in observations on the entities (here, countries) over time. The effects that cannot be detected in cross-section or time-series data are better identified by panel data. Econometrically, (Baltagi, 2014) the model is:

$$y_{it} = \alpha + \beta x_{it} + u_{it} + \delta_i + \gamma_t, \quad (1)$$

where y_{it} is the dependent variable, α is the intercept, β is a *k*x1 vector of parameters to be estimated on the explanatory variables x_{it}, $i = 1,...,N, j = 1,...,T$, *I* – country index, *t* – time index, u_{it} is the residual term, γ_t and δ_i are the (fixed or random, respectively) effects for cross-section unit or for time series. T is the number of periods (19 years) and N is the number of countries (25 European countries).

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

$$\ln RMU_{i,t} = a_1 + a_2 \ln GDPPERCAP_{i,t} + a_3 \ln R\&DEXP_{i,t} + a_4 \ln GMW_{i,t} + \delta_i + \varepsilon_{i,t}. \quad (2)$$

The second panel data model is:

$$\ln GDPPERCAP_{i,t} = b_1 + b_2 \ln RMU_{i,t} + b_3 \ln R\&DEXP_{i,t} + b_4 \ln GMW_{i,t} + \delta_i + \varepsilon_{i,t}, \quad (3)$$

where $a_k, b_k, k = 1,...,4$ are the coefficients to be estimated, δ_i are (fixed or random) specific effects for the cross-sectional units, and $\varepsilon_{i,t}$ is the residual term.

The following panel data estimators are used: pooled OLS and fixed effects estimator, by applying the Hausman test (Hausman, 1978). Pooled OLS estimator starts from the hypothesis that all cross-sectional units are identical and does not take into account heterogeneity. Fixed effects estimator assumes the unobserved heterogeneity across the cross-sectional units. In determining the choice between the random and fixed effects model, Hausman test is applied. The Hausman test compares the random effects and the within estimator. If the null hypothesis is rejected, the fixed effects model is accepted.

After fitting the best fixed effects models (FEM) and Tobit models, the pairwise duality by means of Dumitrescu–Hurlin (2012) panel causality test is studied.

3. Results of the research

The range the four variables for the 25 European countries over the period 2000–2018 is represented in Figure 1.

OLS for fixed /random effects panel is used. The first step in analyzing a panel is to decide the most appropriate model: pooled OLS regression (POLS) or a panel model (Baltagi, 2014). Thus, redundant Fixed Effects Tests will be used, and two tests, Cross-section F and Cross-section Chi-square, are intended to assess the similar significance of the effects of the cross section.

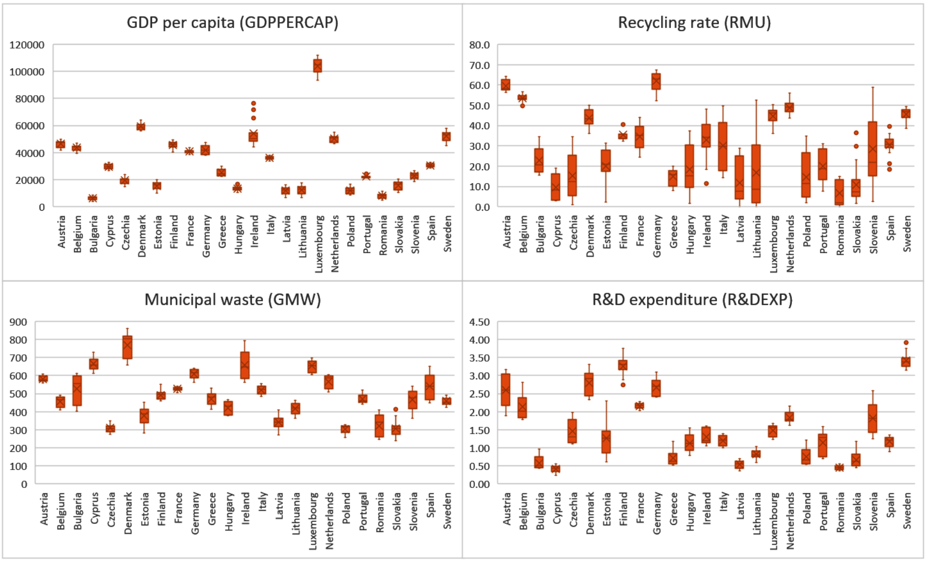

Figure 1. Box plot of the four indicators during 2000–2018

For this purpose, Redundant Fixed Effects Tests – Likelihood Ratio is performed. The hypotheses of the Redundant Fixed Effects Tests are:

H_0: POLS is preferred.

H_1: Fixed effects model (FEM) is preferred.

Table 2. Summary of the Redundant Fixed Effects test

Effects test	Statistic	d.f	Prob.
Cross-section F	20.595511	(24,441)	0.0000
Cross-section Chi-square	352.600849	24	0.0000

The probabilities associated with the two tests (cross-section F test and cross-section Chi-square) are 0.000 < 0.05 (Table 2), suggesting that the null hypothesis is strongly rejected. In other words, the fixed effect model (FEM) is preferred rather than POLS.

The next step is to conduct the Hausman test to decide between FEM or random effects model (REM). The hypotheses of the Hausman test are:

H_0: REM is preferred.

H_1: FEM is preferred.

According to Table 3, the *p*-value of the Hausman test (Hausman, 1978) is 0.00 < 0.05, suggesting that null hypothesis H_0 was rejected. In conclusion, FEM will be applied.

According to Table 4, FEM is statistically significant (R^2 = 0.79). Adjusted R^2 is 0.78, which means that about 78% of RMU variation is explained by the independent variables in model (2). Fixed effects are justified by the country-specific aspects, which are quite stable in time. One can see that all coefficients, except GMW Generation of municipal waste per capita are statistically significant at 5% significance level.

Table 3. Summary of the Hausman test

Test Summary		Chi-Sq. statistic	Chi-Sq. d.f.	Prob.
Cross-section random		191.852903	3	0
Cross-section random effects test comparisons				
Variable	Fixed	Random	Var(Diff.)	Prob.
ln R&DEXP	1.014523	0.886746	0.007224	0.1327
ln GMW	–0.072356	–0.433917	0.021549	0.0138
ln GDPPERCAP	2.889271	1.020424	0.024237	0

Table 4. Summary of FEM-Determinants of recycling rate of municipal waste

Variable	Coefficient	Std. error	t-statistic	Prob.
C	–26.16501	2.426929	–10.78112	0
ln R&DEXP	1.014523	0.131963	7.687904	0
ln GMW	–0.072356	0.244706	–0.295686	0.7676
ln GDPPERCAP	2.889271	0.195546	14.77541	0
Cross-section fixed (dummy variables)				
Root MSE	0.462126	R-squared		0.794783
Mean dependent var	3.056675	Adjusted R-squared		0.782219
S.D. dependent var	1.021215	S.E. of regression		0.476571
Akaike info criterion	1.413444	Sum squared resid		100.1598
Schwarz criterion	1.661241	Log likelihood		–303.4526
Hannan-Quinn criterion	1.510942	F-statistic		63.25729
Durbin-Watson stat	0.568825	Prob(F-statistic)		0

Economic development represented by GDP per capita has a positive effect on Recycling rate of municipal waste, confirming Hypothesis 1. 1% increase in GDP per capita leads to 2.88% increase in RMU. Research and development expenditure (R&DEXP) has a positive impact on Recycling rate of municipal waste, confirming Hypothesis 2. Similarly, 1% increase in R&DEXP leads to 1.014% increase in RMU.

Next, the Tobit model will be applied.

Table 5. Determinants of RMU – summary of the Tobit model

Variables	Tobit model			Expected sign
	Coefficient	Z-Statistics	Prob.	
C	–3.822328	–4.943868	0.0000	
ln R&DEXP	0.827170	12.09392	0.0000	+
ln GDPPERCAP	0.245357	3.115116	0.0018	+
ln GMW	0.680393	4.468058	0.0000	+

In Table 5 one can see that all coefficients are statistically significant at 5% significance level. Economic development has a positive effect on Recycling rate of municipal waste, which confirms Hypothesis 1. 1% increase in GDP per capita leads to 0.245% increase in RMU. The same hypothesis is confirmed by Ghazi Alajmi (2016) for Saudi Arabia.

Generation of municipal waste per capita (GMW) has a positive impact on RMU, confirming Hypothesis 4. 1% increase in GMW leads to 0.68% increase in RMU.

Research and development expenditure (R&DEXP) has a positive impact on RMU, confirming Hypothesis 2. 1% increase in R&DEXP leads to 0.827% increase in RMU.

The confirmation of Hypothesis 2 can be interpreted that technology development (Walker et al., 2020), by a decreasing life of products, leads to an increase of waste generation (Gardiner & Hajek, 2020). This is a negative aspect in the circular economy model, thus environmentally friendly technologies should be produced.

Table 6. Summary of the Redundant Variables Likelihood Ratio test

Null hypothesis: ln R&DEXP, ln GMW and ln GDPPERCAP are jointly insignificant			
	Value	d.f.	Prob.
Likelihood ratio	390.149	3	0

It is tested whether the explanatory variables GDP per capita, R&DEXP and GMW contribute to the fit of the model. The Redundant Variables Likelihood Ratio test is applied, having as null hypothesis the jointly insignificance of all explanatory variables. Since the *p*-value is $0.00 < 0.05$, it follows that the null hypothesis is rejected (Table 6).

Next, the second model is under discussion, when ln GDPPERCAP is the dependent variable, and ln RMU, ln R&DEXP and ln GMW are regressors.

Table 7. Summary of the Redundant Fixed Effects test

Effects test	Statistic	d.f.	Prob.
Cross-section F	312.459549	(24,441)	0.0000
Cross-section Chi-square	1355.704229	24	0.0000

The probabilities associated with the two tests (cross-section F test and cross-section Chi-square) are $0.000 < 0.05$ in Table 7, suggesting that the null hypothesis is strongly rejected. In other words, the fixed effect model (FEM) is preferred rather than POLS.

According to Table 8, the *p*-value of the Hausman test is $0.00 < 0.05$, suggesting that the null hypothesis was rejected. In conclusion FEM will be applied.

According to Table 9, the general performance of the FEM model is very satisfactory. The explanatory power of the regression is very high ($R^2 = 0.98$).

Adjusted R^2 is 0.98, which means that about 98% of GDP per capita variation is explained by the independent variables in model (3). One can see that all coefficients, except generation of municipal waste per capita (GMW) are statistically significant at 1% significance level.

Table 8. Summary of the Hausman test

Test summary		Chi-Sq. statistic	Chi-Sq. d.f.	Prob.
Cross-section random		30.098675	3	0
Cross-section random effects test comparisons				
Variable	Fixed	Random	Var(Diff.)	Prob.
ln RMU	0.114604	0.113361	0	0.0158
ln R&DEXP	0.092745	0.115967	0.000027	0
ln GMW	0.051745	0.094252	0.000069	0

Table 9. Summary of FEM – determinants of GDP per capita

Variable	Coefficient	Std. error	t-Statistic	Prob.
C	9.49803	0.301066	31.54797	0
ln RMU	0.114604	0.007756	14.77541	0
ln R&DEXP	0.092745	0.027637	3.35579	0.0009
ln GMW	0.051745	0.048679	1.062998	0.2884
Cross-section fixed (dummy variables)				
Root MSE	0.092038	R-squared		0.98239
Mean dependent var	10.18818	Adjusted R-squared		0.981311
S.D. dependent var	0.694298	S.E. of regression		0.094915
Akaike info criterion	–1.813834	Sum squared resid		3.97287
Schwarz criterion	–1.566037	Log likelihood		453.344
Hannan-Quinn criterion	–1.716335	F-statistic		911.1531
Durbin-Watson stat	0.299641	Prob(F-statistic)		0

Recycling rate of municipal waste has a positive effect on GDP per capita, validating Hypothesis 1. If Recycling rate of municipal waste were to increase by 1%, GDP per capita would increase by 0.11%.

Research and development expenditure (R&DEXP) has a positive impact on GDP per capita, confirming Hypothesis 3. If Research and development expenditure were to increase by 1%, GDP per capita would increase by 0.09%. Hypothesis 3 is validated by several studies, in the sense that investments in R& D are among the main determinants of GDP per capita, leading to increased productivity (Santos & Catalao-Lopes, 2014; Gumus & Celikay, 2015).

Generation of municipal waste per capita (GMW) has a positive impact on economic development, confirming Hypothesis 5. If GMW were to increase by 1%, GDP per capita would increase by 0.05%. Hypothesis 5 is also validated by Razzaq et al. (2021), who argued that by municipal solid waste recycling and composting, economic activity and implicitly, sustainable development is achieved. Presently municipal solid waste is presently treated much more by recycling and incineration, instead of landfilling (Joseph et al., 2020; Trulli et al., 2013). Other authors (Khajuria et al., 2012) proved that for India, GMW increases, then decreases when GDP increases, respecting the inverted U-shape of EKC.

Table 10. Determinants of GDP per capita – summary of the Tobit model

Variables	Tobit model			Expected sign
	Coefficient	Z-statistics	Prob.	
C	3.0679	31.547	0.0000	
ln RMU	0.0826	14.775	0.0018	+
ln R&DEXP	0.4924	3.355	0.0000	+
ln GMW	1.0967	1.062	0.0000	+

Applying the Tobit model (Table 10), it is found out that all the regressors are statistically significant and the expected sign is correct.

Table 11. Summary of the Redundant Variables Likelihood Ratio test

Null hypothesis: ln RMU, ln R&DEXP and ln GMW are jointly insignificant			
	Value	d.f.	Prob.
Likelihood ratio	538.7135	3	0

It is tested whether the explanatory variables ln RMU, ln R&DEXP and ln GDP contribute to the fit of the Tobit model (Table 11). The Redundant Variables Likelihood Ratio test is applied, having as null hypothesis the jointly insignificance of all explanatory variables.

Since the p-value is $0.00 < 0.05$, it follows that the null hypothesis is rejected, therefore all explanatory variables contribute jointly to the fit of the Tobit model, when GDP per capita is the dependent variable. Consequently, all explanatory variables contribute jointly to the fit of the Tobit model.

The Dumitrescu–Hurlin (2012) causality test is applied to test Granger causality for heterogeneous data panels (Granger, 1969). By means of the Wald test, the Dumitrescu-Hurlin test checks the null hypothesis of no causal relation for the cross-sections in the panel. The alternative hypothesis is the existence of Granger causality for some proportion of the cross-sectional data. For one lag, Wbar and Zbar statistics are contained within Dumitrescu–Hurlin test. Wbar statistics takes into account an average statistic of the test, while Zbar statistics takes into account a standard normal distribution (Dumitrescu & Hurlin, 2012). One does not reject the null hypothesis if the p-value is greater than 5%.

In Table 12, with bold letters the cases when p-value is significant at 10% level are emphasized, revealing a one-way causality. A one-way causality is detected from ln RMU to ln R&DEXP, from ln R&DEXP to ln GMW, from ln GDPPERCAP to ln R&DEXP and from ln GDPPERCAP to ln GMW. Bidirectional causality exists between ln GMW and ln RMU, ln GDPPERCAP and ln RMU. The causality from lnGDPPERCAP to lnGMW can be interpreted as follows: economic development leads to a rapid urbanization, meaning an improvement of the public infrastructure, an increase in consumption and therefore more waste generation (Gui et al., 2019).

Table 12. Summary of the Dumitrescu–Hurlin panel causality test

Null hypothesis	Causality	W-stat	Zbar-stat	P-value
ln RDEXP $\nrightarrow$ ln RMU		2.94178	0.88304	0.3772
ln RMU $\nrightarrow$ ln R&DEXP	**ln RMU $\longrightarrow$ ln R&DEXP**	**5.06029**	**4.42904**	**9.E-06**
ln GMW $\nrightarrow$ ln RMU	**ln GMW $\longrightarrow$ ln RMU**	**4.08417**	**2.79519**	**0.0052**
ln RMU $\nrightarrow$ ln GMW	**ln RMU $\longrightarrow$ ln GMW**	**4.08684**	**2.79965**	**0.0051**
ln GDPPERCAP $\nrightarrow$ ln RMU	**ln GDPPERCAP $\longrightarrow$ ln RMU**	**5.47545**	**5.12394**	**3.E-07**
ln RMU $\nrightarrow$ ln GDPPERCAP	**ln RMU $\longrightarrow$ ln GDPPERCAP**	**3.52085**	**1.85230**	**0.0640**
ln GMW $\nrightarrow$ ln RDEXP		3.36565	1.64261	0.1005
ln R&DEXP $\nrightarrow$ ln GMW	**ln RDEXP $\longrightarrow$ ln GMW**	**6.57013**	**7.09353**	**1.E-12**
ln GDPPERCAP $\nrightarrow$ ln R&DEXP	**ln GDPPERCAP $\longrightarrow$ ln R&DEXP**	**7.24559**	**8.24251**	**2.E-16**
ln R&DEXP $\nrightarrow$ ln GDPPERCAP		2.56016	0.27244	0.7853
ln GDPPERCAP $\nrightarrow$ ln GMW	**ln GDPPERCAP $\longrightarrow$ ln GMW**	**6.63185**	**7.19853**	**6.E-13**
ln GMW $\nrightarrow$ ln GDPPERCAP		2.31018	–0.15278	0.8786

4. Discussion and policy implications

Economic growth requires raw materials and other natural resources together with human capital and technology. The implemented economic model has vast social, economic, and environmental consequences. In the circular economy, the main policy challenge is to manage waste and improve resource efficiency, while ensuring efficient use of materials from their extraction to be used in manufacturing and consumption until their recovery and disposal (cf. OECD, 2021). The focus was on the economic development of 25 European economies and the associated municipal waste they generate and analyzed the effects of R&D expenditures and recycling rates of the municipal waste in the economic growth process. Table 13 summarizes the effects of the independent variables for (i) recycling rate of municipal waste and for (ii) GDP per capita as shown by FEM and Tobit models.

Only positive statistically significant relations were observed: (i) the recycling rate of municipal waste increases, the higher is GDP growth, the amount of municipal waste, as well as R&D expenditures, implying that EU governments, in general, are taking actions to recycle with growing production (even FEM model suggested negative effect of growing waste, which, however, was not statistically significant, which suggests that in some economies the relation is negative) and their R&D expenditures have been effective towards circular economy; similarly, (ii) the faster economic growth was observed with the higher recycling rate, expenditures on R&D, as well as, amounts of municipal waste, which implies that policies to enhance the waste management and to invest in R&D are effective to achieve economic growth, which can also be achieved by growing municipal waste, a less favorable aspect.

Table 13. Statistically significant determinants of municipal waste and economic growth

(i) Recycling rate of municipal waste (ln RMU) as dependent variable		
	FEM	TOBIT
ln R&DEXP	+	+
ln GMW		+
ln GDPPERCAP	+	+
(ii) GDP per capita (ln GDPPERCAP) as dependent variable		
	FEM	TOBIT
ln RMU	+	+
ln R&DEXP	+	+
ln GMW	+	+

The found causality relations are summarized in Figure 2. Long-term causalities run (i) to the recycling rate of municipal waste (ln RMU) from GDP per capita (ln GDPPERCAP) and the amount of municipal waste (ln GMW), but not from R&D, which was significant in regressions, and (ii) to GDP per capita from the recycling rate of municipal waste (not from ln R&D nor ln GMW, which were significant in regressions). According to Magazzino et al. (2020) increasing the waste recycling capacity leads to a decrease of waste generation, so this may explain the causality from ln RMU to ln GMW. The causality from ln GDPPERCAP to ln GMW is in accordance with economic theory, since economic wealth induces an increase in consumption, which generates more waste (Magazzino et al., 2020).

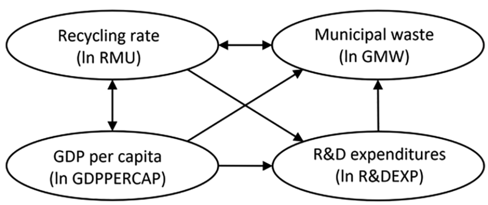

Figure 2. Statistically significant causality relations

The results imply certain policy recommendations. Since the positive effect of waste generation on GDP per capita is not a favorable aspect, innovation policies towards the design of environmentally friendly technologies should be stimulated aiming to reduce waste generation and to obtain sustainable development. Policymakers should stimulate producers and consumers to increase waste recycling capacity, by incentives, subsidies, and taxes (cf. Magazzino et al., 2020). Further, the regression results suggested that EU governments may achieve higher economic growth (although causality direction was detected only from GDP to R&D expenditures) as well as better recycling rates (also supported by the causality test) by directing government funds to R&D.

Conclusions

The paper's contribution to the literature on circular economy consists in the application the Tobit model as another instrument in studying the determinants of GDP per capita and recycling rate of municipal waste.

The implications, per hypothesis, can be summarized as follows: (H1) Recycling rate of municipal waste has a positive effect on economic development and conversely; (H2) Research and development expenditure has a positive effect on recycling rate of municipal waste as well as on economic development (H3); (H4) Generation of municipal waste per capita has a positive effect on recycling rate of municipal waste; and (H5) Generation of municipal waste per capita has a positive effect on economic development. The conclusion of Hypothesis 2 is that technology development, by a decreasing life of products, leads to an increase of waste generation. Therefore, environmentally friendly technologies should be produced. The efficiency of the waste collection and management should be assessed by means of Data Envelopment Analysis (DEA), among the policies used by governmental agencies.

As another research direction, the applied linear panel data approach can be enriched with the application of GMM estimator and quartile-regression approach. The fixed effects approach could be continued with dynamic models, using consistent estimators. Other research direction will be testing the EKC hypothesis for circular economy and socio-economic development indicators for various forms of Kuznets curve in quadratic and cubic parametric models.

Even if fixed-effects models are powerful instruments in the analysis of longitudinal data, there are some limitations such as: low statistical power, measurement errors, unobserved heterogeneity, time invariance or restricted short periods considered in the analysis.

Disclosure statement

The authors declare no conflict of interest.

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