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CIRCULAR ECONOMY AND WASTE MANAGEMENT: EFFECTS OF THE WASTE MANAGEMENT ON ECONOMIC GROWTH IN THE EUROPEAN UNION AND TÜRKİYE

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Abstract

The circular economy represents a transformative economic paradigm designed to align growth with sustainable development objectives. Unlike the traditional linear economy, this system promotes environmental sustainability and resource efficiency. This study examines the relationship between economic growth and key circular economy indicators, including biological waste recycling rates, total environmental taxes, patents related to environmental technologies, and population density. Using panel data analysis for 27 EU countries and Türkiye over the period 2008-2019, we address heterogeneity among European Union countries by conducting separate analyses for EU core and periphery countries. Following diagnostic tests revealing heteroscedasticity, autocorrelation, and cross-sectional dependence, we employ the Driscoll- Kraay estimator for robust estimation. Our findings reveal a positive relationship between economic growth and waste management in EU core countries, while a negative relationship emerges for EU periphery countries and Türkiye, attributed to high initial implementation costs. This study contributes to the literature by being the first to include Türkiye alongside a core-periphery EU classification in examining waste management's impact on economic growth.

Keywords: Economic Growth, Circular Economy, Waste Management, Panel Data Analysis, European Union.
JEL Classification: Q01, Q53**,** Q56

DÖNGÜSEL EKONOMİ VE ATIK YÖNETİMİ: AVRUPA BİRLİĞİ VE TÜRKİYE'DE ATIK YÖNETİMİNİN EKONOMİK BÜYÜME ÜZERİNDEKİ ETKİLERİ

Öz

Döngüsel ekonomi, büyümeyi sürdürülebilir kalkınma hedefleriyle uyumlu hale getirmek için tasarlanmış değişen bir ekonomik paradigmayı temsil eder. Geleneksel doğrusal ekonominin aksine, bu sistem çevresel sürdürülebilirliği ve kaynak verimliliğini teşvik eder. Bu çalışma, ekonomik büyüme ile biyolojik atık geri dönüşüm oranları, toplam çevre vergileri, çevre teknolojileriyle ilgili patentler ve populasyon yoğunluğu da dahil olmak üzere temel döngüsel ekonomi göstergeleri arasındaki ilişkiyi incelemektedir. 2008-2019 döneminde 27 AB ülkesi ve Türkiye için panel veri analizi kullanarak, AB merkez ve çevre ülkeleri için ayrı analizler yürüterek Avrupa Birliği ülkeleri arasındaki heterojenlik ele alınmıştır. Heteroskedastisite, otokorelasyon ve yatay kesit bağımlılığını ortaya koyan tanı testlerinin ardından, dirençli tahmin için Driscoll-Kraay tahmincisini kullanıyoruz. Sonuç bulguları, AB merkez ülkelerinde ekonomik büyüme ve atık yönetimi arasında pozitif bir ilişki ortaya koyarken, AB çevre ülkeleri ve Türkiye için yüksek başlangıç maliyetlerine atfedilen negatif bir ilişki ortaya koymaktadır. Bu çalışma, atık yönetiminin ekonomik büyüme üzerindeki etkisini incelerken Türkiye'yi merkez-çevre AB sınıflandırmasının yanına dahil eden ilk çalışma olması nedeniyle literatüre katkıda bulunmaktadır.

Anahtar Kelimeler: Ekonomik Büyüme, Döngüsel Ekonomi, Atık Yönetimi, Panel Veri Analizi, Avrupa Birliği
Jel Sınıflaması: Q01, Q53**,** Q56

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1.Introduction

The linear economic system that adopts the principle of take, make, and dispose is not very compatible with sustainable development goals because it is based on unlimited profit and does not consider the environment and limited resources. The raw materials used are turned into waste at the end of the product's use, causing new problems. In this system, resource efficiency is low, and irreversible negative effects on nature are quite high.

The circular economy is "an economy in which the value of products, materials, and resources is kept in the economy for as long as possible and the amount of waste is minimized" (European Commission [EC], 2015). Instead of the linear cycle in which raw materials entering the production process end up as waste, the concept of the circular economy suggests a closed cycle, which refers to using material that is waste from one production process as raw material for another production process (Jørgensen and Pedersen, 2018: 107). In this context, it requires fewer raw materials and limits potentially environmentally deteriorating effects.

The basic principle of the circular economy is based on the 3R functions of reuse, reduce, and recycle (Onder, 2018: 23). That is, the flow of activity in the circular economy takes the form of feedback through "raw material," "product," and "reusable raw material" (Türk, 2020: 56). It is also possible to expand this basic principle into 9R. The expanded 9R principles are recover, repurpose, recycle, reuse, refurbish, refuse, repair, reduce, and rethink (Potting et al., 2017: 15). As mentioned here, the "Zero Waste Management" approach is valid for the circular economy, one of whose basic principles is based on recycling, namely waste management.

Raw materials designed in the linear economy are used in the production process and become waste. These wastes are disposed of through incineration or storage. The circular economy is a multi-layered and stable system based on reducing waste generation as much as possible and preventing the creation of new waste. If waste is intended to be reduced through source separation but cannot be separated, it is considered waste and is not disposed of in ways that harm the environment, such as incineration and storage; instead, cleaner recycling options are preferred. In this way, the same raw materials are reprocessed and reused. The circular economy focuses on increasing the recycling rate of waste and therefore resource efficiency through processes such as source separation (Curran and Williams, 2012: 4). With the circular economy model, the construct of waste management has been expanded to "waste and resource

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management" (Türk, 2020: 54). According to this model, that is, the circular economy, waste constitutes the source of another production process. Only materials that cannot be used as new resources are considered waste. Therefore, less waste is generated in this system, resources are used more efficiently, and thus environmental waste problems are prevented.

The circular economy aims to reduce the concept of waste as much as possible and then integrate waste into the economy by recycling it with the most appropriate approach (Türk, 2020: 55). With this, the circular economy is parallel to the "Zero Waste Management Approach." This approach essentially envisages that products are designed with "eco-design" before the production phase and thus have a longer life and are reusable. The zero-waste approach aims to transform waste from the cradle-to-grave cycle to the cradle-to-cradle cycle (Zaman, 2013: 683). In other words, waste is no longer a problem to be eliminated because it becomes the raw material for another production process. In this way, the rate of depletion of scarce resources will slow down, and resource efficiency will increase. If the zero-waste strategy is correctly integrated into business processes, it will create innovative business processes to prevent and reduce waste of resources and energy (Türk, 2020: 62). In this case, companies will both have cost advantages and minimize damage to the environment. On the other hand, they will eliminate the disposal costs spent on products that have become waste in the linear economic system.

2. Literature Review

The circular economy fundamentally relies on recycling, reuse, and reduction principles, with recycling and reduction directly connected to waste management practices. Existing literature suggests that waste management based on circular economy principles positively influences economic growth. However, empirical studies examining these relationships remain limited in the applied literature.

Following the EU's 'Circular Economy Action Plan' and sustainable development principles, research examining waste management's impact on economic growth has increased substantially. Pelău and Chinie (2018) investigated relationships between education, recycling rates, internet access, and per capita national income across European countries, finding that higher income levels positively correlate with recycling rates, while lower income levels show negative correlations.

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Vuţă et al. (2018) analyzed the effects of municipal, biological, and packaging waste on economic growth using data from 28 EU member countries (2005-2016). Their results demonstrated positive relationships between household waste recycling rates, waste reuse and recycling expenditures, economic growth, and resource efficiency, emphasizing the circular economy's positive contribution to sustainable development.

Onder (2018) conducted panel data analysis examining energy and resource efficiency, recycling, material use, urbanization rates, and waste generation across 27 European countries (2010-2013). Results indicated that GDP increases correspond with higher waste generation, while urbanization and resource efficiency improvements reduce waste production. However, energy efficiency, recycling, and material usage variables showed statistical insignificance.

Recent studies by Trica et al. (2019) and Busu (2019) demonstrated the circular economy's importance through econometric analysis, concluding that the extended Mankiw-Romer-Weil model is influenced by recycling rates, environmental innovation, green energy use, environmental employment, and resource efficiency.

Utkulu and Bilik (2020) explore waste management and economic growth relationships across EU member countries. They analyzed municipal waste recycling rates, electronic waste recycling rates, and household material use, and their findings confirm that waste management significantly and positively affects economic growth. The study showed that waste management's impact on economic growth diverges according to per capita income levels.

Acci et al. (2022) have examined the interdependence of the circular economy (or some of its indicators) and economic growth across 24 EU countries (2004-2018). Their findings confirm that recycled raw material trade, municipal waste recycling rates, population density, real labor productivity per capita, and gross capital formation positively affect GDP per capita, whereas environmental tax revenue has a negative impact on GDP per capita.

Radivojevic et al. (2024) tested the role of circular economy in driving economic growth across 27 EU countries (2000-2021). Their findings demonstrated that there was a positive and statistically significant impact of Resource Productivity, Generation of municipal waste per capita, and Recycling rate of municipal waste on economic growth.

In addition to these studies, Su et al. (2013) investigated circular economy policies' impact on economic growth in China, concluding that waste management policies positively influence economic growth while considering regional differences. George, Lin, and Chen (2015)

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developed theoretical models for circular economy analysis within the framework of the Kuznets Curve.

3. Theory and Model

3.1. Theory

This study's theoretical framework builds upon the Cobb-Douglas production function model developed by Di Vita (2001) and Cogoy (2009) to measure waste management's impact on economic growth within the circular economy context.

Based on the Cobb-Douglas production function, the model created by Di Vita (2001) and Cogoy (2009) is defined as follows:

$$Y = f\left(K, A, H_{Y,} E, M\right) = K^{\alpha 1} A^{\alpha 2} H_Y^{\alpha 3} (E + M)^{\alpha 4}, \quad \sum_{i=1}^{4} \alpha i = 1. \tag{1}$$

where:

"Y = total output

K = total capital

H = human capital

E = usage rate of exhaustible resources

M = secondary capital stock obtained from waste recycling"

$$g_Y = \frac{\dot{Y}}{Y} = \frac{\alpha_1 \beta (1 - x - \alpha_{4)}}{(1 - \alpha_4)} + \frac{z H_A (\alpha_4)}{(1 - \alpha_4)} \tag{2}$$

Equation (2) expresses the growth rate considering the waste recycling process. The direct impacts of waste management on growth rate are explained by this equation. $\alpha_4 g_A$ symbolizes the direct effects of waste recycling.

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$$g_{Y_p} = \frac{\dot{Y}_p}{Y_p} = \frac{\alpha_1 \beta (1 - x - \alpha_4)}{(1 - \alpha_4)} = \frac{z\alpha_2 (H_A + H_B)}{(1 - \alpha_4)} \quad (3)$$

Equation (3) is the economic growth model in which the secondary capital stock is not included. Equations (2) and (3) are equivalent in their second parts (Di Vita, 2001, 561).

Equation (2) assumes that β and γ have a positive relationship. This suggests that the growth rate will rise in line with an increase in the output-capital ratio. Considering all these factors, it is expected that the growth rate will accelerate relative to industrialized countries, particularly in developing nations. Governments can also influence this by increasing their investments in human resources employed in the research industry. Specifically, it should be (Di Vita, 2001: 561–562).

"Welfare is affected by the size of the waste stock. Di Vita's (2001) view is also supported by Hosoda (2001)". Accordingly, if waste is eliminated, unlimited economic growth can be achieved.

According to the circular economy approach, the aim is not only to reuse waste but also to develop methods that will create less waste. Human capital must be equipped to develop methods that will provide this. Resources taken from nature and used in production after going through a specific process are known as unprocessed materials. Therefore, unprocessed materials constitute a part of the materials obtained from the environment in the formation of the output (Cogoy, 2009: 6).

$$m_v = \eta \mathrm{v}, \qquad 0 \leq \eta \leq 1 \quad (4)$$

v are unprocessed materials, m_v are useful materials converted from unprocessed materials. η is the eco-efficiency coefficient. This coefficient depends on human resources. If η is equal to 1, it shows that the process is completely efficient, and no material is lost in production. If η is zero in the equation given by 4, it shows that the process is inefficient (fully inefficient), and no waste is produced at the end of the process. In other words, all inputs have become waste. If less material is lost in production (less waste is produced), η gradually approaches 1.

"The coefficients of productivity (π), eco-efficiency (η), and quality of consumption (ϑ) are all affected by human capital (Cogoy, 2009: 10):

$$\pi = \pi(\mathrm{H}), \qquad \pi' > 0, \qquad \pi'' < 0, \quad (5)$$

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$$\eta = \eta(H), \qquad \eta' > 0, \qquad \eta'' < 0, \tag{6}$$

$$\vartheta = \vartheta(H), \qquad \vartheta' > 0, \qquad \vartheta'' < 0, \tag{7}$$"

H represents human capital. In equations (5) and (6), it is assumed that knowledge is external; the same knowledge accumulation will increase the efficiency of all capital, and at the same time, it will increase eco-efficiency and consumption quality. Eco-efficiency is largely dependent on the effectiveness of human capital. With the increase in eco-efficiency factors, there are significant changes in production, and less waste is produced. However, at lower eco-efficiency levels, waste production is also very high (Cogoy, 2009: 14). As is known, only a part of this waste can be used in reproduction; most of it needs to be destroyed.

Di Vita (2001) calculated the growth rates with and without recycling by changing the value parameters in his study. The growth rate was higher with the inclusion of the recycling process than without it (Di Vita, 2001: 562). The acquired result was in line with the anticipated outcome and further supported the model's preference.

3.2.Data and Model

In this study, the connection between economic growth and the recycling rate of biological waste, total environmental taxes, and patents related to environmental technologies will be analyzed with panel data analysis for the years 2008-2019 with data from 27 EU countries and Türkiye. Information on the variables is summarized in the table below.

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Table 1. Variables Used in the Analysis

Variable	Defining Variables	Abbreviation	Source
Economic Growth	Real gross domestic product per capita (constant 2010 prices, Euro)	GDP	Eurostat
Recycling rate of biological waste	Recycling rate of biological waste (kg per person)	BIO_RECYLE	Eurostat
Total Environmental Taxes	Total environmental taxes (per capita, million euros)	ENV_TAX_GDP	Eurostat
Patents related to Environmental Technologies	Number of patents related to environmental technologies	PATENTS	OECD Data
Population Density	People per sq. kilometer of land area	POP_DENS	World Data Bank

Source: Prepared by the author.

With the dependent and independent variables previously defined, we have the following regression equation:

$$GDP_{it} = \beta_0 + \beta_1(B\dot{I}O\_RECYLE_{it}) + \beta_2(ENV\_TAX\_GDP_{it}) + \beta_3(PATENTS_{it}) + \beta_4(POP\_DENS_{it}) + e_{it}$$

where:

i= represents countries (I=1,2,…,28)

t= represents time periods (t=2008,2009,….,2019)

which:

- Economic growth is calculated as the growth rate of GDP/income per capita.
- The recycling rate of biological waste was used as a main variable to measure the impact of recycling on economic growth.

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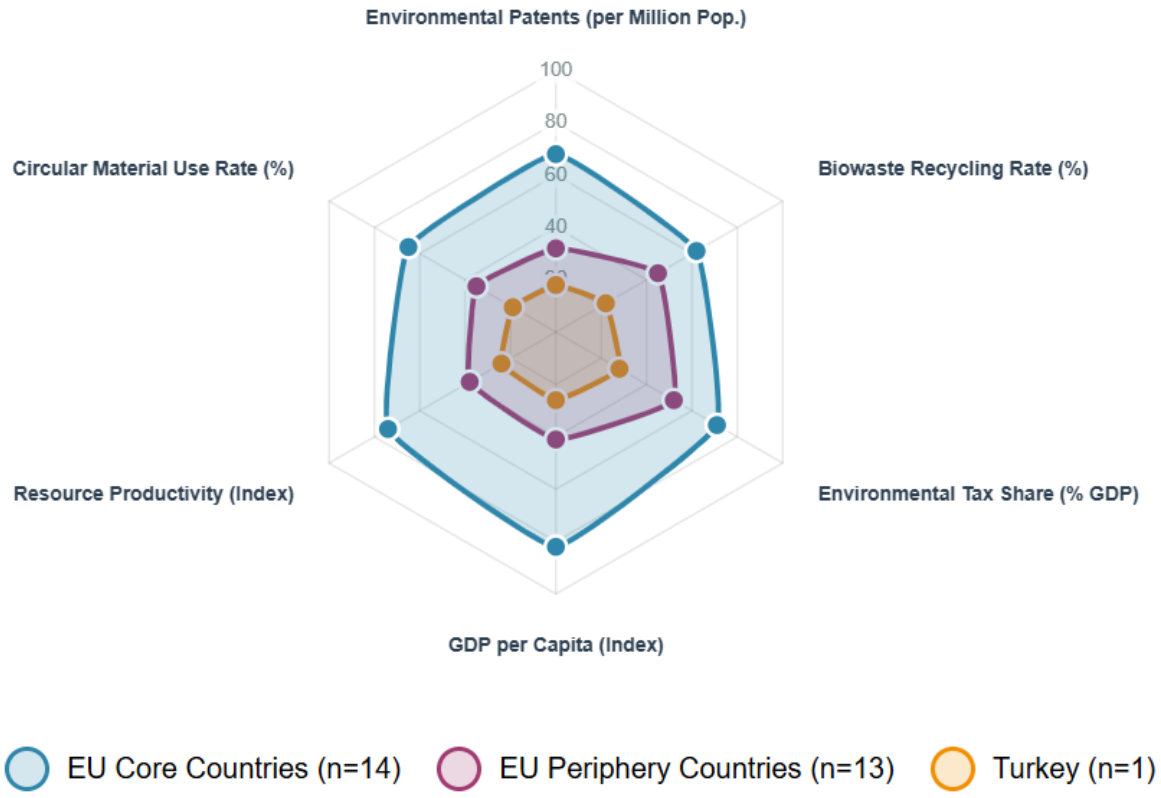
- Total environmental taxes are calculated at million euros per capita. In our model, environmental taxes are included in the model as a proportion of GDP.
- Patents related to environmental technologies describe the total number of patents pertaining to environmental technologies. This shows that each country's economic growth is positively affected by many creative patents.
- Population density is people per sq. kilometer of land area. This variable was added to the model as a control variable.

Data collected from the Statistical Office of the European Union (EUROSTAT), OECD Data, and the World Data Bank. All analyses were performed using Stata 17.

Figure 1: EU Core Countries vs Periphery Countries vs Türkiye (2008-2019 Average) Circular Economy Performance Comparison



Source: Prepared by the author.

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The radar chart analysis reveals significant disparities in circular economic performance across the three country groups during the 2008-2019 period. EU core countries consistently outperform both periphery countries and Türkiye across all six indicators, demonstrating the advantages of established institutional frameworks, higher economic development levels, and mature environmental policy systems.

EU core countries exhibit particularly strong performance in GDP per capita (82 points), environmental tax share (71 points), and resource productivity (74 points), reflecting their capacity to implement comprehensive circular economy policies while maintaining economic competitiveness. These countries—including Belgium, Denmark, Germany, Ireland, Greece, Spain, France, Italy, Luxembourg, Netherlands, Austria, Portugal, Finland, and Sweden—benefit from well-developed institutional capacities and longer experience with environmental policy integration within EU frameworks.

EU periphery countries, comprising post-1995 members such as Poland, the Czech Republic, Hungary, Slovakia, Slovenia, Estonia, Latvia, Lithuania, Cyprus, Malta, Romania, Bulgaria, and Croatia, demonstrate moderate performance levels with notable variations across indicators. Their strongest performance appears in environmental taxation (52 points) and biowaste recycling (45 points), suggesting successful policy harmonization with EU standards in these areas. However, significant gaps persist in environmental patents (32 points) and resource productivity (38 points), indicating structural challenges in innovation capacity and resource efficiency that reflect their transitional economic status during the analysis period.

Türkiye, as a candidate country, exhibits the lowest performance across all indicators, with scores ranging from 18 to 28 points. This pattern reflects the challenges faced by candidate countries in aligning their environmental and economic policies with EU standards while managing domestic development priorities. The relatively narrow performance gap between Türkiye and periphery countries in certain indicators (particularly environmental taxation and biowaste recycling) suggests potential for convergence through targeted policy interventions and EU integration processes.

4. Results

4.1. European Union Core Countries Analysis

Following recognition of heterogeneity among European Union countries, we conduct separate analyses for EU core and periphery countries. EU core countries include economically

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advanced nations with established circular economy infrastructure, while periphery countries encompass newer EU members with developing economies.

Table 2. Descriptive Statistics - EU Core Countries

Variable	Lgdp	lbiorecyle	lpatent	gdpicindekienv_tax	lpop_dens
Mean	13.294	0.924	5.424	2.199	4.748
Median	13.212	0.86	5.781	2.319	4.757
Maximum	15.434	2.02	8.554	4.029	6.244
Minimum	10.572	0.03	2.169	0.188	2.861
Standard Deviation	1.265	0.459	1.589	0.933	0.894

Diagnostic tests indicate the presence of heteroscedasticity (Modified Wald test: $\chi^2 = 884.41$, $p < 0.001$), autocorrelation (Wooldridge test: $F = 208.737$, $p < 0.001$), and cross-sectional dependence (Pesaran CD test: 13.978, $p < 0.001$). These findings necessitate robust estimation methods.

Table 3. Driscoll-Kraay Estimation Results-EU Core Countries

Driscoll-Kraay Model			**Method: Fixed Effects Regression**		
Number of observations: 168			**Number of groups: 14**		
Group variable (i): id			**F(15, 11) = 904.96**		
R^2 = 0.8806			**Prob > F = 0.0000**		
Variable	Coefficient	Std. Error	t-Statistic	P-value	95% CI
lnpatent	0.082	0.024	3.36	0.006	[0.028, 0.136]
biorecyle	0.029	0.034	0.84	0.421	[-0.047, 0.104]
env_tax_gdp	-0.225	0.025	-8.86	0.000	[-0.281, -0.169]
lnpopden	0.694	0.250	2.78	0.018	[0.144, 1.244]
Constant	9.945	1.235	8.05	0.000	[7.227, 12.663]
Time Fixed Effects	Included (12 years)				

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The coefficient for biowaste recycling rate, while exhibiting a positive sign, does not achieve statistical significance. However, the direction of the relationship suggests that higher biowaste recycling rates are associated with increased GDP per capita. The patent variable, representing the number of patents related to environmental technologies, demonstrates statistical significance with a positive coefficient. Specifically, a one percent increase in environmental technology patents corresponds to a 0.082 percent increase in GDP per capita.

The environmental tax variable (env_tax_gdp), measuring total environmental taxes as a percentage of GDP, exhibits statistical significance with a negative coefficient. The results indicate that a one-percent increase in environmental taxation is associated with a 0.225 percent reduction in GDP per capita. Population density demonstrates statistical significance with a positive coefficient. For EU core countries, the analysis reveals that a one-percent increase in population density correlates with a 0.69 percent increase in GDP per capita.

4.2.European Union Periphery Countries and Türkiye Analysis

Table 4. Descriptive Statistics - EU Periphery Countries and Türkiye

Variable	Lgdp	lbiorecyle	Lpatent	gdpicindekienv_tax	Lpop_dens
Mean	11.992	0.180	2.499	1.901	4.584
Median	10.990	0.12	2.553	2.003	4.625
Maximum	17.679	1.31	5.006	3.917	7.361
Minimum	8.733	0	-1.609	0.006	3.409
Standard Deviation	2.393	0.214	2.393	1.194	0.872

The Hausman test ($\chi^2 = 37.98$, $p < 0.001$) indicated that the fixed effects model was appropriate for estimation. The Pesaran CD test (14.981, $p < 0.001$) confirmed the presence of cross-sectional dependence among panel units.

Subsequent diagnostic tests revealed violations of classical panel data assumptions. The Modified Wald test ($\chi^2 = 2587.91$, $p < 0.001$) detected heteroscedasticity, while the Wooldridge test ($F = 191.353$, $p < 0.001$) indicated first-order autocorrelation. The Pesaran test (-2.34, $p = 0.019$) confirmed inter-unit correlation.

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Similarly, these diagnostic results indicate the presence of heteroscedasticity, autocorrelation, and cross-sectional dependence, necessitating robust estimation methods to ensure reliable parameter estimates.

Table 5. Driscoll-Kraay Model Results

Driscoll-Kraay Model			**Method: Fixed Effects Regression**		
Number of observations: 168			**Number of groups: 14**		
Group variable (i): id			**F(15, 11) = 9.56**		
R^2 = 0.8681			**Prob > F = 0.0003**		
Variable	Coefficient	Std. Error	t-Statistic	P-value	95% CI
lnpatent	0.023	0.0085	2.77	0.018	[0.0049, 0.0427]
biorecyle	-0.112	0.0208	-5.37	0.000	[-0. 157, -0.661]
gdpicindekienvtax	-0.140	0.039	-3.53	0.005	[-0.281, -0.0528]
lnpopden	-0.408	0.185	-2.20	0.050	[-0.817, 0.0002]
Constant	13.921	0.889	15.65	0.000	[11.963, 15.879]
Time Fixed Effects	Included (12 years)				

The biowaste recycling rate (biorecyle) demonstrates statistical significance with a negative coefficient of -0.112 ($p < 0.001$). Contrary to expectations, this result suggests that a one-unit increase in biowaste recycling rate is associated with an 11.2 percent decrease in GDP per capita. This unexpected negative relationship may reflect short-term adjustment costs or structural economic factors. The patent variable (lnpatent), representing environmental technology patents, exhibits statistical significance with a positive coefficient of 0.023 ($p = 0.018$). This indicates that a one percent increase in environmental technology patents corresponds to a 0.023 percent increase in GDP per capita, suggesting that innovation in environmental technologies contributes positively to economic performance.

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The environmental tax variable (gdpicindekienvtax) is statistically significant with a negative coefficient of -0.140 (p = 0.005). The results indicate that a one percent increase in environmental taxation relative to GDP is associated with a 0.140 percent reduction in GDP per capita, consistent with the potential short-term economic costs of environmental policy implementation.Population density (lnpopden) demonstrates marginal statistical significance with a negative coefficient of -0.408 (p = 0.050). This finding suggests that a one percent increase in population density correlates with a 0.408 percent decrease in GDP per capita, which may reflect diseconomies of scale or resource constraints in densely populated areas.

5. Discussion

The empirical results reveal significant differences between EU core and periphery countries regarding the impact of waste management on economic growth. For EU core countries, environmental patents demonstrate a positive and statistically significant relationship with economic growth ($\beta = 0.082$, $p < 0.01$), indicating that a 1% increase in environmental patents corresponds to an 8.2% increase in GDP per capita. This finding aligns with the theoretical expectation that technological innovation drives economic growth within circular economy frameworks.

Environmental taxes show negative coefficients in both samples ($\beta = -0.225$ for core countries; $\beta = -0.140$ for periphery countries), suggesting that increased environmental taxation reduces short-term GDP growth. This result may reflect adjustment costs associated with environmental policy implementation rather than long-term negative effects.

The most striking difference appears in biological waste recycling impacts. While this variable shows no statistical significance for EU core countries, it exhibits a negative and significant relationship for periphery countries and Türkiye ($\beta = -0.112$, $p < 0.001$). This finding suggests that waste management investments in developing economies may initially reduce economic growth due to high implementation costs and infrastructure requirements.

These results support the theoretical framework proposed by Di Vita (2001) and Cogoy (2009), particularly regarding development level differences in circular economy transitions. EU core countries, with established infrastructure and higher human capital, can more effectively transform waste management investments into economic benefits. Conversely, periphery countries face significant upfront costs that may temporarily constrain economic growth.

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6. Conclusions and Policy Implications

This study provides new empirical evidence on the heterogeneous effects of waste management on economic growth across different development levels (core-periphery) in the European Union and Türkiye. Our findings aim to contribute to the circular economy literature by demonstrating that waste management effects vary significantly between core and periphery EU countries.

The results indicate that environmental patents consistently act as a catalyst for economic growth, regardless of the development level of the countries studied. This effect is stronger in developed EU countries, while it is more limited in developing periphery EU countries. The findings demonstrate that technological progress is a decisive factor in ensuring an effective transition to circular economy frameworks. The positive correlation between environmental technology patents and GDP per capita suggests that capital allocation to environmental R&D not only supports environmental sustainability but also creates a structural interaction that fosters economic growth and innovation-based welfare.

Environmental taxation mechanisms have negative short-term consequences on economic performance across the countries studied. This finding suggests that while environmental taxes serve both regulatory and fiscal functions, the timing, scope, and supporting policies should be carefully planned to minimize potential negative economic impacts during implementation. This inverse relationship suggests that policymakers should adopt harmonizing approaches, such as phased implementation strategies or compensatory mechanisms, to achieve a balance between environmental objectives and economic stability.

An examination of organic waste recycling reveals varying impacts across different country groups and highlights the diverse characteristics of circular economy transformations within the European framework. While core EU countries exhibit a neutral correlation between biowaste recycling and economic performance, peripheral countries exhibit an inverse relationship. This difference reflects fundamental differences in infrastructure capabilities, technological readiness, and institutional structures required for efficient waste management operations.

6.1. Policy Implications

For the EU's core countries, continuous capital allocation to research and development activities and support for innovation centers to maintain and strengthen environmental innovation

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networks should be key policy priorities. These countries, thanks to their strong institutional and technological infrastructures, have the capacity to lead the transition to a circular economy. A strategic approach for these countries requires building integrated policy structures that simultaneously support environmental objectives and economic growth by leveraging their existing strengths in technological and regulatory areas. This necessitates effective collaboration and knowledge sharing among universities, the private sector, and public institutions. Moreover, these countries are expected to develop flexible and adaptable policy instruments that will both adhere to circular economy principles and respond quickly to new technological and economic developments. Additionally, they are in a key position to facilitate technology transfer with peripheral countries and promote regional cooperation in line with the EU's overall objectives.

Moreover, policy frameworks for the EU's peripheral countries and Türkiye should consider these countries' existing structural constraints and development priorities. The gradual implementation of circular economy practices through a transitional process will ensure the development of infrastructure and institutional capacity while maintaining economic stability. In this process, financial and technical support provided through EU structural funds or bilateral cooperation can play a critical role, particularly in establishing waste management, recycling, and environmental monitoring infrastructures. Programs focusing on technical know-how, institutional capacity, and human resource development are the cornerstones of a sustainable transition. Furthermore, public-private partnerships facilitate cost and risk sharing while also leveraging the private sector's innovation and efficiency potential to strengthen implementation.

7. Limitations and Future Research Suggestions

7.1. Study Limitations

This study acknowledges several limitations that should be considered when interpreting the results. The analysis is constrained to the 2008-2019 period, which may not capture the full long-term effects of circular economy policies, particularly in the post-COVID-19 context where environmental policies and economic structures have significantly evolved. Data availability constraints, particularly for newer EU member states during earlier years, and potential inconsistencies in data collection methodologies across countries may introduce measurement errors. The core-periphery classification, while theoretically grounded, represents a simplified categorization that may not fully capture within-group heterogeneity. Finally,

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despite robust econometric techniques, the panel data analysis cannot definitively establish causal relationships due to potential endogeneity issues and reverse causality concerns.

7.2. Future Research Suggestions

Future research should address these limitations by extending temporal coverage to include post-2019 data and COVID-19 impacts, expanding geographical scope beyond Europe, conducting sectoral and regional disaggregated analyses, employing advanced econometric techniques such as threshold regression and instrumental variables to address endogeneity concerns, developing more comprehensive circular economy indicators, and incorporating broader sustainability dimensions including social equity measures. These research directions would enhance understanding of circular economy transitions and provide evidence-based policy guidance.

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