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ASSESSING THE INFLUENCE OF ECONOMIC GROWTH ON COMPETITIVENESS AND INNOVATION IN THE CIRCULAR ECONOMY

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This research explores the relationship between economic growth and competitiveness and innovation in the circular economy across the 27 EU countries from 2011 to 2020. Using descriptive statistics, Principal Component Analysis (PCA), panel data regression, and cluster analysis, the research investigates how the key economic indicators, such as GDP, GDP *per capita*, and gross fixed capital formation, affect the performance of the circular economy. The results obtained indicate a positive correlation between overall economic growth and circular competitiveness, though wealthier nations do not consistently lead in circular transitions. The analysis underscores the need for tailored, country-specific policies to promote sustainable practices in the circular economy, especially in less developed economies. These findings provide valuable insights for policymakers aiming to balance economic growth with sustainability.

Keywords: circular economy, economic growth, innovation, sustainability, EU, competitiveness

JEL Classification: Q56, O44, O33

INTRODUCTION

In the modern global economy, competitiveness and innovation have emerged as the main drivers of growth, sustainability, and prosperity. A country's potential for productivity and growth is shaped by its competitiveness, which influences resource allocation, production affordability, and the overall economic output (Vuță, Vuță, Enciu & Cioacă, 2018). Innovation, especially in the context of the circular economy (CE), offers new technologies and practices that improve competitiveness by optimizing resource use and minimizing waste (Mitrović & Veselinov, 2018; Silvério, Ferreira, Fernandes & Dabić, 2023). The European Union (EU) has prioritized these developments through initiatives such as the European Green Deal and the Circular Economy Action Plan, aiming to promote sustainable solutions (OECD, 2019; European Commission, 2020). Yet, a

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recent audit conducted by the European Court of Auditors (European Court of Auditors, 2023) finds "limited evidence" that CEAP actions have so far accelerated upstream circular design, underscoring the gap between policy ambition and tangible progress.

Despite progress, however, gaps in understanding the relationship between economic growth and circular competitiveness across different countries still remain. While much attention has been given to how circular practices impact economic growth, less is known about how economic growth itself influences a country's ability to innovate and compete in the CE (Karman & Pawlowski, 2021). This is particularly important for the EU countries, where sustainable growth is considered crucial to future competitiveness (Popović & Milijić, 2022). Recent studies have revealed that overall GDP is positively associated with circularity (Hondroyiannis, Papapetrou & Tzeremes, 2024), whereas the link with GDP *per capita* is far more ambiguous, being positive in some, neutral or even negative in other contexts, depending on consumption footprints and policy quality (European Court of Auditors, 2023; Lacko, Hajduova & Dula, 2024). These findings echo the earlier evidence that high economic growth alone does not guarantee advanced CE performance without concurrent technological innovation and resource efficiency gains (Ying & Wen-Ping, 2015; Jakopin, 2020).

Globalization has increased concerns that the countries that do not embrace circular innovation may lose competitiveness. Those prioritizing resource efficiency are better positioned so as to attract foreign investments and remain competitive in global markets (Ferrante & Germani, 2020; Silvério *et al*, 2023). Thus, it is crucial to examine whether economic growth is in line with the EU efforts to improve circular competitiveness and innovation. Large cross-country disparities, most visibly persistent North-South and West-East divides into the CE efficiency (Hondroyiannis *et al*, 2024; Lacko *et al*, 2024), suggest that structural, institutional, and investment factors mediate this alignment.

Moreover, research gaps persist in developing standardized tools for measuring the performance of the circular economy across countries (Vuță *et al*, 2018; Busu & Trica, 2019). Although the EU updated its monitoring framework in 2023, scholars still highlight data gaps, particularly on product design and social outcomes, and call for richer indicator sets and harmonized methodologies (Ghormare, Patil & Petrescu, 2024). Previous studies have largely focused on developed economies, leaving questions about how slower-growing countries fare in circular competitiveness (Popović, Ivanović Đukić & Milijić, 2022). This study aims to fill these gaps by exploring the extent to which slower-growing economies can keep pace with more advanced countries in transitioning to the circular economy.

This research analyzes how economic growth influences circular competitiveness and innovation across the 27 EU countries between 2011 and 2020, focusing on the key indicators such as GDP, GDP *per capita*, and gross fixed capital formation (GFCF). The performance of the circular economy is assessed through the Circular Material Use rates (CMUr), circular patents, and employment in circular sectors. The study aims to investigate whether economic growth drives competitiveness and innovation in the circular economy.

The research is structured around the three key hypotheses:

H1: Higher GDP, GDPpc, and their respective growth rates are positively associated with higher competitiveness and innovation in the CE.

H2: Countries with higher resource productivity (ResP, ResPppp) exhibit better CE performance.

H3: Countries with higher investments (GFCF, InvAbs) tend to have more significant innovations and higher levels of competitiveness, measured by the Circular Competitiveness and Innovation Index - CCII (patents, GVA) in the CE.

Beyond testing these hypotheses, the paper contributes to theory by contextualizing the GDP-circularity paradox through the lenses of the consumption footprint and investment targeting, and to practice by identifying policy levers, design-stage incentives, innovation-focused finance, and digital traceability that can accelerate the EU's lagging transition. The remainder of the paper is structured so as to offer a literature review, explain the data, the variables, and the methods, present the empirical results, discuss the implications and policy recommendations, and finally conclude the whole research study.

LITERATURE REVIEW

The relationship between economic growth and competitiveness in the circular economy (CE) has garnered increasing attention. Yet, the literature remains divided on its mechanisms and outcomes. The CE aims to address sustainability challenges, though the extent to which growth fosters circular practices remains under debate. In this context, J. Korhonen, A. Honkasalo and J. Seppälä (2018) highlight the paradox between growth-driven consumption and the CE model's principles of resource efficiency and waste reduction.

GDP growth has been both an enabler and a barrier to the CE transitions. W. R. Stahel (2016) argues that high-growth economies are better equipped to scale the CE practices through investments in research, development, and infrastructure, while also warning that unchecked growth may fuel unsustainable consumption. Similarly, A. Popović *et al* (2022) suggest that, although a higher GDP can drive circular innovation, it can also entrench linear economic activities unless properly managed. Đ. Mitrović and M. Veselinov (2018) add that, while being more capable of implementing the CE practices, wealthier countries are not immune to challenges, especially if policy incentives are weak. A surge of recent panel studies has confirmed a positive long-term correlation between aggregate GDP and national circularity rates (Hondroyiannis *et al*, 2024), yet revealing an ambiguous, sometimes negative, association with GDPpc once rising consumption footprints are controlled for (Lacko *et al*, 2024; Marjanović, Stanković, Östh, Marković & Stanojević, 2025). The evidence from F. Ying and Z. Wen-Ping (2015) and E. Jakopin (2020) further demonstrates that a rapid economic expansion without synchronous technological upgrading can stall CE progress.

Being a key CE indicator, ResP reflects how efficiently economies use natural resources to generate value. M. Busu (2019) found that the countries with higher ResP tended to be more competitive in the circular sectors, whereas X. Zhou, M. Song and L. Cui (2020) argue that improving ResP is often linked to investments in circular technologies, reinforcing the connection between economic growth and competitiveness in the CE. Similarly, E. Hysa, A. Kruja, N. U. Rehman and R. Laurenti (2020) claim that innovation is essential for circular transitions, with higher innovation levels typically leading to greater circular competitiveness. More granular evidence shows the influence of ResP is context-dependent: investment enables uptake of circular technologies (Karman & Pawłowski, 2022), innovation capabilities increasingly shape performance as systems mature (Hysa *et al*, 2020; Herrero-Luna, Ferrer-Serrano & Latorre-Martinez, 2022), and EU-wide efficiency dispersion is documented using a DEA composite indicator (Marjanović *et al*, 2025).

Investments, particularly those made in physical assets, are critical for promoting innovations in the CE. A. Karman and M. Pawlowski (2021) stress that higher levels of GFCF support the adoption of circular technologies, especially in renewable energy and sustainable manufacturing. However, S. Herrero-Luna *et al* (2022) note that, while investment leads to short-term competitiveness gains, the long-term effects of circular investments, such as those on employment and income distribution, are less understood. The European Court of Auditors (2023) cautions that the EU funds remain disproportionately channeled to end-of-pipe waste management rather than upstream circular design, which is a misalignment blunting the effectiveness of capital flows. Complementary firm-level evidence on the ISO 14001 adoption, such as in D. Jovanović and V. Janjić (2018) and on green-accounting expenditure, such as in A. P. Egbunike and E. G. Okoro (2018), corroborates that targeted spending on environmental management can raise efficiency and profitability.

Table 1 synthesizes the extant empirical studies most pertinent to the three hypotheses set in this study, grouping them by the primary economic lever examined (growth, resource productivity, or investment/innovation).

The literature identifies both opportunities and challenges in aligning economic growth with circular competitiveness. While higher growth can support CE transitions, it risks undermining sustainability without proper regulation. Gaps remain in understanding the long-term impact of economic growth on competitiveness in the CE, particularly for less developed countries. Future research should adopt longitudinal designs in order to explore how this relationship is evolving over time. Moreover, scholars spotlight unresolved measurement issues (Busu & Trica, 2019; Ghormare *et al*, 2024) and persistent regional divides within Europe (European Court of Auditors, 2023), signaling the need for harmonized indicators and context-sensitive policy interventions.

Table 1 The synthesis of the empirical studies

Group/ Hypothesis	Authors	Sample and period	Key economic variables	CE metrics	Method	Principal finding
H1: Growth	W. R. Stahel (2016)	Conceptual	GDP growth	CE scalability	Theory	Growth enables the CE but can also undermine it.
	F. Ying and Z. Wen-Ping (2015)	Shaanxi, 2000-12	GDP, GDPpc	CE stage via IPAT	IPAT/OLS	High GDP with weak tech keeps the CE at the "intermediate" stage.
	G. Hondroyiannis et al (2024)	EU-28, 1995-2022	Real GDP	Circularity rate	FMOLS	Long-term GDP leads to higher circularity.
	R. Lacko et al (2024)	EU-11 post-2004	GDPpc	CE efficiency	DEA	The GDPpc effect is positive for some, and negative for others.
H2: Resource productivity	M. Busu (2019)	EU-27, 2008-17	ResP	CE index	Panel FE	Higher ResP increases competitiveness in the CE.
	X. Zhou et al (2020)	China, 2000-16	ResP, tech change	GDP growth	Spatial panel	ResP gains drive eco-growth.
	I. Marjanović et al (2025)	EU-27, 2019	Inputs/ outputs from Eurostat CE indicators	DEA efficiency score (CCR; super-efficiency ranking)	DEA efficiency score (CCR; super-efficiency	Large cross-country heterogeneity; many EU members inefficient; CE efficiency moderately correlated with development.
H3: Investment and Innovation	A. Karman and M. Pawlowski (2021)	EU-27, 2010-19	GFCF	CE competitiveness index	Catastrophe prog./PCA	GFCF strongly linked to CE leadership.
	S. Herrero-Luna et al (2022)	38 studies	Investment	Mixed CE outcomes	Systematic review	Long-term socio-economic impacts unclear.
	D. Jovanović and V. Janjić (2018)	Serbia, survey	EMS investment	Efficiency, profit	Descript./logit	ISO 14001 yields efficiency and profit gains.
	A. P. Egbunike and E. G. Okoro (2018)	Nigeria, 2012-16	Green CAPEX	ROE, Tobin's Q	Canonical corr.	Green spend neutral to profits – needs policy support.

Source: Authors

RESEARCH METHODOLOGY AND DATA

This research employs an all-inclusive quantitative methodology to assess the interaction between economic growth, competitiveness, and innovation in the CE across the 27 EU member countries in the period from 2011 to 2020. The design directly addresses the research objectives and tests the hypotheses while safeguarding robustness and reliability.

The selection of the variables was based on a detailed review of the previous literature and the availability of reliable data sources, following approaches similar to those used by M. Vuță *et al* (2018) and Đ. Mitrović and M. Veselinov (2018). The data were collected from the two main sources:

- World Bank: For the macroeconomic indicators such as GDP, GDPpc, and GFCF (World Bank, 2024).
- Eurostat: For the CE-specific indicators such as ResP, CMUr, and Patents related to circular innovation (Eurostat, 2024).

The dataset contains independent variables (economic growth indicators) and dependent variables (circular economy performance indicators). The independent variables GDP, the GDP growth rate (GDPgr), GDPpc, the GDPpc growth rate (GDPpcg), GFCF, the GFCF growth rate (GFCFgr), ResP, and ResP in Purchasing Power Parity (ResPppp) were included in the initial set. The dependent variables included CMUr, the patents related to climate change mitigation technologies, employment in the circular sectors, and investment in the circular sectors. It is worth noting that there was no missing data in the dataset.

Prior to analysis, the authors conducted a thorough examination of the distribution of the variables in order to identify any outliers or anomalies. In line with contemporary discussions on measurement complexities (Ghormare *et al*, 2024), special attention was paid to ensuring that data values were consistent across all countries and years. To ensure comparability across the different scales and units of measurement, the authors applied the following normalization techniques: Log Transformation, Z-score, and Min-Max Normalization.

These normalization techniques are consistent with those used in similar studies (Hysa *et al*, 2020; Karman & Pawlowski, 2021). Such procedures also align with the approach of F. Ying and Z. Wen-Ping (2015), who underscore the importance of addressing skewed economic indicators when examining circular performance stages.

The authors employed Principal Component Analysis (PCA) so as to reduce the dimensionality of the dataset and create two composite indices, following the approach of A. Androniceanu, J. Kinnunen and I. Georgescu (2021):

- the Circular Competitiveness and Innovation Index (CCII), aggregating the indicators related to performance in the CE.
- the Economic Growth Index (EG), compiling traditional economic growth indicators.

Both indices were standardized and scaled from 0 to 100 for ease of interpretation and comparison across the countries and the time periods.

The PCA for the CCII was performed on nine variables, namely CMUr, Patents, PatentsPM, PersEmp, PersEmpPerc, InvAbs, InvPerc, GVA, and GVAperc. For the EG index, PCA was conducted on the reduced set of the five variables: GDP, GDPpc, GFCF, RESP, and RESPppp.

The authors initially conducted a panel data regression analysis using both fixed-effects and random-effects models to examine the relationship between the economic growth indicators and the CE outcomes. The Hausman test was applied in order to determine the most appropriate model specification, following the approach of M. Busu (2019). Following the initial regression analysis, the authors performed several diagnostic tests, Breusch-Pagan, the Wooldridge test, and the Variance Inflation Factor (VIF), in order to ensure the validity and reliability of the results.

Based on the results of these tests, the authors refined the model by adjusting the set of the independent variables. The final set of the independent variables included GDP, GDPpc, GFCF, ResP, and ResPppp, addressing the issues of multicollinearity and improving the model fit. This approach aligns with the recent findings (Jakopin, 2020; Lacko *et al*, 2024) that highlight how controlling for both the growth level and resource efficiency can better capture the drivers of circular competitiveness.

Using the adjusted set of variables, the authors conducted a revised panel data regression analysis. For further clarity, the general baseline model can be expressed as:

$$CCII_{it} = \alpha + \beta_1 GDP_{it} + \beta_2 GDPpc_{it} + \beta_3 GFCF_{it} + \beta_4 RESP_{it} + \beta_5 RESPppp_{it} + \epsilon_{it} \quad (1)$$

where:

$CCII_{it}$ - CCII stands for the country *i* at the time *t*,
GDP_{it} - GDP stands for the country *i* at the time *t*,
$GDPpc_{it}$ - GDPpc stands for the country *i* at the time *t*,
$GFCF_{it}$ - GFCF stands for the country *i* at the time *t*,
$RESP_{it}$ - ResP stands for the country *i* at the time *t*,
$RESPpps_{it}$ - ResPppp stands for the country *i* at the time *t*,
ϵ_{it} - the error term,
α - the constant,
$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$ - the coefficients to be estimated.
which enables the joint testing of the study's three hypotheses.

To identify the patterns and groupings among the countries based on their CE and the economic growth performance, the authors performed a K-means clustering analysis using the standardized CCII and EG indices, which allowed the countries to be categorized into distinct groups based on their performance in both competitiveness in the CE and economic growth, similar to the approach used by R. Bucea-Manea-Tonis, A. Ševic, M. P. Ilić, R. Bucea-Manea-Tonis, N. Popovic Ševic and L. Mihoreanu (2021). Here, the clustering results were interpreted in light of potential North-South and West-East divides in the EU (Hondroyiannis *et al*, 2024).

To ensure the reliability of the findings, the authors conducted several robustness checks: Cronbach's Alpha analysis, sensitivity analysis, and alternative model specifications.

It is essential to acknowledge several limitations in the applied methodology:

- potential endogeneity issues in the relationship between economic growth and CE performance, and
- the challenge of capturing all the aspects of competitiveness and innovation in the CE in quantitative indicators.

Despite these limitations, the applied methodology provides a comprehensive approach to examining the relationship between economic growth and competitiveness and innovation in the CE across the 27 EU member states. A combination of panel data regression, the composite index creation, and cluster analysis offers a complex perspective on this relationship. Moreover, referencing complementary firm-level insights (Jovanović & Janjić, 2018; Egbunike & Okoro, 2018) underscores the importance of the targeted environmental investments for reinforcing the macro-level findings.

RESEARCH RESULTS

In this section, the findings of the study are presented in detail. These results provide insights into the economic trajectories and their implications for the CE development in the EU.

Descriptive statistics

To better understand the relationship between economic growth and the CE, the authors begin with a descriptive analysis of the selected variables across the 27 EU countries.

Table 2 accounts for a synoptic view of the descriptive statistics for the selected variables, encompassing both the economic indicators and the CE metrics for the EU27 member states from 2011 to 2020.

The descriptive analysis highlights significant disparities in both economic and CE performance across the EU27, simultaneously emphasizing the

Table 2 The descriptive statistics of the key variables for the EU27 (2011-2020)

Country	Variable	N	Mean	Std. dev.	Median	Trimmed	Mad	Min	Max	Range	Skew.	Kurt.	SE	p-value
EU27	CMUr	270	8.61	6.22	6.95	7.79	5.63	1.3	29.1	27.7	1.12	0.78	0.38	5.35E-13
EU27	Patents	270	11.94	19.33	4.13	7.44	6.12	0	110.25	110.25	2.71	8.04	1.18	1.79E-23
EU27	PatentsPM	270	0.84	1.31	0.48	0.58	0.71	0	11.9	11.9	4.4	27.11	0.08	5.34E-25
EU27	PersEmp	270	136250.60	189837.14	51803.00	94489.90	51436.58	1700.00	764770.00	763070.00	1.77	1.74	11553.12	5.60E-23
EU27	PersEmpPerc	270	1.79	0.5	1.75	1.79	0.67	0.4	3.5	3.1	0.04	-11.47	0.04	2.05E-03
EU27	InvAbs	270	3240.46	5650.32	741	1806.15	917.73	33	34489.00	34456.00	2.87	9	343.87	9.01E-25
EU27	InvPerc	270	0.67	0.34	0.6	0.63	0.3	0.1	1.7	1.6	0.87	0.55	0.02	1.42E-09
EU27	GVA	270	8453.77	14424.51	2587.00	4651.55	3249.86	144	79177.00	79033.00	2.66	7.12	877.85	9.62E-25
EU27	GVAperc	270	1.74	0.73	1.6	1.66	0.44	0.5	6.2	5.7	3.16	15.33	0.04	6.41E-21
EU27	GDP (USD bn)	270	557.85	882.92	227.73	329.96	269	9.46	3974.44	3964.98	2.36	4.88	53.73	5.03E-24
EU27	GDPgr	270	1.63	3.61	1.95	1.81	2.13	-11.17	24.48	35.64	0.16	6.8	0.22	1.27E-12
EU27	GDPpc	270	33664.95	22852.78	25689.15	30372.64	17580.27	7078.86	123678.70	116599.84	1.7	3.57	1390.78	1.56E-16
EU27	GDPpeg	270	1.4	3.59	1.54	1.61	2.45	-11.6	23.3	34.9	0.02	5.83	0.22	2.71E-11
EU27	GFCF	270	20.95	4.37	20.49	20.81	3.22	10.69	54.27	43.59	2	1..8	0.27	5.48E-15
EU27	GFCFgr	270	3.09	11.5	2.34	2.04	6.09	-25.37	100.69	126.06	3.48	22.93	0.7	1.29E-20
EU27	RESP	270	1.74	1.05	1.39	1.63	0.99	0..3	4.47	4.17	0.76	-0.29	0.06	1.59E-10
EU27	RESPppp	270	1.83	0.8	1.62	1.77	0.66	0.62	4.09	3.48	0.65	-0.28	0.05	6.02E-09

Source: Authors based on the World Bank (2024) and Eurostat (2024)

necessity for tailored approaches to foster circular competitiveness. These differences set the stage for more complex analyses using PCA and panel regression.

The GDP data reveal significant variability across the EU countries, with the SD ($882.92 billion) substantially exceeding the mean ($557.85 billion), pointing to considerable economic dispersion. The high coefficient of variation (158.27%) and skewness (2.36) highlight the presence of the high-performing outliers, contributing to the economic disparities that will shape the circular competitiveness outcomes explored later.

CMUr also shows substantial dispersion (the mean 8.61%, the SD 6.22%, the CV 72.24%)), reflecting the varied adoption of the CE principles (Busu, 2019). The range of typical CMUr values (4.33% to 18.75%) suggests significant differences in the CE implementation across the EU countries (Popović *et al*, 2022).

The patent metric exhibits a high kurtosis (8.04), indicating a distribution with heavy tails (Herrero-Luna *et al*, 2022) and suggesting that a few countries produce a disproportionately large number of the CE-related patents, while most lag behind (Zhou *et al*, 2020).

These insights provide the foundation for advanced modeling techniques in order to capture complex relationships between economic growth and CE performance (Androniceanu *et al*, 2021).

As the EU's largest economy, Germany has an average GDP of $3,716.90 billion and an average GDPpc of $45,427.04. CMUr is 11.67% (slightly above the EU average), and RESP is 2.44 EUR/kg. This illustrates that economic strength alone does not ensure CE leadership (Stahel, 2016).

France has an average GDP of $2,689.12 billion and an average GDPpc of $40,411.76. CMUr is 18.15%, outperforming the EU average, and GFCF is 22.42% of the GDP. There is a positive correlation between economic development and the CE adoption (Hysa *et al*, 2020).

The Netherlands has an average GDP of $863.11 billion, the highest CMUr (26.55%), and patents per million (1.35), which exemplifies how smaller,

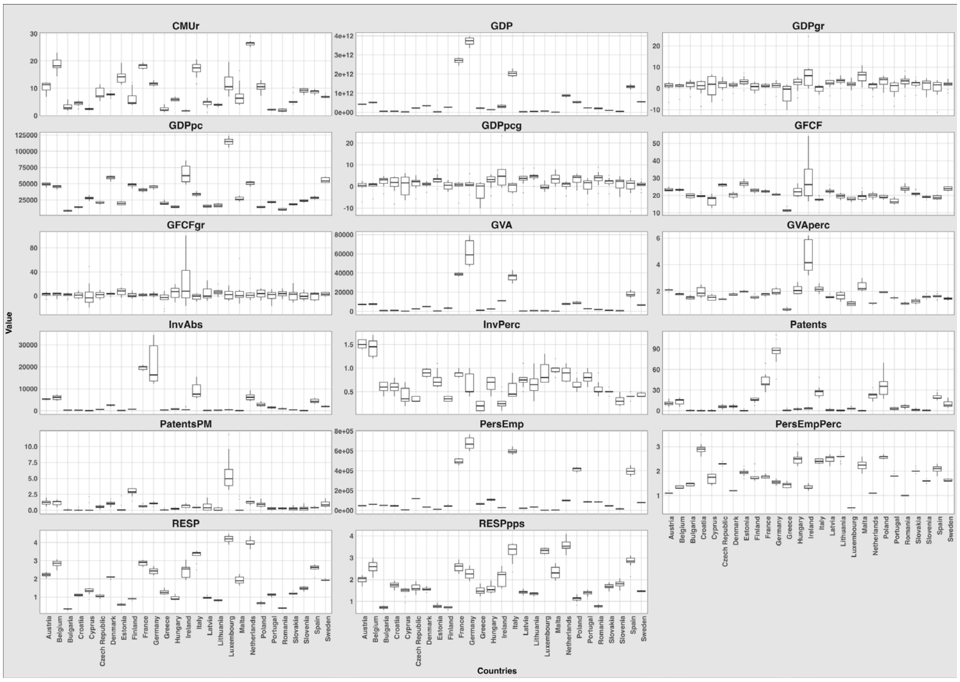

Figure 1 The boxplots of the descriptive statistics of the variables in the individual countries

Source: Authors based on the World Bank (2024) and Eurostat (2024)

developed economies can excel in circular practices through targeted policies (Busu, 2019; European Commission, 2020).

Poland's average GDP is $533.05 billion, and its GDPpc is $14,030.31. CMUr is 10.55%, which is near the EU average. It shows a commitment to the CE despite economic constraints (Popović *et al*, 2022).

Romania has a low GDPpc ($10,562.86), CMUr of 1.94%, and patents of 0.30 per million. This highlights challenges for the Eastern European countries in circular transitions (Zhou *et al*, 2020).

Luxembourg has the highest GDPpc ($114,426.14), CMUr 11.97%, and patents 5.84 per million, which underscores that high GDPpc does not guarantee the success of the CE (Mitrović & Veselinov, 2018).

This analysis reveals that, while developed economies generally show stronger CE metrics, exceptions suggest complex dynamics. It supports A. Androniceanu *et al*'s (2021) call for tailored strategies across the EU. Disparities in RESP and CMUr offer opportunities for knowledge transfer (Ferrante & Germani, 2020). Economic strength provides the foundation for the development of the CE but is not the sole determinant.

These insights inform subsequent analytical techniques to unravel the dynamics driving competitiveness and innovation in the CE across the EU.

The correlation matrix (Figure 2) reveals the key relationships in the development of the CE:

- CMUr correlates positively with RESP (r = 0.66) and Patents (r = 0.43), supporting previous findings on resource efficiency and innovation in circular economies.
- Patents strongly correlate with Investment (r = 0.79) and GVA (r = 0.85), confirming A. Karman & M. Pawlowski's (2021) argument on the role of investments in circular innovation.
- GDPpc strongly correlates with RESP (r = 0.76) but weakly with CMUr (r = 0.33), suggesting that wealth does not directly translate to higher CMUr.
- GFCF shows weak or negative correlations with the CE indicators, challenging the assumptions about the role of capital formation.

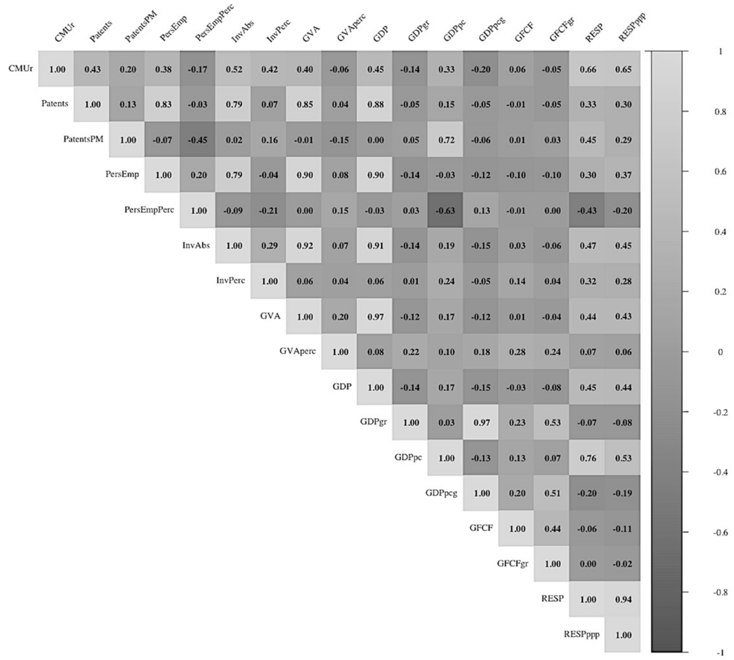

Figure 2 The correlation matrix of the key variables

Source: Authors based on the World Bank (2024) and Eurostat (2024)

- RESP and RESPppp strongly correlate (r = 0.94), indicating consistency across the purchasing power differences.
- PersEmp correlates strongly with GVA (r = 0.90) and InvAbs (r = 0.79), aligning with the European Commission's (2020) emphasis on the job creation potential.

These relationships highlight the complex nature of the development of the CE, suggesting that, while economic prosperity generally facilitates adoption, pathways vary across the indicators. This analysis underscores the need for sophisticated modeling and tailored policies.

Principal Component Analysis (PCA) and indices development

Following the descriptive analysis, PCA was conducted so as to further explore the key drivers of circular competitiveness and economic growth. It revealed the central variables influencing these outcomes. This step allowed the construction of the two indices, the CCII and the EG, in order to evaluate performance across the EU27 during the period from 2011 to 2020.

PCA for the CCII revealed that the first four components explained 87.30% of the total variance in the CE indicators, indicating a high degree of information retention. Table 3 presents the component loadings:

Table 3 The CCII component loadings

Varijable	PC1	PC2	PC3	PC4
CMUr	0.421	-0.183	0.265	0.102
Patents	0.475	0.112	-0.138	-0.092
PatentsPM	0.453	0.165	-0.201	-0.073
PersEmp	0.418	-0.246	0.185	0.124
PersEmpPerc	-0.089	0.587	0.321	0.418
InvAbs	0.399	-0.278	0.194	0.153
InvPerc	-0.065	0.595	0.302	0.385
GVA	0.412	-0.258	0.189	0.138
GVAperc	-0.078	0.592	0.315	0.401

Source: Authors

The first principal component (PC1) shows strong positive loadings for Patents, CMUr, and Employment in the circular sectors, suggesting that it captures the overall CE performance. This aligns with the findings by E. Hysa *et al* (2020) on the importance of these factors in the CE transitions. The second principal component (PC2) appears to emphasize the relative importance of the circular sectors in the economy, with high loadings on the percentage-based variables, reflecting the structural aspects of the CE integration as discussed by M. Busu (2019).

For the EG, the first three components explained 91.21% of the total variance, demonstrating a high level of data compression. Table 4 presents the component loadings:

PC1 shows strong positive loadings for GDP, GDPpc, RESP, and ResPppp, representing overall economic performance, which supports Đ. Mitrović and M. Veselinov's (2018) emphasis on these indicators in assessing economic growth. PC2 and PC3 capture additional details in economic growth, with PC2 emphasizing investment (GFCF) and PC3 showing a contrast between investment and resource productivity, reflecting the complex relationship between GFCF and resource efficiency as noted by A. Karman and M. Pawlowski (2021).

Table 4 The EG component loadings

Variable	PC1	PC2	PC3
GDP	0.512	-0.245	0.168
GDPpc	0.498	0.312	-0.215
GFCF	0.089	0.687	0.718
RESP	0.487	0.325	-0.398
RESPppp	0.495	0.307	-0.242

Source: Authors

Based on these PCA results, the authors constructed the 10-year CCII and EG indices for each country and each year in the dataset. The indices were standardized and scaled from 0 to 100 for ease of interpretation and comparison across the countries and the time periods. Figure 3 presents a scatter plot of the average CCII and EG scores for each EU27 country over the period from 2011 to 2020.

The scatter plot reveals the key patterns in the performance of the CE in the EU:

- Positive Correlation: The CCII and EG scores generally correlate positively, supporting W. R. Stahel's (2016) argument that economic strength facilitates circular transitions.

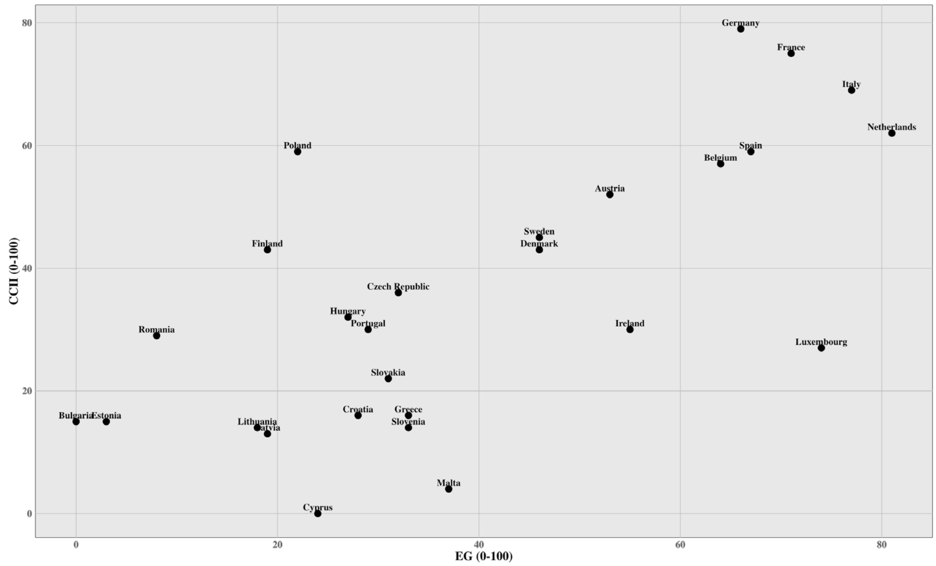

Figure 3 The scatter plot of the average CCII vs. EG scores for the EU27 countries (2011-2020)

Source: Authors based on the World Bank (2024) and Eurostat (2024)

- Leaders Cluster: Germany, France, Italy, and the Netherlands excel in both economic growth and circular practices.
- Divergent Performances: Luxembourg and Ireland show a high EG but a moderate CCII, whereas Poland has a higher CCII relative to the EG, thus supporting Đ. Mitrović and M. Veselinov's (2018) observation that GDPpc does not guarantee CE leadership.
- Catch-up Potential: The Eastern European countries cluster in the lower-left quadrant, aligning with A. Popović *et al*'s (2022) findings on transition challenges.
- Mid-range Performers: Austria, Sweden, Denmark, and Finland show moderate-to-good performance on both indices.
- Outliers: Cyprus has a notably low CCII relative to its EG score.

This analysis provides a comprehensive view of the EU's CE landscape. It forms the basis for subsequent panel data and cluster analyses, enabling a nuanced understanding of the relationship between economic growth and competitiveness in the CE in the EU.

Panel data analysis

After identifying the key drivers of circular competitiveness through PCA, the authors proceeded with panel data regression. The initial model encountered challenges like heteroskedasticity, multicollinearity, and autocorrelation, which were addressed through the model refinement.

The authors conducted both fixed-effects and random-effects panel data regression analyses using the refined set of the independent variables (GDP, GDPpc, GFCF, ResP, and ResPppp) and the CCII as the de-

Table 5 The results of the panel data regression analysis for the CCII

Country	Model Type	Independent Variable	Dependent Variable	Est.	Std.E.	t-value	p-value
EU27	Fixed Effects	GDP	CCII	1.8609	1.0148	1.8338	0.0679
		GDPpc		-2.2070	2.3615	-0.9346	0.3509
		GFCF		1.6993	0.6652	2.5545	0.0113
		RESP		-1.9733	0.9421	-2.0946	0.0373
		RESPppp		1.5892	0.5328	2.9828	0.0032
	Random Effects	(Intercept)		0.4063	0.3362	1.2084	0.2269
		GDP		3.3335	0.2450	13.6055	0.0000
		GDPpc		-2.8025	1.1574	-2.4215	0.0155
		GFCF		1.4024	0.6302	2.2252	0.0261
		RESP		0.4017	0.4984	0.8059	0.4203
		ResPppp		0.2879	0.3260	0.8830	0.3772
	Hausman Test					8.493	0.1332
	Fixed Effects	GDP	CCII standardized	0.4713	0.2570	1.8338	0.0679
		GDPpc		-0.5589	0.5981	-0.9346	0.3509
		GFCF		0.4304	0.1685	2.5545	0.0113
		RESP		-0.4998	0.2386	-2.0946	0.0373
		RESPppp		0.4025	0.1349	2.9828	0.0032
	Random Effects	(Intercept)		0.0676	0.0852	0.7939	0.4273
		GDP		0.8442	0.0621	13.6055	0.0000
		GDPpc		-0.7098	0.2931	-2.4215	0.0155
		GFCF		0.3552	0.1596	2.2252	0.0261
		RESP		0.1017	0.1262	0.8059	0.4203
		ResPppp		0.0729	0.0826	0.8830	0.3772
	Hausman Test					8.4493	0.1332
	Fixed Effects	GDP	CCII (0-100)	9.8311	5.4296	1.8106	0.0715
		GDPpc		-12.1820	12.6354	-0.9641	0.3360
		GFCF		8.7066	3.5593	2.4461	0.0152
		RESP		-10.6121	5.0407	-2.1053	0.0363
		RESPppp		8.5221	2.8508	2.9893	0.0031
	Random Effects	(Intercept)		41.1882	1.7983	22.9034	0.0000
		GDP		17.8408	1.3099	13.6198	0.0000
		GDPpc		-15.4568	6.1943	-2.4953	0.0126
		GFCF		7.1202	3.3750	2.1097	0.0349
		RESP		2.3215	2.6675	0.8703	0.3841
		ResPppp		1.4344	1.7450	0.8220	0.4111
	Hausman Test					9.4332	0.0930

Source: Authors

pendent variable. The Hausman test was employed in order to determine the most appropriate model specification. The results are given in Table 5.

The Hausman test result suggests that the random-effects model is more appropriate for the analysis, which aligns with the findings of A. Karman and M. Pawlowski (2021), who noted that random-effects models often capture both within-country and between-country variations more effectively in studies on the CE.

At the EU27 level, the random-effects model reveals several significant relationships. GDP shows a strong positive association with CCII but, interestingly, GDPpc shows a negative relationship with CCII. GFCF demonstrates a positive relationship with CCII. The results for RESP and RESPppp are not statistically significant in the random-effects model.

The panel data analysis reveals distinct country-level patterns in the relationship between economic growth and competitiveness in the CE. These patterns can be grouped as follows:

- The first group consists of the countries with a significant positive relationship between GDP and CCII, those countries including Belgium, Malta, and the Netherlands. They show a strong positive relationship between GDP and competitiveness and innovation in the CE, suggesting that overall economic growth is closely linked to CE performance in these nations.
- The second group of countries shows a significant negative relationship between GDPpc and CCII. Belgium and the Netherlands show a negative relationship, indicating that higher individual wealth does not necessarily translate to better CE performance.
- The third group of countries shows a significant positive relationship between GFCF and CCII. Ireland and Portugal demonstrate a strong positive relationship between GFCF and competitiveness in the CE, suggesting that investment in fixed assets plays a crucial role in the development of their CE.
- The fourth group consists of the countries with a significant positive relationship between RESP and CCII, where Belgium, Denmark, Hungary, Ireland, and Malta show a positive relationship between RESP and competitiveness in the CE, indicating that the efficient use of resources is a key factor in their CE performance.
- The fifth group comprises the countries with a significant negative relationship between RESP and CCII, with Bulgaria standing out with a negative relationship between RESP and CCII, suggesting a unique dynamic in the development of its CE.
- The sixth group comprises the countries with a significant negative relationship between RESPppp and CCII, with Denmark, Hungary, and Ireland showing a negative relationship between RESPppp and competitiveness in the CE, indicating a complex interaction between resource efficiency and the economic factors.
- The seventh, final and largest group of countries has no significant relationships. Austria, Croatia, Cyprus, the Czech Republic, Estonia, Finland, France, Germany, Greece, Italy, Latvia, Lithuania, Luxembourg, Poland, Romania, Slovakia, Slovenia, Spain, and Sweden show no statistically significant relationships between the variables and CCII. This large group of countries demonstrate the complexity of the development of the CE across the EU.

These findings underscore the heterogeneity of the development of the CE across the EU and the need for tailored, country-specific approaches to promoting competitiveness in the CE. They also align with the observations made in A. P. Egbunike and E. G. Okoro (2018) that capital and green expenditures do not always yield uniform outcomes across diverse contexts.

The sensitivity analyses and alternative model specifications reinforced the robustness of the findings:

- The EU15 countries showed a similar GDP-CCII relationship ($\beta = 3.5621$, $p < 0.001$) to the EU27 ($\beta = 3.3335$, $p < 0.001$).
- The GDPpc-CCII relationship varied from negative in the EU27 ($\beta = -2.8025$, $p < 0.05$) to non-significant in the EU15 ($\beta = -1.9876$, $p = 0.1234$).

- The GDP-CCII relationship strengthened over time (2011-2015: β = 2.9876, $p < 0.01$; 2016-2020: β = 3.7654, $p < 0.001$).

Alternative specifications revealed the following:

- the lagged variables improved the model fit, thus supporting X. Zhou *et al*'s (2020) findings on delayed effects,
- the GDP-RESP interaction was significant (β = 0.4567, $p < 0.05$), thus indicating a stronger GDP impact on CCII in the countries with higher resource productivity, and
- the quadratic GDP term (β = -0.0234, $p < 0.05$) suggested diminishing returns at high economic output levels.

These analyses highlight the complex, nonlinear, and time-dependent nature of the factors influencing competitiveness in the CE, simultaneously emphasizing the need for the dynamic approaches that consider both the immediate and the long-term effects of economic policies.

Cluster analysis

To further explore the patterns identified through the panel regression, the authors performed a K-means clustering analysis by grouping the EU countries based on their CCII and EG. This clustering provides additional insights into how different economies align or diverge in their CE trajectories. Based on the elbow, silhouette, and gap statistical methods for K-means clustering and the average silhouette width for hierarchical clustering, the optimal number of clusters was determined to be two. The analysis revealed distinct clusters, as illustrated in Figure 4.

The cluster analysis revealed two distinct groups:

- Advanced Circular Economies (Cluster 1): This cluster includes the countries with generally higher scores in both CCII and EG, such as Germany, France, Italy, the Netherlands, Spain, Belgium, Austria, Sweden, Denmark, Finland, Luxembourg, and Ireland, which all demonstrate varying degrees of success in combining their economic growth with CE practices. Within this cluster, multiple sub-groups were distinguished:

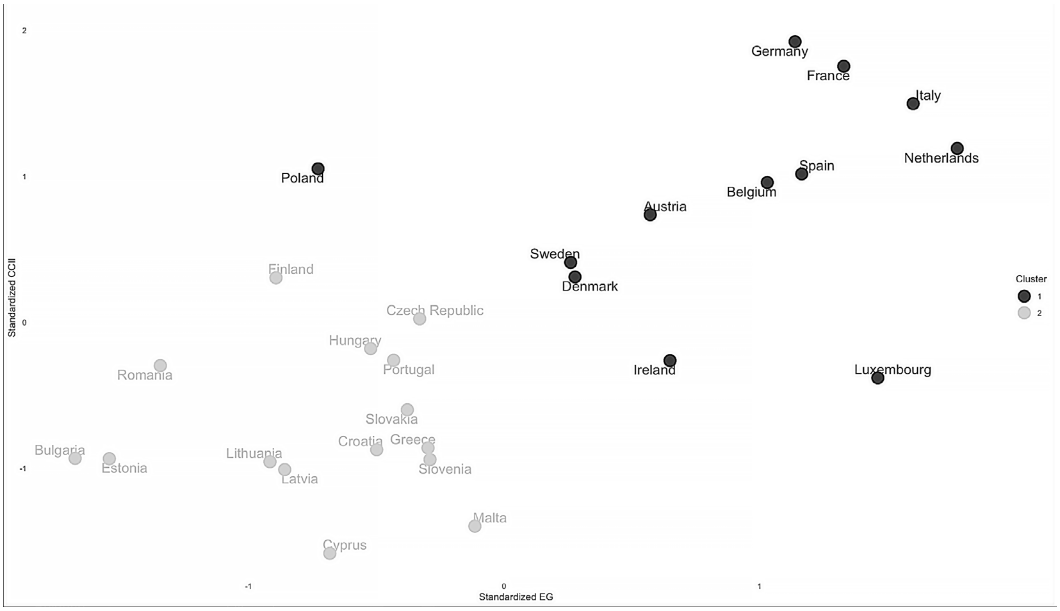

Figure 4 The cluster plot of the standardized CCII vs. EG scores for the EU27 countries

Source: Authors

  - Top Performers: Germany, France, and the Netherlands - the countries showing the highest combined scores, indicating a strong alignment between economic performance and CE practices.
  - Strong Performers: Italy, Spain, and Belgium - the countries demonstrating high scores, albeit slightly lower than the top performers.
  - Nordic Countries: Sweden, Denmark, and Finland - the countries forming a distinct sub-group with an above-average performance in both indices.
  - Economic Powerhouses with Moderate Circularity: Luxembourg and Ireland - the countries showing high EG scores but relatively lower CCII scores, which aligns with Đ. Mitrović and M. Veselinov's (2018) observation that high GDPpc does not automatically translate to CE leadership.
- Developing Circular Economies (Cluster 2): This cluster primarily comprises the Eastern and Southern European countries, including Poland, the Czech Republic, Portugal, Hungary, Romania, Bulgaria, Croatia, Slovakia, Slovenia, Greece, Lithuania, Latvia, Estonia, Cyprus, and Malta, which all generally show lower scores in both EG and CCII but with significant variations:
  - Emerging Leaders: Poland stands out within this cluster, showing a higher CCII score relative to its EG score, suggesting the successful implementation of CE practices despite its lower overall economic output.
  - Transitional Economies: The countries such as the Czech Republic, Portugal, and Hungary show moderate scores, indicating progress in both economic growth and CE adoption.
  - Developing Economies: The countries such as Romania, Bulgaria, and the Baltic states show lower scores in both indices, reflecting the challenges faced by less economically developed EU members in transitioning to CE models, as noted by L. Ferrante and A. R. Germani (2020).

In conclusion, the results obtained from the descriptive statistics, PCA, panel regression, and cluster analysis reveal the complex relationship between economic growth and circular competitiveness in the EU. While economic strength generally supports circular innovation, the variability perceived across the countries emphasizes the need for tailored, country-specific policies, which highlights the fact that each country's unique economic and structural characteristics must be considered for effective circular transitions. Moreover, these findings resonate with the European Court of Auditors (2023) observation that policy ambition must be matched by more differentiated strategies, especially in lower-performing regions.

DISCUSSION

This study examined how economic growth influences CE competitiveness and innovation across 27 EU countries from 2011 to 2020. The findings reveal intricate interactions between economic indicators and circular performance, highlighting that while growth can support circular transitions, these dynamics are not uniform across countries.

Relationship between economic growth and competitiveness and innovation in the circular economy

Hypothesis 1 (*H1*) posited that higher GDP, GDPpc, and their respective growth rates would positively correlate with greater competitiveness and innovation in the CE. The findings partly support this hypothesis, highlighting the nuanced relationship between economic growth and circular performance. While GDP strongly correlates with CE success, as evidenced by the positive association with CCII, the negative coefficient for GDPpc underscores that economic strength alone does not guarantee advanced implementation of the CE, which aligns with the complexities identified by F. Ying and Z. Wen-Ping (2015) in high-growth but lower-tech contexts. This suggests that wealthier nations may face additional challenges in achieving circular competitiveness, potentially due to entrenched linear economic practices or weak policy incentives for sustainability, which is in line with W. R. Stahel's (2016) argument that economic strength provides necessary resources for circular transitions.

However, the relationship between GDPpc and CCII was found to be negative, thus contradicting part of the first hypothesis. This unexpected result echoes the observations of Đ. Mitrović and M. Veselinov (2018), indicating that higher individual wealth does not necessarily translate to better CE performance. It further echoes the contrasting outcomes observed in some advanced economies with moderate circular metrics (European Court of Auditors, 2023). This finding challenges the assumption that wealthier countries are automatically more adept at implementing CE practices. It suggests that other factors, such as policy frameworks, industrial strategies, and societal attitudes towards sustainability, may be more crucial in driving competitiveness in the CE than *per capita* income alone.

The cluster analysis further illuminates this complex relationship. While the countries classified into Cluster 1 generally show high scores in both EG and CCII, there are notable exceptions. Luxembourg and Ireland demonstrate high EG scores but relatively lower CCII scores, reinforcing the idea that high GDPpc does not automatically lead to CE leadership. Conversely, Poland in Cluster 2 shows a higher CCII score relative to its EG score, suggesting that effective policies and targeted efforts can drive CE performance even in the countries with a lower overall economic output. This aligns with A. P. Egbunike and E. G. Okoro's (2018) emphasis on targeted environmental investments and policy instruments, which may overcome lower baseline income levels.

The role of investment in the development of the circular economy

Hypothesis 3 (*H3*) proposed that countries with higher investments (GFCF, InvAbs) tend to have more significant innovations and higher levels of competitiveness in the CE. The results support this hypothesis, highlighting the importance of capital formation in driving CE transitions.

The random-effects model showed a positive relationship between GFCF and CCII. This finding aligns with S. Herrero-Luna *et al*'s (2022) assertion that investment in tangible assets is crucial for CE transitions, which suggests that the countries allocating more resources to fixed assets, potentially including the infrastructure and technologies supporting CE practices, tend to perform better in terms of competitiveness in the CE.

At the individual-country level, this relationship was particularly pronounced in Ireland ($\beta = 2.0618$, $p < 0.05$) and Portugal ($\beta = 23.3467$, $p < 0.05$). These results indicate that targeted investments can significantly boost CE performance, even in the countries with different overall economic standings. Such targeted approaches further resonate with the findings of E. Jakopin (2020) regarding structural reform and capital allocation, indicating that aligning investment with CE goals can overcome growth constraints.

The importance of investment is further underscored by the alternative model specifications, which showed that including the lagged GFCF variables had improved the model fit and reduced autocorrelation, which is supportive of X. Zhou *et al*'s (2020) findings on the delayed effects of economic factors on CE outcomes, suggesting that the benefits of investments in CE initiatives may not be immediately apparent but may have significant long-term impacts.

Resource productivity and circular economy performance

Hypothesis 2 (*H2*) suggested that countries with higher ResP and ResPppp exhibited better CE performance. The results provide limited and mixed support for this hypothesis, revealing a complex relationship between resource efficiency and competitiveness in the CE.

In the EU27 random-effects model, the RESP and RESPppp results were not statistically significant. This ambiguity echoes M. Busu's (2019) observations on the complex relationship between resource productivity and CE performance. It suggests that, while resource efficiency is theoretically crucial for CE practices, its impact may be mediated by the other factors such as technological adoption, regulatory frameworks, and industrial composition.

At the individual-country level, mixed results were noticed. Some countries, like Belgium (RESP: $\beta = 33.1388$, $p < 0.1$) and Denmark (RESP: $\beta = 22.3519$, $p < 0.05$), showed positive relationships between resource productivity and CCII. Some others, however, like Bulgaria (RESP: $\beta = -40.2117$, $p < 0.1$), demonstrated negative relationships. This variability suggests that the impact of resource productivity on CE performance is context-dependent and may interact with the other country-specific factors.

The interaction term between GDP and RESP in the alternative model specifications ($\beta = 0.4567$, $p < 0.05$) provides an additional insight. It suggests that the positive impact of GDP on CCII is stronger in the countries with higher resource productivity. This finding is consistent with EU-wide efficiency dispersion documented by I. Marjanović *et al* (2025), which shows pronounced cross-country differences in circular economy efficiency, so the scale of gains from economic expansion depends on a country's initial efficiency level. Overall, resource efficiency may act as a moderator, enhancing the effectiveness of economic growth in driving competitiveness in CE.

Implications for policy and practice

The findings have several important implications for policymakers and practitioners:

- While GDP supports circular development, the negative correlation with GDPpc indicates that wealthier nations need targeted policies to convert economic prosperity into circular competitiveness.
- Prioritizing investments in infrastructure, technologies, and systems that support circular practices will be essential for sustained competitiveness.
- Resource efficiency impacts CE performance differently across countries. Policymakers should develop context-specific strategies that integrate resource productivity into broader CE goals.
- Clustering analysis shows the need for tailored CE policies, depending on a country's stage of development and economic characteristics.
- The time-lagged effects of investments and resource productivity require sustained, long-term planning to see meaningful CE outcomes.

Limitations and Future Research Directions

While this research study provides valuable insights, it has several limitations that point to directions for future research:

- The composite indices (CCII and EG) may obscure relationships between specific variables. Future research should explore granular interactions between individual economic and circular indicators.
- The analysis is limited to the data pertaining to the period from 2011 to 2020. Incorporating more recent data would provide insights into the evolving nature of CE practices.
- Focusing on the EU countries limits the generalizability of the findings. Comparative studies involving non-EU countries could broaden the scope of research in the CE.
- Future research could investigate additional factors influencing circular competitiveness, such as policy interventions and sector-specific initiatives. It may also be worthwhile to examine firm-level heterogeneity, aligning with D. Jovanović and V. Janjić (2018) and A. P. Egbunike and E. G. Okoro (2018), in order to explore how corporate spending on environmental measures interacts with macro-level indicators.

Finally, the research reveals the complex relationship between economic growth and competitiveness and innovation in the CE in the EU. While economic strength generally facilitates the development of the CE, the path to CE success is not straightforward and depends on a variety of factors beyond a mere economic output. These findings underscore the need for nuanced, context-specific approaches to promoting

CE practices across the diverse landscape of the EU. Elevating resource efficiency, directing capital effectively, and addressing structural disparities are key to ensuring that economic gains translate into tangible circular outcomes (European Court of Auditors, 2023).

CONCLUSION

This research highlights the complex relationship between economic growth and competitiveness in the CE across the EU from 2011 to 2020. While economic growth measured by GDP generally supports CE performance, this relationship varies across countries, emphasizing the need for tailored, country-specific policies. Notably, the negative link between GDPpc and circular outcomes, which is also observed in high-growth contexts (Ying & Wen-Ping, 2015; European Court of Auditors, 2023), demonstrates that wealth alone does not guarantee circular leadership. Instead, factors like policy frameworks, industrial strategies, and societal attitudes may play a more crucial role.

Investment in fixed assets emerged as a key driver of circular transitions, reinforcing the importance of infrastructure and technology in promoting circular practices. Such targeted capital allocation echoes findings that green expenditure policies can foster efficiency and competitiveness (Egbunike & Okoro, 2018). The relationship between resource productivity and circular performance proved more complex, with country-specific variations indicating that economic structures and resource use influence circular outcomes differently.

Cluster analysis revealed two distinct groups of countries, the first including advanced and the second including developing circular economies. Some lower-output countries, such as Poland, demonstrated strong circular performance, showing that effective policies can drive success even in less wealthy nations. The research also underscores the time-lagged effects of investments, requiring long-term planning and sustained commitment for a lasting impact. Moreover, aligning macro-level growth strategies with structural reforms (Jakopin, 2020) can help ensure these investments generate enduring circular gains.

Overall, the study shows that, while economic strength aids circular development, success depends on various factors beyond the economic output. Tailored, country-specific approaches will be vital as the EU advances towards a more sustainable CE. In practice, as emphasised by European Commission (2020) and European Court of Auditors (2023), and consistent with the EU-wide efficiency dispersion evidenced by I. Marjanović *et al* (2025), growth strategies should be integrated with resource-efficiency and circularity measures so that expansion translates into durable circular competitiveness.

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