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Evaluating the Impact of Material Efficiency in the Circular Economy on Economic Growth in European Countries

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Abstract: *This research evaluates the impact of material efficiency within the circular economy (CE) framework on economic growth in European countries from 2012 to 2021. Focusing on key indicators - Recycling Rate of Municipal Waste, Resource Productivity, and Domestic Material Consumption per Capita - the research employs panel data analysis and Principal Component Analysis (PCA). The findings reveal that Resource Productivity significantly contributes to GDP per capita growth, particularly in EU27 countries, underscoring the importance of efficient resource use in driving sustainable economic development. Conversely, Resource Productivity and Domestic Material Consumption per capita exhibit a more complex relationship with economic growth, lacking statistical significance in the main models. The research highlights the necessity for policymakers to prioritize resource efficiency strategies to foster economic prosperity while advancing CE practices. These insights are crucial for designing targeted policies that balance material efficiency with broader economic objectives across diverse European contexts.*

1. INTRODUCTION

The transition towards a circular economy (CE) is fundamental to sustainable development strategies in Europe, shifting from a traditional "take-make-dispose" model to the new model that emphasizes resource efficiency, waste reduction, and the continual use of materials (European Commission, 2020). Material efficiency optimizes the use of resources in order to drive economic growth while minimizing environmental impact, making it crucial to understand its relationship with economic growth amid concerns over resource depletion and environmental degradation.

Current research suggests that the CE can stimulate economic growth. Busu and Trica (2019) found a positive relationship between CE indicators - such as recycling rates and resource productivity - and economic growth in the EU. Similarly, Androniceanu et al. (2021) highlighted the CE as a strategic option for promoting sustainable economic growth and human development within the European Union. However, there are still gaps present regarding non-EU Balkan countries, comprehensive analyses of multiple CE indicators, and country-specific variations in the impacts of material efficiency.

The authors address these gaps by evaluating the impact of material efficiency within the CE framework on economic growth in EU27 and non-EU Balkan countries. Through the focus on three critical indicators, the recycling rate of municipal waste (RECR), resource productivity (RESP), and domestic material consumption per capita (DMCpc), the study examines their relationships with gross domestic product per capita growth (GDPpcgr) to provide empirical insights into how material efficiency drives economic prosperity.

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The following hypotheses guide this study:

H1: There is a positive relationship between the recycling rate of municipal waste (RECR) and GDP per capita growth (GDPpcgr).

H2: Higher resource productivity (RESP) leads to increased GDP per capita growth.

H3: Lower domestic material consumption per capita (DMCpc) is associated with higher GDP per capita growth.

The primary research question utilized in this paper is: How does efficient material use within the CE framework influence economic growth in EU27 and Balkan countries? Through the exploration of the specific impacts of RECR, RESP, and DMCpc on GDPpcgr, the paper aims to provide valuable insights for policymakers, economists, and environmental scientists seeking to enhance material efficiency and promote sustainable economic development.

2. LITERATURE REVIEW

The CE concept is supposed to reconcile economic growth with environmental sustainability. Lehmann et al. (2022) emphasized that investment and innovation are critical drivers in leveraging the CE for economic performance, with innovation reducing environmental degradation and investment promoting resource efficiency. Similarly, Hysa et al. (2020) developed an integrated model demonstrating that CE innovation and environmental sustainability positively impact economic growth in EU countries.

Recycling, as a key identified element of the CE, enables the reintegration of waste materials into production. Busu (2019) found that higher municipal waste recycling rates significantly contribute to economic growth in the EU by reducing environmental burdens and enhancing resource availability. Smol et al. (2017) proposed indicators to measure the integration of eco-innovation and CE practices, highlighting the importance of recycling rates in assessing regional progress.

The second indicator in the focus of this research, resource productivity, defined as economic output per unit of material consumed, is crucial for material efficiency. Androniceanu et al. (2021) used principal component analysis to show that resource productivity significantly contributes to sustainable economic growth and human development in EU countries. This aligns with Busu and Trica (2019), who demonstrated that increased resource productivity leads to higher GDP growth rates.

Furthermore, domestic material consumption per capita measures the total material used directly by an economy. Ferrante and Germani (2020) explored the relationship between CE practices and economic growth, noting that reducing material consumption per capita is associated with positive socio-economic outcomes, as lower DMCpc indicates more efficient resource use leading to enhanced economic performance.

Despite growing research, several gaps persist. Most studies focus on EU countries, with limited attention to non-EU Balkan countries. Bucea-Manea-Țoniș et al. (2021) highlighted the need for more research on the Balkan region, noting that Romania and Serbia require increased R&D investments to align with EU standards in CE practices. Additionally, comprehensive analyses incorporating multiple CE indicators are scarce. Karman and Pawłowski (2021) emphasized evaluating various factors collectively to understand their combined impact on economic growth.

Many studies utilize cross-sectional data or short time periods, limiting the understanding of long-term effects. Popović et al. (2022) pointed out the insufficient exploration of country-specific heterogeneity in CE implementation and its economic impacts across Europe. Moreover, research focusing specifically on GDP per capita growth in relation to CE measures is limited, as most studies use broader economic indicators.

EU policies have been instrumental in promoting CE practices. The EU Circular Economy Action Plan sets ambitious targets for waste reduction, recycling, and resource efficiency (European Commission, 2020), aiming to decouple economic growth from resource use. Building on policy frameworks, Todorović et al. (2023) discussed how ecological innovations, supported by EU policies, contribute to sustainable development. However, the effectiveness of these policies varies among member states and neighboring countries, highlighting the need for tailored approaches.

Methodologies used to examine the impact of CE practices on economic growth include panel data regression models (Busu & Trica, 2019; Hysa et al., 2020), principal component analysis to create CE indices (Androniceanu et al., 2021), and comparative analyses across countries (Popović et al., 2022). Despite these advances, further research is needed to comprehensively control for economic factors and explore potential non-linear relationships.

3. RESEARCH METHODOLOGY

This study employs a quantitative approach to evaluate the impact of material efficiency within the circular economy framework on economic growth in EU27 and selected Balkan countries from 2012 to 2021. The methodology includes data collection and preparation, data preprocessing, descriptive statistical and panel data analysis, Principal Component Analysis (PCA) for composite indices, and robustness checks.

3.1. Data Collection, Preparation, and Variables

The data used in this research were sourced from reliable, open-source international databases, such as Eurostat and the World Bank, to ensure reliability and consistency across countries and over time. The dataset includes 27 EU member states and select Balkan countries, covering 2012–2021. The inclusion of non-EU Balkan countries addresses gaps in the literature, where limited attention has been given to these regions (Bucea-Manea-Țoniș et al., 2021; Popović et al., 2022).

Table 1. Variables used in the analysis

Name	Variable	Type
GDPpcgr	GDP per capita growth (annual %)	Dependent
RECR	Recycling rate of municipal waste	Independent
RESP	Resource productivity	Independent
DMCpc	Domestic material consumption per capita	Independent
GFCF	Gross capital formation (current US$)	Control
INF	Inflation, GDP deflator (annual %)	Control
UNEMP	Unemployment, total (% of total labor force)	Control
ENU	Energy use (kg of oil equivalent per capita)	Control
RNWC	Renewable energy consumption (% of total)	Control
GGFC	General government final consumption expenditure (% of GDP)	Control

Source: World Bank (2024) and Eurostat (2024)

Data were sourced from reliable international databases such as Eurostat and the World Bank, ensuring consistency across countries and over time. The dataset covers 27 EU member states and selected Balkan countries, addressing gaps in the literature concerning non-EU Balkan regions

(Bucea-Manea-Țoniș et al., 2021; Popović et al., 2022). The key variables are summarized in Table 1. These variables align with previous studies examining the economic impacts of circular economy initiatives (Busu, 2019; Lehmann et al., 2022).

3.2. Data Preprocessing and Logarithmic Transformation

To ensure comparability across variables with diverse units and scales, data preprocessing involved normalization and standardization techniques, following methodologies used in prior research (Hysa et al., 2020). Variables exhibiting positive skewness, such as GFCF, ENU, and DMCpc, were log-transformed to address heteroscedasticity and approximate normality (Lehmann et al., 2022), improving the accuracy and interpretability of regression models.

3.3. Descriptive Statistical Analysis, Panel Data Analysis with Individual Variables

Descriptive statistics were calculated to understand the central tendencies and dispersion of each variable. After preprocessing, variables were standardized, resulting in means approximately equal to zero and unit variances, confirming the effectiveness of the preprocessing steps (Karman & Pawłowski, 2021).

Panel data analysis leveraged both cross-sectional and time-series dimensions, enhancing the efficiency of econometric estimates and controlling for unobserved heterogeneity (Hsiao, 2014). The initial model included GDPpcgr as the dependent variable and the independent and control variables.

In the research, both Fixed Effects (FE) and Random Effects (RE) models were estimated. The Hausman test determined the most appropriate model specification, favoring the FE model due to correlated individual effects (Baltagi, 2008). Diagnostic tests included:

- **Breusch-Pagan Test** for heteroscedasticity (Breusch & Pagan, 1979).
- **Wooldridge Test** for autocorrelation (Wooldridge, 2010).
- **Variance Inflation Factor (VIF)** for multicollinearity (O'Brien, 2007).

These tests indicated issues with multicollinearity, heteroscedasticity, and autocorrelation, necessitating model refinement.

3.4. Principal Component Analysis (PCA) and Macro and Investment Index Creation

To mitigate multicollinearity and reduce dimensionality, PCA was applied, consistent with methodologies from Androniceanu et al. (2021) and Karman and Pawłowski (2021). PCA transformed correlated variables into composite indices:

- **Macro_Index:** Derived from INF, UNEMP, and GGFC.
- **Invest_Index:** Derived from log_GFCF, log_ENU, and RNWC.

Following the example from previous research, these indices reduced multicollinearity and improved model interpretability (Jolliffe & Cadima, 2016).

3.5. Revised Panel Data Analysis with Composite Indices

The panel data analysis was re-estimated with the composite indices. The FE model remained appropriate, and diagnostic tests showed improvements, with lower VIF values indicating reduced multicollinearity and mitigated heteroscedasticity and autocorrelation.

Robustness checks included:

- **Alternative Model Specifications:** Testing interaction terms (e.g., INF × UNEMP) to explore potential moderating effects, inspired by Hysa et al. (2020).
- **Subsample Analyses:** Splitting the sample into EU27 and Balkan countries to investigate regional variations, addressing gaps noted by Bucea-Manea-Țoniș et al. (2021).

This comprehensive methodology allowed for a robust evaluation of the impact of material efficiency on economic growth, contributing valuable insights to the circular economy literature.

4. RESEARCH RESULTS

This study examines the impact of material efficiency within the circular economy on economic growth in EU27 and selected Balkan countries from 2012 to 2021 using a quantitative research design. The analysis incorporates data collection, preprocessing, descriptive statistics, panel data analysis, the creation of composite indices via Principal Component Analysis (PCA), and robustness checks.

An initial examination of the dataset, comprising 320 observations, reveals substantial variability across key variables. For instance, GDP per capita growth (GDPpcgr) shows a mean of 2.11% with a standard deviation of 4.00%, indicating substantial fluctuations in economic performance. Variables such as Domestic Material Consumption per capita (DMCpc) and Energy Use (ENU) demonstrate high positive skewness (1.40 and 2.47, respectively), highlighting disparities across countries (Table 2). The Shapiro-Wilk test confirms that none of the variables follow a normal distribution ($p < 0.05$), necessitating transformations for parametric analysis.

Table 2. Descriptive Statistics of Original Dataset

Variable	N	Mean	SD	Median	Min	Max	Skew	Kurt	W	p-value
GDPpcgr	320	2.11	4.00	2.19	-15.21	23.30	0.04	4.40	0.94	1.6E-10
RECR	320	31.40	18.35	32.35	0	70.3	-0.09	-0.92	0.97	1.5E-06
RESP	320	1.59	1.14	1.22	0	5.50	0.86	-0.01	0.92	5.5E-12
DMCpc	320	15.90	7.82	14.37	0	48.61	1.40	3.68	0.89	1.3E-14
INF	320	1.92	1.60	1.71	-2.05	8.30	0.80	1.25	0.96	7.6E-08
UNEMP	320	10.08	6.04	7.97	2.02	31.10	1.32	1.22	0.87	4.6E-16
GFCF	320	1.0E+11	1.8E+11	2.9E+10	8.1E+08	9.9E+11	2.74	7.31	0.59	6.9E-27
GGFC	320	19.47	3.45	19.34	10.84	26.47	-0.08	-0.13	0.98	3.0E-05
ENU	320	30.80	46.96	12.75	0.5	221	2.47	5.82	0.63	1.3E-25
RNWC	320	23.02	12.09	19.50	2.7	57.9	0.67	-0.44	0.94	4.7E-10

Source: Own calculations

To address non-normality and heteroscedasticity, several variables, including GFCF, UNEMP, ENU, and DMCpc, were log-transformed to stabilize variance. Variables like INF, RNWC, and RESP were transformed by square root due to moderate skewness. Post-transformation, variables were standardized to have a mean of zero and a standard deviation of one, enhancing comparability across different scales.

4.1. Panel Data Analysis with Individual Variables

Initial panel data analysis employed Fixed Effects (FE) and Random Effects (RE) models to explore the relationships between GDPpcgr and the independent variables. The FE model controls for country-specific, time-invariant heterogeneity, while the RE model assumes uncorrelated individual-specific effects (Baltagi, 2008). The results of the initial Panel Data Analysis are in Table 3.

Table 3. Fixed and Random Effects Model Estimates

Variable	Fixed Effects Model (FE)					Random Effects Model (RE)				
	Est.	SE	t-value	Pr(>|t|)		Est.	SE	t-value	Pr(>|t|)	
Intercept	-	-	-	-		~0	0.0609	~0	1	
RECR	0.4324	0.2074	2.085	0.038	*	-0.0202	0.1201	-0.168	0.8663	
RESP	0.8975	0.3729	2.407	0.0167	*	-0.0361	0.1192	-0.303	0.7621	
log_DMCpc	0.5122	0.4953	1.034	0.3019		0.0109	0.0696	0.157	0.8751	
INF	0.365	0.0649	5.623	4.56E-08	**	0.3189	0.0578	5.516	3.46E-08	**
log_UNEMP	0.3859	0.1483	2.602	0.0097	**	0.0219	0.0873	0.251	0.8016	
log_GFCF	0.2343	0.6646	0.353	0.7247		0.5143	0.3161	1.627	0.1038	
GGFC	-1.2228	0.1728	-7.078	1.19E-11	**	-0.33	0.0702	-4.703	2.57E-06	**
log_ENU	1.928	1.6892	0.2547	0.0167	*	-0.4546	0.2863	-1.588	0.1123	
RNWC	-0.2779	0.2192	-1.268	0.2059		0.0181	0.0742	0.244	0.8074	

Note: Significance levels are indicated as follows: *** p < 0.01; ** p < 0.05; * p < 0.1.

Source: Own calculations

The Hausman test results ($\chi^2 = 81.60$, $p < 0.001$) favored the FE model over the RE model.

Key findings from the FE model include:

- **RECR (Recycling Rate of Municipal Waste):** A positive and significant impact on GDP growth ($\beta = 0.432$, $p = 0.038$), aligning with the hypothesis that higher recycling rates contribute to economic growth through resource savings.
- **RESP (Resource Productivity):** A positive and significant coefficient ($\beta = 0.898$, $p = 0.017$), reinforcing the importance of efficient material use in driving growth.
- **INF (Inflation):** A positive and significant effect on growth ($\beta = 0.365$, $p < 0.001$), possibly reflecting demand-pull inflation in growing economies.
- **GGFC (Government Expenditure):** A negative and highly significant impact on growth ($\beta = -1.223$, $p < 0.001$), suggesting that higher government spending has the potential to crowd out private investment.

4.2. Principal Component Analysis (PCA) and Composite Index Creation

PCA was conducted to address multicollinearity and streamline the analysis, resulting in two indices: Macro_Index (comprising INF, UNEMP, and GGFC) and Invest_Index (comprising log_GFCF, log_ENU, and RNWC) and the loadings of the analysis are presented in Table 4.

Table 4. Macro and Invest PCA Loadings

Variable	Index	PC1	PC2	PC3
INF	Macro_Index	-0.7097	-0.2711	0.6503
log_UNEMP		0.7044	-0.2916	0.6472
GGFC		0.0142	0.9173	0.3978
log_GFCF	Invest_Index	0.6813	0.1847	0.7083
log_ENU		0.6793	0.2010	-0.7058
RNWC		-0.2728	0.9620	0.0115

Source: Own calculations

4.3. Panel Data Analysis with Index Control Variables

The revised Fixed Effects (FE) model, incorporating the composite indices Macro_Index and Invest_Index, yielded insights into the relationships between material efficiency, macroeconomic stability, and investment activities on economic growth (Table 5).

Table 5. Fixed Effects Model with Composite Indices

Variable	Fixed Effects Model				
	Estimate	Std. Error	t-value	Pr(>|t|)	
RECR	-0.0865	0.2142	-0.404	0.6868	
RESP	0.6542	0.3338	1.960	0.0510	*
log_DMCpc	0.0323	0.4828	0.067	0.9466	
Macro_Index	-0.2911	0.0853	-3.412	7.38E-04	***
Invest_Index	1.6257	0.6576	2.472	0.0140	*

Significance levels: *** p < 0.01; ** p < 0.05; * p < 0.1

Source: Own calculations

The inclusion of Macro_Index and Invest_Index improved the model's explanatory power. A significant negative effect of Macro_Index ($p < 0.001$) indicates that adverse macroeconomic conditions negatively impact GDP growth. In contrast, Invest_Index shows a positive and significant effect ($p < 0.05$), underscoring the importance of investment activities in driving economic growth within the circular economy framework. RESP (Resource Productivity) approaches significance ($p = 0.0510$), reinforcing its role in fostering resource efficiency and economic performance. However, RECR and log_DMCpc did not exhibit significant impacts on growth in this model.

4.4. Subgroup Analysis: EU27 vs. Balkan Countries

Separate FE models were estimated for the EU27 and Balkan countries to explore regional heterogeneity in the impact of material efficiency on economic growth. The results reveal divergent patterns, with macroeconomic stability and investment activities playing key roles in both groups (Table 6).

Table 6. Panel Data Analysis of Subgroups

Variable	FE EU27 SUBGROUP					FE BALKAN SUBGROUP				
	Est.	SE	t-value	Pr(>|t|)		Est.	SE	t-value	Pr(>|t|)	
RECR	0.0353	0.2261	0.156	0.876		-0.3898	1.0146	-0.384	0.703	
RESP	0.6533	0.3424	1.908	0.058	*	-3.8596	3.5883	-1.076	0.289	
Log_DMCpc	-0.1518	0.5543	-0.274	0.784		0.4085	1.5606	0.262	0.795	
Macro_Index	-0.2125	0.0984	-2.160	0.032	*	-0.7496	0.2280	-3.288	0.002	**
Invest_Index	2.1541	0.8527	2.526	0.012	**	0.7094	1.1724	0.605	0.549	**

Note: Significance levels are indicated as follows: *** p < 0.01; ** p < 0.05; * p < 0.1.

Source: Own calculations

In the EU27, RESP (Resource Productivity) approaches significance ($p = 0.058$), suggesting its importance in resource-efficient economies, while Macro_Index and Invest_Index both exhibit significant impacts, highlighting the role of macroeconomic stability and investments. In Balkan countries, Macro_Index has a significant negative effect ($p < 0.01$), indicating that unfavorable macroeconomic conditions hinder growth, while Invest_Index shows no significant impact.

The findings underscore the importance of macroeconomic stability and investment in driving GDP growth within the circular economy framework. While RESP shows potential in resource-efficient economies like the EU27, it has a more uncertain role in the Balkans. RECR and log_DMCpc fail to reach significance, suggesting broader economic factors likely moderate their impacts. These results set the stage for a deeper discussion of the theoretical implications, regional differences, and practical applications in the next section.

5. DISCUSSION

This research assessed how material efficiency within the circular economy influences economic growth in EU27 and Balkan countries, focusing on recycling rates (RECR), resource productivity (RESP), and domestic material consumption per capita (DMCpc).

The findings significantly support Hypothesis 2 (H2): higher resource productivity (RESP) leads to increased GDP per capita growth. RESP positively affects GDP growth in both the overall model and the EU27 subgroup, aligning with Androniceanu et al. (2021), who emphasized efficient material use in promoting sustainable economic performance.

Hypothesis 1 (H1), regarding the positive relationship between recycling rates (RECR) and GDP growth, received partial support. RECR was significant in the initial analysis but lost significance in the revised model with composite indices. This suggests that recycling's direct impact on growth may be less robust than anticipated, possibly due to regional disparities in circular economy development. Busu (2019) also found that recycling's influence on economic growth is context-dependent and influenced by broader macroeconomic factors.

Hypothesis 3 (H3), proposing that lower DMCpc is associated with higher GDP growth, was not supported. DMCpc remained non-significant across models, indicating a complex relationship between material consumption and economic growth. Factors like technological advancements and policy frameworks may mediate this relationship, as noted by Lehmann et al. (2022).

The subgroup analysis revealed regional differences. In EU27 countries, macroeconomic stability and investment activities (Macro_Index and Invest_Index) are key growth drivers, highlighting the role of resource efficiency in developed economies. Conversely, Balkan countries are more sensitive to macroeconomic conditions, with Macro_Index showing a significant negative impact on growth. This underscores structural differences and opportunities to improve material efficiency in less-developed economies (Popović et al., 2022).

These results suggest avenues for future research, such as exploring how macroeconomic stability moderates the effectiveness of circular economy initiatives and conducting sector-specific analyses of material consumption. Longitudinal studies on the long-term impacts of circular economy practices across diverse economic contexts would provide valuable insights for enhancing sustainable growth.

6. CONCLUSION

This research demonstrates that resource productivity (RESP) plays a significant role in driving economic growth in EU27 and Balkan countries, confirming Hypothesis 2. Higher resource efficiency positively impacts economic performance, reinforcing RESP importance in sustainable development. In contrast, recycling rates (RECR) and domestic material consumption per capita (DMCpc) have a more complex and less direct influence on growth, as their impacts were not statistically significant in the main model.

For policymakers, these findings highlight the need to prioritize resource productivity in transitioning to a circular economy. While recycling and reducing material consumption are vital for sustainability, their direct economic benefits may require supportive macroeconomic and investment frameworks. Policymakers can leverage these insights to design strategies that balance material efficiency with broader economic goals.

Investing in technologies and processes that enhance resource productivity is crucial for businesses and environmental organizations. Such investments contribute to environmental sustainability and align with the economic imperative for efficient resource use. Further exploration of the interaction between macroeconomic factors, material efficiency, and economic growth is essential for guiding future circular economy policies.

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