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Circular material use and regional club convergence of resource productivity in the European union

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Abstract

This study investigates whether Circular Material Use (CMU) fosters convergence in resource productivity across the 27 European Union (EU) countries, relying on data spanning 2000–2023. Using Phillips and Sul’s club convergence framework, we identify four distinct convergence clubs, demonstrating persistent disparities. Our ordered probit analysis reveals that higher CMU significantly increases a country’s likelihood of belonging to a higher resource productivity club. These findings underscore CMU’s role in bridging resource productivity gaps and emphasize the need for targeted circular economy policies.

Keywords Resource productivity · Club convergence · Circular material use · European union

JEL Classification Q32 · Q38 · Q50

1 Introduction

In the pursuit of sustainable development, the European Union (EU) has increasingly prioritized enhancing resource productivity through circular material use (CMU) (Rybárová 2024). CMU, defined as the share of materials derived from recycled or reused sources, plays a pivotal role in improving resource productivity (measured as GDP divided by domestic material consumption). It boosts resource productivity by decoupling economic growth from material use, reducing reliance on virgin resources through increased recycling and reuse, thus lowering environmental impact

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and enabling more economic output per unit of material input (Blomsma and Brennan 2017; Moraga et al. 2022). Over the past two decades, the EU has achieved a remarkable 44% increase in resource productivity (Eurostat 2024b), following the introduction of strategic policies such as the Roadmap to a Resource-Efficient Europe in 2011 and the Circular Economy Action Plan in 2015 (Domenech and Bahn-Walkowiak 2019). These policies, together with other national policies, express the EU's fundamental interest in substantially improving resource productivity and circular economy within its territory. Despite this progress, significant disparities persist among member states. For instance, in 2023, resource productivity index varied widely across EU countries, with Spain reporting 266 compared to Romania's 63.9, while CMU rates ranged from 30.6% in the Netherlands to just 1.3% in Romania, which highlights structural disparities in both resource productivity and recycling capacity, with Romania ranking last in both indicators (Eurostat 2024a, b). These disparities raise critical questions: Does resource productivity converge across EU countries, or do distinct convergence clubs emerge? And how does CMU influence this process?

The empirical relationship between resource productivity and CMU remains underexplored, with existing studies often assuming uniform convergence paths or overlooking heterogeneity (Cui and Zhang 2022; Di Maio et al. 2017; Rybárová 2024). While some studies highlighted the environmental benefits of CMU (Alola and Adebayo 2023; Mushafiq and Prusak 2023) or identified drivers of resource productivity (Rybárová 2024), they do not account for the potential formation of convergence clubs, groups of countries with similar trajectories in resource productivity growth. Existing studies typically adopt a one-size-fits-all approach by assuming that all countries are progressing along similar developmental trajectories. However, such assumptions may obscure critical differences in economic structures, policy frameworks, and levels of resource productivity. As a result, they fail to account for the potential emergence of convergence clubs, which are distinct groups of countries exhibiting internally coherent but externally divergent patterns of resource productivity growth. This gap is significant because understanding club convergence, rather than uniform convergence, is essential for tailoring policy interventions to specific groups of countries within the EU to align with the concept of a multi-speed Europe (Vale 2024).

This paper fills these research gaps and contributes to the literature in two significant ways. First, unlike previous studies that assume uniform convergence paths, we explicitly test for the existence of convergence clubs in resource productivity across EU member states. We employ the Phillips and Sul (2007, 2009) methodology to identify convergence clubs, which provides a robust framework for understanding heterogeneous growth patterns and accounts for structural and policy differences that may lead to persistent disparities in resource productivity. This approach has been applied to classify EU countries based on domestic material consumption and material footprint (Karakaya et al. 2021) and find regional disparities in financial inclusion in Turkey (Takmaz et al. 2024). However, the current paper extends the approach to focus on resource productivity as the outcome variable. Second, this study incorporates CMU as a central explanatory variable in analyzing convergence clubs. While earlier works have examined the environmental and economic benefits of CMU (Moraga et al. 2022) and developed measures of resource efficiency (Di Maio et al.

2017), they have not explored its role in shaping convergence patterns. Our analysis bridges this gap by quantifying the impact of CMU on resource productivity convergence. The ordered probit model is employed to assess the influence of CMU. This approach addresses potential issues of cross-sectional dependence and endogeneity (Bangjun et al. 2023), which are often overlooked in resource productivity studies.

The results reveal four distinct convergence clubs among EU countries and confirm CMU as a key driver of resource productivity. Importantly, the findings suggest that increasing investment in CMU can help countries converge toward higher productivity levels. Given varying starting points, the policy implication is that while CMU development should be prioritized across the EU, efforts should also consider national differences in current CMU performance to maximize effectiveness.

The remainder of this paper is structured as follows: Sect. 2 presents the data and methodology, Sect. 3 discusses the results, and Sect. 4 concludes with policy implications.

2 Methodology and data description

2.1 Club convergence

This study applies the Phillips and Sul (2007, 2009) club convergence approach, which, unlike traditional β - and σ -convergence tests that assume uniform growth patterns, accounts for heterogeneous transitional dynamics. Resource productivity (RP_{it}) for country i at time t is modeled as:

$$RP_{it} = \delta_{it}\mu_t \quad (1)$$

where δ_{it} is a time-varying component capturing country-specific deviations, and μ_t represents the common trend across all countries. Full convergence requires:

$$\lim_{t \rightarrow \infty} \delta_{it} = \delta, \quad \forall i. \quad (2)$$

To isolate the idiosyncratic component and assess whether δ_{it} converges to a constant δ , Phillips and Sul (2007) define the relative transition parameter h_{it} as:

$$h_{it} = \frac{RP_{it}}{\frac{1}{N} \sum_{j=1}^N RP_{jt}} = \frac{\delta_{it}}{\frac{1}{N} \sum_{j=1}^N \delta_{jt}}. \quad (3)$$

which measures each country's deviation from the regional trend. Under full convergence, h_{it} approaches unity, and its cross-sectional variance declines over time, which is defined as:

$$H_t = \frac{1}{N} \sum_{i=1}^N (h_{it} - 1)^2, \quad (4)$$

The log t regression test for convergence is then estimated as:

$$\log \left(\frac{H_1}{H_t} \right) - 2 \log(\log t) = \hat{a} + \hat{b} \log t + \varepsilon_t. \quad (5)$$

Following Phillips and Sul (2007), the log t-test is conducted over $t = [rT], [rT] + 1, \dots, T$ with $r = 0.3$, where the convergence rate coefficient is given by $\beta = 2\alpha$. The null hypothesis of full convergence ($H_0 : \hat{b} \geq 0$) is rejected if the t-statistic falls below -1.65 at the 5% significance level, indicating divergence.

If full convergence is rejected, we test for club convergence using the Phillips and Sul (2009) algorithm. Countries are ranked by resource productivity, and a core group with strong convergence tendencies is selected. The log t-test is applied iteratively, adding countries if their t-statistic exceeds zero; otherwise, they form separate clubs. The process repeats until all countries are classified. The implementation follows Du (2017) in Stata.

2.2 Impacts of CMU: ordered probit model

Literature on the determinants of club convergences uses both ordered probit (Bangjun et al. 2023; Zhu and Lin 2020) as well as ordered logit (Wang et al. 2014; Bhattacharya et al. 2020; Bai et al. 2019; Takmaz et al. 2024). The choice between ordered probit and ordered logit models depends on the assumed distribution of the error term in the latent variable model. The ordered probit assumes a standard normal distribution, whereas the ordered logit assumes a logistic distribution (Wooldridge 2010). In our case, the ordered probit model is more appropriate because of continuous nature of resource productivity differences across clubs, aligning well with the assumptions of the normal distribution. Moreover, in small samples, the probit model is less sensitive to extreme values and produces slightly more conservative estimates, which improves robustness in settings like ours with limited observations (N=27 countries). The *ordered probit model* takes the following form:

$$Y_i^* = X_i' \beta + \varepsilon_i, \quad Y_i = \begin{cases} 1, & \text{if } Y_i^* \leq k_1, \\ 2, & \text{if } k_1 < Y_i^* \leq k_2, \\ \vdots \\ J, & \text{if } Y_i^* > k_{J-1}. \end{cases} \quad (6)$$

where Y_i^* is the latent variable representing a country's propensity to belong to a higher-productivity club, where X_i is a vector of explanatory variables, including the CMU rate and control variables, and β is the corresponding coefficient vector.

2.3 Data description

The dataset covers 27 EU countries. For the club convergence analysis, we use resource productivity, measured as GDP (in 2015 constant PPP euros) per unit of Domestic Material Consumption (DMC), covering the period from 2000 to 2023. Resource productivity data are sourced from Eurostat's Material Flow and Resource

Productivity database (Eurostat 2024b). To mitigate distortions caused by business cycle fluctuations, we extract the trend component of resource productivity using the Hodrick–Prescott filter (Hodrick and Prescott 1997) with a smoothing parameter of 6.25 (Ravn and Uhlig 2002) before applying the club convergence algorithm.

Our primary variable of interest in the ordered probit analysis is Circular Material Use (CMU), defined as the percentage share of recycled materials in total material consumption. CMU data, covering 2010–2023, are obtained from Eurostat’s Circular Economy Indicators database (Eurostat 2024a)¹.

Additionally, we include several control variables in our ordered probit model. Drawing on existing literature (Kerner and Wendler 2022; Afolabi 2023; Fang et al. 2024), these variables are total natural resource rents (expressed as a percentage of GDP), GDP per capita (measured in constant 2015 US dollars), industrial structure (proxied by industry value added as a percentage of GDP), and urbanization (captured as the share of the urban population in the total population). The control variables span the period from 2000 to 2021 and are obtained from the World Bank’s World Development Indicators database (World Bank 2025). Following common practice in the literature (e.g., Bai et al., 2019; Bhattacharya et al., 2020; Zhu and Lin, 2020; Takmaz et al., 2024), these variables are averaged over the sample period. This averaging approach is consistent with the cross-sectional nature of our dependent variable, which is static and does not vary over time.

3 Results

The log t-test results, presented in the panel A of Table 1, reject the null hypothesis of full convergence at the 5% significance level, as the t-statistic (-29.047) falls well below the critical threshold of -1.65 . This result indicates that resource productivity does not follow a single, unified growth path across EU countries. However, rejecting the null hypothesis does not automatically preclude the presence of convergence clubs, where subsets of countries may still follow distinct convergent trajectories (Phillips and Sul 2007). To investigate this, we apply the Phillips and Sul (2009) clustering algorithm and identify four initial convergence clubs. Panel B of Table 1 highlights how different country groups exhibit varying degrees of convergence. Club 1 comprises high-income Western European countries such as Germany, France, the Netherlands, and others. Club 2 includes Austria, Czechia, Sweden, and others. Club 3, consisting of 5 Baltic and Eastern European countries such as Estonia, Hungary, Latvia, and others, while Club 4 consists of 2 countries, including Bulgaria and Romania.

Since the Phillips and Sul (2007) method tends to overestimate the number of clubs, we test whether adjacent clubs tend to merge into larger groups. The Panel C of Table 1 presents the club merger test results. The null hypothesis of convergence was rejected for all club pairs, confirming that the four identified clubs remain distinct, with significant divergence preventing mergers. The final classification, shown

¹ EU-level CMU data are available from 2004 onward. Due to the stable trajectory of EU-level CMU over time, we assume minimal variation if earlier country-level data were available.

Table 1 Initial Club Convergence and Merger Analysis

Club[N]	Convergence Speed (\hat{b})	t-Statistic ($t_{\hat{b}}$)
<i>Panel A: Log t-test on the whole sample</i>		
Full Sample [27]	-0.710	-29.047
<i>Panel B: Initial classification</i>		
Club 1 [10]	0.040	1.351
Club 2 [10]	0.063	1.750
Club 3 [5]	0.426	2.282
Club 4 [2]	3.768	2.497
<i>Panel C: Club Merger Tests</i>		
Club 1 + 2 [20]	-0.435	-11.435
Club 2 + 3 [15]	-0.491	-22.121
Club 3 + 4 [7]	-0.491	-28.418

Note: Numbers in brackets indicate countries per club. Convergence speed (\hat{b}) measures the rate of convergence; t-statistic ($t_{\hat{b}}$) tests significance. Full sample convergence is rejected if $t_{\hat{b}} < -1.65$ (5% level); A negative convergence speed (\hat{b}) and highly negative t-statistic in the merger tests suggest that clubs remain separate

Table 2 Final Convergence Clubs

Club	Countries	Convergence Speed (\hat{b})	t-Statistic ($t_{\hat{b}}$)
Club 1	Belgium, France, Germany, Greece, Ireland, Italy, Luxembourg, Malta, Netherlands, Spain	0.040	1.351
Club 2	Austria, Croatia, Cyprus, Czechia, Denmark, Poland, Portugal, Slovakia, Slovenia, Sweden	0.063	1.750
Club 3	Estonia, Finland, Hungary, Latvia, Lithuania	0.426	2.282
Club 4	Bulgaria, Romania	3.768	2.497

in Table 2, confirms four stable clubs with distinct convergence speeds, as measured by the \hat{b} coefficient. Club 1 consists of 10 countries, including Belgium, France, Germany, Greece, and several others, exhibiting relatively slow convergence, as indicated by a \hat{b} coefficient of 0.040 and a t-statistic of 1.351. Club 2, also comprising 10 countries such as Austria, Czechia, Denmark, and Sweden and several others, follows a slightly stronger convergence trajectory, with a \hat{b} coefficient of 0.063 and a t-statistic of 1.750. Club 3, which includes 5 countries - Estonia, Finland, Hungary, Latvia, and Lithuania - demonstrates a more pronounced convergence process, as reflected in its higher \hat{b} coefficient of 0.426 and a t-statistic of 2.282. Finally, Club 4, consisting only of Bulgaria and Romania, exhibits the strongest convergence trend, with a \hat{b} coefficient of 3.768 and a t-statistic of 2.497.

The average resource productivity trends for the final clubs, depicted in Fig. 1, reveal distinct patterns of growth among the clubs. Club 1, which comprises high-income western EU countries, exhibits a stable and relatively high increase in resource productivity, reflecting a mature stage of efficiency improvements. Club 2 follows a slower growth trajectory and a steady advancement in resource productiv-

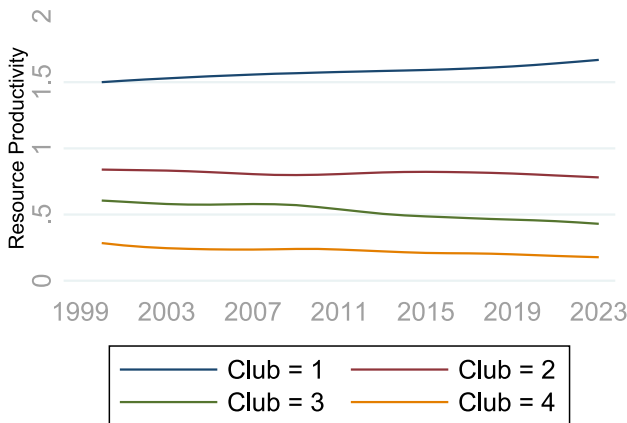


Fig. 1 Average convergence path

Table 3 Ordered Probit Regression Results: Impact of CMU on Club Membership

Variables	Coefficients	Marginal Effect			
		Club 1	Club 2	Club 3	Club 4
CMU	0.143*** (0.051)	0.041*** (0.010)	-0.002 (0.008)	-0.021** (0.009)	-0.018 (0.011)
N	27	Pseudo R ²		0.146	
χ^2	9.79***	Log likelihood		-28.60	

Note: *** and ** represent significance levels at 1%, 5%, respectively; values in parentheses are robust standard errors. The dependent variable is an ordinal ranking of convergence clubs from 1 to 4, where a higher rank indicates a club with higher resource productivity. *N* represents number of countries. CMU denotes the circular material use rate

ity. In contrast, Club 3 and Club 4 demonstrate a decline in resource productivity growth, although the latter has a slower pace. This indicates that these countries may still be undergoing structural adjustments and economic transformations that affect their resource productivity patterns.

Before estimating the ordered probit model, we rank the convergence clubs according to their average resource productivity levels. Following standard practices in the literature (e.g., Bai et al., 2019; Bhattacharya et al., 2020), we assign the highest numeric rank to the convergence club with the highest average resource productivity and the lowest rank to the club with the lowest productivity. Club Rank 4 corresponds to Club 1, the highest average productivity; Club Rank 3 is assigned to Club 2, which exhibits moderately high average resource productivity; Club Rank 2 is attributed to Club 3; and Club Rank 1 corresponds to Club 4, the lowest average resource productivity.

Table 3 shows the results of the ordered probit model, estimating the impact of the CMU rate on convergence club membership. The coefficient for CMU is positive and statistically significant at the 1% level. This indicates that countries with higher CMU rates have a greater probability of belonging to convergence clubs with higher resource productivity. Thus, such countries are more likely to fall into Club

Table 4 Ordered Probit Regression Results: Impact of CMU on Club Membership

Variables	Coefficients	Marginal Effect			
		Club 1	Club 2	Club 3	Club 4
CMU	0.165** (0.075)	0.029*** (0.009)	-0.002 (0.007)	-0.016 (0.010)	-0.011* (0.006)
RR	-1.391** (0.550)	-0.241*** (0.082)	0.019 (0.062)	0.131 (0.064)	0.091** (0.046)
lnGDP	0.882 (0.573)	0.153 (0.102)	-0.012 (0.043)	-0.083* (0.050)	-0.058 (0.042)
IS	-0.074 (0.061)	-0.013 (0.010)	0.001 (0.003)	0.007 (0.006)	0.005 (0.004)
UP	-0.018 (0.028)	-0.003 (0.005)	0.0003 (0.001)	0.002 (0.003)	0.001 (0.002)
<i>N</i>	27		<i>Pseudo R</i> ²	0.442	
χ^2	29.63***		<i>Log likelihood</i>	-18.69	

Note: ***, **, and * represent significance levels at 1%, 5%, and 10%, respectively; values in parentheses are robust standard errors. RR = Resource Rents; lngdp = Natural log of GDP per Capita; IS = Industrial Structure; UP = Urban Populations

Rank 4 (i.e., the highest productivity group, corresponding to Club 1) or Club Rank 3 (second-highest productivity, corresponding to Club 2), while countries with lower CMU rates are more likely to belong to lower-productivity groups, namely Club Ranks 1 or 2 (corresponding to Club 4 or Club 3 respectively). The marginal effects further reveal that an increase in CMU significantly raises the probability of a country belonging to Club 1, the highest resource productivity club, by 4.1 percentage points. Conversely, a higher CMU significantly reduces the likelihood of being in Club 3 by 2.1 percentage points, whereas its impacts on Clubs 2 and 4 are negative but statistically insignificant. These findings underscore the role of circular economy policies in driving productivity improvements and bridging efficiency gaps across EU countries.

We extend our regression analysis by controlling for the effect of control variables - natural resource rent, GDP per capita, industrial structure, and urbanization. Natural resource rent captures resource-abundance, as resource-rich economies may rely on extracting primary materials and could have lower incentives to use resources efficiently (Afolabi 2023), a phenomenon analogous to the classic resource curse, where abundant natural resources can impede efficiency and innovation (Fang et al. 2024). GDP per capita measures the level of economic development, as more developed economies typically have more advanced technologies and stronger institutions, which can enhance resource productivity and are often associated with membership in high-productivity convergence clubs (Kerner and Wendler 2022). Countries with a large industrial sector tend to have more material-intensive production (Babatunde and Afolabi 2024). Lastly, urbanization has an ambiguous effect, as highly urbanized countries may benefit from economies of scale in recycling and resource management, yet may also experience higher resource consumption and waste production due to urban lifestyles. (Mendez et al. 2023).

Table 4 presents the results of the extended ordered probit regression, which yields several noteworthy insights. First, the coefficient on CMU remains positive and statistically significant at the 5% level, after introducing all control variables.

This robustness check confirms our core finding: higher circular material use significantly increases the probability of a country belonging to a higher resource productivity club. The marginal effects further illuminate the practical implications of this relationship. Specifically, a 1 percentage point increase in CMU is associated with a 2.9 percentage point increase in the probability of belonging to Club 1, the highest-performing group in terms of resource productivity. Even when we account for differences in income, economic structure, and resources, countries with higher CMU are more likely to belong to the clubs with higher resource productivity. This result reinforces the answer to our research question that circular economy practices play an important role in fostering convergence toward greater resource efficiency.

Among the control variables, the coefficient of resource rent is negative and highly significant, indicating that countries with higher resource rent tend to belong to lower productivity clubs. This finding is consistent with the notion that a heavy reliance on primary resources can be detrimental to relative efficiency performance, possibly due to complacency in improving resource use when natural materials are plentiful and cheap (Afolabi 2023; Fang et al. 2024). The other controls—GDP per capita, industrial structure, and urbanization—are statistically insignificant. Notably, this finding differs from Mendez et al. (2023) global analysis where urbanization was a significant predictor of productivity, suggesting that within the EU the range of urbanization is too narrow or its influence is suppressed by other factors. Although these variables are not statistically significant in this model, we believe that they still serve an important role in controlling for structural economic differences between countries. Overall, the results show that resources-based variables (CMU and natural resource rents) are critical in determining resource productivity across clubs². The inclusion of control variables substantially improves the explanatory power of the model, for example, Pseudo R² increases from 0.15 in the baseline to 0.44 in the extended model.

4 Conclusion

This paper investigates whether EU countries converge towards similar levels of resource productivity or form distinct convergence clubs, and explores how circular material use influences these convergence patterns. Employing the Phillips and Sul (2007) club convergence framework, we identify four distinct convergence clubs across the EU member countries, underscoring the persistence of heterogeneous resource productivity growth trajectories. Through ordered probit regression analysis, we demonstrate that higher CMU rates significantly increase a country's likelihood of belonging to a higher resource productivity convergence club. Furthermore, the inclusion of additional control variables confirms the independence and strength of CMU's positive impact on convergence. Of particular note, resource rent exhibits a strong negative effect, implying that resource-abundant countries typically face greater challenges in improving resource efficiency, possibly due to reliance on

²To ensure robustness, we also estimated an ordered logit model. The results remained consistent, with CMU and resource rents (RR) being the only variables that showed statistically significant coefficients.

readily available natural resources and associated disincentives for efficient resource management.

This finding reinforces the importance of circular economy policies in driving resource productivity improvements across the EU. From a policy perspective, our results underscore the pivotal role circular economy measures can play in bridging resource productivity gaps across member states. Therefore, policymakers aiming to accelerate convergence towards higher productivity should prioritize circular economy strategies tailored to national contexts. Countries with lower productivity should particularly strengthen circular economy frameworks, such as enhancing recycling infrastructure, incentives for sustainable product design, and waste management systems, to elevate their resource efficiency performance. Countries with high resource productivity should focus on refining and expanding their circular economy practices, fostering innovation in sustainable resource use, and sharing best practices to support broader convergence toward higher efficiency across the EU. Additionally, resource-rich countries require targeted policies to overcome structural impediments associated with resource dependency, leveraging circularity as a countermeasure to the negative resource rent effects.

Author contributions Md Rohidul Islam: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Software, Visualization, Writing– original draft, Writing– review & editing, Validation, Resources, Project administration. Joshua Adeyemi Afolabi: Methodology, Formal analysis, Validation, Writing– original draft, Writing– review & editing, Supervision, Conceptualization, Resources.

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Data availability Data is provided within the manuscript or supplementary information files. And the data used for this study are publicly available. The data sources are cited in the manuscript.

Declarations

Conflict of interest The authors declare no conflict of interests.

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