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Circularity Gains in the European Union, 2010–2024: Convergence, Income and the Decoupling of Material Use

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Abstract: The European Union has committed to doubling its circular material use rate (CMUR) by 2030, yet it is unclear which countries are gaining circularity, whether laggards are catching up, and what drives the gains. This paper examines circularity gains in the 27 EU Member States from 2010 to 2024 using official Eurostat material-flow and waste statistics combined with real GDP per capita. Four analyses are conducted: β- and σ-convergence tests, an Environmental Kuznets curve (EKC) test of circularity against income, a Tapio decoupling analysis of domestic material consumption (DMC) against real GDP, and an exact Shapley decomposition of each country's circularity change into domestic waste recovery, net trade in recyclables and material consumption. The average CMUR rose from 7.9% to 10.9%, with 22 countries gaining and 5 losing. Circularity converges in relative terms: countries that started lower grew faster ($\beta = -0.030$, $p = 0.002$; implied half-life about 17.5 years), and the coefficient of variation fell by 0.007 per year ($p < 0.001$). Absolute dispersion nevertheless widened, so the gap in percentage points between leaders and laggards grew. No EKC is found: neither a linear nor a quadratic income term is significant once country and year effects are included. At the EU level, real GDP grew by 18.2% between 2010 and 2022 while DMC fell by 1.2%, a case of strong decoupling, but only 9 of 27 countries decoupled strongly. The decomposition shows that higher domestic waste recovery was the dominant source of circularity change in 21 of 27 countries, contributing 0.83 of the 0.90-point aggregate gain. The results suggest that circularity is driven by waste-management capacity and policy rather than by income growth, and that laggard countries need targeted investment in recovery infrastructure to close the absolute gap.

Keywords: *Circular Economy; Environmental Economics; Circular Material Use Rate; Convergence; Environmental Kuznets Curve; Decoupling; Shapley Decomposition; European Union.*

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I. INTRODUCTION

Environmental economics has long asked whether economic growth eventually reduces environmental pressure, and under what conditions. The circular economy (CE) reframes this question around materials: instead of asking only how much a country extracts and consumes, it asks how much of what it uses comes back from waste as secondary raw material (Ghisellini et al., 2016; Kirchherr et al., 2017). The European Union has made this the headline target of its 2020 Circular Economy Action Plan, which aims to double the circular material use rate (CMUR) within a decade (European Commission, 2020). Progress has been slow: the EU rate stood at about 12% in 2024 (Eurostat, 2025).

Aggregate figures hide large differences between Member States. In 2024 the CMUR ranged from 1.3% in Romania to 32.7% in the Netherlands. Some countries more than doubled their rate after 2010, while others went backwards. These differences raise three questions that matter for both theory and policy. First, are countries converging, so that the EU target can be reached by laggards catching up, or are leaders pulling away? Second, does circularity rise with income, as an Environmental Kuznets curve (EKC) logic would suggest, or is it determined by policy and infrastructure? Third, what are the sources of circularity gains: more waste recovered, more recyclables imported, or less material consumed?

Empirical work on these questions remains limited. Studies of EU circularity tend to rank countries at a point in time (Mazur-Wierzbicka, 2021) or to build monitoring frameworks (Mayer et al., 2019), and the large EKC literature focuses on emissions rather than material loop closing (Stern, 2004). Convergence methods from growth economics (Barro and Sala-i-Martin, 1992) and decoupling analysis (Tapio, 2005) have rarely been applied to the CMUR itself.

This paper fills that gap with a panel of the 27 EU Member States for 2010–2024. It makes four contributions. It

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documents circularity gains and losses by country over the longest available period. It tests β- and σ-convergence of the CMUR. It tests for an EKC between real income and circularity, and between income and material consumption. Finally, it decomposes each country's circularity change into its three accounting components with an exact Shapley decomposition, which identifies the sources of gains without the circularity bias of regressing an indicator on its own components.

Section 2 sets out the theoretical background and hypotheses. Section 3 describes the data and methods. Section 4 presents the results, Section 5 discusses them and Section 6 concludes.

II. THEORETICAL BACKGROUND AND HYPOTHESES

➢ *Convergence in Environmental Performance*

Convergence analysis comes from growth theory. β-convergence holds when units that start lower grow faster; σ-convergence holds when cross-sectional dispersion falls over time (Barro and Sala-i-Martin, 1992). Applied to environmental indicators, convergence would arise from diffusion of technology and best practice, common EU regulation and funding, and diminishing returns to further improvement in leading countries. In the EU, the Waste Framework Directive and recycling targets apply to all Member States, and cohesion funds have financed waste infrastructure in newer members. These forces predict that laggards gain faster.

- *H1 (β-Convergence)*

Countries with a lower initial CMUR experience faster growth in circularity.

- *H2 (σ-Convergence)*

The dispersion of the CMUR across EU countries declines over time.

➢ *Income and Circularity: An Environmental Kuznets Curve?*

The EKC hypothesis holds that environmental pressure first rises and then falls with income, because richer societies demand cleaner environments and can afford cleaner technology (Grossman and Krueger, 1995). The evidence is strongest for local pollutants and weakest for resource use and global pressures (Stern, 2004). Applied to circularity, the EKC logic suggests that circular material use rises with income, possibly after a threshold. An alternative view holds that circularity depends mainly on waste-management systems and the structure of material use, which income does not determine (Haas et al., 2015; Mayer et al., 2019).

- *H3 (Circularity EKC)*

Circularity is positively, and possibly non-linearly, related to real income per capita.

➢ *Decoupling*

Decoupling describes the relationship between economic growth and environmental pressure. Tapio (2005) classifies it by the elasticity of the pressure with respect to GDP: strong decoupling when the pressure falls while GDP grows, weak decoupling when it grows more slowly than GDP, and coupling when it grows in step or faster. Systematic reviews find relative decoupling of material use to be common but absolute decoupling to be rare and often too slow (Haberl et al., 2020; Parrique et al., 2019).

- *H4 (Decoupling).*

EU economic growth between 2010 and 2022 was accompanied by at least relative decoupling of domestic material consumption.

➢ *Sources of Circularity Gains*

By construction, the CMUR rises when more waste is recovered domestically, when a country exports less or imports more waste for recovery, or when its material consumption falls. Which of these channels dominates is an empirical question with clear policy relevance: gains from recovery reflect real loop closing, while gains from falling consumption may reflect recession or deindustrialisation. Section 3.5 explains why this question is answered by decomposition rather than regression.

III. DATA AND METHODS

➢ *Data*

The panel covers the 27 EU Member States (EU27_2020 composition) from 2010 to 2024. Material-flow and waste variables are official Eurostat statistics; real GDP and population come from the Maddison Project Database as distributed by Our World in Data (Table 1). The Eurostat series were used as unmodified official snapshots archived by Bakon (2026) and retrieved from Eurostat in September 2026.

Table 1 Variables, Definitions and Sources

Variable	Definition	Source	Years
CMUR	Circular material use rate, % of total material use	Eurostat env_ac_cur	2010–2024
DMC	Domestic material consumption, thousand tonnes	Eurostat env_ac_mfa	2010–2024
Waste recovered	Waste treated in recovery operations (excluding energy recovery and backfilling), tonnes	Eurostat env_wastrt	biennial, 2010–2022
Imports / exports of recyclables	Imports and exports of waste and scrap for recovery, thousand tonnes	Eurostat env_ac_sd	2010–2024
Real GDP per capita	GDP in international dollars at 2011 prices (PPP), per person	Maddison Project Database 2023 via Our World in Data	2010–2022
Population	Total population	Our World in Data	2010–2024

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Table 2 Descriptive Statistics, EU-27

Variable	N	Mean	SD	Min	Max
CMUR (%)	405	9.05	6.51	1.20	32.70
DMC per capita (t)	405	16.89	7.32	7.03	46.42
Real GDP per capita (int. $ 2011)	351	32,509	10,693	14,661	60,350
Waste recovered per capita (t)	189	1.70	1.75	0.09	11.97
Net imports of recyclables per capita (t)	405	0.17	0.93	−0.46	6.06

➢ *Convergence Tests*

β-convergence is tested on the cross-section of countries, regressing the average annual growth of the CMUR between 2010 and 2024 on its initial (log) level:

$$\frac{1}{14}\ln\frac{CMUR_{i,2024}}{CMUR_{i,2010}} = \alpha + \beta \ln CMUR_{i,2010} + \gamma \ln y_{i,2010} + \varepsilon_i$$

Where y is real GDP per capita. A negative β indicates convergence; γ = 0 gives absolute convergence and γ free gives conditional convergence. The implied annual speed of convergence is $\lambda = -\ln(1 + 14\beta)/14$ and the half-life is $\ln 2/\lambda$. A panel version regresses the annual log change of the CMUR on its lagged log level with country and year fixed effects; with 15 years, the Nickell (1981) bias in this specification is modest but not zero. σ-convergence is tested by regressing the yearly standard deviation and coefficient of variation (CV) of the CMUR on a time trend.

➢ *Environmental Kuznets Curve*

The EKC is estimated for 2010–2022 as:

$$CMUR_{it} = \beta_1 \ln y_{it} + \beta_2 (\ln y_{it})^2 + \mu_i + \lambda_t + \varepsilon_{it}$$

With year effects λ and, in the preferred specification, country effects μ. An inverted U requires $\beta_1 > 0$ and $\beta_2 < 0$; the turning point is $\exp(-\beta_1/2\beta_2)$. The same model is estimated with log DMC per capita as the dependent variable (a material EKC). Standard errors are clustered by country (Cameron and Miller, 2015).

➢ *Decoupling*

The Tapio (2005) decoupling elasticity for 2010–2022 is the percentage change in DMC divided by the percentage change in real GDP. With GDP growing, an elasticity below 0 indicates strong decoupling, 0 to 0.8 weak decoupling, 0.8 to 1.2 expansive coupling, and above 1.2 expansive negative decoupling.

➢ *Decomposition of Circularity Change*

Following Eurostat's (2018) method, the CMUR is the ratio of circular use U to total material use:

$$CMUR = \frac{U}{DMC + U}, \qquad U = R - M + X$$

Where R is domestic waste recovered, M imports and X exports of waste for recovery. Because R, M and X are components of the indicator, regressing the CMUR on them would largely reproduce an accounting identity. Instead, the change in each country's CMUR between 2010 and 2022 (the first and last years with waste data) is decomposed exactly into the contributions of recovery (R), net exports of recyclables (X − M) and DMC using the Shapley value, which averages each factor's marginal effect over all orders of substitution and sums exactly to the total change (Shorrocks, 2013). Rates reconstructed from the components match Eurostat's published CMUR closely (correlation 0.995, mean absolute difference 0.51 percentage points over 189 country-years); the remaining gap reflects Eurostat's estimation adjustments.

IV. RESULTS

➢ *Circularity Gains, 2010–2024*

Most EU countries gained circularity, but the gains were uneven. The unweighted mean CMUR rose from 7.85% in 2010 to 10.92% in 2024, an average gain of 3.07 percentage points (median 3.2). Twenty-two countries gained and five lost (Figure 1). Malta (+13.3 points), Estonia (+11.5) and Italy (+10.3) gained most. Luxembourg (−12.7), Finland (−8.5), Poland (−3.4), Spain (−3.0) and Romania (−2.2) lost ground.

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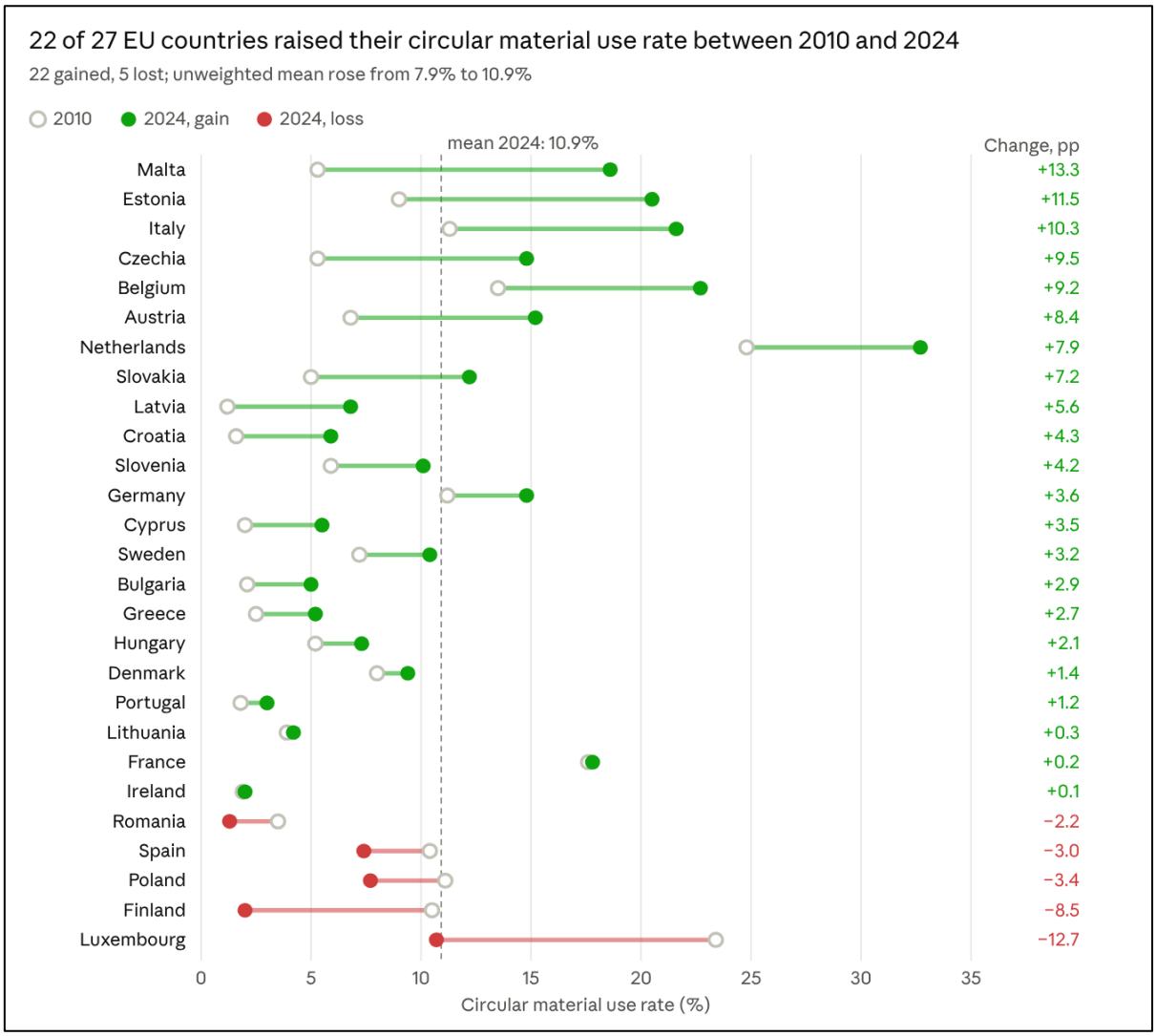


Fig 1 Circular Material Use Rate, 2010 and 2024.
Source: Eurostat env_ac_cur; author's calculations.

➢ *Convergence (H1, H2)*

Table 3 reports the β-convergence tests. In levels, the initial CMUR does not predict the size of the gain (column 1). In logs, which measure proportional growth, convergence is clear: a 10% lower initial rate is associated with about 0.3 percentage points faster annual growth (β = −0.030, p = 0.002). This implies a convergence speed of about 4.0% a year and a half-life of about 17.5 years. The result holds when initial income is controlled for (column 3), and income itself is not significant. The panel model with country and year fixed effects also shows strong mean reversion (column 4), but its implied half-life of 2.7 years measures convergence of each country towards its own long-run level, not towards the others, and is likely inflated by year-to-year noise. H1 is supported for proportional growth.

Table 3 β-Convergence of the Circular Material Use Rate

	(1) Annual change, pp	(2) Annual log growth	(3) Annual log growth	(4) Δln CMUR, panel
CMUR 2010	−0.015 (0.019)			
ln CMUR 2010		−0.030*** (0.010)	−0.027** (0.012)	
ln real GDP per capita 2010			−0.014 (0.034)	
ln CMUR (t−1)				−0.229*** (0.069)
Country and year FE	No	No	No	Yes
Observations	27	27	27	378
R^2	0.047	0.234	0.240	0.110 (within)

Note: Columns 1–3 are Cross-Sections with Heteroskedasticity-Robust (HC1) Standard Errors; Column 4 Uses Country-Clustered Standard Errors. * p < 0.10, ** p < 0.05, *** p < 0.01.

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The σ-convergence evidence is mixed in an informative way. The coefficient of variation fell from 0.80 in 2010 to 0.70 in 2024, a decline of 0.007 per year ($p < 0.001$, $R^2 = 0.66$), so relative dispersion narrowed. The standard deviation, however, rose from 6.28 to 7.63 percentage points, an increase of 0.089 per year ($p < 0.001$, $R^2 = 0.67$). Laggards are growing faster in proportional terms, but from such a low base that the absolute gap to the leaders has widened. H2 is supported only in relative terms.

➢ *Income and Circularity (H3)*

Table 4 finds no Environmental Kuznets curve for circularity. In the pooled model with year effects (column 1), the income terms have the inverted-U signs, but neither is significant ($p = 0.13$ and 0.15), and the implied turning point of about $47,000 lies near the top of the sample range ($14,661–$60,350). With country fixed effects (column 2) the signs reverse and both terms are far from significance; a linear income term is also insignificant (column 3). Within countries, rising income over the period did not raise circularity. For material consumption, the pooled model shows a weakly significant U shape (column 4, $p \approx 0.06$), which disappears with country fixed effects (column 5). H3 is not supported.

Table 4 Environmental Kuznets Curve Tests, 2010–2022

	(1) CMUR	(2) CMUR	(3) CMUR	(4) ln DMC pc	(5) ln DMC pc
ln real GDP per capita	241.02 (159.40)	−16.53 (104.66)	1.89 (5.65)	−15.14* (8.03)	4.10 (3.72)
(ln real GDP per capita)²	−11.20 (7.78)	0.92 (5.36)		0.746* (0.386)	−0.133 (0.187)
Country FE	No	Yes	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	351	351	351	351	351
R^2	0.265	0.042 (within)	0.036 (within)	0.108	0.095 (within)
Implied shape (turning point)	Inverted U ($47,214), n.s.	n.s.	—	U ($25,573)	n.s.

Note: Country-Clustered Standard Errors in Parentheses. Real GDP Per Capita in International Dollars at 2011 Prices. n.s. = Not Significant. * p < 0.10, ** p < 0.05, *** p < 0.01.

➢ *Decoupling (H4)*

The EU as a whole achieved strong decoupling between 2010 and 2022: real GDP of the 27 countries grew by 18.2% while their combined DMC fell by 1.2%. Country results vary widely (Table 5). Nine countries decoupled strongly, nine weakly, five showed expansive coupling and three expansive negative decoupling, where material use grew faster than GDP. Greece is a special case of recessive decoupling: GDP fell by 9.3% and DMC by 40.4%. H4 is supported for the EU aggregate and for 18 of 27 countries. Decoupling and circularity are distinct achievements: the rank correlation between the decoupling elasticity and the CMUR gain is weak and insignificant (Spearman $\rho = -0.21$, $p = 0.30$). Italy and the Netherlands combine both, while Spain decoupled strongly but lost circularity and Malta gained circularity while its material use grew as fast as its economy.

Table 5 Tapio Decoupling of DMC from Real GDP, 2010–2022

Country	Real GDP change (%)	DMC change (%)	Elasticity	Decoupling status	CMUR change 2010–2024 (pp)
Italy	2.7	−25.3	−9.48	Strong decoupling	+10.3
Spain	9.8	−26.4	−2.70	Strong decoupling	−3.0
Portugal	10.6	−19.6	−1.84	Strong decoupling	+1.2
Cyprus	25.5	−22.9	−0.90	Strong decoupling	+3.5
Netherlands	20.8	−15.5	−0.74	Strong decoupling	+7.9
Slovakia	27.1	−14.4	−0.53	Strong decoupling	+7.2
France	14.0	−5.5	−0.39	Strong decoupling	+0.2
Germany	18.4	−7.2	−0.39	Strong decoupling	+3.6
Slovenia	29.3	−5.3	−0.18	Strong decoupling	+4.2
Czechia	26.4	0.2	0.01	Weak decoupling	+9.5
Belgium	19.1	1.0	0.05	Weak decoupling	+9.2
Austria	17.7	2.0	0.11	Weak decoupling	+8.4
Croatia	25.8	2.9	0.11	Weak decoupling	+4.3
Poland	54.7	7.4	0.14	Weak decoupling	−3.4
Finland	12.1	1.9	0.16	Weak decoupling	−8.5
Estonia	45.0	10.8	0.24	Weak decoupling	+11.5
Ireland	39.0	14.6	0.37	Weak decoupling	+0.1
Hungary	42.3	31.4	0.74	Weak decoupling	+2.1
Lithuania	51.3	48.0	0.94	Expansive coupling	+0.3
Sweden	23.6	24.2	1.02	Expansive coupling	+3.2

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Denmark	25.7	26.5	1.03	Expansive coupling	+1.4
Malta	86.9	94.0	1.08	Expansive coupling	+13.3
Luxembourg	31.2	34.6	1.11	Expansive coupling	−12.7
Bulgaria	26.9	34.8	1.30	Expansive negative decoupling	+2.9
Latvia	42.8	59.1	1.38	Expansive negative decoupling	+5.6
Romania	50.4	102.1	2.02	Expansive negative decoupling	−2.2
Greece	−9.3	−40.4	4.34	Recessive decoupling	+2.7

Note: Elasticity = % Change in DMC / % Change in Real GDP. Countries Sorted by Elasticity.

➢ *Sources of Circularity Change*

Domestic waste recovery is the main engine of circularity change. In the Shapley decomposition (Figure 2), recovery is the largest contributor in absolute terms in 21 of 27 countries, DMC in 5 and net trade in recyclables in only 1. On average across countries, recovery contributed +2.82 points to the 2010–2022 change in the reconstructed CMUR, net trade +0.06 and DMC −0.27, for a total of +2.61. For the EU aggregate, the reconstructed rate rose from 10.41% to 11.31%: recovery contributed +0.83 points, lower DMC +0.12 and net trade −0.04. The losers lost for the same reason the winners won: Luxembourg, Finland, Spain and Poland recorded falling recovery. Falling material consumption helped Italy, the Netherlands, Spain and Greece, but in Spain and Greece it partly reflected the post-2010 recession rather than circular practice.

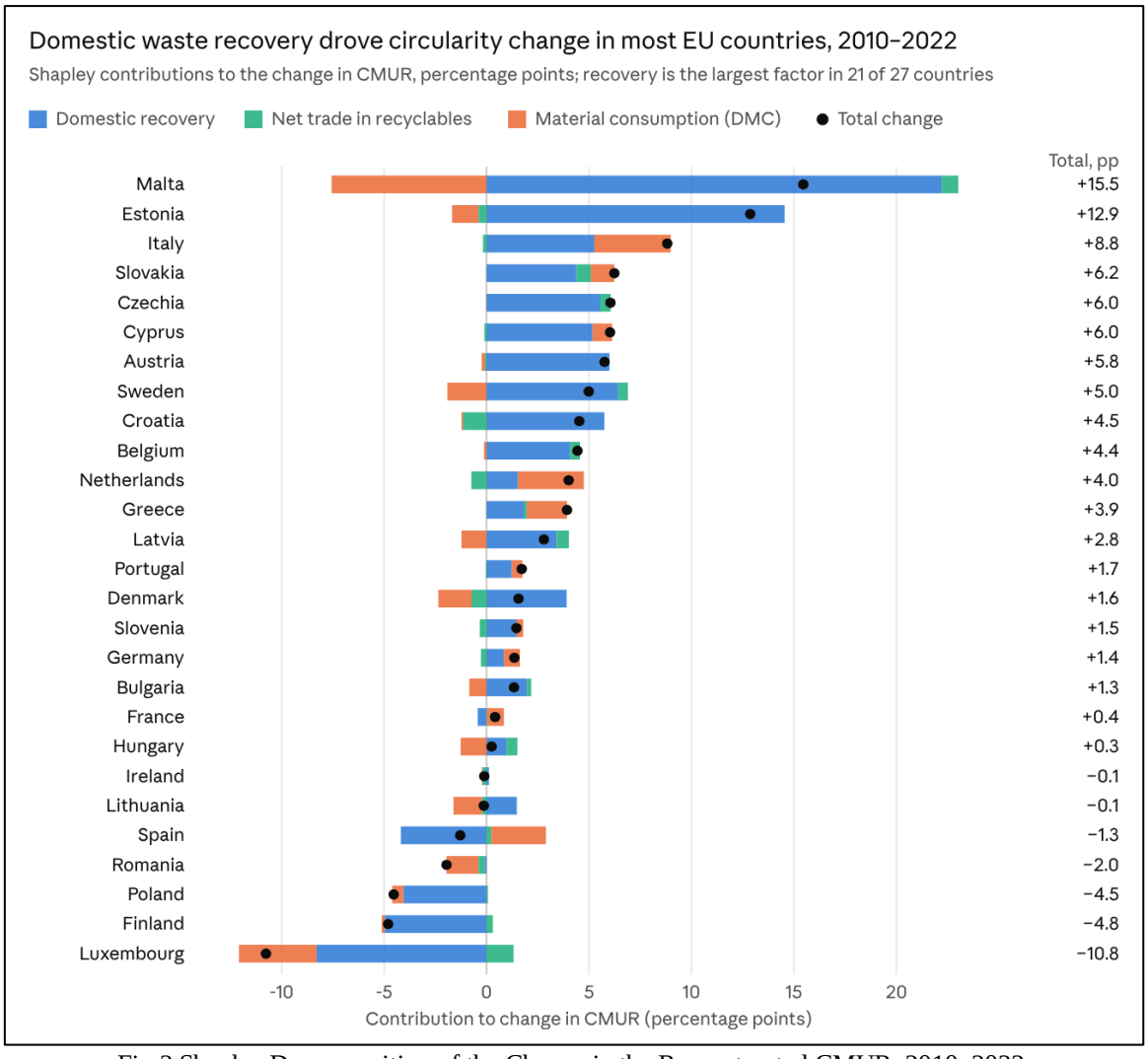


Fig 2 Shapley Decomposition of the Change in the Reconstructed CMUR, 2010–2022.
Source: Eurostat env_wastrt, env_ac_sd, env_ac_mfa; author's calculations.

V. DISCUSSION

➢ *Circularity is Built, not Bought*

The absence of an EKC is the paper's most important negative finding. Income growth within countries did not raise circularity, and the cross-country relation between income and circularity is weak. This contrasts with the EKC literature on local pollutants (Grossman and Krueger, 1995) and fits the view that material loop closing depends on systems rather than affluence (Haas et al., 2015; Mayer et al.,

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2019). The decomposition points to what those systems are: waste recovery capacity. Countries that expanded material recovery, such as Malta, Estonia, Czechia and Austria, gained circularity regardless of their income level, while rich countries whose recovery stagnated or fell, such as Luxembourg and Finland, lost ground. In environmental-economics terms, circularity behaves less like a normal good that rises automatically with income and more like a public good that requires deliberate investment and regulation.

➢ *Relative Convergence, Absolute Divergence*

The convergence results carry a warning for the EU's doubling target. Laggards are growing faster in proportional terms, consistent with the diffusion of EU waste rules and cohesion funding. Because they start from rates of 1–5%, however, even fast proportional growth adds few percentage points, while leaders such as the Netherlands, Belgium and Italy add more in absolute terms. The result is a widening absolute gap and a half-life of roughly 17 years, longer than the remaining horizon of the 2030 target. Reaching the target therefore depends both on continued gains in leading countries and on a step change in recovery capacity in the east and south of the Union.

➢ *Decoupling is not the Same as Circularity*

The EU achieved strong aggregate decoupling between 2010 and 2022, in line with evidence that relative decoupling of materials is common in high-income economies (Haberl et al., 2020). Decoupling and circularity, however, are only weakly related across countries. Lower material consumption raises the CMUR mechanically, but it can result from recession, deindustrialisation or offshoring rather than from closing loops. Spain and Greece illustrate this: both cut material use sharply during the post-2010 crisis without a matching rise in recovery. Conversely, Malta raised circularity strongly while its material use grew in step with its economy. Monitoring should therefore track the recovery component directly rather than reading improvements in the ratio as evidence of loop closing.

➢ *Policy Implications*

Three implications follow. First, policy should target recovery capacity directly through investment in collection, sorting and recycling, especially in countries with CMURs below 5%. Second, the EU's monitoring framework would benefit from reporting the decomposition shown here alongside the headline rate, so that gains from recovery can be distinguished from gains caused by falling consumption. Third, growth and convergence policy cannot be relied upon to deliver circularity indirectly. For economies outside the EU, including Saudi Arabia under Vision 2030 and its circular carbon economy framework, the European experience suggests that recovery infrastructure and secondary-material markets should be built early rather than expected to follow income growth.

VI. CONCLUSIONS

Between 2010 and 2024, circularity rose in 22 of the 27 EU Member States, and the average circular material use rate increased by about 3 percentage points. Countries that started lower grew faster in proportional terms, but the absolute gap between leaders and laggards widened. Income growth did not raise circularity, and no Environmental Kuznets curve is found. The EU decoupled material consumption from real GDP in absolute terms, but decoupling and circularity are distinct achievements. Gains came overwhelmingly from higher domestic waste recovery. Circularity, in short, is an outcome of deliberate investment in recovery systems rather than a by-product of growth.

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