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Two-Speed Europe in Renewable Transition? Sigma And Beta Convergence of Renewable Energy Shares in the EU-27 (2004–2024) *

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Abstract

This study investigates whether the renewable energy transition in the EU-27 has followed a common path or a "two-speed" pattern characterised by persistent leaders and laggards. Although successive EU policy frameworks RED I, RED II, and the European Green Deal established shared objectives, empirical evidence on convergence dynamics remains limited for the post-2020 period, particularly in light of the methodological revision introduced in the SHARES framework in 2021. This paper addresses this gap by extending convergence evidence through 2024 and explicitly accounting for the definitional break. Using harmonised EUROSTAT data for a balanced panel of 27 Member States over 2004–2024 (567 country-year observations), we apply σ-convergence, based on the cross-sectional standard deviation of log renewable shares tested via HAC-robust trend regression, and β-convergence, estimated through both an endpoint cross-sectional specification and a fixed-effects panel model with country-clustered standard errors. Robustness checks include a logit transformation appropriate for bounded shares and separate estimation for the 2004-2020 and 2021-2024 subperiods. The findings reveal a dual pattern. Relative convergence is strong: log-based dispersion declined from 1.2567 in 2004 to 0.3997 in 2024, and β-convergence implies an annual adjustment rate of 7-8% with a half-life of approximately nine years. However, absolute stratification persists the max-min gap widened from 38.325 to 48.510 percentage points between 2004 and 2024. The results support a "two-speed" interpretation of the EU renewable transition, combining relative convergence with persistent level disparities.

Keywords: European Green Deal, RED I/RED II targets, renewable energy transition, EU-27 energy transition,

Introduction

Climate and energy integration in the European Union hinges on whether Member States advance toward higher renewable energy shares along a broadly common path, or whether persistent leaders and laggards imply a "two-speed" transition (Presno & Landajo, 2021; Puertas & Marti, 2022; Renou-Maissant et al., 2022). EU-wide policy milestones—RED I (binding national targets for 2020), RED II (higher ambition for 2030), and the European Green Deal (climate neutrality by 2050)—created shared objectives, yet empirical research continues to document substantial cross-country heterogeneity and clustering(Hainsch et al., 2022; Panarello & Gatto, 2023). In this context, convergence can be assessed using sigma-convergence (declining dispersion of renewable shares) and beta-convergence (catch-up dynamics), with existing evidence often pointing to partial convergence and club formation rather than uniform equalisation across the EU (Presno & Landajo, 2021; Renou-Maissant et al., 2022; Saba & Ngepah, 2022) (Renou-Maissant et al., 2022; Saba & Ngepah, 2022).

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A growing body of empirical research has examined renewable energy convergence in Europe, with most studies reporting evidence consistent with both σ-convergence (a narrowing dispersion of renewable shares) and β-convergence (catch-up by initially low-share countries), although the adjustment is typically gradual (Berk et al., 2020; Butnaru et al., 2020; Szép, 2016). Using panel and other quantitative frameworks, this literature repeatedly finds that laggard countries tend to increase renewable shares faster in proportional terms, while cross-country dispersion declines over time, suggesting a broad—though incomplete—tendency toward homogenisation in renewable energy deployment across the EU. At the same time, the estimated speed of convergence is often characterised as slow, with implied half-lives indicating that closing a substantial share of initial gaps can take decades, which implies that observable catch-up does not automatically translate into near-term level equalisation even under a common policy framework.Equally important, the literature reveals that convergence in renewables has not been uniform across all member states. A number of studies find that the EU exhibits distinct "convergence clubs" rather than a single unified convergence path(Berk et al., 2020; Butnaru et al., 2020; Jankiewicz, 2021; Popescu & Covrig, 2023; Presno et al., 2021; Szép, 2016; Török, 2025; Turturean et al., 2022). In club-convergence frameworks, EU countries do not necessarily converge toward a single common benchmark; instead, they form distinct groups that display internal convergence toward different steady-state renewable energy shares. Empirical applications illustrate both the existence and the multiplicity of such clubs: for example, club-based tests identify several sub-groups among EU members, including evidence of five clubs for the EU-27 during 2015–2021 (Popescu & Covrig, 2023) and multiple clusters within the EU-15 (Kasman & Kasman, 2019). A further recurring finding is that clustering often aligns—at least partially—with membership "vintages," with older Western European members and newer post-2004 entrants tending to populate different convergence paths, consistent with heterogeneous starting points and institutional/policy contexts. Taken together, these results imply that aggregate convergence can coexist with persistent stratification: some countries progress rapidly toward high renewable shares, while others converge more slowly and may remain anchored to lower long-run levels, meaning that EU-wide averages may obscure structurally distinct transition trajectories (Grafström, 2018; Pinar, 2024; Saba & Ngepah, 2022; Weremczuk & Grębowiec, 2025).

Although EU renewable-energy policy has advanced through successive frameworks—moving from binding 2020 targets under RED I toward higher ambition under RED II and the European Green Deal—synthesized evidence still points to persistent cross-country disparities in renewable uptake rather than a fully unified transition pathway (Hainsch et al., 2022; Puertas & Marti, 2022; Renou-Maissant et al., 2022). Existing syntheses also highlight that heterogeneity is associated with factors such as institutional capacity and cross-border (spatial) spillovers, while divergence in innovation and public R&D support may further entrench uneven trajectories (Belkahla, 2025; Grafström et al., 2020; Kijek et al., 2021). Importantly, the same materials flag limited post-2020 empirical coverage, leaving open whether convergence has continued or whether stratification has widened in the years following the 2020 milestone and subsequent (Clemente-Suárez et al., 2021; Panarello & Gatto, 2023).

To address this gap, this paper tests whether the EU-27 renewable transition resembles a "common front" or a de facto two-speed pattern by examining σ-convergence (dispersion dynamics) and β-convergence (catch-up) in the renewable energy share in gross final energy consumption over 2004–2024. We implement convergence metrics that are standard in empirical research on EU renewable shares and related dynamics, while tailoring the design to our dataset and robustness strategy (Berk et al., 2020; Butnaru et al., 2020; Jankiewicz, 2021; Weremczuk, 2025).

Our results provide nuanced evidence on Europe's renewable-energy convergence over 2004–2024. We document strong relative convergence, as dispersion in log renewable shares declines markedly and β-convergence indicates systematic catch-up by initially low-share countries, consistent with earlier econometric evidence on EU renewables (Berk et al., 2020; Jankiewicz, 2021; Presno & Landajo, 2021). However, convergence remains incomplete in levels: absolute gaps in percentage points between frontier and laggards persist (and in our endpoint comparison widen by 2024), echoing the broader view that aggregate convergence can coexist with persistent heterogeneity in the EU energy transition (Kasman & Kasman, 2019; Presno et al., 2021; Weremczuk & Milewski, 2025). The contribution is threefold: we extend convergence evidence beyond the 2020 horizon to 2024, explicitly account for the documented 2021 methodological break via subperiod reporting and robustness checks, and clarify the distinction between proportional convergence and level stratification that is central to the "two-speed vs common front" interpretation.

The empirical analysis examines convergence in the share of renewable energy in gross final energy consumption across the EU-27 over 2004–2024. The study is based on the SHARES reporting framework (harmonised renewable energy statistics), using annual country-level data for the overall indicator RES (%)—the share of renewable energy in gross final energy consumption—recorded as a fraction in the interval (0,1). To ensure a consistent country composition over the full observation window, the sample is restricted to the current EU-27 membership: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden. Countries outside the EU-27 (e.g. the United Kingdom, EFTA countries, and candidate countries) are excluded from the core analysis.

A key feature of the dataset is the documented change in SHARES calculation rules from 2021 onwards, reflecting the transition from the methodology aligned with Directive 2009/28/EC (up to 2020) to that aligned with Directive (EU) 2018/2001 (from 2021). Because convergence indicators may be sensitive to definitional discontinuities, the empirical strategy explicitly addresses this break through subperiod analysis, interaction terms in panel models, and robustness checks. The years 2021–2024 are therefore interpreted cautiously, as the observed shifts may reflect both methodological revision and real macro-energy adjustments affecting the numerator and denominator of the RES share.

Materials and methods

Variable definition and transformations

Let $RES_{i,t} \in (0,1)$denote the renewable energy share for country $i = 1, \ldots, N$in year $t = 2004, \ldots, 2024$, where $N = 27$.

Two transformations are used.

First, the baseline specification uses the logarithm of the renewable share:

$$y_{i,t} = \ln(RES_{i,t})$$

This transformation is standard in convergence analysis because it supports a proportional growth interpretation and reduces scale differences between countries with low and high initial shares. Since all observations are strictly positive, the logarithm is well defined throughout the sample.

Second, as a robustness check for the bounded nature of the dependent variable, the logit transformation is also considered:

$$z_{i,t} = \ln\left(\frac{RES_{i,t}}{1 - RES_{i,t}}\right)$$

This transformation maps the bounded interval $(0, 1)$onto the real line. The main conclusions are treated as robust if the qualitative pattern of convergence remains unchanged when $y_{i,t}$is replaced by $z_{i,t}$.

Descriptive results are reported in percentage points where appropriate, while the econometric analysis is conducted in logarithms or logits. Rescaling the variable from fractions to percentages does not affect convergence estimates in log specifications, as it changes the intercept but not slope parameters.

Sigma-convergence

Sigma-convergence is assessed by examining whether cross-country dispersion in renewable shares declines over time. The baseline dispersion measure is the cross-sectional standard deviation of log-shares:

$$\sigma_t = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_{i,t} - \bar{y}_t)^2}, \bar{y}_t = \frac{1}{N}\sum_{i=1}^{N} y_{i,t}$$

A decline in $\sigma_t$over time indicates sigma-convergence, whereas an increase indicates divergence in relative terms. To test the time trend in dispersion, the following regression is estimated:

$$\sigma_t = \alpha + \delta t + u_t$$

Sigma-convergence is supported when $\delta < 0$. Because $\sigma_t$is a short annual time series and may exhibit serial correlation and heteroskedasticity, inference is based on heteroskedasticity- and autocorrelation-consistent (HAC/Newey–West) standard errors. Given the limited time dimension, HAC-based inference is interpreted cautiously and complemented by descriptive evidence from alternative dispersion measures.

The analysis is reported for three horizons: the full period 2004–2024, the pre-break period 2004–2020, and the post-break period 2021–2024. Results for the post-break subperiod are treated as indicative only because of the short sample length and the presence of the definitional discontinuity.

To assess whether the observed pattern is sensitive to the particular dispersion metric used, several additional indicators are computed:

$$CV_t = \frac{sd(RES_{i,t})}{\bar{RES}_t}$$

where CV_t is the coefficient of variation in levels and $\bar{RES}_t$ is the cross-sectional mean of RES in year t, as well as the median absolute deviation (MAD) and the interquartile range (IQR) of $y_{i,t}$. Robustness is assessed by checking whether these alternative measures yield the same qualitative conclusion regarding the direction of dispersion change over time.

Beta-convergence: cross-sectional specification

Beta-convergence tests whether countries with lower initial renewable shares experience faster subsequent growth than countries starting from higher levels. The baseline cross-sectional specification uses the average annual growth rate in log-shares between the initial and final year:

$$g_i = \frac{1}{H}(y_{i,2024} - y_{i,2004})$$

where $H = 2024 - 2004 = 20$ denotes the endpoint horizon in years. This notation distinguishes the horizon length H from the number of annual observations in the panel.
The estimated regression is:

$$g_i = \alpha + \beta y_{i,2004} + \varepsilon_i$$

Unconditional beta-convergence is supported when $\beta < 0$, meaning that countries with lower initial renewable shares tend to record faster subsequent proportional growth.
Following the standard convergence mapping for endpoint regressions, the implied annual speed of convergence λ is computed as:

$$\lambda = -\frac{1}{H}\ln(1 + \beta H)$$

and the implied half-life, defined as the time needed to eliminate one half of the initial gap, is:

$$t_{1/2} = \frac{\ln 2}{\lambda}$$

These quantities provide an economically interpretable summary of the estimated catch-up dynamics.

Beta-convergence: panel specification

As a complementary approach, beta-convergence is also tested in a panel framework that exploits annual variation:

$$\Delta y_{i,t} = y_{i,t} - y_{i,t-1} = \alpha + \beta y_{i,t-1} + \mu_i + \tau_t + \varepsilon_{i,t}$$

where μ_i denotes country fixed effects capturing time-invariant heterogeneity, such as geography, institutional characteristics, and structural energy endowments, and τ_t denotes time fixed effects capturing common EU-wide shocks, macroeconomic conditions, and policy cycles.
Beta-convergence is supported when $\beta < 0$. The model is estimated using fixed effects, with standard errors clustered at the country level to account for within-country serial correlation and heteroskedasticity. This panel equation is treated as a complementary descriptive convergence model rather than a fully structural causal specification.
For the annual panel model, the implied annual speed of convergence is computed as:

$$\lambda_{panel} = -\ln(1 + \beta)$$

with the corresponding half-life:

$$t_{1/2} = \frac{\ln 2}{\lambda_{panel}}$$

Structural break handling and robustness

Given the definitional change introduced from 2021, the study implements three complementary safeguards.

First, all sigma- and beta-convergence results are reported separately for the pre-break period (2004–2020), the full sample (2004–2024), and the post-break period (2021–2024). The post-break estimates are interpreted as descriptive and indicative rather than structural because the time span is short and the first year of the subperiod coincides with the methodological transition.

Second, in the panel specification, sensitivity checks allow the speed of convergence to differ after 2021 by introducing an interaction between the lagged dependent variable and a post-2021 dummy:

$$\Delta y_{i,t} = \alpha + \beta_1 y_{i,t-1} + \beta_2 (D_{t\geq 2021} \cdot y_{i,t-1}) + \mu_i + \tau_t + \varepsilon_{i,t}$$

where $D_{t\geq 2021} = 1$for years 2021–2024 and 0 otherwise. In this formulation, $\beta_2$tests whether the strength of catch-up changed after the methodological break, while the inclusion of year fixed effects absorbs common period shifts. Third, the key estimations are repeated using the logit transformation $z_{i,t}$instead of the log transformation $y_{i,t}$. If the sign, magnitude, and statistical significance of the main convergence parameters remain qualitatively similar, the findings are interpreted as robust to the bounded nature of the RES share.

Results

Using a balanced panel of 27 EU Member States observed annually over 2004–2024, the dataset contains 21 yearly observations per country and 567 country-year observations in total. The evidence points to a substantial increase in the renewable energy share in gross final energy consumption (RES) across the Union as a whole, while also showing that aggregate progress did not eliminate cross-country disparities. The unweighted mean RES share increased from 12.322% in 2004 to 27.909% in 2024, and the median rose from 8.345% to 23.229%, indicating a marked upward shift in the cross-sectional distribution. The lower tail improved strongly: the minimum value increased from 0.102% (Malta, 2004) to 14.336% (Belgium, 2024). At the upper end of the distribution, Sweden remained the highest-share country at both endpoints, with RES increasing from 38.427% in 2004 to 62.846% in 2024. At the same time, the max-min gap widened from 38.325 percentage points in 2004 to 48.510 percentage points in 2024, indicating that broad-based improvement did not translate into level equalisation.

Table 1. EU-27 distribution of RES shares (unweighted), 2004 vs 2024

Year	Mean (%)	Median (%)	Min (%)	Min country	Max (%)	Max country	Gap max-min (pp)
2004	12.322	8.345	0.102	MT	38.427	SE	38.325
2024	27.909	23.229	14.336	BE	62.846	SE	48.510

Source: Author's own calculations based on the integrated RES dataset (2004–2024).

At the country level, endpoint changes measured in percentage points also reveal considerable heterogeneity in level gains. The largest increases over 2004–2024 were recorded in Denmark (+31.622 pp), Sweden (+24.418 pp), and Finland (+22.868 pp), whereas some countries experienced much smaller increases; for example, Croatia recorded a gain of +3.304 pp. Poland's RES share rose from 6.882% in 2004 to 17.770% in 2024, corresponding to an increase of +10.888 pp. These endpoint changes are informative descriptively, but they should be interpreted as level gains rather than as direct evidence of beta-convergence.

Following the baseline methodology, sigma-convergence is assessed using the cross-sectional standard deviation of log renewable energy shares, $\sigma_t = sd(\ln RES_{i,t})$, which captures relative dispersion. The results show a pronounced long-run decline in dispersion: $\sigma_{2004} = 1.256656$, $\sigma_{2020} = 0.422102$, $\sigma_{2021} = 0.442127$, and $\sigma_{2024} = 0.399683$. Overall, this corresponds to a 68.195% reduction in the log-based dispersion measure between 2004 and 2024, which is consistent with strong sigma-convergence in relative terms. A linear trend regression of

σ_t with HAC (Newey-West) standard errors also yields a negative and statistically significant slope for both the full sample and the pre-break period. For 2004–2024, the estimated slope is $\delta = -0.044293$ (SE = 0.003284, $t = -13.489$, $p < 0.001$, R^2 = 0.936); for 2004–2020, the slope is $\delta = -0.051745$ (SE = 0.002715, $p < 0.001$, R^2 = 0.954). Given the short time dimension, these trend regressions should be interpreted together with the descriptive dispersion measures rather than in isolation.

The evidence differs, however, when dispersion is measured in absolute percentage-point terms. The cross-sectional standard deviation of RES levels increased from 10.107 pp in 2004 to 12.424 pp in 2024, while the coefficient of variation declined from 0.820 to 0.445. This pattern is substantively coherent: Member States became more similar in proportional terms as renewable shares increased across the board, but absolute differences in levels remained substantial and, depending on the metric, widened.

Table 2. Dispersion dynamics (selected years)

Year	$\sigma_t = sd(\ln RES)$	SD in levels (pp)	CV in levels
2004	1.256656	10.107	0.820
2020	0.422102	11.270	0.463
2021	0.442127	12.082	0.487
2024	0.399683	12.424	0.445

Source: Author's own calculations based on the integrated RES dataset (2004–2024).

Taken together, the sigma-convergence results point to a clear reduction in relative dispersion but not to the disappearance of level inequalities. The marked decline in σ_t indicates that countries with initially low renewable shares increased them fast enough, in proportional terms, to compress the cross-sectional distribution on a multiplicative scale. Yet this relative convergence did not eliminate absolute differences in outcomes. The max-min gap widened from 38.325 pp in 2004 to 48.510 pp in 2024, showing that the frontier-laggard distance remained substantial in level terms. The results therefore support a characterization of the EU renewable transition as one of relative convergence combined with persistent level stratification.

The transition from 2020 to 2021 is associated with a heterogeneous reshuffling of annual country outcomes, which is relevant for interpreting convergence estimates over short windows. Between 2020 and 2021, 12 of the 27 Member States recorded a decline in RES, with the largest reductions in Bulgaria (-3.925 pp, from 23.319% to 19.394%) and Ireland (-3.215 pp, from 16.160% to 12.945%), while the largest increase was observed in Denmark (+9.813 pp, from 31.681% to 41.494%). These changes likely reflect both the documented methodological revision in the SHARES framework and real macro-energy adjustments affecting the denominator and numerator of the RES share. For this reason, the main interpretation focuses on the pre-break period (2004–2020) and the full sample (2004–2024), while post-break estimates for 2021–2024 are treated as indicative only.
Turning to beta-convergence, the cross-sectional endpoint regression provides strong evidence of proportional catch-up across the EU. Estimating the average annual growth rate in log-shares over the 20-year horizon,

$$g_i = \frac{1}{20}\left(\ln RES_{i,2024} - \ln RES_{i,2004}\right),$$

as a function of the initial log level yields a strongly negative slope:

$$g_i = \alpha + \beta \ln RES_{i,2004} + \varepsilon_i,$$

with $\beta = -0.038019$ (SE = 0.002091, $t = -18.178$, $p = 6.35 \times 10^{-16}$, R^2 = 0.930). This implies that countries with lower initial renewable shares tended to record faster subsequent proportional growth. Table 3 summarises the cross-sectional and fixed-effects panel estimates, together with the implied annual speed of convergence and half-life.

Table 3. Beta-convergence estimates and implied convergence speed

Model	**β**	**SE**	**t**	**p-value**	**R^2**	**λ (per year)**	**Half-life (years)**
Cross-section (2004–2024)	-0.038019	0.002091	-18.178	6.35e-16	0.930	0.071436	9.703
Cross-section (2004–2020)	-0.044202	0.002058	-21.476	1.25e-17	0.949	0.076774	9.028
Cross-section (2021–2024)	-0.041561	0.015061	-2.760	0.0107	0.233	—	—
Panel FE (2004–2024)	-0.080343	0.014249	-5.638	1.72e-08	0.347	0.083755	8.276
Panel FE (2004–2020)	-0.078417	0.018040	-4.347	1.38e-05	0.353	0.081662	8.488

Source: Author's own calculations based on the integrated RES dataset (2004–2024).

Across both the cross-sectional and panel frameworks, the beta coefficient is consistently negative and statistically significant for the full horizon and for the pre-break period, indicating systematic catch-up among EU-27 Member States. The implied convergence speeds are economically meaningful. In the cross-sectional specification, the estimated coefficient for 2004–2024 corresponds to an annual speed of convergence of $\lambda = 0.071436$, or 7.144% per year, and to a half-life of 9.703 years. For 2004–2020, the estimated speed is slightly higher at $\lambda = 0.076774$, implying a half-life of 9.028 years. The post-break cross-sectional regression for 2021–2024 also produces a negative coefficient, but its explanatory power is much lower, which supports treating this estimate as indicative rather than structural.

Complementary panel evidence based on annual dynamics and controlling for country fixed effects and common time shocks leads to the same qualitative conclusion. Estimating

$$\Delta \ln RES_{i,t} = \alpha + \beta \ln RES_{i,t-1} + \mu_i + \tau_t + \epsilon_{i,t}$$

on 540 observations yields $\beta = -0.080343$ (SE = 0.014249, $p = 1.72 \times 10^{-8}$, $R^2 = 0.347$). Using the panel mapping $\lambda = -\ln(1 + \beta)$, this corresponds to an annual speed of convergence of 8.376% and a half-life of 8.276 years. For the pre-break sample, $\beta = -0.078417$ (SE = 0.018040, $p = 1.38 \times 10^{-5}$, $R^2 = 0.353$), implying $\lambda = 0.081662$ and a half-life of 8.488 years. These estimates are close to those obtained from the endpoint regressions and reinforce the interpretation of non-negligible proportional catch-up over time.

Taken together, the sigma- and beta-convergence results support a coherent but qualified interpretation. In relative terms, the EU renewable transition displays a common pattern of catch-up: log-based dispersion declined sharply and initially low-share countries tended to grow faster in proportional terms. In absolute terms, however, substantial disparities remain. The frontier-laggard distance increased from 38.325 pp in 2004 to 48.510 pp in 2024, with Sweden remaining the leading country at 62.846% and the lower tail in 2024 still concentrated around mid-teen shares, including Belgium (14.336%), Luxembourg (14.742%), Ireland (16.064%), Malta (17.210%), and Poland (17.770%). Overall, the evidence points to strong relative convergence in renewable energy shares within the EU-27, but not to level equalisation by 2024.

Conclusions

The convergence analysis of the renewable energy share in gross final energy consumption (RES) in the EU-27 over 2004–2024 yields a coherent but nuanced picture of Europe's renewable transition. On the one hand, the evidence points to strong relative convergence: the Union-wide distribution shifts upward, the cross-sectional dispersion of log renewable shares declines markedly, and β-convergence estimates are consistently negative across both cross-sectional and fixed-effects panel specifications, indicating systematic proportional catch-up by initially low-share Member States. On the other hand, this relative homogenisation does not translate into level equalisation. Dispersion measured in percentage points remains substantial and, in endpoint comparisons, increases, implying that absolute frontier-laggard gaps persist despite broad-based progress. Hence, the results support a common-front interpretation in relative terms, while a level-based assessment points to persistent cross-country stratification in outcomes.

From a distributional perspective, improvements extend to the lower tail, as reflected in the substantial rise in the minimum RES share, yet sustained leadership at the frontier implies that absolute distances do not mechanically close. This pattern can be described as "convergence without equality": when baseline levels rise across all countries, relative dispersion may contract even while absolute deviations remain high or widen if leading countries continue to accumulate gains from higher starting points. The β-convergence results further indicate economically meaningful adjustment dynamics, with implied half-lives close to a decade, underscoring that even under stable catch-up mechanisms, level equalisation is slow and not guaranteed within short policy horizons.
Methodologically, the documented SHARES definitional break from 2021 introduces short-run heterogeneity that may affect inference over very short post-break windows. Subperiod reporting and supplementary robustness checks, including a logit transformation appropriate for bounded shares, are consistent with the central conclusion that the observed relative convergence is not merely an artefact of measurement change, while persistent level stratification remains a substantive feature of the data. In policy terms, the findings are consistent with the view that common EU targets may support diffusion and proportional catch-up, but narrowing absolute gaps likely requires more differentiated, capacity- and infrastructure-oriented interventions in lagging Member States. Future

research could extend the analysis to conditional and club-convergence frameworks, as well as sectoral decompositions, in order to identify the structural determinants of persistent level stratification.

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