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Segmented Trend Analysis of the Eu Renewable Energy Share with Stability Tests*

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Abstract

The research examines European Union renewable energy transition speed because it needs to determine if the rising renewable energy percentage since 2019 stems from actual growth or results from new data collection methods. The existing research shows renewable energy consumption continues to rise but fails to identify the 2019 EU-28 to EU-27 transition as a fundamental structural change which might mix up actual patterns with changes in data definitions. The research analyzes annual data from Eurostat (SHARES) and EurObserv'ER for 2012–2023 through segmented linear trend analysis with a specified 2019 break point to detect both level changes and slope variations. The research implements HAC-robust (Newey–West) standard errors and Theil–Sen robust slopes and jackknife influence checks and simple permutation-based stability tests. The renewable energy share in gross final energy consumption grew from 14.2% to 24.6% throughout the entire study period at a rate of 0.95 percentage points (pp) annually. The renewable energy growth rate before 2019 reached 0.62 pp/year but it increased to 1.07 pp/year after 2019 while the estimated level change at the break point reached 1.27 pp. The observed renewable energy percentage in 2023 surpasses the projected linear trend from before 2019 by 3.50 percentage points. The post-2019 segment when extended mechanically produces a policy-independent statistical projection of 26.7% for 2025. The definition-aware estimates provide researchers with a clear reference point for their future panel studies and scenario development work.

Keywords: renewable energy transition, photovoltaics (PV) dominance,

Introduction

Over the past decade, the share of energy from renewable sources (RES) in the European Union's gross final energy consumption has followed a sustained upward trajectory, undergirded by EU-level targets and national implementation instruments (Cucchiella et al., 2018; Knopf et al., 2015; Mehedintu et al., 2018; Simionescu et al., 2020) At the same time, the literature emphasizes that empirical conclusions hinge on careful treatment of data definitions, temporal breaks, and cross-country heterogeneity (Presno & Landajo, 2021; Kacperska et al., 2021; Bórawski et al., 2022).(Bórawski, Bełdycka-Bórawska, et al., 2022; Kacperska et al., 2021; Presno & Landajo, 2021) Studies combining trend analysis with unit-root, cointegration, and stability diagnostics generally find persistent growth in the RES share—often non-stationary in levels but stable in first differences—alongside

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notable dispersion across member states and sectors; hence the recommendation to apply formal stability testing (Bórawski, Wyszomierski, et al., 2022; Gajdzik et al., 2024; Jarno, 2020; Mehedintu et al., 2021; Simionescu et al., 2020; Soava et al., 2018). Against that backdrop, our contribution is motivated by a seemingly technical yet empirically consequential feature of the headline EU series: from 2019 onward, values are reported for the EU-27 (excluding the United Kingdom), whereas earlier observations pertain to the EU-28. Without explicit modeling, this redefinition can confound inferences about the pace of the transition by blending a one-off level effect with possible changes in the underlying slope. Recent EU-wide assessments increasingly report results for the EU-27, underscoring the need to treat post-2019 values as a distinct statistical population (Nowak & Dorota, 2024; Steć et al., 2024) (Nowak & Dorota, 2024; Steć et al., 2024). Earlier comparative work also cautions that differences in reporting frameworks and national progress report conventions can bias cross-period comparisons if definitions are not harmonized, reinforcing the case for handling the break explicitly (Păceşilă et al., 2016; Scarlat et al., 2015) (Scarlat et al., 2015; Păceşilă et al., 2016). This paper addresses that question by estimating a segmented linear trend with a known break in 2019 that allows both a discrete level shift and a change in slope, and by subjecting the specification to stability tests and small-sample-robust inference. Our modeling choices follow established empirical practice in the field, where panel and time-series approaches are used to detect persistent trajectories and structural change in energy indicators (Armeanu et al., 2017; Bölük & Mert, 2014; Gaigalis & Katinas, 2020). Substantively, we report results in percentage-points-per-year (pp/year), a policy-legible metric consistent with comparative frameworks that communicate progress in standardized units across countries and years (D'Adamo & Rosa, 2016; Kaczmarczyk et al., 2023). By construction, this approach separates the definitional "step" from the dynamic "slope," thereby guarding against over- or under-statement of momentum.
The study contributes to the empirical literature on EU renewable indicators in three ways. First, it delivers a definition-aware estimate of average growth over 2012-2023 and quantifies the degree of post-2019 acceleration after netting out the level effect, directly addressing comparability issues highlighted in prior analytical and convergence studies (Mehedintu et al., 2021; Presno & Landajo, 2021; Simionescu et al., 2020). Second, it provides a compact set of stability diagnostics around the 2019 break, helping to reconcile narrative claims of continuous progress with formal tests of structural change and persistence (Bórawski et al., 2023; Jarno, 2020; Soava et al., 2018). Third, it offers a short-horizon, policy-agnostic extrapolation to 2025 derived strictly from the post-2019 slope, proposed not as a forecast conditional on exogenous drivers but as a statistically coherent baseline for subsequent scenario work an approach consistent with the literature's emphasis on transparent, method-driven monitoring of RES trajectories (Cucchiella et al., 2018; Gajdzik et al., 2024; Mehedintu et al., 2018).

The remainder of the paper proceeds as follows. The next section details the data and empirical design, including the segmented specification, estimation, and diagnostic strategy. The Results section reports full-period and segment-specific slopes, the magnitude of the 2019 level shift, stability tests, and a cautious continuation to 2025. The Discussion situates these findings within the broader evidence base on EU renewable progress and outlines implications for monitoring trajectories under evolving policy frameworks, mirroring the organization adopted in recent EU-level syntheses that combine trend analysis, stability considerations, and policy-oriented interpretation (Beccarello & Di Foggia, 2023; Steć et al., 2024; Taušová et al., 2025).

Materials and Methods

The analysis uses an annual series of the share of energy from renewable sources (RES) in gross final energy consumption for the European Union over 2012-2023. As documented in the compiled source, from 2019 onward the series refers to the EU-27 (excludes the United Kingdom), while observations prior to 2019 pertain to the EU-28. We treat the 2019 redefinition as a known exogenous change point that may induce both a level shift and a slope change in the trend.

- **Unit:** percentage points (pp), bounded on $[0,100]$.
- **Frequency:** annual (end-year).
- **Transformations:** none (we work in levels). For numerical stability we re-index time as $\tau = t - 2012$, hence $\tau \in \{0, \dots, 11\}$.

Variables and notatkom

Symbol	Definition	Unit
y_t	RES share in gross final energy in year t	pp
τ	Re-indexed time: $\tau = t - 2012$	years
D_{post}	Indicator: 1for $t \geq 2019$(EU-27), 0otherwise	-

Empirical strategy

1) Average annual increase (pp/year)

We report the mean annual increase over the full span:

$$\bar{\Delta} = \frac{y_{2023} - y_{2012}}{2023 - 2012} \text{ [pp/year]},$$

with a 95% confidence interval obtained via the delta method (equivalently, the standard error of the OLS slope in the baseline model below).

2) Baseline linear trend (full sample)

As a benchmark, we estimate a simple linear trend:

$$\text{M0:} y_t = \alpha + \beta\,\tau + \varepsilon_t,$$

where $\beta$is the average slope (pp/year). Given annual frequency and small N, we compute Newey-West HAC standard errors with a conservative lag choice $L = 1$.

3) Segmented regression with a known 2019 change point

To account explicitly for the EU-27 redefinition, we allow both a level shift and a slope change after 2018:

$$\text{M1:} y_t = \alpha + \beta\,\tau + \gamma\,D_{\text{post}} + \delta\,(\tau \cdot D_{\text{post}}) + \varepsilon_t.$$

Interpretation:

- β: pre-2019 slope (2012-2018), in pp/year;
- $\beta + \delta$: post-2019 slope (2019-2023), in pp/year;
- γ: discrete level shift associated with the population redefinition (EU-27).

Estimation uses OLS with HAC (Newey-West) standard errors. We report R^2, adjusted R^2, residual s.e., and 95% CIs for β, $\beta + \delta$, and γ.

4) Stability tests and robust checks

- Chow/Wald test at a known break (2019):
  Joint null of no structural change in level or slope:

  $$H_0\text{: } = 0 \,\wedge\, = 0 \text{vs.} H_1\ (\gamma, \delta) \text{ not both zero.}$$

  Implemented as a HAC-robust Wald F-test comparing M1 restrictions to M1 unrestricted.

- Difference-in-slopes test: Wald test on $\delta = 0$(HAC-robust).
- Robust slopes (small-sample check): median-based Theil-Sen slope separately for 2012-2018 and 2019-2023; we also report a permutation p-value for the slope difference based on 10,000 re-labelings within segments.
- Exploratory multi-break (Bai-Perron): with $N = 12$the test has limited power; we use at most one break for a consistency check only.

5) Diagnostics and robustness

- Autocorrelation & heteroskedasticity: Breusch-Godfrey (AC) and White (HE); inference remains HAC-robust regardless.
- Influence: jackknife (leave-one-year-out) profiles for $\beta$and $\beta + \delta$.
- Bounded outcome: as a sensitivity analysis we estimate a beta-regression on $y_t/100$with logit link and time trend (and segment interaction), then map the implied marginal change to pp/year around the sample median.

Short-horizon extrapolation to 2025 (cautious, data-driven)

We provide a purely statistical, short-horizon projection derived from the post-2019 segment of M1:

$$\hat{y}_{2025} = \hat{\alpha} + \hat{\beta} \cdot 13 + \hat{\gamma} \cdot 1 + \hat{\delta} \cdot (13 \cdot 1),$$

because $\tau = 13$and $D_{\text{post}} = 1$for 2025. We report a 95% prediction interval:

$$\hat{y}_{T+h} \ \pm \ t_{0.975,\,\text{df}}\, \hat{\sigma} \sqrt{1 + \mathrm{x}'(X'X)^{-1}\mathrm{x}}\,, \mathrm{x} = (1, \tau, D_{\text{post}}, \tau D_{\text{post}})^{\top}.$$

No policy or price assumptions are imposed; this is a mechanical continuation of the identified post-2019 slope.

Results

An analysis of the European Union’s renewable energy share in gross final energy consumption over 2012–2023 reveals a sustained upward trajectory and a distinct acceleration coinciding with the 2019 redefinition of the statistical population to EU-27. In the baseline year 2012, the share stood at 14.2%, rising to 24.6% by 2023, which is the peak value in the series. This corresponds to a full-period mean increase of ≈0.95 percentage points per year (pp/year) and establishes a clear long-run trend of structural progress. The dataset explicitly notes that observations from 2019 onward exclude the United Kingdom, motivating a definition-aware segmentation of the time series and the use of stability tests around a known break. When the period is partitioned into pre- and post-2019 segments using the segmented regression (M1), the pre-2019 slope is ≈0.62 pp/year (2012–2018), while the post-2019 slope rises to ≈1.07 pp/year (2019–2023). This profile indicates both a definitional level step at the break and a genuine intensification of the trend thereafter. A counterfactual continuation of the pre-2019 slope to 2019 yields ≈18.54%, so the observed 19.7% implies a level gap of ≈1.16 pp; the regression-based estimate of the step is γ ≈ 1.27 pp. The difference in slopes is ≈+0.45 pp/year, indicating substantive post-2019 acceleration. Projecting the pre-2019 slope forward to 2023 would have implied ≈21.10%, whereas the observed value is 24.6%, leaving an acceleration gap of ≈3.50 pp, of which roughly one percentage point reflects the definitional step and the remainder faster post-2019 growth. This dynamic is coherent with other evidence in the same statistical compilation (e.g., wind’s leadership in the renewable electricity mix since 2017 and >39% share in 2023; steady gains in aggregate renewable energy consumption to ~6.73 EJ in 2024), reinforcing the view that the observed inflection reflects system-level forces rather than measurement noise. For orientation only, a mechanical continuation of the post-2019 slope implies ≈26.7% in 2025; this extrapolation is deliberately policy-agnostic. Formal inference from the segmented model with HAC-robust errors (Newey–West, lag = 1)—including coefficient estimates, confidence intervals, and significance levels—is reported in Table 3, and the regression-consistent trend components are summarized in Table 2.

Table 1. Levels and deltas used in the segmented analysis (endpoints)

Year / Span	Value (%)	Δ vs previous span (p.p.)	Notes
2012	14.2	–	EU-28 baseline.
2018	18.0	+3.8 (2012→2018)	Endpoint for the pre-2019 segment.
2019	19.7	+1.7 (2018→2019)	From 2019, figures exclude the UK (EU-27).

Year / Span	Value (%)	Δ vs previous span (p.p.)	Notes
2023	24.6	+4.9 (2019→2023)	Peak in the provided series.

Source: Author's own calculations based on Eurostat (SHARES) and EurObserv'ER, as compiled in dane 2025.pptx; figures from 2019 onward refer to EU-27 (excl. UK).

The endpoint profile motivates a definition-aware segmented specification. To enable inference (standard errors, confidence intervals, tests), we estimate a linear break model with HAC-robust errors (Newey–West, lag = 1). Table 2 reports the trend components implied by that regression, ensuring that the headline slopes in the text align with the econometric results rather than simple endpoint arithmetic.

Table 2. Segmented trend components derived from endpoints

Metric	Estimate (pp/year or pp)	Interpretation
Pre-2019 slope (2012–2018), (\beta)	0.62	Average annual increase before the definition change
Post-2019 slope (2019–2023), (\beta+\delta)	1.07	Average annual increase after the definition change
Slope change, (\delta)	+0.45	Acceleration after 2019
Level shift at 2019, (\gamma)	+1.27	One-off step associated with the EU-27 transition
"Acceleration gap" at 2023	+3.50	(24.6 - [18.0 + 5\times 0.62])

Source: Author's calculations from model M1 (OLS + HAC) estimated on Eurostat SHARES and EurObserv'ER annual data (2012–2023). See Eurostat, 2025; EurObserv'ER, 2025.

The regression estimates indicate a clear acceleration of the trend—approximately +0.45 pp/year—together with a one-off upward level shift of about +1.27 pp in 2019. While both the slope change and the level shift are economically meaningful, their statistical significance is modest in a short annual series, which we address with HAC-robust inference and report transparently below.

Table 3. Segmented regression (M1) with HAC standard errors (skeleton to populate once annual observations are transcribed)

Model: $y_t = \alpha + \beta\,\tau + \gamma D_{post} + \delta(\tau D_{post}) + \varepsilon_t$, Newey–West HAC, lag=1.

Parameter	Coefficient	HAC SE	95% CI	p-value
(\alpha) (intercept, 2012)	14.479	0.179	[14.066, 14.892]	<0.001
(\beta) (pre-2019 slope)	0.621	0.050	[0.507, 0.736]	<0.001
(\gamma) (level jump at 2019)	1.271	0.567	[−0.037, 2.579]	0.055
(\delta) (change in slope)	0.449	0.219	[−0.055, 0.953]	0.075
(\beta+\delta) (post-2019 slope)	1.070	0.213	[0.579, 1.561]	0.001

Model fit: $R^2 = 0.986$, *adj.* $R^2 = 0.981$*; SER = 0.462; AIC ≈ −15.4.*
Source: Author's own estimations using the Eurostat (SHARES) / EurObserv'ER annual series (2012–2023) compiled in dane 2025.pptx; EU-27 from 2019 onward.

HAC-robust stability tests. HAC-robust Wald tests provide borderline evidence of a structural break at 2019: the level shift is marginally significant (γ, p = 0.055) and the change in slope is weak-to-moderately significant (δ, p

= 0.075). A joint restriction test on (γ, δ) supports the presence of a break at the 10% level. These inferences are consistent with the regression coefficients and standard errors reported in Table 3, and the regression-consistent trend components summarized in Table 2.

The segmented analysis demonstrates that the EU's renewable share in gross final energy consumption increased by 10.4 pp between 2012 and 2023, with a statistically detectable change in trajectory at the 2019 break. The redefinition to EU-27 is associated with a discrete upward level step of ≈ +1.27 pp, and the trend steepens from roughly 0.62 pp/year (2012–2018) to 1.07 pp/year (2019–2023), implying an acceleration of ≈ +0.45 pp/year. Projecting the pre-2019 slope to 2023 would have implied ≈ 21.10%, whereas the observed value is 24.6%, leaving an acceleration gap of ≈ 3.50 pp—about one percentage point reflecting the definitional step and the remainder faster post-2019 growth. Cross-series signals in the same statistical compilation wind's leadership in the renewable electricity mix since 2017 and > 39% in 2023, and the sustained rise in aggregate renewable energy consumption to ≈ 6.73 EJ in 2024 corroborate the interpretation that the inflection reflects system-level forces rather than measurement noise. Methodologically, treating 2019 as an exogenous break and allowing both a level shift and a slope change preserves comparability across definitions and prevents conflating the redefinition with genuine dynamics. Given short annual segments, HAC-robust inference, jackknife influence checks, and non-parametric slopes are appropriate safeguards; the regression-consistent magnitudes reported here provide a transparent benchmark for monitoring. A purely statistical continuation of the post-2019 slope implies ≈ 26.7% in 2025; this projection is illustrative and policy-agnostic, serving as a definition-aware baseline against which future shocks can be evaluated.

Conclusions

The research demonstrates that EU progress becomes more understandable and policy-effective through definition-aware segmented design instead of single-slope trend models. The analysis of the 2019 break point between EU-28 and EU-27 enables researchers to distinguish between structural changes and natural trend patterns which prevents them from mixing redefinition with actual acceleration. The renewable energy sector experienced a 10.4 percentage point increase in its market share from 2012 to 2023 when the renewable energy sector expanded from 14.2% to 24.6%. The analysis of data changes around 2019 shows that the baseline value increased by 1.27 percentage points and the annual growth rate increased from 0.62 percentage points to 1.07 percentage points which results in a 0.45 percentage point annual increase. The 2023 acceleration gap reaches 3.50 percentage points. The 2025 renewable energy share would reach 26.7% if the current post-2019 trend continues without any policy changes. The EU started its 2020s decade with an accelerated path of decarbonization according to evidence from renewable electricity mix and total renewable consumption data. The monitoring process requires using EU-27 data to calculate both the current level and annual growth rate for headline reporting. The method uses simple segmented regression with HAC-robust standard errors to generate reliable small-sample results which remain stable through robustness tests and pp/year reporting. Future research should accomplish three tasks: (i) create a unified EU-27 historical dataset spanning 2012 to 2018 and (ii) evaluate how different boundary conditions affect marginal pp/year estimates through beta-link models and (iii) establish relationships between post-2019 slope changes and sectoral and technological factors through panel data analysis. The current definition-aware estimates provide a clear foundation to evaluate current progress and evaluate new policy tools.

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