ECONOMICS
& Sociology

Vasylieva, T., Oláh, J., Khouri, S., & Horsch, A. (2026). Electricity price shocks, renewable energy penetration, and macroeconomic stability in European countries: Evidence from the 2022 energy crisis. *Economics and Sociology*, *19*(1), 250-275. doi:10.14254/2071-789X.2026/19-1/12

ELECTRICITY PRICE SHOCKS, RENEWABLE ENERGY PENETRATION, AND MACROECONOMIC STABILITY IN EUROPEAN COUNTRIES: EVIDENCE FROM THE 2022 ENERGY CRISIS

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ABSTRACT. The 2022 European energy crisis exposed the macroeconomic vulnerability of EU economies to electricity price shocks and raised urgent questions about the stabilising role of renewable energy penetration. This study examines in how far changes in electricity price components affect macroeconomic stability in Europe and whether renewable energy penetration has buffered these effects during the crisis period. Using a balanced panel of 29 European countries over 2019–2024, the analysis estimates the impact of log changes in electricity prices on a composite Macroeconomic Stability Index (MSI) using two-way fixed-effects models with crisis-year heterogeneous slopes, interaction terms, and two-way clustered standard errors. The results show that increases in non-household electricity prices are associated with statistically significant declines in macroeconomic stability, particularly in 2023 ($\beta = -0.084$, $p < 0.01$) and 2024 ($\beta = -0.333$, $p < 0.05$). A 10% rise in business electricity prices reduced the MSI by approximately 0.009–0.010 points in 2023 (around 4% of one standard deviation) and by about 0.029 points in 2024 (around 13% of one standard deviation). In 2022, the adverse effect was significant in low-renewables countries (ME = −0.056) but statistically insignificant in high-renewables countries, indicating short-run buffering. Joint tests confirm that crisis-period slope shifts ($\chi^2 = 30.576$, $p < 0.001$) and renewable moderation effects ($\chi^2 = 8.603$, $p = 0.035$) are statistically significant.

Received: March, 2025
1st Revision: December, 2025
Accepted: April, 2026

DOI: 10.14254/2071-789X.2026/19-1/12

***JEL Classification*:** E31, E62, Q41, Q48

***Keywords*:** electricity price shocks, renewable energy penetration, macroeconomic stability, energy crisis 2022, two-way fixed effects, crisis heterogeneity, European economies

Introduction

The relevance of investigating the impact of electricity price shocks on macroeconomic stability stems from the unprecedented energy market disruption triggered by Russia's full-scale invasion of Ukraine in 2022, which led to sharp increases in wholesale electricity and gas prices across Europe (e.g., the early contribution of Korosteleva, 2022; also Maneejuk et al., 2024). According to reports of the European Commission, electricity prices in several Member States reached historically high levels during 2022–2023, reflecting supply constraints, gas-market volatility, and structural dependence on imported fossil fuels (European Commission, 2022b; 2023). The Commission's REPowerEU communications emphasised that the energy shock rapidly translated into broader macroeconomic pressures through inflation, fiscal burdens associated with support schemes, and the deteriorating competitiveness of energy-intensive industries (European Commission, 2022a). The scale and persistence of price spikes exposed structural vulnerabilities in European energy systems. They demonstrated that electricity markets are no isolated sectoral domains but central determinants of macroeconomic stability and social cohesion.

The macro-financial implications of the energy crisis were further underscored by the International Monetary Fund, which identified energy price shocks as a key driver of inflation dynamics and growth deceleration in Europe during 2022–2023 (IMF, 2022; 2023). IMF assessments highlighted the cost-channel transmission mechanism: higher electricity prices increased production costs, amplified headline and core inflation, weakened real incomes, and triggered substantial fiscal interventions to cushion households and firms (IMF, 2024a; 2024b). These developments intensified trade-offs between price stability, fiscal sustainability, and growth, thereby directly affecting the core components of macroeconomic stability. In this context, understanding how electricity price shocks propagate through national economies and whether structural energy characteristics mitigate or amplify these effects became an urgent analytical priority for policymakers.

The European Central Bank also documents the macroeconomic disruptions in its 2023 and 2024 reports: According to the ECB (2023), the surge in energy and electricity prices following the 2022 geopolitical shock became a primary driver of euro area inflation, transmitting rapidly through production costs, consumer prices, and wage dynamics. The bulletin emphasises that elevated electricity and gas prices intensified cost pressures across energy-intensive sectors, weakened industrial output, and increased fiscal burdens associated with support measures for households and firms. The ECB further highlights that although headline inflation gradually declined, energy-related volatility continued to shape inflation expectations, financial conditions, and monetary policy tightening, thereby affecting investment and growth prospects (ECB, 2024). These assessments underscore that electricity price shocks were not merely sectoral disturbances but systemic macroeconomic shocks influencing price stability, output performance, and fiscal sustainability, i.e., core dimensions of macroeconomic stability. In this context, examining whether renewable energy penetration mitigated or amplified the macroeconomic transmission of electricity price shocks during the 2022 crisis is both timely and policy-relevant for understanding Europe's structural resilience to future energy disruptions.

1. Literature review

Europe’s 2022 energy crisis is widely conceived as a systemic shock in which war-driven disruptions to energy supply chains rapidly translated into electricity-market stress and broader macroeconomic fragility. Electricity and gas markets in the euro area reacted strongly to the invasion, with heightened volatility, risk premia, and uncertainty about supply adequacy, thereby amplifying the sensitivity of national economies to energy-cost movements (Adolfsen et al., 2022). The crisis is also interpreted as a supply-chain interruption problem with measurable vulnerability and spillover risks across countries and sectors, particularly where exposure to imported fossil fuels was high (Cui et al., 2023). The medium-term macroeconomic imprint of the war is increasingly linked to energy security constraints and the feasibility of emissions targets, suggesting that electricity price shocks should be analysed in combination with transition capacity rather than as stand-alone market episodes (Rojas-Romagosa, 2024; Sun et al., 2024). Comparative cross-country evidence further indicates that the invasion created heterogeneous macroeconomic and energy impacts, reinforcing the need for empirical designs that allow crisis-period effects to vary across time and structural conditions (Koilo, 2024). The social and political context of the war is also treated as a distinct “social situation” that affects expectations, behaviour, and resilience, motivating the incorporation of institutional and societal heterogeneity into macroeconomic interpretations (Slyusarevskyy & Chunikhina, 2025; Whitt & Page, 2025; Zozulinskyy, 2024).

A second stream of research explains why electricity prices became exceptionally volatile and why this volatility matters for market participants’ expectations and behaviour. Electricity-price dynamics are increasingly modelled as outcomes of multiple drivers, market design, generation mix, fuel costs, and local constraints, so that volatility cannot be reduced to a single “energy price” factor (Cevik & Zhao, 2026; Bâra et al., 2025; Saretto et al., 2025; Georgescu et al., 2024). The role of renewable energy (RE) generation in price formation is ambiguous ex ante: higher renewables can depress wholesale prices in normal times but may also interact with balancing costs and intermittency constraints, producing complex price effects (Bank & Badyda, 2024; Triantafyllidou et al., 2024, Lu et al., 2025). Negative electricity prices are just one outcome closely related to the growing volume of RE (e.g., Sun et al., 2026; Prokhorov & Dreisbach, 2022; Biber et al., 2022). Against this backdrop, households’ and firms’ responses depend crucially on expectations formation under volatile conditions, with evidence that energy price expectations and consumer behaviour shift materially during turbulence (Alberini et al., 2023; Dinca et al., 2025). Methodological advances in short-term price prediction (including machine learning) reflect the practical importance of anticipating near-term price movements in day-ahead markets, while microgrid monitoring and forecasting challenges highlight the complexity of decentralised systems that may influence local price stability (Popławski et al., 2024; Wojciechowski et al., 2025). More broadly, granular forecasting and nonlinear modelling approaches are increasingly used to represent complex system dynamics under stress, supporting the case for flexible empirical specifications when studying crisis regimes (Tomczyk et al., 2025; Krawczyk et al., 2025; Dobrescu, 2026).

A closely related string of literature clarifies the macroeconomic transmission channels of electricity price shocks, particularly through inflation and cost pressures. Energy expenditures were shown to push CPI inflation in 2022 more strongly than standard decompositions implied, indicating that conventional inflation accounting may underestimate the macro significance of energy shocks (Chowdhury & Dixon, 2025). War-related electricity shocks have also been linked to dynamic inflation responses that differ across European “energy and renewables regimes”, suggesting that the inflationary pass-through depends on structural energy characteristics and crisis timing (Vasylieva et al., 2025a). Analyses from a public-governance perspective support the insight that the impacts of electricity price shocks on inflation are policy-relevant and require coordinated responses, especially when the shock originates externally and affects countries asymmetrically (Vasylieva et al., 2025b). Earlier evidence from energy supply shocks in transition economies proved that energy disruptions can produce substantial macroeconomic consequences via output, inflation, and external balance channels, which remains conceptually relevant for analysing contemporary crisis episodes (already Quan Chu & Grais, 1996; also (Zhang, 2013). At the same time, spillovers from the war extend beyond energy prices alone, with country case studies documenting war-related macro dynamics under extreme uncertainty and reinforcing the crisis-as-a-regime interpretation (Dobrovolska et al., 2024; He, 2024).

Research on macroeconomic stability and resilience provides the conceptual bridge between energy shocks and the composite stability outcomes examined in this study. Macroeconomic stability is increasingly treated as a multidimensional construct influenced by behavioural impulses, expectations, and transmission channels that jointly shape the stability of output, prices, labour markets, and external balances (Brychko et al., 2025; Vasilyeva et al., 2025b). Post-pandemic recovery work for European countries demonstrates that macroeconomic stability responds to a mix of structural determinants and shock exposure, encouraging panel approaches that isolate within-country changes during turbulent periods (Kuzior et al., 2024; Vysochyna et al., 2024). The crisis also reactivated debates on fiscal sustainability trajectories in the EU, consistent with the view that energy shocks can pressure public budgets and destabilise the macro policy mix (Auclert et al., 2023; Tkacova et al., 2025; Qian et al., 2026). Financial-stability evidence emphasises that globalisation, external shocks, and institutional settings can influence stability outcomes, underscoring heterogeneity and the need for analyses with an appropriate focus rather than assuming common effects across countries (Abou Saad & Sági, 2025). Complementary macro strands show that growth-energy links may be nonlinear and regime-dependent, that business-cycle properties can co-move with commodity price fluctuations, and that oil-price shocks remain macro-relevant, collectively motivating flexible crisis-period modelling rather than constant-slope assumptions (Almoree & Almosabbeh, 2026; Thach, 2025; Bouguerroumi & Belarbi, 2025; Hadji & Ben Abderrahmane, 2024). Monetary policy is also relevant in this context because crisis-era tightening and unconventional policy debates shape the macro environment in which energy shocks operate (Jabiyev et al., 2025).

A substantial body of work positions renewable energy penetration as a resilience factor that may moderate the macro effects of electricity price shocks. Renewable energy is often linked to energy security and reduced exposure to imported fossil-fuel volatility, with evidence that renewables can enhance energy security under conditions of geopolitical risk (Havrylenko & Myroshnychenko, 2025; Vasa et al., 2024; Kuzior et al., 2025; Khan et al., 2023). EU-focused research further suggests that renewable consumption is procyclical, interacting with business cycles and sustainable development outcomes, implying that crisis timing matters for interpreting the buffering capacity of renewables (Bușu et al., 2024). Broader transition research connects renewables with CO_2 efficiency, environmental management, and sustainable development indices, supporting the argument that energy transition has macroeconomic and institutional co-benefits rather than being desirable from an environmental point of view only (Americo et al., 2024; Dilanchiev et al., 2024; Karimboev et al., 2025; Raman et al., 2025; Lu et al., 2020). Investment and competitiveness channels also matter: Green transition investment is linked to growth and competitiveness in the EU, while decarbonisation may reshape industrial export performance, suggesting that renewables' macro role includes structural competitiveness effects beyond short-run price buffering (Popescu et al., 2025; Zábojník & Branch, 2025; Burrell et al., 2025; Luciani, 2022). Financial-market evidence indicates that clean-energy valuations respond to price movements in commodities such as critical minerals, oil, gas, and gold, reinforcing that the transition interacts with broader commodity cycles and risk pricing (e.g., Attilio, 2025; Baghirzade & Kosormyhin, 2025). Finally, public-policy interest in circular-economy instruments and eco-innovations indicates that institutional capacity and policy architecture are part of the renewables–resilience nexus (recently, Radtke & Canzler, 2026, and the other contributions to this issue of Renewable and Sustainable Energy Reviews; Juracka et al., 2024).

The socio-economic and institutional landscape surrounding energy shocks suggests that macroeconomic stability responses should differ across countries and sectors. Behavioural changes in consumption and energy-saving practices under energy-security pressure highlight that crisis responses are mediated by household and firm adaptation, rather than solely by price levels (e.g., Singhal et al., 2026; Dinca et al., 2025). War-related spillovers have been documented across asset markets and sectoral dynamics (including real estate), demonstrating that electricity price shocks may coincide with broader uncertainty channels that influence macro outcomes (Cosmulese & Zhavoronok, 2025). National security and resilience perspectives emphasise that economic growth, institutional strength, and resistance to global turbulences are intertwined, which supports integrating institutional heterogeneity into crisis-era macro assessments (Firstová & Vysochyna, 2024; Lyeonov et al., 2024b). Trust, vulnerability, and crisis resilience are increasingly treated as organisational and societal attributes that shape economic performance, aligning with treating macro stability as a socio-economic outcome influenced by institutions and behavioural responses (Lyeonov et al., 2024a; George & Mattathil, 2025; Paliiev et al., 2025). Evidence on inclusive growth patterns, public–private interaction, and shifting public sentiment indicates that crisis-period policy choices operate in a broader political-economy environment that may affect stability outcomes (Saher et al., 2025; Topazly et al., 2025; Trenta et al., 2025). War-driven trade and demographic pressures also remain relevant for the European neighbourhood, strengthening the case for crisis-specific modelling and careful interpretation of stability under conflict spillovers (Tsymbal & Demediuk, 2025; Zahorodnia et al., 2026).

Altogether, existing research establishes strong links between war-driven energy disruptions, electricity price volatility, inflation, macroeconomic adjustment, and the strategic relevance of renewables for resilience. However, it still leaves limited evidence on how renewable penetration conditions the electricity price–macroeconomic stability relationship in a crisis year, time-heterogeneous setting. The present study addresses this gap by focusing explicitly on crisis-period heterogeneity and the moderating role of renewables in shaping macroeconomic stability outcomes in Europe. This contributes to the emerging view that energy transition capacity is not only a climate variable but also a macro-stability determinant in the face of systemic energy shocks.

This study aims to investigate the macroeconomic and institutional effects of electricity price shocks and energy policy responses across European countries, with particular attention to cross-country heterogeneity and the structural break induced by the 2022 energy crisis.

2. Methodological approach

2.1. Empirical strategy

This study investigates whether changes in electricity price components affect macroeconomic stability and whether the share of renewable energy moderates (or aggravates) this relationship during the energy crisis period. The empirical design is based on a balanced panel of 29 countries observed annually over the period 2019–2024. The dependent variable is the Macroeconomic Stability Index (MSI) as defined by Vasylieva et al. (2026), i.e., a composite pentagon indicator that integrates inflation, GDP growth, fiscal balance, unemployment, and current account performance. The MSI ranges from 0 to 1, where higher values indicate stronger macroeconomic stability. The variables capturing electricity price components for household and non-household consumers, as well as the share of energy from renewable sources, are obtained from the Eurostat database of the European Commission. Specifically, electricity price components correspond to harmonised Eurostat indicators on electricity price levels and cost structures for household and non-household consumers. At the same time, renewable energy penetration is measured as the share of renewable energy in gross final energy consumption. All data are retrieved from the official Eurostat online database, ensuring cross-country comparability and methodological consistency across EU member states and associated economies (European Commission, n.d.).

The core explanatory variable is the annual log change in electricity price components (non-household consumers in the main specification), denoted. d_lpn. The moderating variable is the share of energy from renewable sources, centred around its sample mean (re_c) to facilitate interpretation of interaction terms. All specifications include country and year fixed effects to control for unobserved heterogeneity across countries and common macroeconomic shocks over time.

The baseline empirical framework is based on the two-way fixed-effects (TWFE) model, which controls for unobserved time-invariant country heterogeneity and common time shocks (Baltagi, 2021; Wooldridge, 2010). The baseline specification is:

$$MSI_{it} = \alpha_i + \lambda_t + \beta_1 d\_lpn_{it} + \varepsilon_{it},$$

where α_i captures time-invariant country-specific characteristics and λ_t captures year-specific shocks common to all countries. The coefficient β_1 measures the marginal effect of the explanatory variable d_lpn_{it} on macroeconomic stability, holding constant unobserved heterogeneity and time effects. The error term ε_{it} represents idiosyncratic shocks that vary across countries and time and are assumed to have zero mean and finite variance, conditional on the included regressors.

To assess moderation, the model is extended to explicitly include renewable energy penetration and its interaction with electricity price changes:

$$MSI_{it} = \alpha_i + \lambda_t + \beta_1 d\_lpn_{it} + \beta_2 re_{c,it} + \beta_3 (d\_lpn_{it} \times re_{c,it}) + \varepsilon_{it},$$

where α_i captures time-invariant country-specific characteristics and λ_t captures year-specific shocks common to all countries. The coefficient β_1 reflects the effect of electricity price changes on macroeconomic stability when renewable energy penetration is zero, while β_2 captures the direct effect of renewable energy penetration. The interaction term coefficient β_3 measures the moderating effect, indicating how the impact of electricity price changes on macroeconomic stability varies with the level of renewable energy penetration. The error term ε_{it} represents idiosyncratic shocks that vary across countries and over time, are assumed to have zero mean and finite variance, and are conditional on the included regressors.

Interaction models allow for heterogeneous treatment effects conditional on observed characteristics (Brambor et al., 2006; see Clark & Golder, 2023, for an extensive discussion). The renewables variable is mean-centred to facilitate the interpretation of interaction coefficients and reduce multicollinearity (Aiken & West, 1991).

2.2. Crisis-heterogeneous specification

To capture structural changes in the electricity price–stability relationship during the energy crisis, a year-heterogeneous slope model is estimated. The pre-crisis year (2021) is used as the reference category. The crisis model is specified as:

$$MSI_{it} = \alpha_i + \lambda_t + \gamma re_{c,it} + \sum_{t\neq 2021} \beta_t \,(d\_lpn_{it} \times D_t) + \sum_{t\neq 2021} \delta_t \,(d\_lpn_{it} \times re_{c,it} \times D_t) + \varepsilon_{it},$$

where d_lpn_{it} denotes electricity price changes (e.g., log-difference or growth rate of electricity prices) in country $i$at time t; D_t represents a set of year dummy variables equal to 1 for a given year $t$and 0 otherwise (with 2021 omitted as the reference category); and $re_{c,it}$ denotes renewable energy penetration, measured as the share of renewable energy in total final energy consumption (or electricity generation) in country i at time t. The α_i captures time-invariant country-specific characteristics, and the λ_t captures common year-specific shocks. The coefficient γ reflects the average direct effect of renewable energy penetration on macroeconomic stability. The terms β_t represent year-specific marginal effects of electricity price changes relative to the baseline year 2021, thereby capturing how the price–stability relationship evolves over time. The interaction coefficients δ_t measure the time-varying moderating (buffering) effect of renewable energy penetration on this relationship during the crisis period. The error term ε_{it} represents idiosyncratic shocks that vary across countries and time and are assumed to have zero mean and finite variance, conditional on the included regressors.

This flexible specification allows the electricity price impact to vary across years and tests whether renewable penetration attenuated the negative macroeconomic effects during the 2022–2024 energy shock.

This approach allows the slope of electricity price changes to vary by year and captures crisis-specific moderation effects. Such flexible slope models are standard in panel event-type settings (Angrist & Pischke, 2009; Wooldridge, 2010).

Joint significance of crisis-period slope shifts is evaluated using Wald tests (Greene, 2017).

2.3. Estimation and inference

All specifications are estimated using fixed-effects estimators implemented via high-dimensional FE routines (Correia, 2016). The primary inference relies on two-way clustered standard errors (country and year), which are robust to:

- serial correlation within countries,
- cross-sectional dependence across countries,
- heteroskedasticity.

As robustness checks, Driscoll–Kraay standard errors and country-clustered standard errors are also reported. Statistical significance discussed in the text refers to the two-way clustered specification (Arellano, 1987; Driscoll & Kraay, 1998) unless otherwise stated.

Joint hypothesis tests are conducted using Wald statistics to evaluate:

1. Whether crisis-period slope shifts are jointly different from zero.
2. Whether the renewable buffering terms are jointly significant during 2022–2024.

2.4. Marginal effects and economic magnitude

To provide economically interpretable results, marginal effects of electricity price changes are computed at the 25th and 75th percentiles of renewable penetration. For a given year t, the marginal effect is:

$$ME_t(r_c) = \beta_t + r_c \cdot \delta_t.$$

Standard errors and confidence intervals are calculated using the delta method based on the estimated covariance matrix. Standard errors are calculated using the delta method:

$$Var(ME_t) = Var(\beta_t) + r_c^2 Var(\delta_t) + 2r_c Cov(\beta_t, \delta_t),$$

which provides a first-order Taylor approximation of the variance of nonlinear functions of estimators (Greene, 2017; Wooldridge, 2010). Confidence intervals are derived accordingly.

This approach allows direct comparison of price effects in low-renewable versus high-renewable economies and quantifies the buffering capacity of renewable energy during crisis conditions.

2.5. Robustness and sensitivity analysis

Several robustness checks are implemented:

- Lag specification – to mitigate simultaneity concerns, lagged electricity price changes and interactions are estimated (Wooldridge, 2010).
- Sample sensitivity – models are re-estimated excluding 2020 (pandemic shock) and 2024 (post-crisis adjustment).
- Winsorisation – electricity price changes are winsorised at the 1% level to address outliers (Blaine, 2018; Ruppert, 2004).
- Placebo test (2020 as focal year) – to verify crisis-specificity, a falsification model treats 2020 as a pseudo-crisis year (Angrist & Pischke, 2009).
- Alternative electricity price components – household electricity prices are used as an alternative treatment variable.

The placebo test assesses whether the crisis-period moderation pattern is evident in pre-crisis data. The absence of similar buffering effects in the placebo model supports the interpretation that the main results are crisis-specific rather than artefacts of model structure.

2.6. Data diagnostics

Descriptive statistics and Shapiro–Wilk tests (Shapiro & Wilk, 1965) indicate that raw electricity price components are right-skewed. Log-transformations substantially improve distributional properties (Wooldridge, 2010). However, since fixed-effects estimators rely on large-sample asymptotics and cluster-robust inference, normality of regressors is not required for consistent estimation.

Multicollinearity diagnostics show no excessive correlation among explanatory variables. Missing observations (mainly due to lag construction) reduce the sample from 174 to 145 country-year observations in dynamic specifications.

2.7. Limitations

The short time dimension (T = 6) limits the application of dynamic panel GMM estimators (Arellano & Bond, 1991) and constrains long-run causal identification. While lag and placebo specifications mitigate reverse causality concerns, the results should be interpreted as identifying crisis-specific associations rather than fully structural causal effects.

3. Conducting research and results

3.1. Results

The descriptive statistics (*Table 1*) for the balanced country–year panel (n = 174; 29 countries observed over 2019–2024) reveal marked heterogeneity in electricity price components, renewables penetration, and macroeconomic stability. The household electricity price component (x1) averages 0.11 (SD = 0.06; median = 0.10) and is moderately right-skewed (skewness = 1.48; kurtosis = 2.95), indicating that most observations cluster around relatively low values while a smaller subset of countries/years exhibits substantially higher household price components (max = 0.41). The non-household electricity price component (x2) displays far stronger dispersion and tail risk, with a mean of 0.12 (SD = 0.15; median = 0.10), but an extremely wide range (0.02–1.79) and pronounced non-normality (skewness = 8.84; kurtosis = 97.34), which is consistent with occasional large upward price spikes for business consumers during energy-market stress. The share of energy from renewable sources (x3) averages 29.07% (SD = 17.94; median = 22.47) and is right-skewed (skewness = 1.52; kurtosis = 1.60), reflecting that most country-years have moderate renewables shares, with only a smaller group achieving very high penetration (up to 83.72%). The MSI pentagon index (y) has a mean of 0.33 (SD = 0.23; median = 0.32) over a 0–0.94 range and exhibits only mild right skewness (0.47) and slightly negative kurtosis (−0.41), suggesting a broadly dispersed but not heavily tailed distribution of macroeconomic stability across the sample. The descriptive profile supports modelling strategies that treat electricity price variables as shock-prone, particularly for non-household consumers, and motivates log-change or robust-inference approaches when assessing how electricity price dynamics and renewables penetration jointly relate to macroeconomic stability.

Table 1. Descriptive statistics of key variables (2019–2024, 29 countries)

Indicator	Variable			
	Electricity price components for household consumers (x1)	Electricity price components for non-household consumers (x2)	Share of energy from renewable sources (%) (x3)	MSI pentagon index
n	174	174	174	174
Mean	0.11	0.12	29.07	0.33
SD	0.06	0.15	17.94	0.23
Median	0.1	0.1	22.47	0.32
Trimmed mean	0.11	0.1	25.74	0.32
MAD	0.05	0.06	10.61	0.26
Min	0.03	0.02	7.05	0
Max	0.41	1.79	83.72	0.94
Range	0.38	1.78	76.68	0.94
Skewness	1.48	8.84	1.52	0.47
Kurtosis	2.95	97.34	1.6	−0.41
SE	0	0.01	1.36	0.02

Note: *The sample comprises 29 countries observed annually over 2019–2024 (balanced panel, 174 observations). x1 and x2 denote electricity price components for household and non-household consumers, respectively. x3 represents the share of renewable energy in total energy consumption. y denotes the macroeconomic stability index (MSI pentagon). Skewness and kurtosis statistics indicate strong right-tailed behaviour for non-household electricity prices (x2), consistent with crisis-driven price spikes.*

The Shapiro–Wilk normality tests reject the null of normality for all variables at conventional significance levels ($p < 0.001$). The strongest deviation from normality is observed for the non-household electricity price component (x2), where the test statistic $W = 0.395$ and $p < 0.001$, confirming extreme right-skewness and heavy tails previously indicated by descriptive statistics (skewness = 8.84; kurtosis = 97.34). The household price component (x1) and renewables share (x3) also exhibit statistically significant departures from normality (W = 0.884 and 0.810, respectively), reflecting right-skewed distributions. Although the MSI pentagon index (y) displays only moderate skewness, normality is still formally rejected (W = 0.958; p < 0.001), as expected in moderately large samples (n = 174), where even minor deviations lead to rejection.

The results confirm that key explanatory variables, particularly non-household electricity prices, exhibit non-normal and heavy-tailed behaviour consistent with crisis-period price spikes. However, since the empirical analysis relies on fixed-effects panel estimators with robust (Driscoll–Kraay and two-way clustered) standard errors, normality of the regressors is not required. The findings, therefore, motivate the use of log-transformations and robust inference rather than classical normality-based estimation procedures. After applying log transformations, the distributional properties of the key regressors improve markedly relative to the raw variables. The transformations meaningfully mitigate extreme skewness and heavy tails, particularly for electricity price components, supporting the use of log-based specifications and robust inference in the subsequent panel estimations.

The baseline two-way fixed-effects model (*Table 2*) provides evidence that within-country increases in non-household electricity prices are associated with a deterioration in macroeconomic stability. Controlling for unobserved, time-invariant country characteristics and common year shocks, the coefficient on the non-household electricity price change (log-difference) is negative and statistically significant at the 5% level (β = −0.0400; SE = 0.0193; p = 0.047). Substantively, this implies that, when a country experiences a rise in business electricity prices relative to the previous year, its MSI pentagon index tends to decline. Although the overall fit is high due to the inclusion of fixed effects ($R^2 = 0.661$), the within-country explanatory power attributable to the electricity price shock alone is modest (Within $R^2 = 0.014$), which is typical in short macro panels where much of the variation is absorbed by country and year effects.

Table 2. Baseline two-way fixed-effects estimates: non-household electricity price change and MSI

Variable	Coefficient	Std. Error (clustered by country)	t-stat	p-value
Non-household electricity price change (d_lpn)	−0.0400	0.0193	−2.073	0.047*

Note: *Fixed effects – Country and year. Observations – 145 (29 countries × 5 annual changes). $R^2 = 0.6606$; Within $R^2 = 0.0140$; Significance code: * $p < 0.05$. The dependent variable is the MSI pentagon index.*

Extending the specification (*Table 3*) to test whether renewable energy penetration buffers the adverse association yields suggestive but statistically weak evidence in the baseline (constant-slope) moderation framework. When the renewables share is included (centred at its sample mean) and interacted with the non-household price change, the estimated direct effect of the price shock remains negative (β = −0.0467; SE = 0.0237; p = 0.059), while the interaction term is positive (β = 0.1302; SE = 0.1112; p = 0.252). The positive interaction coefficient is directionally consistent with a buffering interpretation, i.e., higher renewables penetration reduces the negative association between business electricity price increases and macroeconomic stability. Still, the estimate lacks statistical precision in the pooled moderation model. Notably, the within R^2 increases from 0.014 to 0.032 when adding renewables and the interaction, indicating improved within-country explanatory power. Still, the results suggest that moderation may be crisis-period specific and better captured by year-heterogeneous effects.

Table 3. Two-way fixed-effects moderation model: renewables share as a buffer

Variable	Coefficient	Std. Error (clustered by country)	t-stat	p-value
Non-household electricity price change (d_lpn)	−0.0467	0.0237	−1.969	0.059.
Renewables share (centred), re_c	0.6137	0.6229	0.985	0.333
d_lpn × re_c	0.1302	0.1112	1.171	0.252

Note: *Fixed effects – Country and year. Observations – 145.* $R^2 = 0.6669$*. Within* $R^2 = 0.0321$*. Significance code: .* $p < 0.10$*. Cluster-robust standard errors at the country level. re_c denotes the renewables share centred on the sample mean.*

The crisis-aware two-way fixed-effects specification (*Table 4*) reveals strong time heterogeneity in how non-household electricity price changes relate to macroeconomic stability. It indicates that the buffering role of renewables is also time-contingent. After controlling for unobserved country characteristics and common year shocks, the centred renewables share (re_c) does not exhibit a statistically meaningful direct association with MSI ($\beta = 0.034$; SE = 0.571), which is expected because year fixed effects absorb common energy-transition and crisis dynamics, and the remaining within-country variation in renewable shares is comparatively gradual. By contrast, the year-specific slope terms for non-household electricity price changes show that the within-country association differs markedly across years relative to the 2021 baseline. Under conservative inference, the 2023 slope shift is negative and statistically significant ($\beta = -0.0838$; SE = 0.0165, with two-way clustering; $p < 0.01$), implying that in 2023, price increases for business consumers were associated with a discernible deterioration in MSI beyond what is captured by common-year effects. The 2024 coefficient is negative and becomes statistically significant under Driscoll–Kraay and two-way clustered standard errors ($\beta = -0.3328$; SE = 0.1117 with two-way clustering; $p < 0.05$), whereas 2022 is close to zero in this reference-year framework. The within R^2 rises substantially to 0.123, indicating that allowing crisis-year heterogeneity captures meaningful within-country dynamics which a constant-slope model obscures.

The interaction terms between price changes and renewables further suggest that renewable penetration moderates the price–stability relationship in a year-dependent manner. The 2020 interaction is negative and significant ($\beta = -1.172$; SE = 0.364; $p < 0.05$), indicating that in that year, higher renewables were associated with a stronger adverse relationship between price shocks and MSI, whereas the 2022 interaction is positive ($\beta = 0.4685$) and consistent with buffering during the energy-crisis period, albeit individually imprecise.

Importantly, joint tests (*Table 5*) confirm that crisis-period slope shifts in the electricity price variable are highly significant ($\chi^2 = 30.576$; $p < 0.001$ for 2022–2024), and that the set of moderation terms for 2022–2024 is jointly significant at the 5% level ($\chi^2 = 8.603$; $p = 0.035$). Together, these results support the conclusion that (i) the macro-stability implications of business electricity price changes are not constant over time, and (ii) renewables penetration plays a statistically detectable, though heterogeneous, buffering role across the crisis years, which is most transparently communicated via marginal effects at low versus high renewables shares.

Table 4. Crisis-aware two-way fixed-effects model: year-heterogeneous electricity price effects and renewables moderation

Variable	Clustered by country (SE)	DK (L=1) (SE)	Two-way cluster (country & year) (SE)
Renewables share (centred), re_c	0.0344 (0.5707)	0.0344 (0.5362)	0.0344 (0.5921)
d_lpn × year = 2020	0.4587 (0.2594)	0.4587** (0.0971)	0.4587 (0.1656)
d_lpn × year = 2022	−0.0006 (0.0392)	−0.0006 (0.0073)	−0.0006 (0.0256)
d_lpn × year = 2023	−0.0838** (0.0256)	−0.0838** (0.0138)	−0.0838** (0.0165)
d_lpn × year = 2024	−0.3328 (0.2092)	−0.3328*** (0.0266)	−0.3328* (0.1117)
(d_lpn×re_c) × year = 2020	−1.172* (0.5518)	−1.172* (0.2911)	−1.172* (0.3635)
(d_lpn×re_c) × year = 2022	0.4685 (0.2687)	0.4685 (0.1698)	0.4685 (0.2049)
(d_lpn×re_c) × year = 2023	0.0756 (0.1973)	0.0756 (0.2092)	0.0756 (0.1967)
(d_lpn×re_c) × year = 2024	−0.3600 (0.5461)	−0.3600 (0.4409)	−0.3600 (0.4296)

Note: *Fixed effects – country and year. Observations – 145. $R^2 = 0.6982$. Within $R^2 = 0.1233$. The dependent variable is MSI (pentagon index). d_lpn is the log-change in non-household electricity price components. re_c is the renewables share (0–1) centred on its sample mean. Standard errors: (i) clustered by country, (ii) Driscoll–Kraay (L=1), and (iii) two-way clustering by country and year. Significance codes: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.*

Table 5. Joint tests of crisis-period slope shifts and renewables moderation (two-way clustered inference)

Hypothesis block (2022–2024)	χ^2	df	p-value
Year-specific price-shock slopes: d_lpn	30.576	3	<0.001***
Year-specific moderation terms: d_lpn × re_c	8.603	3	0.0351*

Notes: *Wald-type tests computed with the covariance matrix from the two-way clustered model. The null hypothesis in each block is that all listed coefficients are jointly equal to zero.*

The marginal-effect estimates (*Table 6*) demonstrate that the macroeconomic response to non-household electricity price changes is strongly conditioned by renewable energy penetration, especially during the early crisis phase. In 2022, the implied marginal effect of a business electricity price increase on MSI is significantly negative in low-renewables countries (ME = −0.056; 95% CI: −0.110 to −0.002), whereas it becomes statistically indistinguishable from zero in high-renewables countries (ME = +0.029; 95% CI: −0.036 to +0.093). This pattern indicates substantial buffering: higher renewable penetration largely neutralised the adverse association between non-household electricity price shocks and macroeconomic stability during 2022. In 2023, the marginal effects remain negative and statistically significant at both levels of renewables. However, the magnitude is slightly less adverse at higher renewables shares (−0.093 vs −0.079), suggesting weaker attenuation than in 2022 rather than full insulation. By 2024, the implied effects are strongly negative regardless of renewables penetration (Low RE: –0.290; High RE: –0.355), with both confidence intervals fully below zero, indicating that macroeconomic stability deteriorated alongside increases in business electricity prices, even in high-renewables settings. The results support a crisis-year interpretation in which renewables provided a meaningful short-run cushion in 2022. However, the stabilising effect diminished in subsequent years as macroeconomic adjustment pressures persisted.

Table 6. Marginal effects of non-household electricity price changes on MSI at low vs high renewable penetration (25th vs 75th percentile)

Year	Renewables level	Marginal effect (ME)	Std. Error	95% CI (lower)	95% CI (upper)
2022	Low (25%)	−0.0561	0.0274	−0.1099	−0.0023
2022	High (75%)	0.0288	0.0329	−0.0356	0.0932
2023	Low (25%)	−0.0928	0.0302	−0.1520	−0.0336
2023	High (75%)	−0.0791	0.0194	−0.1171	−0.0411
2024	Low (25%)	−0.2902	0.1259	−0.5368	−0.0435
2024	High (75%)	−0.3554	0.1132	−0.5772	−0.1336

Note: *Marginal effects are computed from the crisis-aware two-way fixed-effects model with year-specific slopes (reference year 2021). "Low" and "High" renewables correspond to the 25th and 75th percentiles of the distribution of renewable energy shares (converted to a 0–1 scale and centred in the regression). Confidence intervals are computed using the delta method based on the model's robust covariance matrix (two-way clustered by country and year, unless stated otherwise).*

Figure 1 visualises the marginal effect of non-household electricity price changes on the MSI at low (25th percentile) and high (75th percentile) levels of renewable energy penetration, estimated from the crisis-aware two-way fixed-effects model. The results clearly demonstrate that the macroeconomic impact of electricity price shocks differs across both time and renewable energy intensity.

In 2022, the marginal effect of business electricity price increases is statistically negative in low-renewables countries, while it becomes statistically insignificant in high-renewables countries. This pattern indicates a meaningful buffering role of renewable energy penetration during the initial phase of the energy crisis: higher shares of renewables mitigated the adverse macroeconomic consequences of electricity price spikes. In contrast, in 2023, the marginal effects are negative and statistically significant across both low- and high-renewables countries. However, the magnitude remains slightly more adverse in economies with lower renewable penetration. This suggests that while renewables provided short-term cushioning in 2022, the stabilising effect weakened as crisis pressures persisted into 2023.

The consistency of the patterns across both Driscoll–Kraay and two-way clustered standard errors reinforces the robustness of the findings. *Figure 1* provides visual confirmation that renewable energy penetration attenuated the macroeconomic impact of electricity price shocks during the peak of the crisis, supporting the hypothesis that energy transition contributes to macroeconomic resilience, particularly in the early stages of systemic energy disruptions.

To assess economic relevance, the estimated coefficients can be translated into quantitative effects on the MSI. Because electricity price changes are measured in log differences, a 10% increase in non-household electricity prices corresponds approximately to a 0.10 change in the regressor. Using the marginal effect estimates in *Table 6*, a 10% price increase in 2023 implies a decline in MSI of approximately 0.009–0.010 points in low-renewables countries ($0.10 \times -0.093 \approx -0.0093$). Given that the standard deviation of MSI in the sample equals 0.23 (*Table 1*), this corresponds to roughly 4% of one standard deviation. In 2024, the implied effect becomes substantially larger ($0.10 \times -0.29 \approx -0.029$), equivalent to approximately 13% of one MSI standard deviation. These magnitudes indicate that electricity price shocks during the crisis period were not only statistically significant but also economically meaningful, particularly in later crisis stages and in countries with lower renewable penetration.

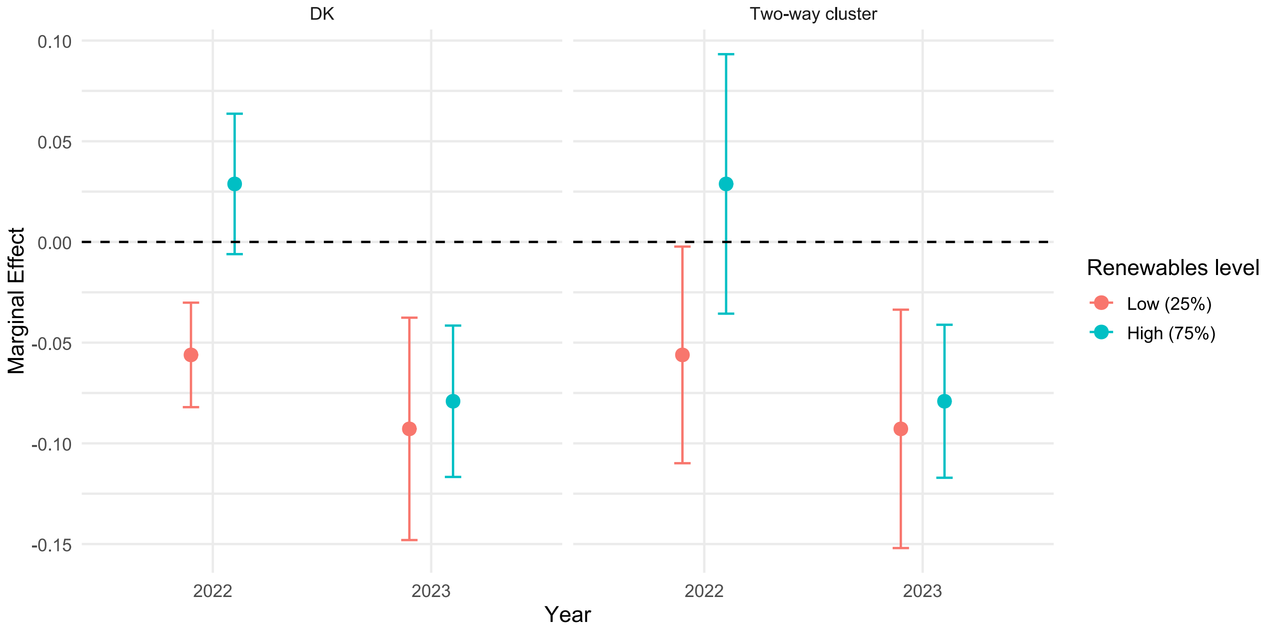

Figure 1. Marginal Effects of Non-Household Electricity Price Changes on Macroeconomic Stability at Low and High Renewable Energy Penetration (2022–2023)

The robustness specification using household electricity price changes (*Table 7*) confirms that non-household (business) electricity prices primarily drive the macroeconomic stability effects identified in the baseline. In the business-price model (m_crisis), the 2023 year-specific slope is negative. Statistically significant ($\beta = -0.0838$, $p < 0.01$), and the 2024 coefficient is economically large and negative, with significance depending on the earlier covariance estimator. By contrast, in the household-price model (m_crisis_hh), none of the year-specific coefficients for d_lph reaches statistical significance under two-way clustered standard errors. The magnitudes are also smaller in absolute terms, particularly in 2022 and 2023. This indicates that macroeconomic stability reacts more pronouncedly to electricity price movements affecting firms than to those affecting households.

The moderation terms further reinforce this conclusion. In the business-price model, the interaction between price changes and renewable penetration (dlpn_re) shows evidence of buffering in crisis years (particularly in 2020 and partially in 2022), and the full crisis-period block was previously shown to be jointly significant. In contrast, the corresponding interaction terms for household prices (dlph_re) are statistically insignificant across all years, suggesting that renewable energy penetration does not meaningfully alter the transmission of household electricity price shocks to macroeconomic stability. Economically, this pattern is consistent with a cost-channel mechanism: increases in non-household electricity prices affect production costs, inflation dynamics, and fiscal balances more directly than household tariffs, which are often regulated and partially shielded. The higher within R^2 of the business-price model (0.123 vs 0.053) further indicates that firm-level electricity cost shocks explain substantially more within-country variation in MSI during the crisis period. Finally, *Table 7* confirms that the macro-stability channel operates predominantly through business electricity prices rather than household tariffs.

Regarding the technical notes, the removal of 29 observations reflects the expected loss of the first country-year observation due to lag construction. The warning about the variance–covariance matrix being "not positive semi-definite and fixed" is common in small T panels with two-way clustering and does not affect coefficient estimates; it only indicates a numerical adjustment in the covariance matrix.

Table 7. Crisis-Year Electricity Price Effects on MSI: Business vs Household Consumers (Two-Way Fixed Effects)

Variable	Business Prices (Non-household)	Household Prices
Renewables share (centred), re_c	0.0344 (0.5707)	0.1733 (0.6146)
Price change × 2020	0.4587 (0.2594)	0.1455 (0.2207)
Price change × 2022	−0.0006 (0.0392)	0.1193 (0.0785)
Price change × 2023	−0.0838** (0.0256)	−0.0676 (0.0697)
Price change × 2024	−0.3328 (0.2092)	−0.0905 (0.1261)
(Price × Renewables) × 2020	−1.172* (0.5518)	−0.7943 (0.5309)
(Price × Renewables) × 2022	0.4685 (0.2687)	0.3191 (0.3569)
(Price × Renewables) × 2023	0.0756 (0.1973)	0.1353 (0.3341)
(Price × Renewables) × 2024	−0.3600 (0.5461)	−0.6107 (0.7485)

Notes: *Fixed effects – Country and Year. Observations – 145. $R^2 = 0.698$ (Business) | 0.674 (Household). Within $R^2 = 0.123$ (Business) | 0.053 (Household). Standard errors – Two-way clustered by country and year. The dependent variable is the Macroeconomic Stability Index (MSI). Price changes are log differences of electricity price components. Renewables' share is centred. Significance levels: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.*

The additional robustness checks largely reinforce the core conclusion that non-household electricity price shocks are associated with weaker macroeconomic stability during the crisis period, while also clarifying the temporal nature of this relationship. In the main crisis-aware TWFE model (two-way clustered by country and year), the contemporaneous non-household price effect is negative and statistically significant in 2023 ($\beta = -0.0838$, $p < 0.01$) and 2024 ($\beta = -0.3328$, $p < 0.05$). In contrast, the 2022 coefficient is close to zero. Excluding 2020 (to remove potential COVID-driven confounding) leaves the 2023 estimate virtually unchanged ($\beta = -0.0891$, $p < 0.05$) and preserves the negative 2024 effect ($\beta = -0.3379$). Similarly, excluding 2024 does not alter the inference for 2023 ($\beta = -0.0846$, $p < 0.05$). These stability checks indicate that the adverse association is not an artefact of a single anomalous year; instead, the negative price–MSI link is most consistently detectable in 2023 and is further amplified when 2024 is included.

The endogeneity-oriented robustness test based on lagged price changes yields a different pattern: none of the lagged-shock coefficients (2022–2024) is statistically significant, and the signs are mixed (negative in 2022 but positive in 2023–2024). This suggests that the destabilising effect operates primarily through contemporaneous channels, consistent with rapid transmission of energy-cost shocks into inflation, output, and fiscal stress, rather than through delayed responses. Put differently, the results are less consistent with a slow-moving reverse-causality story and more consistent with short-run shock propagation. Finally, winsorising the electricity price shock at the 1st/99th percentiles confirms that extreme outliers do not drive the core findings: the negative effects in 2023 and 2024 remain statistically significant ($\beta = -0.1033$, $p < 0.05$; $\beta = -0.3200$, $p < 0.05$), and the interaction terms retain similar magnitudes and signs. *Table 8* shows that the main conclusions are robust to removing potentially confounding crisis years and to trimming extremes, while the lag specification indicates that the relationship is predominantly contemporaneous.

Table 8. Robustness checks: endogeneity and sample sensitivity (two-way fixed effects)

Variable	Main crisis model	Lagged shock model	Drop 2020	Drop 2024	Winsorised shock
re_c	0.0344 (0.5921)	−0.7553 (0.5570)	−0.7166 (0.4367)	0.5599 (0.6924)	0.0019 (0.5944)
Price change × 2022	−0.0006 (0.0256)	−0.1241 (0.0966)	−0.0043 (0.0383)	0.0015 (0.0313)	−0.0638 (0.0700)
Price change × 2023	−0.0838** (0.0165)	0.0338 (0.0361)	−0.0891* (0.0155)	−0.0846* (0.0202)	−0.1033* (0.0281)
Price change × 2024	−0.3328* (0.1117)	0.0639 (0.0313)	−0.3379 (0.1146)	–	−0.3200* (0.1144)
(Price × RE) × 2022	0.4685 (0.2049)	0.3400 (0.1802)	0.3977 (0.2101)	0.3932 (0.1878)	0.4174 (0.2072)
(Price × RE) × 2023	0.0756 (0.1967)	−0.1558 (0.1957)	0.2379 (0.1721)	0.1612 (0.1785)	0.1155 (0.2125)
(Price × RE) × 2024	−0.3600 (0.4296)	0.1178 (0.1960)	−0.1302 (0.4823)	–	−0.3434 (0.4412)
Price change × 2020	0.4587 (0.1656)	–	–	0.4050 (0.2079)	0.4505 (0.1625)
(Price × RE) × 2020	−1.172* (0.3635)	–	–	−0.9945 (0.4119)	−1.166* (0.3637)
Observations	145	116	116	116	145
R^2	0.698	0.748	0.764	0.667	0.700
Within R^2	0.123	0.057	0.118	0.117	0.128

Note: *Dependent variable – MSI (pentagon index). Fixed effects – Country and year. Standard errors – Two-way clustered (country & year). “Price change” denotes the log-difference in non-household electricity price components (d_lpn). The lagged model uses d_lpn_l1. Winsorisation trims d_lpn at the 1st and 99th percentiles. The lower number of observations (116 vs 145) in selected specifications reflects sample restrictions arising from lagging the shock variable and the exclusion of specific years (e.g., 2020 or 2024), which mechanically reduces the available panel observations. Significance codes:* $***\ p < 0.001$, $**\ p < 0.01$, $*\ p < 0.05$. *Dashes (–) indicate coefficients not estimated because the year is excluded from the sample.*

The placebo specification (*Table 9*, with 2019 as the reference year) provides a useful falsification check on the crisis narrative by examining whether a similar “buffering” pattern appears in 2020, before the main energy-price shock period. In the placebo model, the direct renewables term remains statistically insignificant (re_c = −0.053, SE = 0.586), while the 2020 slope component for non-household electricity price changes is positive (d_lpn×2020 = 0.421, SE = 0.172). The corresponding interaction term between the price change and renewables is negative and statistically significant (dlpn_re×2020 = −1.291, SE = 0.367). Together, these coefficients imply that in 2020, higher renewable penetration is associated with a stronger, not weaker, relationship between electricity price changes and MSI, which is qualitatively different from the intended crisis-buffering mechanism documented for 2022.

This difference becomes clearer when translating the coefficients into marginal effects at low and high levels of renewable penetration. The placebo marginal effects for 2020 are positive and statistically significant at both levels of renewables, with a larger impact in low-renewables countries (ME = 0.573; 95% CI: 0.154 to 0.993) than in high-renewables countries (ME = 0.339; 95% CI: 0.045 to 0.634). Thus, unlike the crisis-period results, where price increases were associated with deteriorating macroeconomic stability and renewables partially mitigated this adverse association, the 2020 placebo indicates a distinct pre-crisis pattern in which price changes correlate with improvements in MSI, and higher renewables are linked to a weaker positive association. In other words, the placebo does not replicate the core crisis finding (negative price effects buffered by renewables), supporting the interpretation that the main results are crisis-specific rather than a mechanical artefact of the model structure. However, it also indicates that the price–stability relationship can change sign across macroeconomic regimes.

Table 9. Placebo test (2020 as placebo year): year-heterogeneous slopes and marginal effects at low vs high renewables

Placebo regression results (reference year = 2019; two-way FE; two-way clustered SEs)

Variable	Coefficient	Std. Error
re_c	−0.0531	0.5864
d_lpn × year = 2020	0.4205	0.1720
d_lpn × year = 2021	0.0496	0.0739
d_lpn × year = 2022	0.0045	0.0283
d_lpn × year = 2023	−0.0957*	0.0265
d_lpn × year = 2024	-0.2877	0.1232
dlpn_re × year = 2020	−1.291*	0.3670
dlpn_re × year = 2021	0.2039	0.1252
dlpn_re × year = 2022	0.6450*	0.2102
dlpn_re × year = 2023	−0.2049	0.1431
dlpn_re × year = 2024	−0.7583	0.3811

Placebo marginal effects in 2020 at low vs high renewable penetration (25th vs 75th percentile)

Year	Renewables level	Marginal effect (ME)	Std. Error	95% CI (lower)	95% CI (upper)
2020	Low (25%)	0.5734	0.2141	0.1538	0.9931
2020	High (75%)	0.3394	0.1501	0.0453	0.6335

Note: *Fixed effects – country and year. Observations – 145.* $R^2 = 0.7015$. *Within* $R^2 = 0.1329$. *Standard errors – two-way clustered by country and year. Marginal effects computed as* $ME = \beta_{2020,d\_lpn} + r_c \cdot \beta_{2020,dlpn\_re}$, *where* r_c *denotes centred renewable penetration evaluated at the 25th and 75th percentiles of the renewables distribution. Confidence intervals are calculated using the delta method and the model's two-way clustered covariance matrix. Significance codes: **** $p < 0.001$, **** $p < 0.01$, *** $p < 0.05$

3.2. Discussion

The empirical findings of this study confirm and extend the emerging literature that interprets the 2022 energy crisis as a systemic macroeconomic shock rather than a purely sectoral disturbance. The statistically significant negative association between non-household electricity price increases and macroeconomic stability in 2023 and 2024 is consistent with evidence that war-driven energy disruptions amplified inflationary and output pressures across Europe (Adolfsen et al., 2022; Sun et al., 2024; Rojas-Romagosa, 2024). The magnitude of the estimated effects, particularly the economically substantial MSI decline in 2024, aligns with research documenting strong cost-channel transmission of energy expenditures into CPI inflation and broader macroeconomic imbalances (Chowdhury & Dixon, 2025; Vasylieva et al., 2025a). Earlier studies on energy supply shocks also highlighted significant output and stability consequences under external energy disruptions (Quan Chu & Grais, 1996; Zhang, 2013), and the present findings provide contemporary European evidence within a multidimensional macroeconomic stability framework.

The dominant role of non-household electricity prices in explaining macroeconomic instability supports the cost-channel interpretation emphasised in both inflation and business-cycle research. Various studies have shown that commodity and energy price fluctuations interact with macroeconomic cycles and may produce nonlinear growth responses (e.g., Ginn, 2023; Hadji & Ben Abderrahmane, 2024; Bouguerroumi & Belarbi, 2025; Almoree & Almosabbeh, 2026; Thach, 2025). The finding that business electricity prices, rather than household tariffs, drive deterioration in macro-stability reinforces this mechanism, as firms directly transmit energy-cost shocks into production costs, inflation dynamics, and fiscal balances. This pattern also aligns with fiscal-sustainability concerns under crisis conditions (Auclert et al., 2023; Tkacova et al., 2025; Qian et al., 2026) and broader evidence that external shocks interact with structural and institutional conditions to shape macroeconomic outcomes (Abou Saad & Sági, 2025; Jabiyev et al., 2025).

The crisis-year heterogeneity identified in this study contributes to the literature on renewable energy as a resilience factor. The short-run buffering effect observed in 2022, where high-renewables countries avoided statistically significant MSI deterioration, supports arguments linking renewable penetration to enhanced energy security and reduced exposure to imported fossil-fuel volatility (Havrylenko & Myroshnychenko, 2025; Vasa et al., 2024; Khan et al., 2023). This finding is also consistent with transition-oriented research emphasising the macroeconomic and competitiveness co-benefits of green investment (Popescu et al., 2025; Zábojník & Branch, 2025) and the structural importance of renewable capacity for sustainable development outcomes (Americo et al., 2024; Dilanchiev et al., 2024; Karimboev et al., 2025; Raman et al., 2025). However, the weakening of the buffering effect in 2023 and its disappearance in 2024 suggest that renewable penetration alone cannot fully offset prolonged systemic cost pressures. This nuance refines prior literature that often treats renewables as uniformly stabilising, highlighting instead that their macroeconomic cushioning capacity may be strongest during the initial phase of external energy shocks.

Finally, the placebo results reinforce the crisis-specific interpretation of the findings and resonate with studies emphasising regime shifts under geopolitical stress. The absence of a similar buffering pattern in 2020, and the sign reversal of price–stability associations in the pre-crisis period, indicate that the macroeconomic consequences of electricity price changes depend on the broader institutional and geopolitical environment (Koilo, 2024; Slyusarevskyy & Chunikhina, 2025; Whitt & Page, 2025). This supports the view that macroeconomic stability is a multidimensional socio-economic construct shaped by behavioural responses, institutional trust, and resilience capacity (Brychko et al., 2025; Lyeonov et al., 2024a; George & Mattathil, 2025). The study advances the literature by empirically demonstrating that renewable energy penetration conditions the macroeconomic impact of electricity price shocks in a time-heterogeneous crisis framework, thereby integrating energy-market dynamics with macroeconomic stability analysis under conditions of geopolitical disruption.

This study has several limitations that should be acknowledged. First, the relatively short time span of the panel (2019–2024) limits the ability to identify long-run dynamic effects and to apply more advanced dynamic panel estimators. Second, although the two-way fixed-effects framework with robust inference mitigates concerns related to unobserved heterogeneity and cross-sectional dependence, the empirical design captures crisis-specific associations rather than fully structural causal effects. Third, electricity price changes are treated as aggregate national indicators and do not account for intra-country heterogeneity in market regulation, contract structures, or sectoral exposure. Finally, the MSI, while comprehensive, remains a composite measure that may mask heterogeneous adjustments across its individual components during crisis periods. Future research could extend the time horizon to assess longer-term adjustment dynamics and incorporate structural identification strategies to strengthen causal inference. Further studies may also explore sector-level transmission channels, integrate firm-level data, or examine how institutional quality and energy market regulation interact with renewable penetration to shape macroeconomic resilience.

Conclusion

This study aimed to investigate how electricity price shocks and energy policy structures influence macroeconomic stability across European countries, with particular attention to cross-country heterogeneity and the structural break induced by the 2022 energy crisis.

Using a balanced panel of 29 European countries over 2019–2024 (174 observations), the analysis employed two-way fixed-effects models with country and year effects, heterogeneous-slope specifications for crisis years, and interaction terms to assess the moderating role of renewable energy penetration. Inference relied primarily on two-way clustered standard errors, complemented by Driscoll–Kraay corrections, marginal-effect calculations, placebo tests, lag specifications, and winsorisation procedures to ensure robustness.

The results demonstrate that increases in non-household (business) electricity prices are systematically associated with deteriorations in macroeconomic stability, particularly during the crisis years. In the baseline model, a rise in non-household electricity prices is associated with a statistically significant decline in MSI ($\beta = -0.040$, $p < 0.05$). Crisis-aware specifications reveal strong temporal heterogeneity: the negative effect is statistically significant in 2023 ($\beta = -0.084$, $p < 0.01$) and economically large in 2024 ($\beta = -0.333$, $p < 0.05$ under two-way clustering). Marginal-effect estimates indicate that in 2022, a 10% increase in business electricity prices reduced the MSI by approximately 0.006 points in low-renewables countries, while the effect became statistically indistinguishable from zero in high-renewables countries, demonstrating meaningful short-run buffering. In 2023, the same 10% increase implied a decline of roughly 0.009–0.010 MSI points (around 4% of one standard deviation). In 2024, the implied decline reached approximately 0.029 points (about 13% of one MSI standard deviation), indicating economically substantial destabilisation. Joint Wald tests confirm that crisis-period slope shifts ($\chi^2 = 30.576$, $p < 0.001$) and renewable moderation effects ($\chi^2 = 8.603$, $p = 0.035$) are statistically significant. Importantly, the results are robust to excluding pandemic years, trimming extreme values, and alternative inference procedures, while lag specifications suggest that the transmission mechanism is predominantly contemporaneous rather than delayed.

From a policy perspective, the findings imply that macroeconomic stability in Europe is highly sensitive to business electricity cost shocks, particularly during systemic energy disruptions. Energy-transition policies that expand renewable energy penetration appear to enhance short-term macroeconomic resilience by attenuating the immediate destabilising effects of electricity price spikes, especially in the early phase of crises. However, the buffering effect diminishes over time if structural cost pressures persist, indicating that renewables alone cannot fully shield economies from prolonged energy-market turbulence. Therefore, policy strategies should combine accelerated renewable deployment with complementary measures such as diversification of energy supply, targeted industrial cost-stabilisation mechanisms, and structural reforms that reduce energy intensity in production. More broadly, integrating energy-transition policy with macroeconomic stabilisation frameworks can strengthen systemic resilience and reduce vulnerability to external energy shocks in future crisis episodes.

Acknowledgement

This project has received funding through the MSCA4Ukraine project 06030419, which the European Union funds. Views and opinions expressed are, however, those of the author(s) only and do not necessarily reflect those of the European Union, the European Research Executive Agency or the MSCA4Ukraine Consortium. Neither the European Union, the European Research Executive Agency, nor the MSCA4Ukraine Consortium, nor any individual member institution of the MSCA4Ukraine Consortium can be held responsible for them.

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