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Dynamic inflation responses to war-related electricity shocks: DTW-based evidence from European energy and renewables regimes

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Abstract. Russia's invasion of Ukraine turned wholesale electricity prices into a major, but uneven, driver of inflation across Europe. The article aims to quantify dynamic inflation responses to war-related electricity shocks and to identify distinct energy–inflation regimes conditioned by renewables penetration and structural characteristics. The analysis uses a balanced monthly panel of 26 European countries (2019–2025), combining two-way fixed-effects regressions with event-time "excess" inflation profiles and correlation- and clustering based on Dynamic Time Warping. Early-phase excess inflation around February 2022 ranges from about 0.53 percentage points (cluster 6) to 1.06 percentage points (cluster 3), with clusters 1 and 5 also showing strong overshoots (≈0.94–0.91), while only clusters 1 and 3 sustain elevated excess inflation in the medium phase (≈0.71–0.76) and all regimes converge to within –0.07 to +0.16 by the late phase. DTW clustering reveals six regimes with distinct pre-war configurations of electricity prices (approximately 49–59 EUR/MWh), renewable energy shares (approximately 24–55%), and unemployment rates (approximately 4.45–8.59%). A heterogeneous-slope FE model shows that a 100 EUR/MWh electricity shock raises the monthly HICP by only 0.03 percentage points in cluster 3 and 0.09 in cluster 5. In contrast, the effects in other clusters are small and statistically insignificant, confirming a highly uneven and often muted pass-through.

Keywords: dynamic inflation responses, electricity price shocks, Dynamic Time Warping, renewable energy share, European energy–inflation regimes.

JEL Classification: E31, Q41, Q42, Q48, C38

1. INTRODUCTION

The research question addressed is highly topical because it consists of one of the core macro-financial questions raised by the 2022–2023 European energy crisis: how far, and how unevenly, war-related electricity price shocks are transmitted into consumer inflation across countries with different energy and renewable structures. The European Commission's report on "Energy prices and costs in Europe" documents that wholesale gas and electricity prices rose to historic highs in 2022, before easing only gradually in 2023, and that even after this correction, they remain well above pre-crisis levels (European Commission, 2025b). The Commission explicitly links this spike to Russia's invasion of Ukraine and to the use of energy as a geopolitical instrument, noting that coordinated EU measures and the REPowerEU plan were required to secure supply and stabilise markets (European Parliament, 2023).

From a macroeconomic perspective, analyses by the IMF and ECB indicate that energy prices were a key driver of the post-pandemic inflation surge. IMF staff estimate that import price shocks, especially for gas, accounted for a large share of the 2022–2023 increase in the euro-area consumption deflator, emphasising the role of energy in pushing headline inflation to multi-decade highs (Hansen et al., 2023). ECB and academic work on gas price pass-through similarly conclude that the spike in European gas prices following the invasion was a key factor behind the inflation peak in late 2022, with the intensity of pass-through depending on national market structures and policy responses (López et al., 2024). At the same time, Eurostat data show that electricity and gas bills for households reached record levels in 2022 and remain elevated, despite recent declines, with large cross-country differences driven by network costs, tax changes, and the withdrawal of temporary support measures (European Commission, 2023).

The combination of extreme price volatility, strong yet heterogeneous inflation pressures, and an accelerated clean-energy transition under REPowerEU has profoundly altered Europe's energy–inflation landscape. While policy reports acknowledge that the impact of the energy shock varies across member states, reflecting differences in import dependence, renewable energy penetration, regulation and the scale of fiscal support, there is still limited empirical evidence on how these structural factors shape the dynamic response of inflation to electricity price shocks. However, these contributions largely rely on comparative statics and average pass-through estimates rather than dynamic, country-specific reaction profiles (European Commission, 2025a). By constructing high-frequency "war-excess" inflation paths, clustering countries into distinct energy–inflation regimes, and quantifying heterogeneous electricity price pass-through conditional on those regimes, this study directly responds to the needs identified in European Commission, IMF and ECB assessments: to understand not just how big the energy-inflation shock was on average, but why the inflation response to electricity price spikes differed so sharply across European economies, and what the respective insights imply for the design of future energy-market interventions, renewables policies and macroeconomic stabilisation frameworks.

Against this backdrop, there is a clear need for empirical work that combines high-frequency inflation data, granular energy variables and modern time-series clustering to move beyond average pass-through estimates and uncover distinct national reaction regimes. This study responds to that need by constructing event-time "war-excess" inflation profiles for 26 European countries, grouping them into energy–inflation regimes using correlation- and DTW-based clustering, and estimating heterogeneous electricity price pass-through within a two-way fixed-effects framework. In doing so, it links the dynamics of inflation during the Russia–Ukraine war to underlying energy mixes, renewables penetration and cost-push pressures, thereby providing an evidence base for calibrating future energy-market interventions, renewables policies and macroeconomic stabilisation strategies in a Europe that must simultaneously manage geopolitical risk, inflation control and the clean energy transition.

2. LITERATURE REVIEW

Research on energy price shocks and inflation has a long lineage, establishing that large changes in energy costs can propagate through production structures, labour markets and expectations to generate sizeable macroeconomic effects. Early contributions on energy demand elasticities and macroeconomic performance documented how oil and energy price shocks alter output, inflation and real income, often with asymmetric and state-dependent impacts (Bohi, 1981, 1989, 1991; Kilian, 2008; Thoresen, 1983). Historical analyses of government performance in energy regulation underscored the importance of market design, price controls and institutional credibility for the transmission of energy shocks (Mead, 1979; Quan Chu & Grais, 1996). Later work on energy cost pass-through in manufacturing provided micro-founded evidence that the incidence of higher energy costs depends on sectoral competition, technology and international trade exposure, anticipating current debates on carbon pricing and energy taxes (Ganapati et al., 2020).

More recent literature revisits these questions in the context of the post-pandemic inflation episode and the Russia–Ukraine war. Evidence from advanced economies indicates that changes in retail energy prices elicit sizable but heterogeneous responses in headline inflation, with long-lasting effects when shocks are large, and expectations are weakly anchored (Abdallah & Kpodar, 2023; Chowdhury & Dixon, 2025; Corsello & Tagliabracci, 2023; Vasylieva et al., 2025). Studies for the euro area and individual EU members indicate that the 2022–2023 energy crisis significantly raised inflation above levels implied by conventional Phillips-curve determinants, highlighting strong contributions from import prices, mark-ups, and energy-related taxes (Gradzewicz et al., 2024; Budova et al., 2023). Analyses focusing explicitly on the war in Ukraine emphasise that the shock to gas and electricity markets affected the euro area through both price and quantity channels, with pass-through patterns shaped by pre-existing contracts, storage and reliance on Russian supplies (Adolfsen et al., 2022; Aitken & Ersoy, 2023; Cui et al., 2023; Rojas-Romagosa, 2024; Sun et al., 2024). Beyond realised prices and quantities, recent work shows that news about future energy market conditions and shifts in expectations can alter the composition of renewable and fossil fuel use, and in turn influence how conflict-related energy disturbances propagate through the macroeconomy (Guinea et al., 2024; Sun et al., 2024). Broader macroeconomic assessments suggest that war-related energy shocks interact with other sources of turbulence, such as pandemic legacies, monetary tightening, and corporate leverage, to influence growth, inflation, and debt sustainability (He, 2024; Gajdosikova et al., 2025; Toth et al., 2025; Škare et al., 2023).

The distributional and social consequences of energy-driven inflation have garnered increasing attention, particularly in the context of Europe's cost-of-living crisis. Studies on the global burden of energy price increases indicate that poorer households allocate a larger share of their income to energy, and thus suffer disproportionately from welfare losses when electricity and gas prices surge (Guan et al., 2023). Public health research has linked higher energy costs and resulting fuel poverty to worsened health outcomes, mental stress, and increased mortality risks, especially when compounded by broader cost-of-living pressures (Broadbent et al., 2023; Badreddine & Larbi Cherif, 2024; Matvieieva et al., 2023). Complementary time-series evidence from low-income settings indicates that life expectancy is highly sensitive to broader socioeconomic and policy conditions over the long run, underscoring how prolonged cost-of-living and energy crises can erode hard-won health gains (Baharanyi, Mambo, & Muluma, 2024). Analyses of consumer expectations and behaviour indicate that volatile energy markets reshape energy-saving practices, demand for efficiency investments and perceived energy security, with notable country-specific patterns (Alberini et al., 2023; Dinca et al., 2025). Research on communication and political framing emphasises that support for clean energy and price interventions hinges on how policies are presented and by whom, underscoring the importance of public trust during energy crises (Diamond & Zhou, 2022; Ruiz Molina et al., 2025; Piwowarski, 2024).

A parallel strand of literature focuses on the operation and regulation of electricity markets, which is central for interpreting wholesale price shocks. Multi-country and high-frequency studies identify fundamental drivers of electricity prices, such as demand conditions, fossil fuel costs and market design features, and show that their influence is time-varying and scale-dependent across different power exchanges (Afanasyev et al., 2021; Dragasevic et al., 2021). More broadly, comparative work on deregulated electricity markets underscores the role of institutional and structural factors in shaping price dynamics and volatility (Afanasyev et al., 2021; Dragasevic et al., 2021). Empirical studies of specific day-ahead markets then document how these drivers play out in particular settings, detailing the determinants of spot prices, the role of market power and the degree of competition, often using time-series and time–frequency approaches (Bâra et al., 2023; Georgescu et al., 2025; Paraschiv et al., 2023). Work on individual national markets, such as Romania and Germany, highlights how renewable integration, interconnection capacity and bidding behaviour shape price volatility and congestion patterns, illustrating how broader fundamental relationships manifest in concrete institutional environments (Bâra et al., 2023; Paraschiv et al., 2023). Analyses for Poland and other EU members show that increasing an increasing share of renewables can both reduce average prices and alter the structure of price spikes, with implications for investment incentives and system flexibility (Bank & Badyda, 2024; Zając et al., 2023). Regulatory and policy-oriented studies emphasise that market rules, balancing arrangements, capacity mechanisms, and carbon prices collectively determine how shocks propagate through electricity systems and how credible climate policy is communicated to investors (Mulder, 2023; Sitarz et al., 2024).

Recent work increasingly leverages machine learning, hybrid time-series models and artificial intelligence to forecast electricity prices and study energy–inflation linkages. Studies on the German and Central European spot markets show that hybrid neuro-fuzzy and seasonal autoregressive models, as well as deep learning methods, can improve short-term electricity price forecasts and capture non-linearities and regime shifts (Paraschiv et al., 2023; Popławski et al., 2024; Ciuverca & Oprea, 2025). On the demand side, a growing literature analyses how households and firms adjust consumption in response to higher energy prices, information campaigns and efficiency incentives, highlighting the importance of behavioural responses and demand-side management for mitigating the impact of energy shocks (Dinca et al., 2025; Guan et al., 2023). The broader applications of advanced forecasting methods to inflation and macroeconomic variables underscore the importance of model choice and robustness when addressing structural breaks and multiple shocks (Gondauri, 2025; Janek et al., 2024; Phuc Bui et al., 2025). Studies on return dispersion, portfolio strategies and volatility add further insight into how energy-related price risks can be managed in financial and corporate decision-making (Najmudin et al., 2024; Tapang, 2023; Baghirzade & Kosormyhin, 2025).

The interaction between renewable energy, energy security and inflation is another key theme, particularly in the context of the EU's clean energy transition. Evidence from G7 economies suggests that higher shares of renewables can impact inflation dynamics, with machine learning studies indicating non-linear and country-specific effects (Zhang et al., 2024). Research on non-EU and post-Soviet countries suggests that renewable energy can enhance energy security, particularly in the face of heightened geopolitical risks; however, institutional quality and governance are crucial mediating factors (Havrylenko & Myroshnychenko, 2025; Gasimov et al., 2023). Systematic reviews for selected EU members, such as Greece, map the links between renewable and non-renewable energy use, growth and environmental outcomes, emphasising the need for coordinated sectoral policies (Triantafyllidou et al., 2024; Streimikiene, 2025). Sector-specific studies emphasise that stable and sustainable energy sectors are crucial for broader energy security, with financial and legal frameworks significantly influencing the resilience of energy enterprises to shocks (Zając et al., 2023; Juracka et al., 2024; Halynskyi & Telizhenko, 2024). Multi-criteria assessments of European energy generation systems further show that economic, environmental, and social indicators jointly determine the sustainability and resilience of national energy mixes, highlighting substantial cross-country differences in the ability to absorb price shocks (Drożdż et al., 2023).

Beyond energy-specific analyses, an extensive body of macroeconomic literature examines the determinants of inflation, the role of global prices and the interaction with labour markets and monetary policy. Studies for EU countries analyse how domestic and global output gaps, exchange rates and world commodity prices shape inflation, often finding asymmetric and state-dependent effects (Budova et al., 2023; Obradovic, 2025; Phuc Bui et al., 2025; Sallam, 2025; Senci & Afful, 2025). Research on inflation modelling incorporates complex dynamics and alternative frameworks, such as non-linear ARDL and hybrid models, to capture the impact of shocks and policy responses (Hamadouche et al., 2024; Gondauri, 2025; Jareño et al., 2025). Broader studies on macroeconomic stability and public debt in advanced economies suggest that fiscal positions and expectations have a significant influence on the transmission of shocks to real activity and prices (Toth et al., 2025; Kuzior et al., 2024; Rabhi & Parsons, 2025). Work on human capital, governance and institutional quality further highlights that socio-economic structures influence both the incidence of inflation and the capacity of societies to absorb shocks (Yehorova & Drozd, 2024; Maile & Vyas-Doorgapersad, 2023; Gasimov et al., 2023).

The Russia–Ukraine war has generated a dedicated stream of research on its general economic, political, and social implications, especially its energy-related implications. Analyses of global and regional energy supply chains emphasise heightened vulnerability to disruptions, re-routing of fossil fuel flows and accelerated diversification away from Russian energy sources (Aitken & Ersoy, 2023; Cui et al., 2023; Rojas-Romagosa, 2024; Sun et al., 2024). Studies for Ukraine and other affected countries highlight that energy supply shocks have profound macroeconomic consequences, echoing earlier work on Ukraine's transition and current assessments of wartime adjustments (He, 2024; Quan Chu & Grais, 1996). Complementing these broader perspectives, research on the social meaning of the Russia–Ukraine war characterises the conflict as a profound social situation with persistent effects on public attitudes and institutional trust (Slyusarevskyy & Chunikhina, 2025). Bibliometric analyses and reviews of the financial, economic and social consequences of the war further document the breadth of the emerging literature and highlight energy security, inflation and inequality as central themes (Zozulinskyy, 2024).

Several strands of research bridge energy policy, climate mitigation and broader socio-economic outcomes. Studies on climate policy instruments and circular economy initiatives demonstrate that well-designed public policies, carbon pricing, and eco-innovations can align decarbonization with economic resilience (Juracka et al., 2024; Streimikiene, 2025; Sitarz et al., 2024). Analyses of waste incineration, public health and air pollution demonstrate that energy choices and environmental policy have significant health and social impacts (Matvieieva et al., 2023; Badreddine & Larbi Cherif, 2024). Research on sustainable consumption, tourism services, and generational preferences suggests that shifting social norms and service innovations can support the clean energy transition and influence demand patterns (Ruiz Molina et al., 2025; Tapang, 2023).

The existing literature suggests that energy price shocks are central drivers of inflation, that their effects are mediated by market design, institutions and the energy mix, and that the Russia–Ukraine war has generated an exceptionally large and heterogeneous energy-inflation episode across Europe (Bohi, 1989; Kilian, 2008; Abdallah & Kpodar, 2023; Adolfsen et al., 2022; Rojas-Romagosa, 2024). However, previous work seldom characterises cross-country differences in the dynamic profiles of inflation around the war or systematically links those profiles to electricity markets, renewable shares, and energy-sector resilience. Evidence on heterogeneous electricity price pass-through is also mostly based on average elasticities, without distinguishing groups of countries according to their reaction regimes and energy configurations (Corsello & Tagliabracci, 2023; Chowdhury & Dixon, 2025; Gradzewicz et al., 2024). The present study addresses this gap by combining event-time excess inflation profiles, correlation- and DTW-based clustering and heterogeneous-slope panel models with robust covariance estimation (Driscoll & Kraay, 1998) to identify and explain distinct European energy–inflation regimes in the wake of war-related electricity shocks.

This research aims to quantify how wholesale electricity price shocks associated with the Russia–Ukraine war are transmitted into monthly consumer inflation across European countries, and to identify structurally distinct regimes of inflation response linked to energy-market and renewable configurations.

3. METHODOLOGY

3.1. Data and variables

The empirical analysis utilises a balanced monthly panel of 26 European countries, observed from January 2019 to June 2025 (T = 78, N = 2,028 country–month observations). The dependent variable is the growth rate of the Harmonised Index of Consumer Prices, expressed as the monthly percentage change relative to the previous month. The key explanatory variable is the average wholesale electricity price (EUR/MWh) in day-ahead markets. Monthly HICP inflation, unemployment rates and industrial producer prices were retrieved from the European Commission's Eurostat Data Browser, while average day-ahead electricity prices and the share of renewables in electricity demand were sourced from the International Energy Agency's Real-Time Electricity Tracker (European Commission, n.d.; IEA, n.d.).The model further controls for the share of renewables in electricity demand (in percentage), the unemployment rate (in percentage), and the producer price index for domestic output (excluding construction, sewerage, waste management, and remediation activities), all measured at a monthly frequency. This set of regressors captures, respectively, the direct energy cost channel, the potential buffering role of renewables, domestic demand conditions, and upstream cost-push pressures in the industrial sector.

3.2. Baseline panel specification

The primary econometric framework is a two-way fixed-effects (FE) model estimated on the full 2019–2025 sample (Vasylieva et al., 2025). Monthly HICP inflation for country (i) in month (t) is modelled as

$$y_{it} = \alpha_i + \lambda_t + \beta_1 x_{1,it} + \beta_2 x_{2,it} + \beta_3 x_{3,it} + \beta_4 x_{4,it} + u_{it}$$

where y_{it} denotes monthly HICP growth, $x_{1,it}$ is the wholesale electricity price, $x_{2,it}$ the share of renewables, $x_{3,it}$ the unemployment rate, and $x_{4,it}$ the producer price index. Country fixed effects α_i absorb time-invariant structural differences (e.g. institutional features, geography), and time fixed effects λ_t control for common shocks and seasonal factors. The within estimator is used, so identification comes from deviations of each variable from its country-specific and month-specific means. This baseline specification serves both to benchmark the overall strength of electricity price pass-through and to motivate the subsequent focus on heterogeneity across groups of countries.

3.3. Construction of war-excess inflation profiles

To isolate the inflationary impact of the Russia–Ukraine war, the analysis constructs country-specific profiles of "excess" inflation around the invasion. The pre-war baseline is defined as the average monthly HICP growth for each country over the period from January 2019 to January 2022. For each country (i) and month (t), excess inflation is measured as

$$e_{it} = y_{it} - \bar{y}_i^{pre}$$

where $\bar{y}_i^{pre}$ is the country-specific pre-war mean, this transformation removes level differences in inflation. It focuses on deviations from each country's own normal pattern. Event time is indexed relative to February 2022, treated as the onset of the war shock. (k = 0) corresponds to February 2022, while negative values correspond to pre-war months and positive values correspond to post-war months. For each country, an event-time reaction profile is defined as the sequence of excess inflation over a symmetric window, typically from 12 months before the invasion (k = -12) to 24 months after (k = 24). These profiles summarise the dynamic response of inflation to the war for each country in a comparable format.

3.4. Clustering of dynamic inflation responses

The first stage of the clustering analysis uses correlation-based distances between the event-time reaction profiles. Each profile is standardised by country (row-wise z-scores) to focus on the shape of the response rather than its absolute level. Pairwise distances between countries are computed as one minus the correlation between their standardised profiles, and hierarchical agglomerative clustering with Ward's linkage is applied to this distance matrix. The number of clusters is chosen using internal validity indices, specifically the average silhouette width computed for candidate solutions, which indicates three broad reaction regimes. These regimes capture qualitatively distinct patterns of wartime inflation dynamics (front-loaded shocks, gradual and prolonged responses, and more buffered paths).

Because correlation distances can treat small shifts in the timing of peaks as large differences, a second stage refines the typology using Dynamic Time Warping. (DTW) distances are computed between the same country-level reaction profiles, allowing for local stretching and compression of the time axis so that similar but phase-shifted responses are recognised as close. A k-medoids (i.e., Partitioning Around Medoids or PAM according to Kaufman & Rousseeuw, 1990) clustering algorithm is applied to the DTW distance matrix. The optimal number of clusters is again selected by maximising the average silhouette width over a range of K. This procedure yields six DTW-based clusters, which can be interpreted as finer partitions of the three baseline regimes. For each cluster, the analysis computes (i) the average event-time reaction profile and (ii) pre-war averages of the structural variables (electricity price, renewables share, unemployment, and producer prices), thereby linking dynamic responses to underlying energy and labour-market configurations.

3.5. Heterogeneous electricity price pass-through

To quantify differences in the strength of electricity price pass-through across reaction regimes, the baseline two-way FE model is extended to include interactions between wholesale electricity prices and dummy variables for the DTW clusters. Let D_{ic} denote a dummy equal to one if country (i) belongs to DTW cluster (c) (with cluster 1 as the reference). The heterogeneous-slope model is

$$y_{it} = \alpha_i + \lambda_t + \gamma_1 x_{1,it} + \gamma_2 x_{2,it} + \gamma_3 x_{3,it} + \gamma_4 x_{4,it} + \sum_{c=2}^{6} \delta_c \left(x_{1,it} \cdot D_{ic} \right) + u_{it}$$

In this specification, γ_1 measures the electricity price coefficient in the reference cluster, while $\gamma_1 + \delta_c$ gives the marginal effect of electricity prices on inflation in cluster (c). A Wald test of the joint null hypothesis $\delta_2 = \cdots = \delta_6 = 0$ assesses whether pass-through is homogeneous across clusters or differs significantly between reaction regimes. Cluster-specific marginal effects are then computed to gauge the economic magnitude of the differences.

3.6. Inference and robustness

The error structure in the monthly panel is likely to exhibit both serial correlation within countries and cross-sectional dependence across countries. These features are explicitly diagnosed using panel versions of the Breusch–Godfrey/Wooldridge test for serial correlation in idiosyncratic errors and the Pesaran CD test for cross-sectional dependence. In light of strong rejections of the null hypotheses, inference relies on Driscoll–Kraay standard errors, which are robust to general forms of heteroskedasticity, serial correlation and cross-sectional dependence in large-T panels. All key results, cluster-specific pass-through estimates, structural differences between regimes, and phase-wise excess-inflation profiles are checked for robustness to alternative clustering metrics (correlation versus DTW), choices of the pre-war baseline window, and alternative definitions of event-time horizons.

4. EMPIRICAL RESULTS AND DISCUSSION

The first step in the analysis is to estimate a two-way FE model of monthly HICP growth on wholesale electricity prices, the share of renewables in electricity demand, unemployment, and producer-price inflation for a balanced panel of 26 European countries observed from January 2019 to June 2025. The baseline regressions indicate that producer-price inflation and unemployment exhibit the expected cost-push and demand-side effects, respectively. Meanwhile, the average pass-through from wholesale electricity prices to consumer inflation is small and imprecisely estimated. To study the specific impact of the Russia–Ukraine war, we then construct 'war excess' inflation profiles for each country: monthly HICP growth is expressed as a deviation from its country-specific pre-war mean (2019–January 2022) and indexed in event time k around February 2022.

Using these excess-inflation profiles, we first apply hierarchical clustering based on correlation distances (Ward's method). Silhouette diagnostics point to three broad reaction regimes, which can be interpreted as a front-loaded Southern/Baltic spike, a more gradual and prolonged Central-Eastern response, and a more buffered Western/Nordic pattern. Because correlation distances treat even small timing shifts in peaks as large differences, the next step is to refine this typology using DTW, which allows for local stretching of the time axis. Figure 1 presents the DTW-based silhouette statistics, which motivate the choice of six refined clusters.

Figure 1 plots the average silhouette width for DTW-based clustering as a function of the number of clusters, K, from two to six. The curve dips at $K = 3$, recovers for $K = 4$, shows a slight decline at $K = 5$, and then reaches its highest value at $K = 6$, indicating that a six-cluster solution provides the best overall separation between groups, even when temporal misalignment in the reaction profiles is taken into account. Although absolute silhouette values remain modest, reflecting the high dimensionality and noise of monthly excess-inflation series, the relative pattern clearly favours richer partitions over very coarse ones, supporting the choice of six DTW clusters as the most informative robustness specification.

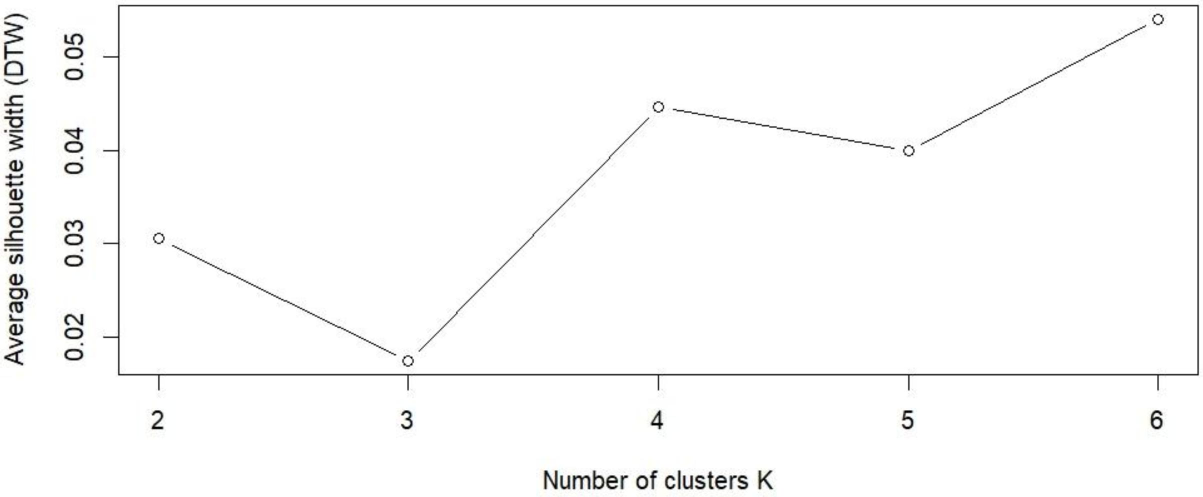

Figure 1. Average silhouette width for DTW-based clustering of dynamic inflation responses

Source: authors' calculations in R Studio.

To check whether our results are sensitive to small differences in the timing of the shock, the estimation base of the clustering using DTW distances between the event-time excess-inflation profiles was provided. DTW allows for local stretching and compression of the time axis, so that two countries with similarly shaped but slightly time-shifted responses can still be treated as close. Using the DTW distance matrix and k-medoids clustering, the silhouette criterion indicated that a partition of six clusters was the optimal solution. The resulting groups are relatively balanced in size (4, 3, 6, 4, 6 and 3 countries, respectively) and show a clear regional and structural logic.

Cluster 1 (Austria, Czech Republic, Poland, Slovakia) comprises four Central European economies with tightly integrated manufacturing sectors and broadly similar macroeconomic and financial architectures. Their DTW-aligned profiles indicate a common pattern of moderately strong and relatively synchronised inflation responses, in which the war-related excess inflation rises quickly around the invasion, remains elevated through the first year, and then gradually subsides. Compared with more peripheral Southern and Eastern economies, these countries display neither the most extreme early spike nor the longest inflationary tail. Instead, they follow a "medium-intensity, medium-duration" trajectory, reflecting a combination of strong exposure to energy-intensive industry and relatively effective policy responses, including tariff regulation and targeted compensation schemes.

Cluster 2 (Belgium, France, Luxembourg) is a compact group of core Western European and euro area economies characterised by high income levels, dense financial sectors and relatively diversified energy mixes. Their DTW profiles are very tightly aligned, with smooth and relatively contained excess-inflation paths: the initial war-related shock is clearly visible but does not reach the amplitudes observed in more vulnerable countries, and the subsequent persistence is moderate. This suggests that a combination of broad fiscal support, regulated retail tariffs and diversified supply cushioned the pass-through of wholesale price spikes, resulting in a more controlled cost-push episode despite substantial exposure to European gas and electricity markets.

Cluster 3 (Bulgaria, Croatia, Hungary, Italy, Latvia, Lithuania) comprises Southern and Eastern European economies that, in the correlation-based clustering, largely belong to the "front-loaded spike" regime. Under DTW, these countries remain close because they share a pronounced early overshooting of inflation relative to pre-war norms, followed by a partial normalisation. The alignment of profiles indicates that the timing of peaks is similar, once small phase shifts are allowed for: excess inflation rises sharply in the months immediately surrounding the invasion and remains high for several quarters before gradually retreating. This pattern is consistent with high sensitivity to energy price shocks, more limited pre-existing RES buffers and delayed effectiveness of protective policy measures, especially in economies with weaker institutional capacity and higher baseline inflation.

Cluster 4 (Denmark, Finland, Romania, and Slovenia) comprises two Nordic and two Central and Eastern European economies. Despite their structural differences, the DTW metric reveals a common two-stage response: a noticeable, but not extreme, initial jump in excess inflation, followed by a second phase in which inflation remains above pre-war norms without further acceleration. These countries appear to have managed the shock in a way that avoids both a very sharp overshoot and a highly persistent second wave, yielding moderate and relatively well-anchored inflation paths. This is compatible with relatively strong institutions and credible policy frameworks, combined with differing degrees of exposure to Russian energy that are nonetheless mitigated by domestic renewables and diversification.

Cluster 5 (Estonia, Germany, Netherlands, Portugal, Spain, Sweden) is a larger and more heterogeneous group; however, the DTW alignment reveals that they share broadly similar, moderately persistent reaction profiles. In these countries, the war shock translates into a clear and sizable increase in inflation, which does not unwind quickly; instead, excess inflation remains positive over an extended horizon, although without extremely sharp peaks. This pattern reflects economies that combine significant roles in European energy and goods markets with relatively high RES penetration and diversified supply, such that the shock is substantial but diffuse, producing a longer "plateau" of elevated inflation rather than a brief spike or a pronounced second wave.

Cluster 6 (Greece, Norway, Switzerland) comprises three structurally distinct but DTW-similar cases. Their profiles are characterised by more idiosyncratic timing and amplitude, which leads them to form a separate group once temporal misalignment is accounted for. Greece exhibits a relatively fragile macro-fiscal position and strong exposure to imported energy; Norway is a major energy exporter with very high RES penetration; Switzerland has a highly credible monetary regime and strong currency. Despite these differences, DTW reveals that the shape of their excess-inflation paths is similar: the initial war-related impulse is comparatively contained and followed by a quick re-anchoring of inflation, resulting in overall more limited and shorter-lived deviations from pre-war patterns than in most other European economies.

The DTW-based clustering refines, rather than overturns, the three-cluster taxonomy obtained from correlation distances. Each of the original reaction regimes is essentially split into more homogeneous subgroups, distinguished mainly by the exact timing and smoothness of the inflation response. While the overarching story – involving a front-loaded Southern/Baltic group, a more gradual and prolonged Central-Eastern group, and a more buffered Western/Nordic group – remains intact, each of the original reaction regimes is essentially split into more homogeneous subgroups. This confirms that our typology of inflation responses to the war in Ukraine is robust to alternative distance metrics that allow for modest timing differences, and that the key drivers of heterogeneity lie in structural energy dependencies, renewable energy penetration, and the design of national price-mitigation policies, rather than in arbitrary phase shifts in the monthly data.

Figure 2 displays the average paths of excess monthly HICP growth for the six DTW clusters over a window from twelve months before to almost two years after February 2022. This horizon is chosen to capture both the build-up phase of energy price tensions before the invasion and the full first two years of adjustment to the war shock, while avoiding the confounding influence of more recent, non-war-related shocks in the later sample. In the pre-war period ($k < 0$), all clusters fluctuate closely around zero, with only small positive and negative deviations, indicating that, on average, countries did not experience systematic departures from their pre-war inflation norms. A gradual build-up becomes visible in the quarters immediately preceding the invasion, as several clusters already move slightly above zero, consistent with mounting energy and supply-chain pressures during 2021.

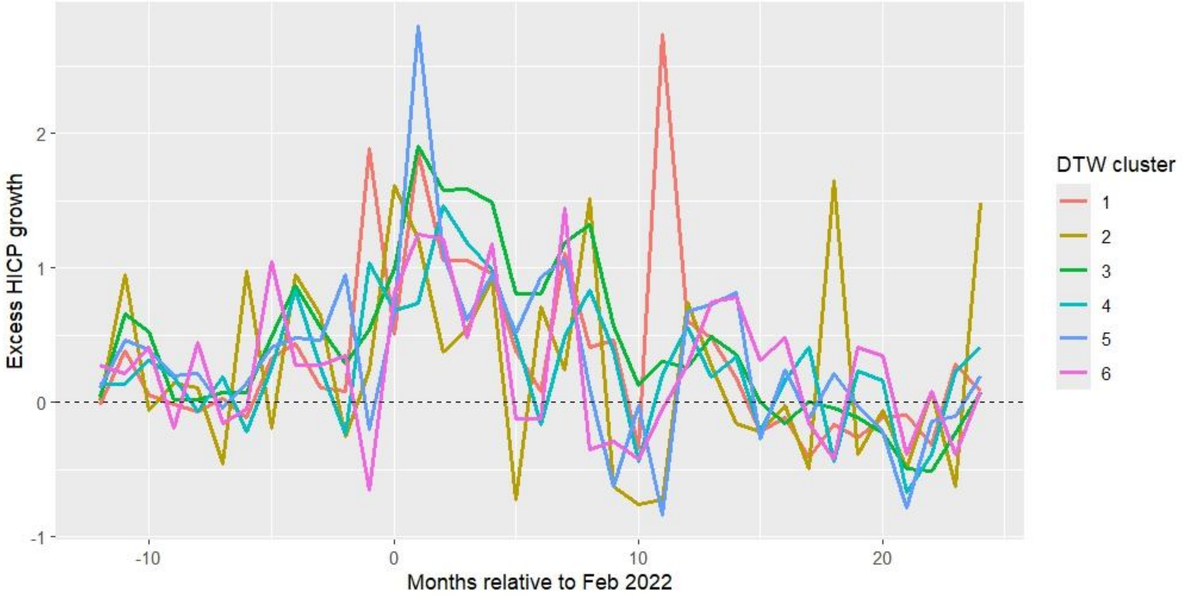

Figure 2. Dynamic excess-inflation profiles by DTW cluster

Source: authors' calculations in R Studio.

Around the event itself (k ≈ 0), every cluster shows a clear jump into positive territory, confirming a broad-based, war-related inflation impulse. The size and timing of peaks differ: clusters 3 and 4 exhibit the strongest early spikes, while cluster 1 records a pronounced second peak roughly ten to twelve months after the invasion, pointing to a more marked "second wave" of pass-through. In the subsequent horizon, all profiles gradually converge back towards zero, with smaller oscillations and only modest positive or negative excess inflation in the second year after the shock. The figure suggests that DTW clustering uncovers heterogeneous reaction shapes; some clusters concentrate the shock in the immediate aftermath, while others display more delayed or multi-peaked dynamics. By the end of the window, the mean excess inflation in all clusters lies close to zero, indicating a re-anchoring of inflation levels. However, some regimes – notably cluster 2 – remain relatively volatile around this renewed baseline.

The pre-war averages show that the DTW clusters differ not only in their dynamic inflation responses, but also in their underlying energy and labour-market conditions (Table 1). Clusters 1 and 2 display the lowest average wholesale electricity prices before the war (around EUR 49–50/MWh), whereas clusters 3 and 6 stand out with clearly higher pre-war prices (about EUR 59 and 56/MWh, respectively). Variation across clusters in electricity prices is therefore non-trivial (between-cluster sum of squares ≈ 81), even though the very small number of clusters implies that the ANOVA result is descriptive rather than inferential.

Table 1

Pre-war structural characteristics by DTW cluster

DTW cluster	**Average electricity price, EUR/MWh (x1)**	**Average RES share in demand, % (x2)**	**Average unemployment rate, % (x3)**	**Average PP index growth, % m/m (x4)**
1	49.0	32.0	4.45	0.595
2	50.1	24.3	6.56	0.897
3	59.4	29.8	6.78	0.827
4	52.5	46.2	5.73	0.880
5	51.1	42.7	7.25	0.676
6	56.4	55.4	8.59	0.509

Source: authors' calculations in R Studio.

In terms of renewables, clusters 2 and 3 are the least decarbonised, with RES shares in electricity demand below 30 per cent. In contrast, clusters 4, 5, and especially 6 are much more renewables-intensive, with average RES shares of 46%, 43%, and 55%, respectively. Pre-war unemployment also differs systematically: cluster 1 combines low electricity prices with the lowest unemployment rate (about 4.5 per cent), whereas cluster 6 combines high RES penetration with the highest unemployment (around 8.6 per cent). Finally, producer-price inflation (PPI) tends to be higher in clusters 2–4 (around 0.83–0.90 per cent month-on-month) and lower in clusters 1, 5 and especially 6. Overall, the DTW clusters map onto distinct structural configurations. Some groups face cheaper but more carbon-intensive electricity and tighter labour markets, others combine more expensive but greener electricity with weaker labour demand and lower pre-war PPI dynamics.

The two-way FE model with cluster-specific interactions between electricity prices and DTW clusters allows the strength of inflation pass-through to differ across reaction regimes (Table 2). The baseline coefficient on wholesale electricity prices (x1) is negative and weakly significant at the 10 per cent level (–0.00093), while the interaction terms modify this effect for clusters 2–6. Evaluated at the cluster level, a 100 EUR/MWh increase in wholesale electricity prices is associated with an approximately –0.09 percentage-point change in monthly HICP growth in cluster 1, –0.14 p.p. in cluster 2, –0.12 p.p. in cluster 4 and –0.15 p.p. in cluster 6. In contrast, the incremental interactions for clusters 3 and 5 are positive and statistically significant, indicating positive pass-through: the same 100 EUR/MWh shock is associated with approximately +0.03 percentage points (p.p.) in cluster 3 and +0.09 p.p. in cluster 5.

These results suggest that the DTW reaction regimes are not merely cosmetic groupings of time profiles, but also capture economically meaningful heterogeneity in the price–inflation link. Clusters 3 and 5, which include many Southern and Western European economies with stronger or more persistent excess-inflation waves, exhibit statistically significant positive pass-through from wholesale electricity to consumer prices. By contrast, the other clusters display small and negative or weakly determined effects, which likely reflect a combination of regulated tariffs, compensating fiscal measures and measurement issues (wholesale prices as a noisy proxy for retail tariffs). The control variables behave as expected: higher unemployment significantly dampens inflation (a short-run Phillips-curve effect). In contrast, higher producer-price inflation exerts a strong and highly significant cost-push effect on HICP growth. Although the overall within R^2 is modest, which is typical for high-frequency inflation data, the joint F-test is highly significant, and the interaction terms clearly indicate that electricity-price shocks propagate very differently across the DTW-defined reaction regimes.

Table 2

Heterogeneous electricity-price pass-through by DTW cluster (two-way FE model)

Two-way effects within the model
Call: plm(formula = y ~ x1 * cluster_dtw + x2 + x3 + x4, data = pdata.frame(df, index = c("country", "date")), effect = "twoways", model = "within")
Balanced Panel: n = 26, T = 78, N = 2028
Residuals:

Min.	**1ST QU.**	**Median**	**3rd Qu.**	**Max.**
-4.187617	-0.314994	-0.018185	0.267537	5.637009

Variable	**Estimate**	**Std. Error**	**t-value**	**Pr(>|t|)**
x1	-0.00093346	0.00056670	-1.6472	0.0996852.
x2	0.00138197	0.00090053	1.5346	0.1250430
x3	-0.03873636	0.01519854	-2.5487	0.0108903*
x4	0.05056144	0.00769907	6.5672	<0.0001***
x1:cluster_dtw2	-0.00041975	0.00057423	-0.7310	0.4648832
x1:cluster_dtw3	0.00120982	0.00048863	2.4759	0.0133748*
x1:cluster_dtw4	-0.00024661	0.00055061	-0.4479	0.6542878
x1:cluster_dtw5	0.00183630	0.00055251	3.3235	0.0009056***
x1:cluster_dtw6	-0.00052586	0.00060687	-0.8665	0.3863181

Total Sum of Squares: 793.14
Residual Sum of Squares: 757.5
R-Squared: 0.044941
Adj. R-Squared: -0.010389
F-statistic: 10.0176 on 9 and 1916 DF, p-value: <0.0001

Signif. codes: '***' – 0.001; '**' – 0.01; '*' – 0.05; '.' – 0.1; 'no symbol' – insignificant.
Source: authors' calculations in R Studio.

The phase-wise averages of excess monthly HICP growth show that all DTW clusters experienced a clear positive war-related inflation impulse in the early phase (k = –3…3), but with different magnitudes (Table 3). Early-phase mean excess inflation ranges from about 0.53 p.p. in cluster 6 to 1.06 p.p. in cluster 3, with clusters 1 and 5 also exhibiting sizeable surges (around 0.9–0.94 p.p.). Clusters 2 and 4 record somewhat smaller, though still substantial, early shocks (0.63 and 0.73 p.p., respectively). This pattern indicates that the immediate impact of the war on inflation was broad-based but uneven, with clusters 3, 1 and 5 at the upper end of the early overshoot spectrum.

Differences become even more informative in the medium phase (k = 4…12), which captures the persistence of the shock. Here, mean excess inflation remains elevated in clusters 1 and 3 (around 0.71–0.76 p.p.), while it drops markedly in clusters 2, 4, 5 and 6 (roughly 0.15–0.37 p.p.). The medium-phase values confirm that clusters 1 and 3 concentrate not only the largest initial shocks but also the most persistent inflationary pressure. In contrast, clusters 2, 5 and especially 6 see a much faster attenuation of excess inflation. By contrast, in the late phase (k = 13…24) all clusters converge close to zero: mean excess ranges between roughly –0.07 and +0.16 p.p., with only clusters 2 and 6 keeping slightly positive deviations. The late-phase ANOVA, therefore, primarily serves as a descriptive check to confirm that war-related excess inflation largely dissipates across all regimes.

These results suggest that the DTW reaction regimes are not merely cosmetic groupings of time profiles, but also capture economically meaningful heterogeneity in the price–inflation link. Clusters 3 and 5, which include many Southern and Western European economies with stronger or more persistent excess-inflation waves, exhibit statistically significant positive pass-through from wholesale electricity to consumer prices. By contrast, the other clusters display small and negative or weakly determined effects, which likely reflect a combination of regulated tariffs, compensating fiscal measures and measurement issues (wholesale prices as a noisy proxy for retail tariffs). The control variables behave as expected: higher unemployment significantly dampens inflation (a short-run Phillips-curve effect). In contrast, higher producer-price inflation exerts a strong and highly significant cost-push effect on HICP growth. Although the overall within R^2 is modest, which is typical for high-frequency inflation data, the joint F-test is highly significant, and the interaction terms clearly indicate that electricity-price shocks propagate very differently across the DTW-defined reaction regimes.

Table 3

Average excess monthly HICP growth by DTW cluster and

Cluster.	_dtw phase	mean_excess
1	early	0.937
1	late	-0.0558
1	medium	0.712
2	early	0.626
2	late	0.0867
2	medium	0.145
3	early	1.06
3	late	-0.0701
3	medium	0.764
4	early	0.732
4	late	0.0351
4	medium	0.371
5	early	0.913
5	late	0.0446
5	medium	0.305
6	early	0.532
6	late	0.157
6	medium	0.172

Note: "early" phase corresponds to k = –3…3, "medium" to k = 4…12, and "late" to k = 13…24 (months relative to February 2022). Mean excess values are rounded to two decimal places.
Source: authors' calculations in R Studio.

The phase-wise analysis reveals that the DTW-defined reaction regimes primarily differ in the strength and persistence of the shock in the first year after the invasion. Clusters 1 and 3 emerge as "high-pressure" regimes with both large early overshoots and sustained medium-phase excess inflation; clusters 4 and 5 experience more moderate persistence; clusters 2 and 6 display relatively small and short-lived deviations from pre-war inflation norms. The separate ANOVAs for early, medium and late phases formalise these differences and highlight that cross-cluster heterogeneity is most pronounced in the first two phases of the adjustment, while late-phase differences are economically negligible.

The Wald test of the joint restrictions $x1 : cluster\_dtw2 = x1 : cluster\_dtw3 = x1 : cluster\_dtw4 = x1 : cluster\_dtw5 = x1 : cluster\_dtw6 = 0$ compares the restricted model, which features a common electricity pass-through across all DTW clusters, with the full model that includes cluster-specific slopes. The test yields a chi-square statistic of 32.59 with 5 degrees of freedom and a p-value of 4.5×10^{-6} (Table 4), so the null hypothesis of homogeneous pass-through is decisively rejected. Statistically, this means that allowing the slope of wholesale electricity prices to vary by DTW reaction regime significantly improves the model fit: the way electricity price shocks feed into monthly HICP growth differs across clusters.

Table 4

Wald test of homogeneous electricity-price pass-through across DTW clusters

Linear hypothesis test:
x1:cluster_dtw2 = 0
x1:cluster_dtw3 = 0
x1:cluster_dtw4 = 0
x1:cluster_dtw5 = 0
x1:cluster_dtw6 = 0
Model 1: restricted model
Model 2: y ~ x1 * cluster_dtw + x2 + x3 + x4

Model	Res.Df	Df	Chisq	Pr(>Chisq)
1	1921			
2	1916	5	32.588	<0.0001***

Signif. codes: '***' – 0.001; '**' – 0.01; '*' – 0.05; '.' – 0.1; 'no symbol' – insignificant.
Source: authors' calculations in R Studio.

The marginal effects table (Table 5) translates the estimated coefficients into cluster-specific pass-through elasticities. For the baseline cluster (cluster 1), a 100 EUR/MWh increase in wholesale electricity prices is associated with an average change in monthly HICP growth of about –0.09 percentage points, i.e. essentially no positive pass-through. Clusters 2, 4, and 6 exhibit similarly small and slightly negative marginal effects (around –0.14 p.p.), again suggesting that wholesale electricity prices, as measured here, do not materially raise consumer inflation in those regimes, most likely due to regulated tariffs, delayed adjustments, and offsetting fiscal measures. By contrast, clusters 3 and 5 exhibit positive pass-through: the same 100 EUR/MWh increase is associated with approximately 0.03 percentage points (pp) in cluster 3 and 0.09 pp in cluster 5. Although the magnitudes are modest, these are the only regimes in which electricity price shocks translate into higher monthly HICP growth on average.

Table 5

Cluster-specific marginal effects of wholesale electricity prices on monthly HICP growth

Cluster_dtw	**tMarginal effect of x1 on y (per EUR/MWh)**	**tMarginal effect (per 100 EUR/MWh)**
1	-0.0009334593	-0.09334593
2	-0.0013532068	-0.13532068
3	0.0002763649	0.02763649
4	-0.0011800687	-0.11800687
5	0.0009028382	0.09028382
6	-0.0014593160	-0.14593160

Note: Marginal effects are computed from the two-way FE model with interactions between x1 and DTW clusters (fe_het). Values are rounded to two decimal places for the per-100 EUR/MWh column.
Source: authors' calculations in R Studio.

The Wald test and the marginal effects indicate that the DTW-defined reaction regimes are economically meaningful: they do not merely differ in the shape of their wartime inflation profiles, but also in the strength and direction of the electricity–inflation link. In some clusters, wholesale price variation is largely absorbed by institutional and policy buffers. In contrast, in others, particularly clusters 3 and 5, it is passed through more clearly into consumer prices, reinforcing the excess inflation observed in the dynamic profiles.

Figure 3 plots the cluster-specific electricity pass-through estimates (change in monthly HICP growth per 100 EUR/MWh) against the pre-war share of renewables in electricity demand. Clusters 3 and 5, which sit at intermediate RES shares (around 30–43%), are the only ones with positive pass-through, indicating that in these regimes, higher wholesale electricity prices tend to translate into higher consumer inflation. By contrast, clusters 1 and 2 (with relatively low RES shares) and clusters 4 and 6 (with higher RES shares, above 45%) all exhibit negative or near-zero pass-through, suggesting that price spikes in wholesale markets are largely absorbed by retail regulation, fiscal compensation, or other buffering mechanisms.

The scatter thus does not show a simple linear relationship between RES penetration and pass-through, but rather a non-monotonic pattern: regimes with very low or very high renewable shares appear more insulated from wholesale shocks, whereas regimes with moderate RES penetration are more exposed. This is consistent with the idea that both highly fossil-dependent systems with heavy regulation and highly decarbonised systems with diversified supply can dampen the transmission of wholesale price volatility. In contrast, mixed systems in transition are more prone to a pass-through of electricity prices into consumer inflation.

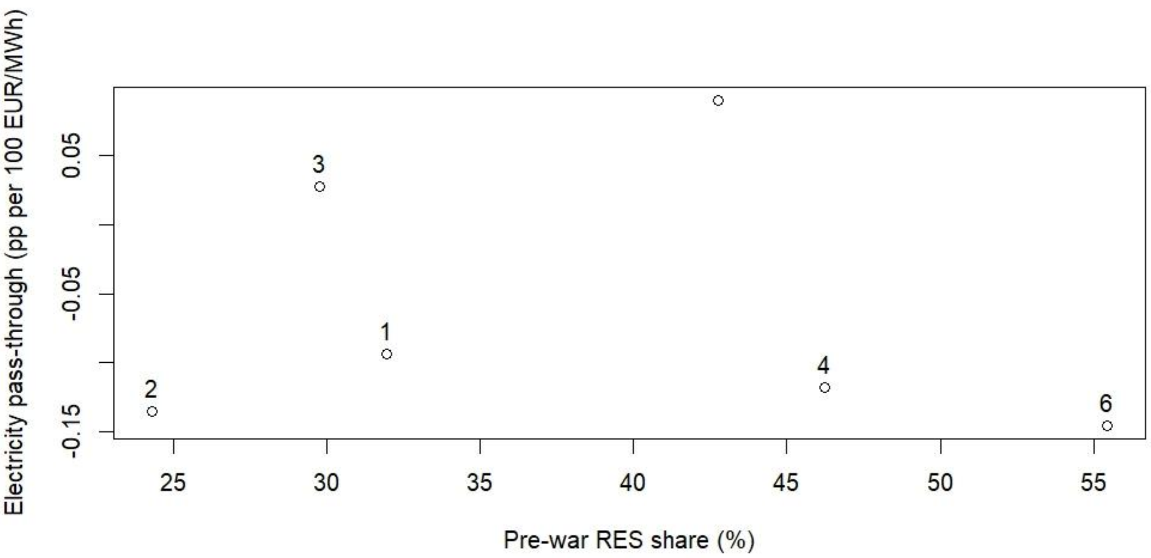

Figure 3. Electricity price pass-through vs pre-war RES share by DTW cluster
Source: authors' calculations in R Studio.

The diagnostic tests indicate that the error structure in the panel is far from classical and that robust inference is required. The Breusch–Godfrey/Wooldridge test strongly rejects the null of no serial correlation in the idiosyncratic errors ($\chi^2 = 536.48$, df = 78, $p < 0.0001$), implying that residuals are serially correlated within countries over time. The Pesaran CD test likewise rejects the null hypothesis of cross-sectional independence ($z = -5.41$, $p < 0.0001$), indicating cross-country correlation in the shocks, which is plausible given common euro area and global energy conditions. Taken together, these results suggest that conventional FE standard errors are biased, and inference must account for both time-series and cross-sectional dependence.

Re-estimating the model with Driscoll–Kraay standard errors (SCC, type = HC0) confirms that the main substantive results are robust while slightly weakening some marginal coefficients. With these robust errors, unemployment continues to have a significant negative effect on monthly HICP growth (x3, $p \approx 0.027$), and producer-price inflation remains strongly positive and highly significant (x4, $p \approx 0.0001$), consistent with a cost-push mechanism. The interactions between electricity prices and DTW clusters 3 and

5 remain statistically significant and positive (p ≈ 0.0004 and p ≈ 0.0038), reinforcing the conclusion that these regimes exhibit meaningful positive pass-through from wholesale electricity prices to consumer inflation. By contrast, the main effect of x1 loses its earlier borderline significance (p ≈ 0.28), and the interactions for clusters 2, 4 and 6 remain insignificant, supporting the view that in those regimes, wholesale prices are largely decoupled from HICP. Thus, once serial correlation and cross-sectional dependence are properly accounted for, the heterogeneity in electricity pass-through across DTW clusters remains a statistically robust feature of the data.

Table 6

Model with Driscoll–Kraay standard errors (SCC, type = HC0)

Variable	Estimate	Std. Error	t value	Pr(>|t|)
x1	-0.00093346	0.00086647	-1.0773	0.2814771
x2	0.00138197	0.00076713	1.8015	0.0717870
x3	-0.03873636	0.01746359	-2.2181	0.0266634
x4	0.05056144	0.01305157	3.8740	0.0001107
x1:cluster_dtw2	-0.00041975	0.00060897	-0.6893	0.4907308
x1:cluster_dtw3	0.00120982	0.00033917	3.5670	0.0003700
x1:cluster_dtw4	-0.00024661	0.00039669	-0.6217	0.5342313
x1:cluster_dtw5	0.00183630	0.00063386	2.8970	0.0038100
x1:cluster_dtw6	-0.00052586	0.00047261	-1.1127	0.2659919

5. DISCUSSION

The findings confirm that the Russia–Ukraine war generated a large but highly uneven energy–inflation shock across Europe, broadly consistent with macro and policy assessments. However, they also reveal patterns that go beyond standard average pass-through estimates. The early-phase excess inflation of roughly 0.5–1.1 percentage points across the six regimes sits in the same order of magnitude as decompositions that attribute a sizeable share of the 2022–2023 inflation surge to retail energy prices and import cost shocks, while the rapid convergence towards negligible excess inflation by the late phase mirrors the observed decline in headline inflation as wholesale prices normalised and policy measures took effect (Abdallah & Kpodar, 2023; Chowdhury & Dixon, 2025; Gradzewicz et al., 2024; Sun et al., 2024). At the same time, the clustering approach shows that only a subset of countries experienced both large early spikes and sustained medium-phase pressure, suggesting that the headline narrative of a uniform "energy-driven inflation" episode conceals substantial cross-country variation in the shape and persistence of the shock (Adolfsen et al., 2022; Budova et al., 2023; Rojas-Romagosa, 2024).

The heterogeneous pass-through results help reconcile these dynamic profiles with the broader literature on the incidence of energy costs and inflation. The marginal effects indicate that a 100 EUR/MWh increase in wholesale electricity prices raised monthly HICP by only about 0.03–0.09 percentage points in the two "high pass-through" regimes, while effects in the remaining four regimes were small, negative and statistically insignificant under Driscoll–Kraay inference. This pattern aligns with evidence that energy price shocks have sizable macroeconomic effects in some contexts but relatively weak direct pass-through in others, due to regulatory buffers, contract structures, and fiscal interventions (Ganapati et al., 2020; Corsello & Tagliabracci, 2023; Abdallah & Kpodar, 2023). The prominence of industrial producer prices and unemployment as drivers of monthly inflation in the models corresponds to findings that cost-push forces and demand conditions, rather than energy prices alone, shaped the post-pandemic inflation episode in Europe (Budova et al., 2023; Hamadouche et al., 2024; Obradovic, 2025). The strong rejection of homogeneous pass-through across clusters aligns with studies that emphasise the differing propagation of energy price shocks, depending on market structures, contract regimes, and the broader policy mix (Kilian, 2008; Mulder, 2023; Gradzewicz et al., 2024).

The structural differences between the DTW regimes underscore the importance of energy mix and market fundamentals highlighted in the energy security and renewables literature. Pre-war electricity prices, renewable energy shares, and unemployment rates differ markedly across clusters, with higher renewable energy penetration and somewhat higher unemployment rates in one group of regimes, and cheaper but more carbon-intensive electricity, combined with tighter labour markets, in another. This pattern aligns with evidence that renewables can enhance energy security and alter price dynamics, but their impact on inflation is non-linear and contingent upon institutions, policy design, and market integration (Havrylenko & Myroshnychenko, 2025; Zhang et al., 2024; Triantafyllidou et al., 2024). The mixed relationship between renewables shares and pass-through—where regimes with moderate, rather than extreme, renewables penetration show the clearest positive pass-through—suggests that decarbonisation alone does not guarantee insulation from electricity shocks; instead, it matters how renewable portfolios interact with market rules, transmission constraints and balancing mechanisms (Bank & Badyda, 2024; Hundt et al., 2021; Sitarz et al., 2024; Zając et al., 2023). The role of energy news and expectations, emphasised in recent work on news shocks and the Russia–Ukraine conflict, provides an additional channel through which structural differences and policy credibility can shape dynamic inflation responses (Guinea et al., 2024; Sun et al., 2024; Alberini et al., 2023).

The results also align with evidence on the broader socio-economic and distributional impacts of the energy crisis. The clusters with the strongest and most persistent excess inflation are likely to be those where households experienced the greatest erosion of real incomes, echoing studies documenting disproportionate burdens on low-income households and heightened public-health and welfare risks in high-inflation, high-energy-price environments (Guan et al., 2023; Broadbent et al., 2023; Badreddine & Larbi Cherif, 2024). The finding that wholesale prices often exhibit muted direct pass-through is consistent with the extensive use of price caps, compensation schemes and tax adjustments documented in policy analyses. It implies that a significant share of the energy shock was absorbed by public budgets and energy companies, with implications for fiscal space and financial stability in the energy sector (Rojas-Romagosa, 2024; Mulder, 2023; Zając et al., 2023). This reinforces arguments that the energy transition and security agenda must be integrated with social protection and fiscal policy to avoid amplifying inequality and macro-financial vulnerabilities (Dinca et al., 2025; Juracka et al., 2024; Streimikiene, 2025; Rabhi & Parsons, 2025).

From a methodological standpoint, the combination of event-time excess profiles, correlation- and DTW-based clustering and heterogeneous-slope panel models extends the literature's ability to describe and explain inflation responses to energy shocks. Previous work typically reports single-country or pooled pass-through coefficients, sometimes with regime switches or non-linearities, but rarely employs dynamic clustering to identify groups of countries with similar reaction profiles and then links these regimes to structural characteristics (Abdallah & Kpodar, 2023; Corsello & Tagliabracci, 2023; Gradzewicz et al., 2024). The DTW approach, which allows for modest timing differences in peaks, demonstrates that the main typology of regimes is robust and that the crucial heterogeneity lies in the magnitude and persistence of excess inflation, rather than in arbitrary phase shifts. The use of Driscoll–Kraay covariance estimation addresses the documented presence of serial correlation and cross-sectional dependence, aligning with best practice in panel settings characterised by common shocks and strong interdependence (Driscoll & Kraay, 1998; Gajdosikova et al., 2025; Kuzior et al., 2024). Overall, the findings support the view that the European energy inflation episode following the Russia–Ukraine war was shaped by a complex interaction of energy markets, renewables, institutions, and policy responses. They demonstrate that a regime-based, dynamic perspective is crucial for understanding and managing such shocks in the future.

This research has several limitations that should be acknowledged. The empirical analysis focuses on 26 European countries over a relatively short window (2019–2025), capturing a single, historically exceptional shock episode, so the identified reaction regimes may not generalise to other periods or regions. Wholesale day-ahead electricity prices are used as the primary energy variable, despite retail tariffs being subject to regulation, taxation, and contract structures that are only imperfectly proxied at this frequency. Additionally, key channels such as gas futures, storage, or fuel mix details are not explicitly modelled. The event-time "excess" profiles and clustering results depend on specific choices of pre-war baseline, time window and distance metrics, and moderate changes to these choices could alter the composition of some clusters, even if the broad typology is robust. The panel model remains a reduced-form model, abstracting from possible endogeneity between inflation and policy responses, and cannot fully disentangle the roles of fiscal measures, monetary tightening, and expectations alongside energy prices. Finally, data constraints and aggregation at the country–month level preclude analysis of within-country heterogeneity, distributional impacts, and micro-level pricing dynamics, which future work could address using household, firm-level, or tariff-level data.

5. CONCLUSION

The study aimed to quantify how war-related wholesale electricity price shocks were transmitted into monthly consumer inflation across European countries and to identify structurally distinct inflation–energy regimes shaped by renewable energy penetration, labour-market conditions, and industrial cost pressures. Focusing on the Russia–Ukraine war as a large, externally driven shock, the analysis aimed to move beyond average pass-through estimates and to characterise the dynamic profiles of inflation around the conflict.

Methodologically, the study employs a two-way FE panel model and an event-study clustering framework on a balanced monthly panel of 26 European countries (2019–2025). Monthly HICP inflation is regressed on wholesale day-ahead electricity prices, the share of renewables, unemployment, and industrial producer prices, with country and time fixed effects, and Driscoll–Kraay standard errors. War-related "excess" inflation profiles in event time around February 2022 are first clustered using correlation-based hierarchies and then refined via DTW-based k-medoids, yielding six reaction regimes that are linked to pre-war structural characteristics and embedded in a heterogeneous-slope FE model through interactions between electricity prices and cluster dummies.

The main empirical results can be summarised along three quantitative dimensions. First, the event-time analysis confirms a broad-based but heterogeneous inflation impulse around the war. Across the six DTW clusters, early-phase "war-excess" inflation ($k = -3\ldots3$) ranges from about 0.53 percentage points (p.p.) in cluster 6 to 1.06 p.p. in cluster 3, with clusters 1 and 5 also showing strong early overshoots of roughly 0.94–0.91 p.p. In the medium phase ($k = 4\ldots12$), excess inflation remains elevated in clusters 1 and 3 at around 0.71–0.76 p.p., but falls to 0.15–0.37 p.p. in clusters 2, 4, 5 and 6, indicating that only two regimes combine large initial shocks with clearly persistent inflationary pressure. By the late phase ($k = 13\ldots24$), all clusters converge close to zero, with a mean excess inflation in a narrow band between approximately –0.07 and +0.16 percentage points, indicating that war-related inflation had largely dissipated by the second year after the invasion. Secondly, the six DTW regimes map onto distinct energy and labour-market configurations: pre-war wholesale electricity prices range from EUR 49–50/MWh in clusters 1 and 2 to about EUR 59/MWh in cluster 3 and EUR 56/MWh in cluster 6; average renewables shares vary from roughly 24–30% in clusters 2 and 3 to 46–55% in clusters 4 and 6; and unemployment spans from 4.45% in cluster 1 to 8.59% in cluster 6, with producer-price inflation also systematically higher in clusters 2–4 than in clusters 1, 5 and 6. Thirdly, the heterogeneous-slope FE model ($N = 2{,}028$; within $R^2 \approx 0.045$) shows that the pass-through of wholesale electricity prices to HICP is statistically different across DTW regimes:

a Wald test on the interaction block yields a chi-square statistic of about 32.6 with 5 degrees of freedom ($p \approx 4.5 \times 10^{-6}$), rejecting homogeneous pass-through. The implied marginal effects indicate that a 100 EUR/MWh increase in wholesale prices is associated with only +0.03 p.p. higher monthly inflation in cluster 3 and about +0.09 p.p. in cluster 5, while the corresponding estimates for clusters 1, 2, 4 and 6 lie between roughly –0.09 and –0.15 p.p. and are statistically insignificant under Driscoll–Kraay errors. Across all specifications, a one-percentage-point increase in unemployment reduces monthly inflation by approximately 0.04 percentage points. In contrast, a one-percentage-point increase in industrial producer-price inflation raises HICP by roughly 0.05 percentage points, underscoring the central role of upstream cost-push pressures and labour-market slack, alongside highly uneven and often muted direct pass-through from electricity prices.

These findings carry several policy implications. The presence of distinct dynamic regimes and heterogeneous pass-through suggests that one-size-fits-all energy and anti-inflation measures are unlikely to be efficient. In regimes with strong and persistent pass-through, crisis interventions should prioritise improving the design of retail tariffs, pass-through rules and hedging instruments, alongside targeted transfers that cushion vulnerable households without fully suppressing price signals. In more buffered regimes, where wholesale shocks are largely absorbed by regulation and fiscal measures, policymakers must balance short-term protection with concerns about fiscal sustainability, investment incentives and the transparency of quasi-fiscal support embedded in energy prices. Across all regimes, increasing renewable energy penetration and strengthening the financial and institutional resilience of the energy sector can enhance energy security and reduce exposure to future price spikes. However, the results indicate that renewables alone do not guarantee insulation from inflationary shocks; market design and social protection architecture are equally important. Finally, the analysis highlights the value of high-frequency, country-level monitoring of energy and inflation dynamics, suggesting that European authorities should invest in integrated data and modelling frameworks capable of capturing heterogeneous reaction patterns when calibrating future responses to energy and geopolitical shocks.

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