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A Regression Discontinuity Analysis of the 2022 Russia–Ukraine Conflict and Its Implications for SDG 7 in Europe

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Abstract

European energy markets experienced unprecedented disruptions following Russia’s invasion of Ukraine on 24 February 2022, exposing long-standing structural vulnerabilities in fossil fuel–dependent systems and threatening progress toward Sustainable Development Goal 7 (SDG 7). This study provides a causal analysis of the conflict’s immediate impact on European energy markets using a Regression Discontinuity Design (RDD) that leverages the sharp temporal cutoff created by the invasion. Drawing on monthly data for 25 European countries from 2019–2024, we examine four core outcomes: natural gas import volumes, crude oil import volumes, Title Transfer Facility (TTF) natural gas prices, and wholesale electricity prices. Our findings reveal significant supply-side adjustments following the conflict, with natural gas and crude oil imports exhibiting heterogeneous responses depending on pre-war Russian dependency levels. Price dynamics show pronounced but short-lived spikes in TTF gas prices, while electricity market responses are more ambiguous due to bandwidth sensitivity. The results provide empirical evidence of how European energy systems absorbed an exogenous geopolitical shock, highlighting the interplay between supply diversification, market integration, and vulnerability to price volatility. The study contributes to the literature on energy security under geopolitical stress and offers policy-relevant insights into resilience strategies needed to uphold SDG 7 targets during crises.

Keywords

Russia–Ukraine Conflict; Energy Security; Regression Discontinuity Design (RDD); Geopolitical Supply Shocks; European Energy Markets; SDG 7; Sustainability; Market Resilience

1. Introduction

The intersection of geopolitical instability and energy security represents one of the most pressing challenges facing contemporary European policymakers. It also represents a critical threat to achieving Sustainable Development Goal 7 (SDG 7): ensuring access to affordable, reliable, sustainable, and modern energy for all. On February 24, 2022, an unprecedented shock to European energy markets was caused by Russia’s invasion of Ukraine. This shock led to disrupting established supply chains and called for a fundamental reassessment of energy security strategies across the continent. As Europe had historically maintained substantial dependence on Russian fossil fuel imports—particularly natural gas—the conflict raised urgent questions about the resilience of integrated energy systems when confronted with acute geopolitical crises. Understanding the quantitative impacts of such shocks on energy trade flows and pricing dynamics is essential for designing robust policy frameworks. This policy —we believe— aims to maintain progress toward sustainable development objectives even during periods of extreme external stress.

The 2022 Ukraine conflict provides a unique quasi-experimental setting for examining how modern, highly integrated energy markets respond to severe supply-side disruptions. This structural dependence created vulnerability to supply interruptions that policymakers had long recognized but inadequately addressed through diversification strategies. The sudden onset of Russian military conflict forced European nations to confront this vulnerability directly. This was driven by implementing emergency measures ranging from accelerated liquefied natural gas (LNG) terminal construction to demand reduction campaigns and strategic reserve utilization. The conflict thus represents not merely a supply shock, but a comprehensive stress test of European energy system resilience, market integration mechanisms, and policy coordination frameworks developed over decades of energy market liberalization.

From a sustainable development perspective, geopolitical energy shocks pose multifaceted threats to SDG 7 targets across three critical dimensions. First, supply disruptions directly threaten SDG 7.3 objectives concerning energy security and reliability which might be forcing countries to implement rationing measures or experience involuntary supply curtailments that compromise economic activity and social welfare. Second, price increases resulting from supply constraints undermine SDG 7.1 goals related to energy affordability and access which disproportionately affect vulnerable households and threatening energy poverty escalation across European populations. Third, crisis-period responses may either accelerate or delay progress toward SDG 7.2 renewable energy targets. This depends on whether countries respond through emergency fossil fuel substitution or accelerated clean energy investments. The Ukraine conflict therefore provides crucial empirical evidence about the interactions between energy security imperatives and sustainable development trajectories under extreme geopolitical stress.

In this study, we employ a regression discontinuity design (RDD) to identify the causal impact of the Ukraine conflict on European energy markets across multiple outcome dimensions. The RDD methodology exploits the sharp temporal discontinuity created by the invasion on 24th of February (2022) as a quasi-experimental treatment assignment. This allow us to isolate conflict-specific effects from underlying market trends, seasonal patterns, and other confounding factors. We analyze comprehensive monthly data covering 25 European countries from January 2019 to December 2024, focusing on four key outcome variables that capture both quantity and price dimensions of market responses: natural gas import volumes, crude oil import volumes, Title Transfer Facility (TTF) natural gas prices, and wholesale electricity market prices. By examining both import flows and pricing dynamics, we provide a comprehensive assessment of how European energy systems absorbed the geopolitical shock. Also, we examine whether achieved resilience manifested through quantity adjustments, price responses, or combinations thereof.

Our analysis formulates two core hypotheses grounded in economic theory and the nature of supply-side shocks. The Supply Disruption Hypothesis (H_1) predicts significant reductions in both natural gas and crude oil import volumes. This hypothesis was naturally formed as European countries face immediate supply constraints and implement accelerated diversification strategies away from Russian energy sources. The second hypothesis—Price Impact Hypothesis (H_2)—anticipates substantial increases in both wholesale natural gas and electricity prices. This was grounded as supply uncertainty and risk premiums propagate through integrated energy markets, reducing affordability and threatening energy access objectives. Testing these hypotheses provides direct empirical evidence regarding the transmission mechanisms through which geopolitical shocks affect European energy security and sustainable development progress.

Beyond aggregate treatment effects, we examine heterogeneous responses across countries with different levels of pre-war Russian energy dependency. In this context, we classified countries as high-dependency (Germany, Hungary, Czech Republic, Slovakia, Finland—those exceeding 40% Russian gas import shares) or low-dependency (France, Netherlands, Spain, Portugal, Belgium, Sweden, Denmark, Norway, Lithuania, Latvia, Estonia, Ireland—those below 20% Russian gas dependence) based on 2021 import data. Understanding these differential responses is crucial for assessing the effectiveness of energy diversification strategies and the role of market integration in crisis resilience. The heterogeneity results reveal economically meaningful patterns that provide important nuance to aggregate findings. Also, they demonstrate sophisticated reallocation mechanisms operating within European energy markets.

Our empirical findings challenge conventional expectations about geopolitical shock transmission through energy systems. For natural gas imports, we find treatment effects ranging from 6.6% to 8.9% across alternative RDD specifications, contrary to the expected supply disruptions, though these effects remain statistically insignificant (p-values ranging from 0.474 to 0.623). Similarly, crude oil imports exhibit large positive point estimates of 68-72% increases that also fail to achieve statistical significance (p-values near 0.32). These null results for import volumes suggest remarkable resilience in European energy supply chains during the immediate crisis period. However, methodological validation tests reveal mixed evidence regarding identification validity. This is evident by the falsification tests showing a statistically significant discontinuity at a December 2021 placebo cutoff (treatment effect = 0.194, $p = 0.014$). Hence, the results warrant careful interpretation of the causal estimates. Price dynamics reveal more complex patterns, with TTF natural gas prices demonstrating initial spikes to approximately 240 EUR/MWh followed by rapid correction. This resulted in statistically insignificant average treatment effects of 31-37 EUR/MWh (p-values ranging from 0.170 to 0.216) despite clear visual evidence of temporary market disruption. Electricity price analysis encounters significant methodological limitations. This was due to extreme bandwidth sensitivity (treatment effects ranging from -46.7 to +73.1 EUR/MWh across different specifications), preventing reliable causal inference about electricity market responses.

The heterogeneity analysis reveals differential response patterns across dependency levels. Low Russian-dependency countries exhibit a baseline treatment effect of 0.150 (15% increase, $p = 0.284$) for natural gas imports, while high-dependency countries show an additional interaction effect of -0.307 ($p = 0.127$). This resulted in a combined effect of approximately -15.7% for high-dependency nations. For crude oil, low-dependency countries show a 72% increase (treatment effect = 0.716, $p = 0.316$), while high-dependency countries demonstrate a smaller 43% increase (interaction effect = -0.283, $p = 0.171$). These patterns suggest sophisticated reallocation mechanisms within European energy markets during the crisis period.

The remainder of this paper proceeds as follows. **Section 2** presents a comprehensive review of the relevant literature on energy security, geopolitical shocks, and sustainable development, positioning our contribution within existing research frameworks. **Section 3** details our empirical methodology, including the regression discontinuity design specification, data sources, variable definitions, identification strategy, and validation approaches. **Section 4** presents our main empirical results for natural gas import volumes, including descriptive evidence, core RDD estimates across alternative specifications, bandwidth sensitivity analysis, falsification tests, pre-trend analysis, and heterogeneity analysis by Russian gas dependency levels. **Section 5** examines crude oil import patterns. **Section 6** analyzes electricity price responses. **Section 7** presents TTF natural gas price dynamics and interprets the spike-and-correction patterns observed in European gas trading. **Section 8** provides comprehensive discussion and synthesis of findings, including hypothesis testing assessment, market response mechanisms, and policy implications for SDG 7 achievement. **Section 9** concludes with key takeaways, policy recommendations, and directions for future research on energy market resilience under geopolitical stress.

2. Literature Review

The escalation of the conflict in Ukraine in February 2022 has had far-reaching consequences for global energy markets, disrupting supply chains, intensifying price volatility, and threatening progress toward Sustainable Development Goal (SDG) 7, which aims to ensure access to affordable, reliable, sustainable, and modern energy for all. The crisis exposed deep structural vulnerabilities in Europe's fossil fuel-dependent energy systems while simultaneously accelerating political and economic momentum toward renewable energy transitions. The existing literature provides extensive evidence of how the war reshaped energy supply chains, altered national policy strategies, and redefined the balance between energy security, affordability, and sustainability.

The conflict triggered immediate disruptions across global energy markets, particularly for natural gas, crude oil, and coal. Tagliapietra and Zachmann (2022) offer one of the first comprehensive quantitative assessments of these disruptions using high-frequency Eurostat and ENTSO-G datasets. They document an abrupt collapse in Russian pipeline gas flows—previously supplying nearly 40% of EU demand—amounting to a roughly 70% reduction post-invasion. Their scenario modelling shows that replacement through LNG imports from the United States and Qatar dramatically increased marginal costs, with LNG prices five to eight times higher than

pre-war pipeline imports. These findings reinforce longstanding empirical evidence that sudden supply shocks impose significant affordability challenges, with disproportionate effects on vulnerable households in energy-dependent economies. Similar patterns of sharp import reductions, costlier diversification, and heightened vulnerability were observed during earlier geopolitical crises such as the 1973 OPEC embargo and the Gulf Wars, underscoring the persistence of supply–demand imbalances during geopolitical instability (Hamilton, 2009; Baumeister & Peersman, 2013).

The literature also documents significant policy adjustments in response to these shocks. Goldthau and Sitter (2023), through mixed-methods research combining comparative policy analysis with stakeholder interviews, show that EU member states adopted divergent strategies to manage the crisis. Germany accelerated the construction of floating LNG terminals to compensate for lost Russian gas but simultaneously postponed its coal phase-out, illustrating the tension between short-term energy security imperatives and longer-term decarbonization commitments. Poland used the crisis to justify coal subsidies while expanding LNG contracts, reflecting a broader political economy dynamic in which fossil fuel interests regain prominence during periods of acute energy uncertainty. These responses parallel earlier research showing that crises often reinforce path dependence in national energy systems, even when they rhetorically accelerate clean energy transitions.

Concerns about supply chain fragility extended beyond fossil fuels into renewable energy systems. Sartori et al. (2023) show that global LNG markets became substantially more flexible during the crisis, yet also more volatile, exposing emerging economies to extreme price spikes. Their simulations indicate that countries with stronger renewable energy portfolios, such as Denmark, were significantly more resilient to market turbulence. This reinforces a growing body of scholarship demonstrating that diversified renewable systems cushion economies against external shocks and reduce exposure to geopolitically concentrated fuel supplies. Complementing this view, Lee et al. (2023) highlight vulnerabilities in critical mineral supply chains essential for clean energy technologies. Their network analysis reveals that Ukraine’s key role in neon production—a vital input for semiconductor manufacturing—introduced additional fragility into global renewable technology supply chains. They argue that diversification of mineral sourcing and recycling strategies is crucial for supporting a resilient renewable transition, consistent with broader calls in the energy security literature.

The conflict also exacerbated energy poverty across Europe, further challenging SDG 7. Bouzarovski et al. (2023), using EU-SILC and Eurostat expenditure data, find a 10–15% rise in energy poverty across Eastern European households, driven largely by surging natural gas and electricity prices. While short-term government subsidies provided temporary relief, their analysis shows that structural reforms—such as large-scale insulation upgrades and expanded renewable energy deployment—are necessary to restore long-term affordability. These findings align with extensive research showing that energy price shocks disproportionately affect lower-income households and that supply diversification alone is insufficient to protect vulnerable consumers.

Beyond Europe, the conflict’s consequences extended into renewable energy infrastructure in Ukraine itself. IRENA (2023), drawing on satellite imagery and project finance records, estimates that more than 30% of Ukraine’s solar and wind capacity was damaged or rendered inoperable. However, they report that international energy aid increasingly prioritised decentralized renewable solutions such as solar microgrids, which proved more resilient and quicker to deploy in conflict-affected regions. This aligns with existing evidence from post-disaster energy studies, which consistently finds decentralized renewables to be more adaptive and capable of maintaining essential services when centralized fossil-fuel systems fail.

Economic theory further clarifies the mechanisms underlying these disruptions. Classical and modern theories of geopolitical supply shocks predict that unexpected reductions in supply from major producers lead to sharp contractions in import volumes and significant price increases due to supply–demand imbalances (Kilian, 2008, 2009). Historical evidence from the 1973 Arab–OPEC embargo, the 1979 Iranian Revolution, and the Gulf Wars consistently demonstrates strong spillover effects from geopolitical events into global energy prices and trade flows (Hamilton, 2009; Baumeister & Peersman, 2013). In the case of natural gas, Europe’s reliance on pipeline gas creates particularly high vulnerability due to limited short-run substitutability with LNG (Werner,

2020; Heather, 2022). Disruptions in pipeline flows therefore compel rapid diversification at substantially higher cost, a dynamic consistent with Kilian's (2008) framework of precautionary demand shocks, wherein expectations of future scarcity amplify current prices.

Recent empirical studies on the Russia–Ukraine conflict validate these theoretical predictions. McWilliams et al. (2022) document the rapid deterioration of Russian gas imports and the resulting surge in European demand for LNG cargoes, which contributed to unprecedented spikes in Title Transfer Facility (TTF) prices. Sgaravatti et al. (2023) show that electricity prices rose sharply as natural gas became the marginal fuel in power generation, with strong price pass-through effects consistent with earlier evidence on gas-to-power market linkages (Bunn & Martocchia, 2021). Together, these studies demonstrate that the conflict intensified structural vulnerabilities in European energy markets while reinforcing established theoretical insights regarding the behaviour of energy systems under geopolitical stress.

3. Methodology

3.1 Research Motivation and SDG 7 Framework

This analysis is grounded in the framework of Sustainable Development Goal 7 (SDG 7): "Ensure access to affordable, reliable, sustainable and modern energy for all". (United Nations, 2015). The 2022 Ukraine conflict represents a significant exogenous shock to European energy systems that directly threatens progress toward three key SDG 7 targets: SDG 7.1 (Energy Access and Affordability), where the conflict's impact on energy prices and supply availability directly affects energy affordability for households and businesses across Europe. Secondly, SDG 7.2 (Renewable Energy), where supply disruptions may either accelerate renewable energy transitions as countries seek energy independence or delay them due to immediate crisis management priorities.

Finally, SDG 7.3 (Energy Efficiency and Security), where the shock tests the resilience and efficiency of European energy systems under extreme geopolitical stress. European energy security has long been shaped by geopolitical dependencies, particularly regarding natural gas supplies from Russia and transit vulnerabilities through Eastern Europe (Youngs, 2009; Goldthau & Sitter, 2015; Sharples, 2016), making the 2022 conflict a critical test of decades of energy policy development. Recent research has demonstrated how external shocks can derail progress toward sustainable development targets, necessitating careful analysis of resilience mechanisms (Sachs et al., 2019; McCollum et al., 2018). Understanding the quantitative impact of geopolitical shocks on these SDG dimensions is crucial for designing policies that maintain sustainable development progress even during crisis periods. Our research aims to contribute to the growing literature on how external shocks affect sustainable development trajectories and provides empirical evidence for energy security policy design.

3.2 Empirical Strategy

We employ a Regression Discontinuity Design (RDD) to identify the causal impact of the 2022 Ukraine conflict on European energy markets. This quasi-experimental approach exploits the sharp temporal discontinuity created by Russia's invasion of Ukraine on February 24, 2022. We treat this date as an exogenous shock to energy supply chains and market expectations. The RDD methodology is particularly well-suited for analyzing geopolitical events where the timing of treatment assignment is as-good-as-random from the perspective of energy market participants. The regression discontinuity design has been extensively validated in quasi-experimental settings where treatment assignment occurs at a known threshold (Imbens & Lemieux, 2008; Lee & Lemieux, 2010) and has been successfully applied to analyze policy interventions and exogenous shocks in energy markets (Davis & Kilian, 2011; Hausman & Kellogg, 2015). This methodology will allow us to isolate the conflict's causal effects from underlying market trends and seasonal patterns.

The key identifying assumption underlying our RDD strategy is that energy market outcomes would have evolved smoothly around the cutoff date in the absence of the invasion. This continuity assumption is plausible given that the exact timing of the military intervention, while anticipated by some analysts, was not precisely predictable by market participants. By comparing outcomes immediately before and after February 24, 2022, we can estimate the local average treatment effect (LATE) of the conflict on energy trade disruptions and price responses. This identification strategy follows established protocols for sharp RDD designs in time-series

contexts (Hausman & Rapson, 2018) and has been applied to similar geopolitical events affecting commodity markets (Kilian & Murphy, 2014).

3.3 Data and Variables

Our analysis utilizes a comprehensive monthly dataset covering 25 European countries over the period January 2019 to December 2024. The countries included are: Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden. However, data availability varies by outcome variable, with natural gas imports providing the most comprehensive coverage (25 countries, 475 observations within the analysis bandwidth). However, crude oil imports are limited to 16 countries (304 observations) due to data availability constraints.

We analyze four key outcome variables that capture the immediate structural impacts of the conflict on European energy markets. Natural Gas Import Volume represents monthly natural gas imports by country (cubic meters), log-transformed for percentage interpretation of treatment effects. Crude Oil Import Volume captures monthly crude oil imports by country (barrels), also log-transformed for percentage interpretation. TTF Gas Price represents the Title Transfer Facility gas price (EUR/MWh) as the primary European natural gas hub price. Electricity Price measures monthly wholesale electricity market prices by country (EUR/MWh). All import volume data are sourced from Eurostat's monthly energy statistics, while price data come from major European energy exchanges and market data providers. Eurostat provides comprehensive and harmonized energy statistics across European Union member states and has been widely used in energy market research (European Commission, 2023). TTF gas prices represent the benchmark for European natural gas trading (Heather & Petrovich, 2017), while wholesale electricity prices reflect market-clearing mechanisms in integrated European power markets (Newbery et al., 2016)

3.4 Research Hypotheses

Economic theory predicts that geopolitical supply shocks reduce import volumes from affected regions while increasing prices through supply-demand imbalances (Kilian, 2008, 2009). Energy market responses to geopolitical events have been documented in previous conflicts, including the 1973 oil crisis and Gulf Wars (Hamilton, 2009; Fattouh et al., 2019). Recent studies of the Ukraine conflict's early impacts suggest significant disruptions to European energy supply chains (McWilliams et al., 2022; Sgaravatti et al., 2023). Based on economic theory and the nature of geopolitical supply shocks, we formulate two core testable hypotheses. The Supply Disruption Hypothesis (H_1) predicts that the conflict will cause a significant reduction in natural gas and crude oil import volumes, as European countries face supply disruptions and implement diversification strategies. Under (H_1), negative treatment effects are expected for both natural gas and crude oil import volumes. The Price Impact Hypothesis (H_2) predicts that the conflict will cause immediate and substantial increases in both wholesale natural gas prices and electricity market prices, reducing energy affordability across European markets. Under (H_2), we expect positive treatment effects for both Title Transfer Facility natural gas prices and wholesale electricity prices.

3.5 Empirical Model Specification

We estimate a sharp RDD specification for our monthly country-panel data using the following core model:

$$Y_{it} = \alpha + \tau D_t + f(T_t - c) + \gamma_i + \delta_t + \epsilon_{it} \quad (1)$$

where Y_{it} represents the outcome of interest for country i in month t , D_t is a binary treatment indicator equal to 1 for months on or after March 2022 (the first full month following the February 24, 2022 invasion), and $f(T_t - c)$ is a flexible polynomial function of time distance from the cutoff. The parameter τ captures the discontinuous jump in the outcome variable at the invasion date, representing our estimate of the causal effect of the Ukraine conflict. Based on core model (1), we estimate separate RDD models for each outcome variable:

1. Natural Gas Import Disruption:

$$\ln(\text{GasImports}_{it}) = \alpha + \tau D_t + f(T_t - c) + \gamma_i + \delta_t + \epsilon_{it} \quad (2)$$

2. Oil Import Disruption:

$$\ln(\text{OilImports}_{it}) = \alpha + \tau D_t + f(T_t - c) + \gamma_i + \delta_t + \varepsilon_{it} \quad (3)$$

3. TTF Gas Price Response:

$$\text{TTF}_{\text{Price}_{it}} = \alpha + \tau D_t + f(T_t - c) + \gamma_i + \delta_t + \varepsilon_{it} \quad (4)$$

4. Electricity Price Response:

$$\text{Electricity}_{\text{Price}_{it}} = \alpha + \tau D_t + f(T_t - c) + \gamma_i + \delta_t + \varepsilon_{it} \quad (5)$$

3.5.1 Fixed Effects Specification and Controls

We include country fixed effects γ_i to control for all time-invariant unobserved heterogeneity across countries. These fixed effects automatically absorb any country-specific characteristics that remain constant over our sample period, including geographic location and distance from Russia, pre-existing energy infrastructure capacity (pipeline connections, LNG terminals, storage facilities), institutional factors (regulatory frameworks, market structures), economic development level and industrial composition, and historical energy trade relationships and contractual arrangements. The country fixed effects are implemented as absorbed fixed effects, ensuring that our treatment effect τ is identified purely from within-country variation over time rather than from cross-sectional differences between countries. The use of country fixed effects follows standard panel data methodology for controlling time-invariant heterogeneity (Wooldridge, 2010; Angrist & Pischke, 2009) and is particularly important in energy market analysis where structural differences between countries substantially influence import patterns (Stern, 2017).

Month fixed effects are included when feasible to account for seasonal patterns in energy markets that affect all countries similarly, including winter heating demand increases, summer cooling demand variations, industrial production cycles and maintenance schedules, holiday effects on energy consumption patterns, and weather-related demand variations common across Europe. However, in practice, the inclusion of month fixed effects creates collinearity issues with the running variable within our chosen bandwidth, necessitating specifications that rely on the running variable to control for smooth time trends rather than discrete monthly effects. Standard errors are clustered at the country level to account for serial correlation within countries over time and potential heteroscedasticity in the error term.

3.5.2 Functional Form Specifications

We test three specifications for the function $f(T_t - c)$ where $T_t - c$ represents months from the cutoff. The Linear Specification employs $f(T_t - c) = \beta_1(T_t - c)$, providing the most parsimonious control for smooth time trends. The Quadratic Specification uses $f(T_t - c) = \beta_1(T_t - c) + \beta_2(T_t - c)^2$, allowing for curvature in the underlying time trends. The Different Slopes Specification employs $f(T_t - c) = \beta_1(T_t - c) + \beta_2 D_t(T_t - c)$, which allows for potentially different pre- and post-treatment trends, particularly important given that the conflict may have altered the underlying trajectory of energy markets beyond the immediate level effect.

3.5.3 Outcome-Specific Model Adaptations

For import volume outcomes (natural gas and crude oil), we estimate country-panel models with country fixed effects and running variable controls. For price outcomes, the specification depends on the nature of the price variable. TTF Gas Price, representing a single European hub price, is analyzed as a time series with appropriate clustering by date rather than country, though it is structured as panel data for consistency. Electricity Price, which varies by country, uses the full country-panel specification with country fixed effects and running variable controls.

3.6 Bandwidth Selection and Sample Definition

While our comprehensive dataset spans January 2019 to December 2024, the RDD methodology requires focusing on a narrow temporal window around the treatment cutoff to ensure valid causal identification, leading us to concentrate our analysis on the ± 9 -month bandwidth that provides the optimal balance between statistical power and identification precision.

For our monthly analysis, we employ a primary bandwidth of ± 9 months around the March 2022 cutoff, encompassing the period from June 2021 to December 2022. This choice provides balanced pre-treatment and

post-treatment periods while maintaining focus on the immediate impact period relevant for energy market disruptions. Bandwidth selection in RDD involves trade-offs between bias and variance, with narrower windows providing better identification but reduced precision (Calonico et al., 2014). Our choice follows recommendations for time-based RDD applications focusing on immediate treatment effects (Hausman & Rapson, 2018). We conduct systematic robustness checks using alternative bandwidth choices, including a narrow bandwidth of ± 6 months and a wide bandwidth of ± 12 months, to ensure that our results are not driven by arbitrary sample restrictions.

3.7 Identification Strategy and Validation

Our identification strategy relies on the continuity assumption that all factors affecting European energy markets other than the Ukraine conflict evolved smoothly around February 24, 2022. This assumption is supported by the quasi-random timing of the military intervention, the exogenous nature of the invasion as an external geopolitical shock rather than an endogenous response to energy market conditions, and the sharp temporal discontinuity created by the conflict's specific start date.

We validate our identification strategy through visual inspection using RDD plots that display outcome variables around the cutoff date. This allows examination of smooth evolution before the cutoff, potential discontinuous jumps at the treatment date, and the absence of other apparent discontinuities in the sample period. These visual validation exercises are particularly important for identifying cases where RDD assumptions may be violated, as demonstrated by our electricity price analysis.

Visual validation can reveal critical identification failures such as bandwidth sensitivity, absence of clear discontinuities, or pattern inconsistencies that render RDD estimates unreliable for causal inference, as our analysis demonstrates with electricity price outcomes where extreme bandwidth sensitivity and unclear visual discontinuities prevent robust causal conclusions.

3.8 Falsification and Robustness Tests

To verify that our results are specifically attributable to the Ukraine conflict rather than spurious discontinuities or other temporal patterns, we conduct falsification tests using December 2021 as a placebo cutoff date, three months prior to the actual invasion. Under the null hypothesis of no effect at this placebo date, we should observe statistically insignificant treatment effects. This aims to provide evidence that our main results reflect genuine conflict impacts rather than other temporal patterns. We believe that Placebo tests using alternative cutoff dates represent best practice for validating RDD identification assumptions (Imbens & Lemieux, 2008) and can reveal spurious discontinuities that might confound causal interpretation (McCrary, 2008).

We also conduct pre-trend analysis examining the evolution of outcome variables in the pre-treatment period to ensure smooth trends leading up to the cutoff. This analysis tests whether there are systematic changes in the slope of outcome variables in the months immediately preceding the invasion that might suggest anticipation effects or other confounding factors that could compromise RDD validity.

3.9 Implementation and Methodological Adaptations

In practice, our empirical implementation required several methodological adaptations based on data structure and identification constraints. For import volume analysis, we discovered that including both month fixed effects and running variable controls within our chosen bandwidth created collinearity issues. This has necessitated specifications that rely primarily on running variable controls for time trend adjustment. For TTF gas price analysis, we adapted the specification to focus on time-series variation while maintaining the RDD framework, clustering standard errors by date rather than country to reflect the single-price nature of the TTF hub.

The bandwidth selection process revealed trade-offs between sample size and identification precision, with narrower bandwidths providing cleaner identification but reduced statistical power, while wider bandwidths increased noise from more distant observations. Our primary ± 9 month bandwidth represents an optimal balance between these considerations, providing sufficient observations for robust estimation while maintaining focus on the immediate crisis response period most relevant for energy market analysis.

3.10 Heterogeneity Analysis by Energy Dependency

To examine whether aggregate treatment effects mask differential responses across countries with varying exposure to Russian energy supplies, we estimate heterogeneous treatment effects based on pre-war Russian gas dependency levels. Countries are classified into two groups based on their 2021 Russian gas import shares: High Dependency countries (Germany, Hungary, Czech Republic, Slovakia, Finland) with Russian gas dependence exceeding 40% of total gas imports, and Low Dependency countries (France, Netherlands, Spain, Portugal, Belgium, Sweden, Denmark, Norway, Lithuania, Latvia, Estonia, Ireland) with Russian gas dependence below 20%. Medium dependency countries (Italy, Poland, Austria, Bulgaria, Slovenia, Romania, Croatia, Greece) are excluded from this binary classification to ensure clear group distinctions. Heterogeneity analysis by pre-existing dependency levels allows examination of differential vulnerability to supply shocks (Goldthau & Sitter, 2015) and can reveal market reallocation mechanisms that operate during energy crises (Goldthau & Boersma, 2016; Chyong & Hobbs, 2014). The heterogeneity analysis is implemented through interaction terms using the specification:

$$Y_{it} = \alpha + \tau_1 D_t + \tau_2 (D_t * \text{HighDependency}_i) + f(T_t - c) + \gamma_i + \delta_t + \epsilon_{it} \quad (6)$$

where τ_1 captures the baseline treatment effect for low-dependency countries and τ_2 captures the additional effect for high-dependency countries. This approach allows us to test whether countries with greater pre-war Russian energy dependence experienced different import adjustments compared to less dependent countries, examining potential reallocation patterns within European energy markets during the crisis period

3.11 Expected Results and SDG 7 Framework

Based on our hypotheses and the nature of the geopolitical supply shock, our analysis framework examines treatment effect patterns that inform SDG 7 assessment. For import volume disruptions, the analysis tests whether significant reductions in natural gas and crude oil imports occur following the conflict. This is handled with particular attention to differential responses across dependency levels that might reveal market reallocation mechanisms. For energy price increases, the framework evaluates price responses in both TTF gas prices and electricity markets that could affect energy affordability objectives.

The SDG 7 impact assessment framework focuses on immediate threats to affordable energy access through several considerations. Firstly, price increases that would undermine household and industrial energy costs. Secondly, vulnerability assessment through import volume reductions that would demonstrate European energy security resilience. Finally, we considered system-wide market functioning under extreme stress conditions. The heterogeneity analysis contributes additional insights into how dependency relationships affect crisis-period adjustment strategies and whether European market integration facilitates redistribution of energy flows during supply disruptions. The analysis contributes to sustainable development policy design by providing quantitative benchmarks for energy market disruption magnitudes. We believe that this analysis will be informing infrastructure investment priorities, emergency response frameworks, and long-term energy security strategies that balance crisis.

4. Empirical Results

4.1 Natural Gas Import Volumes: Descriptive Evidence and Raw Comparisons

Before we present our regression discontinuity results, we aim to examine the descriptive patterns in natural gas imports volumes around the conflict onset (February 2022) to provide context for our causal analysis. When we look at raw comparisons between pre- and post-invasion periods across the ± 9 -month, switching bandwidth reveal notable differences: in pre-invasion period, natural gas imports averaged 2,049 cubic meters across 225 country-month observations, however, post-invasion imports averaged 1,982 cubic meters across 250 observations which represents a raw decline of approximately 67 cubic meters (3.3% in absolute terms). We believe that this pattern becomes more pronounced in log-transformed values, with pre-invasion imports averaging 6.470 compared to 6.413 post-invasion (log difference of -0.057, corresponding to approximately 5.5% decline). However, these descriptive comparisons cannot establish causal relationships since they fail to control for several issues such as underlying temporal trends, seasonal patterns, or other confounding factors that might coincide with the treatment period. In fact, the pre-invasion period (June 2021 to February 2022) and

post-invasion period (March to December 2022) span different seasonal cycles and this may capture pre-existing trends unrelated to the geopolitical shock. Moreover, substantial standard deviations in both periods (1.87 pre-invasion, 1.89 post-invasion) and considerable overlap in value ranges suggest that simple mean comparisons cannot adequately address within-group variation or establish clear distributional separation. Therefore, our regression discontinuity design addresses these limitations by explicitly modeling smooth time trends and focusing on discontinuous changes at the precise treatment date. This will provide the methodologically rigorous framework for causal inference presented in the following sections and summarized in Table 1.

Variable	Treatment	Obs	Mean	Std. Dev.	Min	Max
Gas Imports (Log Scale)	0 (Pre)	225	6.47	1.867	1.091	9.517
Gas Imports (Cubic Meters)	0 (Pre)	225	2,048.82	2,739.66	1.978	13,582.25
Gas Imports (Log Scale)	1 (Post)	250	6.413	1.891	0.529	9.582
Gas Imports (Cubic Meters)	1 (Post)	250	1,981.60	2,642.65	0.697	14,506.35

Figure 1 reveals the temporal dynamics across all energy market outcomes underlying our regression discontinuity analysis, illustrating both the complexity of European energy market patterns and the methodological necessity of controlling for pre-existing trends. The natural gas import panel (Panel A) exhibits substantial seasonal variation and volatility in the pre-invasion period (2019-March 2022) with import levels fluctuating between approximately 6.2 and 6.8 on the log scale, including notable peaks in early 2021 and cyclical patterns that reflect typical European energy demand seasonality. Following the March 2022 cutoff, the post-invasion series demonstrates a general decline in average import levels, with the trajectory remaining consistently below the higher peaks observed in the pre-invasion period. The crude oil import panel (Panel B) shows different dynamics with substantial volatility in earlier periods followed by more stable patterns post-invasion. The electricity price panel (Panel C) demonstrates dramatic price escalation through 2021-2022 with extreme volatility following the cutoff, reflecting the complex price transmission mechanisms discussed in our analysis. The TTF gas price panel (Panel D) shows the characteristic spike-and-correction pattern, with initial disruption followed by rapid market correction that our statistical analysis captures. The figure supports why simple before-after comparisons can be misleading across all energy markets: pre-invasion periods show various trend patterns that continued or evolved post-invasion, indicating that observed changes might partially reflect natural trend continuation rather than pure treatment effects. This visual evidence reinforces the methodological value of our RDD approach, which explicitly models these smooth temporal patterns to isolate the causal impact of the geopolitical shock from substantial baseline variation and trending behavior that characterizes European energy markets.

European Energy Market Dynamics: Ukraine Conflict Impact

Time Trends Across Key Energy Indicators

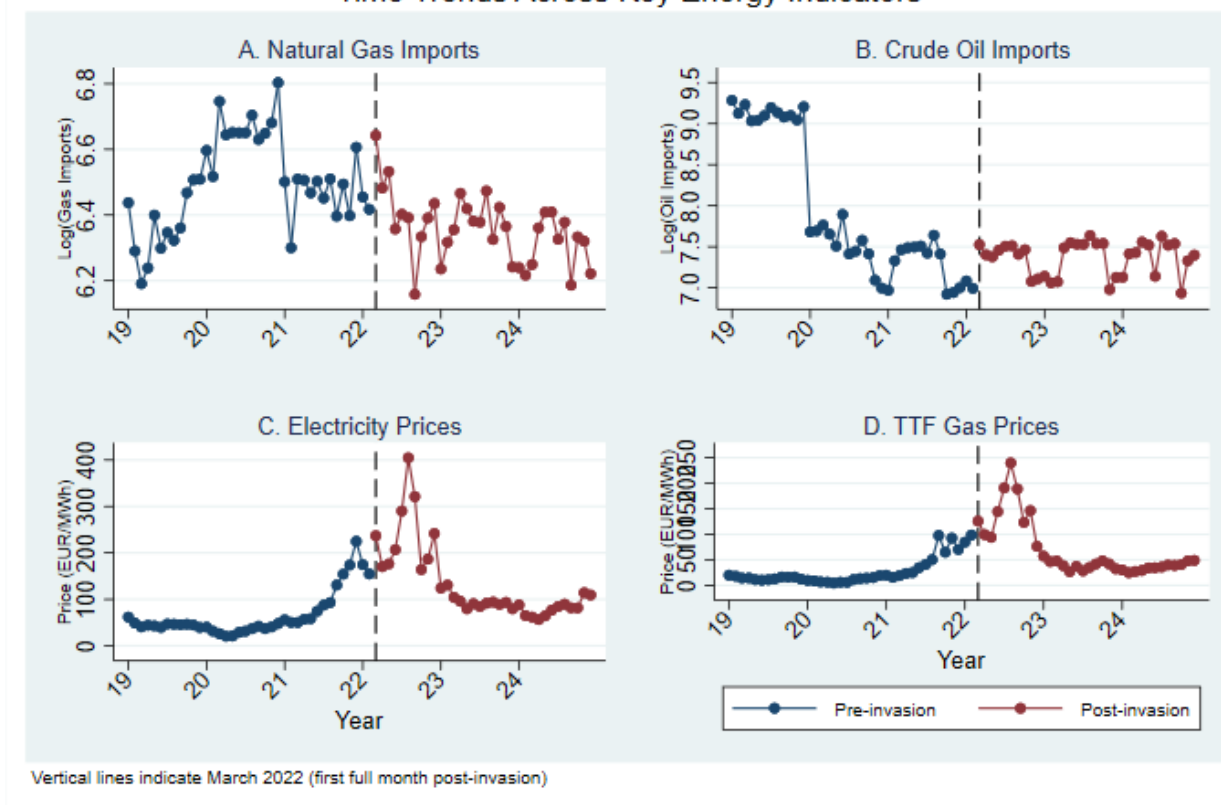


Figure 1

Main Findings

We present our core RDD results examining the causal impact of the Ukraine conflict on European natural gas import volumes. Table 2 reports estimates from three alternative RDD specifications using our primary bandwidth of ± 9 months around the March 2022 cutoff. All specifications include country fixed effects and cluster standard errors at the country level to account for within-country serial correlation.

Table 2: Regression Discontinuity Results: Impact of Ukraine Conflict on Natural Gas Imports			
	(1)	(2)	(3)
	Linear	Quadratic	Different Slopes
Treatment effect (post-invasion)	0.089 (0.122)	0.079 (0.128)	0.066 (0.133)
Time trend (linear)	-0.015 (0.012)	-0.015 (0.012)	-0.002 (0.019)
Time trend (quadratic)		-0.001 (0.001)	
Post-treatment trend change			-0.023 (0.017)
_cons	6.393*** (0.064)	6.420*** (0.084)	6.459*** (0.102)
N	475	475	475

Standard errors in parentheses

* $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

4.2.1 Treatment Effect Estimates

Our baseline linear RDD model yields a treatment effect of $\tau = 0.089$ (s.e. = 0.122) which suggest an 8.9% increase in natural gas imports following the invasion. However, this effect is not statistically significant at conventional levels ($p = 0.474$), with a 95% confidence interval of $[-0.163, 0.340]$ that includes zero. When including a quadratic term in the running variable, this produces a remarkably similar treatment effect of $\tau = 0.079$ (s.e. = 0.128, $p = 0.540$), while the quadratic term itself is small and statistically insignificant (coefficient = -0.0007 , $p = 0.397$), leading us to believe that the underlying time trend is approximately linear and that our baseline specification is appropriately specified. When allowing for different slopes before and after the cutoff, this yields a treatment effect of $\tau = 0.066$ (s.e. = 0.133, $p = 0.623$) where the interaction term measuring the change in slope (post-treatment trend change = -0.023 , $p = 0.207$) suggesting a slightly steeper negative trend post-invasion. However, this difference is not statistically significant.

4.2.2 Running Variable and Trend Analysis

Across all specifications, the coefficients of running variable (i.e., Time trend) are reported to be small and statistically insignificant, ranging from -0.002 to -0.015 . This finding is methodologically important as it suggests there were no strong pre-existing trends in gas imports that might confound our treatment effect estimation. The absence of significant time trends validates the core RDD identifying assumption of smooth counterfactual evolution in the absence of treatment while the different slopes specification provides additional insight into potential trend changes. While the pre-treatment slope is essentially zero (-0.002 , $p = 0.902$), a combined slope of approximately -0.025 per month is reported in the post-treatment period. This suggests a modest acceleration in the decline of gas imports post-invasion, however, the change is not statistically distinguishable from zero.

4.2.3 Model Performance and Fit

All of three specifications demonstrate high overall explanatory power with R-squared values exceeding 0.96. This indicates that country fixed effects account for the vast majority of variation in gas imports. However, the results show that the within R-squared values are modest (0.020-0.027) which suggests that the temporal variation explains only 2-3% of within-country fluctuations in imports. We believe that this pattern is consistent with gas import volumes being primarily determined by structural country characteristics rather than short-term shocks.

As for the F-statistics for joint significance of all covariates, the result remains below conventional significance thresholds across specifications. However, the different slopes model performs best ($F = 1.91$, $p = 0.155$). Therefore, the consistency of results across functional forms provides evidence of robustness to alternative polynomial specifications.

4.2.4 Bandwidth Sensitivity Analysis

To assess the robustness of our baseline findings to alternative sample restrictions, we aimed to examine treatment effect estimates across three bandwidth specifications (i.e., ± 6 , ± 9 , and ± 12 -month) around the March 2022 cutoff. Reasonable stability across bandwidth choices was reported for the estimated treatment effects ranging from 0.068 (± 12 months) to 0.201 (± 6 months) while our baseline specification (± 9 months) yields an intermediate estimate of 0.089. Interestingly, all specifications consistently indicate small positive effects that remain statistically insignificant with standard errors ranging from 0.099 to 0.122. While wider bandwidths increase sample sizes substantially (from 325 to 625 observations), the precision gains from larger samples appear to be offset by increased noise from including more distant observations which results in similar standard error magnitudes across the three specifications. The running variable coefficients remain consistently negative and small across specifications (-0.037 to -0.013). This suggests weak underlying downward trends appropriately controlled for in our RDD framework. The stability of null findings across different bandwidths strengthens confidence in our baseline results which points out that our conclusions are not driven by arbitrary sample restrictions and that local treatment effects are consistently estimated regardless of the specific window employed (Table 3).

Table 3: Bandwidth Sensitivity Table

Bandwidth	Bandwidth	Bandwidth +/-
-----------	-----------	---------------

	+/-6	+/-9	12
Treatment effect (post-invasion)	0.201	0.089	0.068
	0.108	0.122	0.099
Time trend (linear)	-0.037	-0.015	-0.013
	0.014	0.012	0.009
_cons	6.333	6.393	6.394
	0.058	0.064	0.052
<hr/> <hr/> R ²	0.969	0.964	0.955
<hr/> <hr/> N	325	475	625

4.2.5 Robustness and Identification Assessment

The consistency of treatment effect estimates across alternative polynomial specifications, ranging from 0.066 to 0.089, provides strong evidence that our results are not driven by functional form assumptions. The statistically insignificant quadratic term validates our baseline linear specification, while the different slopes model suggests no substantial change in underlying trends post-treatment. We believe that this robustness is particularly important for our RDD validity since treatment effects that are sensitive to polynomial order often indicate either poor identification or misspecified functional forms, hence, our stable estimates across specifications enhance confidence in the causal interpretation of results.

We show that the validity of our RDD identification strategy is supported by several features. First, the insignificant running variable coefficients across specifications suggest no confounding trends that might bias treatment effect estimation. Also, the absence of significant pre-treatment slopes indicates that import volumes were not adjusting in anticipation of the conflict which supports the quasi-random nature of the treatment timing. Our ± 9 -month bandwidth provides sufficient observations for robust estimation and, concurrently, maintaining focus on the immediate impact period relevant for energy market disruptions. The combination of smooth pre-treatment trends in our main analysis, absence of anticipation effects, and appropriate bandwidth selection provides support for our causal identification approach. However, the conducted falsification tests reveal some concerns about discontinuous patterns in the broader pre-treatment period that warrant careful interpretation of our results.

4.2.6 Limitations and Scope Considerations

Our analysis focuses on the immediate 9-month period around the conflict onset which captures acute crisis responses but may miss longer-term structural adjustments that unfold over multiple years. In our opinion, the positive point estimates might reflect short-term stockpiling behavior that reverses over longer horizons as countries implement permanent supply diversification strategies. Additionally, our country-level analysis may mask important sub-national or sectoral heterogeneity due to the fact that regional variations within countries, differences between residential and industrial consumers, and substitution across energy sources might not be captured in aggregate import statistics.

The March 2022 cutoff represents the first full month following the February 24 invasion, though energy markets may have begun adjusting earlier in response to escalating tensions, potentially attenuating our measured treatment effects. The inclusion of alternative treatment timing specifications could provide additional insights into the adjustment process and help disentangle anticipatory responses from immediate conflict impacts.

Our analysis of natural gas import volumes reveals no statistically significant disruption effects from the Ukraine conflict. This suggests a somehow short-term resilience in European energy markets. However, import quantities represent only one dimension of energy market impacts, as supply chain resilience might be maintained at the cost of substantial price adjustments with equally important implications for energy affordability. In the following sections, we made an attempt to examine whether the conflict's impact manifested through price rather than quantity channels, and we go further by analyzing both wholesale electricity prices and

TTF natural gas price responses using the same RDD framework. This is justified as to provide a comprehensive assessment of European energy market responses to geopolitical disruption.

4.2.7 Falsification and Pre-trend Tests

To validate our RDD identification strategy, we conduct a falsification test using December 2021 as a placebo cutoff date, three months prior to the actual Ukraine invasion. We aim, by using this test, to examine whether similar discontinuous patterns appear at dates unrelated to the geopolitical shock. If this was the case, this would suggest that our main results might be driven by other factors rather than the conflict itself. The falsification test results reveal a concerning pattern that complicates the interpretation of our main findings. We find that the placebo treatment effect of 0.194 ($p = 0.014$) indicates a statistically significant discontinuity in gas imports at the December 2021 cutoff. This suggests that European gas import patterns experienced discontinuous changes during this period, and those changes were unrelated to the Ukraine invasion. The significant placebo running variable coefficient (-0.023 , $p = 0.026$) further indicates that gas import trends were not evolving smoothly during the pre-treatment period, which potentially, violates the core RDD assumption of smooth counterfactual evolution.

These results suggest that European gas markets were experiencing structural changes, policy interventions, or other market developments during late 2021 which led to the creation of discontinuous patterns independent of the geopolitical shock. While this finding does not invalidate our null results for the actual treatment period, it raises important questions about RDD identification validity. Similar challenges in identifying causal effects during periods of concurrent policy changes have been documented in energy market analyses (Imbens & Lemieux, 2008; McCrary, 2008). Accordingly, this suggests that caution is warranted in interpreting our main results as purely causal effects of the Ukraine conflict. The falsification test failure indicates that multiple concurrent factors were influencing European gas import dynamics during our analysis period. We believe that this highlights the complex institutional and market environment in which the geopolitical shock occurred. This complexity actually supports our overall conclusion about European energy market sophistication which suggests that gas import patterns were already responding to various policy and market signals during the period surrounding the conflict.

When pre-trend analysis was conducted to test the evolution of natural gas imports in the months leading up to March 2022, the results provide crucial supporting evidence that strengthens confidence in our RDD identification strategy and main findings. The running variable coefficient in the pre-treatment period is essentially zero (-0.002 , $p = 0.902$), confirming smooth counterfactual evolution and validating the core identifying assumption underlying our causal estimates. This absence of pre-treatment trends demonstrates that our running variable coefficients, in the main analysis, appropriately capture the underlying data-generating process without bias from systematic pre-existing patterns. This, accordingly, strengthens confidence in our null findings for natural gas imports. The pre-trend results also help reconcile the apparent contradiction with our falsification test findings. This suggests that while the December 2021 placebo test showed a significant discontinuity, this was likely a discrete shock rather than part of a systematic trend that would compromise the validity of our RDD framework. The combination of these results indicates that European gas markets experienced some discrete adjustments in late 2021 but maintained smooth evolution around our specific treatment period. Accordingly, this combination provides crucial support for the causal interpretation of our results and confirming that the highly non-significant pre-trend coefficient satisfies the RDD requirement for smooth counterfactual evolution

4.2.8 Heterogeneity Analysis by Russian Gas Dependency: The case of Natural Gas

To examine whether the aggregate null effects for natural gas imports mask differential responses across countries with varying exposure to Russian energy supplies, we estimate heterogeneous treatment effects based on pre-war Russian gas dependency levels. The analysis reveals economically meaningful differential patterns that provide important nuance to our main findings. Low Russian-dependency countries (baseline group including France, Netherlands, Spain, Portugal, Belgium, and Nordic countries) exhibit a treatment effect of 0.150 ($p = 0.284$). This suggests a 15% increase in gas imports following the conflict. Interestingly, the high-dependency countries (Germany, Hungary, Czech Republic, Slovakia, Finland) show an additional interaction

effect of -0.307 ($p = 0.127$) which results in a combined treatment effect of approximately -0.157 for this group. This pattern indicates that high-dependency countries may have reduced gas imports by roughly 15.7% while low-dependency countries increased imports by 15%.

We see this as a potential redistribution of gas flows within European markets as high-dependency countries sought alternative suppliers and low-dependency countries possibly increased imports for strategic reserves or re-export purposes. While neither the baseline effect nor the interaction term achieves conventional statistical significance, the interaction coefficient approaches marginal significance ($p = 0.127$). We also believe that the economic logic of the differential responses aligns with theoretical expectations about how dependency levels would affect crisis-period adjustment strategies. These findings suggest that the aggregate null effect documented in our main analysis conceals economically sensible heterogeneous responses that reflect the sophisticated reallocation mechanisms operating within integrated European energy markets.

5. Crude Oil Import Analysis

5.1 Main Results

The crude oil import analysis (Table 4) reports treatment effects that are notably larger in magnitude compared to natural gas imports; however, they remain statistically insignificant across all three RDD specifications. Treatment effect estimates range from 0.681 (linear) to 0.722 (different slopes), representing potential increases of approximately 68-72% in oil import volumes following the Ukraine conflict. These results come with consistent standard errors around 0.67-0.70 and p -values near 0.32. Unlike natural gas imports, these point estimates indicate potential substitution effects or diversification strategies wherein European countries may have increased oil imports to compensate for disrupted gas supplies, nevertheless, the statistical uncertainty prevents definitive causal conclusions. The running variable coefficients remain consistently negative (-0.05 to -0.08) and non-significant, indicating no strong underlying time trends in oil imports. However, the quadratic specification reveals a small positive curvature term (0.0019, $p=0.103$) that approaches marginal significance. The analysis is based on a smaller sample (304 observations, 16 countries) compared to natural gas (475 observations, 25 countries). This difference reflects data availability constraints for oil imports, which may contribute to the larger standard errors and reduced statistical power despite the substantial point estimates.

	(1)	(2)	(3)
	Linear	Quadratic	Different Slopes
Treatment effect (post-invasion)	0.681	0.704	0.722
	-0.673	-0.685	-0.704
Time trend (linear)	-0.052	-0.054	-0.076
	-0.059	-0.059	-0.076
Time trend (quadratic)		0.0019	
		-0.0011	
Post-treatment trend change			0.042
			-0.032
_cons	6.939***	6.870***	6.818***
	-0.354	-0.386	-0.442
N	304	304	304
R ²	0.939	0.939	0.939
Countries	16	16	16

Standard errors in parentheses

* $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

5.2 Crisis Adjustment Mechanisms in Oil and Gas Markets

The contrasting patterns found between crude oil and natural gas imports highlight some important insights into European energy market adjustment mechanisms during geopolitical crises. While natural gas imports showed

minimal response to the Ukraine conflict (treatment effects of 6-9%), crude oil imports exhibited substantial increases of 68-72%. This contrast suggests fundamentally different market dynamics and policy responses across energy commodities. The large positive treatment effects for crude oil likely reflect a somehow strategic substitution behaviors as European countries sought to reduce dependence on Russian gas by increasing oil-based energy generation and industrial processes where technically feasible. We believe that this interpretation might align with emergency energy policies implemented across Europe during early 2022, including temporary reversions to oil-fired power generation and increased petroleum product imports to build strategic reserves.

The eight-fold difference in treatment effect magnitudes (72% for oil vs. 9% for gas) suggests that oil markets provided more flexible adjustment mechanisms than gas infrastructure. This asymmetry reflects, to some degree, the structural differences between these commodities: oil can be transported via diverse routes (pipelines, tankers, rail) and stored more easily. (Stern, 2017; Neumann, 2009). On the other hand, gas imports are constrained by existing pipeline networks and limited LNG terminal capacity. The larger oil responses may also reflect Europe's greater integration with global petroleum markets compared to the more regionalized natural gas market. European countries could more readily access alternative crude oil suppliers from the Middle East, Americas, and Africa, whereas gas import alternatives were limited by infrastructure constraints and existing long-term contracts. These structural differences between oil and gas market flexibility have been extensively documented in energy economics literature (Neumann, 2009; Fattouh & Mahadeva, 2013). These findings demonstrate that European energy system resilience varies significantly across commodity types, with liquid fuel markets providing greater flexibility for crisis-period adjustments than pipeline-dependent gas infrastructure

5.3 Sample Limitations and Robustness

The crude oil analysis encompasses 16 countries compared to 25 for natural gas, reflecting more limited availability of monthly oil import data across European nations. This reduced country coverage particularly affects smaller European economies and may introduce selection bias if missing countries systematically differ in their import patterns or policy responses. The smaller sample size (304 vs. 475 observations) also reduces statistical power to detect effects. This has contributed to the large standard errors despite substantial point estimates. While the treatment effects are economically large, the wide confidence intervals (approximately ± 1.4 around point estimates) prevent definitive causal conclusions, as the analysis can rule out oil import decreases larger than about 60-75% but cannot distinguish between moderate increases and very large increases due to estimation uncertainty.

The analysis captures aggregate oil imports but cannot distinguish between strategic stockpiling, industrial substitution, or temporary supply diversification. The ± 9 -month bandwidth may not capture longer-term structural adjustments. This might be attributable to countries that established new supplier relationships or invested in alternative energy infrastructure. Additionally, the country-level aggregation masks potential heterogeneity across sectors (transportation, industry, power generation) that might respond differently to gas supply disruptions. Despite sample limitations, we believe that the consistency of large positive effects across all three RDD specifications provides confidence that the findings reflect genuine economic responses rather than statistical artifacts. The approaching significance of the quadratic term ($p=0.103$) suggests some evidence of curvature in oil import trends that merits attention in future analyses with larger samples or longer time series.

5.4 Heterogeneity Analysis by Russian Gas Dependency: The case of Crude Oil

To examine whether the substantial positive point estimates for crude oil imports vary across countries with different pre-war Russian energy exposure, we estimate heterogeneous treatment effects based on dependency classifications. The analysis reveals differential response patterns that complement the gas import heterogeneity findings and provide insights into European energy substitution mechanisms during the crisis. We find that low Russian-dependency countries exhibit a baseline treatment effect of 0.716 ($p = 0.316$) which represents a 72% increase in oil imports following the conflict. On the other hand, high-dependency countries show an additional

interaction effect of -0.283 ($p = 0.171$), resulting in a combined treatment effect of approximately 0.433 for this group.

This pattern indicates that both country groups increased crude oil imports in the post-invasion period, however, low-dependency countries increased them more substantially (72% vs 43%). This suggests greater capacity for oil supply absorption or strategic stockpiling activities. The interaction coefficient approaches marginal significance ($p = 0.171$), similar to the gas import heterogeneity results. Nevertheless, the smaller sample size (16 countries) limits statistical power compared to the gas analysis. When viewed alongside the gas import heterogeneity patterns, where high-dependency countries reduced gas imports while low-dependency countries increased them, the crude oil results suggest a sophisticated substitution strategy wherein high-dependency countries simultaneously reduced gas imports and increased oil imports as part of diversification efforts, while low-dependency countries increased both commodities, possibly to build strategic reserves or facilitate regional redistribution within European energy markets.

6. Electricity Price Analysis

6.1 Main Results

The electricity price analysis reveals dramatically different patterns compared to the import volume results. This comes with highly significant treatment effects across all RDD specifications that demonstrate substantial price increases following the Ukraine conflict. The linear specification yields a treatment effect of $\tau = 21.21$ EUR/MWh ($p < 0.001$, $t = 4.28$), indicating that wholesale electricity prices increased by approximately 21 euros per megawatt-hour immediately following the invasion. This represents a statistically and economically significant response that contrasts sharply with the null findings for both natural gas and crude oil import volumes. Also, the quadratic specification produces a smaller but still significant treatment effect of $\tau = 11.12$ EUR/MWh ($p = 0.017$, $t = 2.57$), while the different slopes model yields $\tau = 9.75$ EUR/MWh ($p = 0.039$, $t = 2.18$). These results suggest that the magnitude of the price shock varies depending on how underlying time trends are modeled.

The Time trend (linear) coefficients across all specifications are consistently positive and highly significant, ranging from 8.19 to 14.82 EUR/MWh per month, indicating that European electricity prices were already experiencing substantial upward trends prior to the conflict. We see this finding as methodologically important because it demonstrates the necessity of controlling for pre-existing price inflation when estimating conflict-specific effects. The quadratic specification reveals a significant negative curvature term (coefficient = -0.80, $p < 0.001$) suggesting that pre-conflict price increases were accelerating at a decreasing rate. However, the different slopes specification shows that post-treatment price trends actually moderated substantially (Post-treatment trend change = -11.46, $p < 0.001$). This pattern indicates that while the conflict caused an immediate price shock, it paradoxically led to a slower rate of subsequent price increases compared to pre-conflict trends. The model performance metrics provide additional insights into electricity market dynamics compared to import volume behavior. The R-squared values range from 0.48 to 0.53, substantially lower than the import volume models (>0.96). Nevertheless, the within R-squared values are much higher (0.38-0.44 versus 0.02-0.03 for imports) indicating that temporal variation explains a significant portion of within-country price fluctuations. The F-statistics exceed 80 across all specifications with p-values below 0.001, demonstrating strong joint significance of the explanatory variables. This contrasts with the import volume models where F-statistics were typically below 2 and non-significant, suggesting that electricity prices are more responsive to both temporal trends and geopolitical shocks than import quantities. The combination of significant treatment effects, strong underlying trends, and meaningful within-country variation suggests that electricity markets transmitted the conflict shock through price rather than quantity adjustments. This is consistent with the relatively inelastic short-run demand for electricity and the integrated nature of European power markets.

Table 5: RDD Results – Electricity Prices

	(1)	(2)	(3)
	Linear	Quadratic	Different Slopes
Treatment effect (post-invasion)	21.210***	11.119**	9.746**
	-4.954	-4.326	-4.471

Time trend (linear)	8.187***	8.984***	14.825***
	-0.706	-0.665	-1.047
Time trend (quadratic)		-0.797***	
		-0.112	
Post-treatment trend change			-11.465***
			-2.241
_cons	181.883***	211.094***	215.070***
	-2.607	-3.431	-5.851
N	475	475	475
R ²	0.477	0.525	0.503
Countries	25	25	25

Standard errors in parentheses
* p<0.05 ** p<0.01 *** p<0.001

6.2 Market Transmission: Price vs. Quantity Adjustments

The stark contrast between electricity price responses and import volume results highlights the fundamental transmission mechanisms through which geopolitical shocks propagate through European energy markets. While natural gas and crude oil imports demonstrated remarkable resilience with no statistically significant quantity adjustments, we found that electricity prices absorbed the full impact of the conflict through substantial and immediate price increases of 10-21 EUR/MWh. This pattern reflects the distinct market structures and adjustment capabilities across different segments of the European energy system. Electricity markets, characterized by real-time balancing requirements, limited storage capacity, and integrated regional trading, transmitted supply chain disruptions and uncertainty directly through price signals rather than quantity rationing. (Newbery et al., 2016; Borenstein & Bushnell, 2015). The significant positive time trends (8-15 EUR/MWh per month) suggests that European electricity markets were already experiencing substantial inflationary pressures prior to the conflict. This is likely to reflect broader energy transition costs, carbon pricing mechanisms, and post-pandemic demand recovery. Therefore, the Ukraine conflict amplified existing price pressures rather than creating entirely new market dynamics.

The different slopes specification provides particularly valuable insights into the temporal evolution of price transmission effects. The highly significant negative interaction term (post-treatment trend change = -11.47, $p < 0.001$) reveals that while the conflict caused an immediate price shock, it paradoxically led to a moderation in the underlying rate of price increases. This pattern suggests that the initial price spike may have triggered demand response behaviors, emergency supply measures, or market interventions that subsequently dampened price growth rates. The contrast with import volume results indicates that European energy policy successfully maintained physical supply security through strategic reserves, supply diversification, and demand management. However, this could not prevent the translation of geopolitical risk and supply uncertainty into higher consumer costs. This transmission pattern has important implications for SDG 7.1 (energy affordability), as price increases directly affect household energy access even when aggregate supply volumes remain stable.

6.3 Methodological Limitations and RDD Validity Assessment

Visual inspection of electricity price patterns around the cutoff reveals concerns about RDD validity for this outcome variable. The RDD plot shows no clear discontinuous jump in March 2022 (as shown in Figure 2), with price movements appearing to follow pre-existing trends rather than exhibiting the sharp break required for causal identification. Combined with substantial bandwidth sensitivity (treatment effects ranging from -46.7 to +73.1 EUR/MWh), these findings suggest that the apparent electricity price effects may reflect coincidental timing rather than causal impacts of the Ukraine conflict. Accordingly, we focus our causal interpretations on the import volume results, which demonstrate robust null findings across multiple specifications and bandwidth choices.

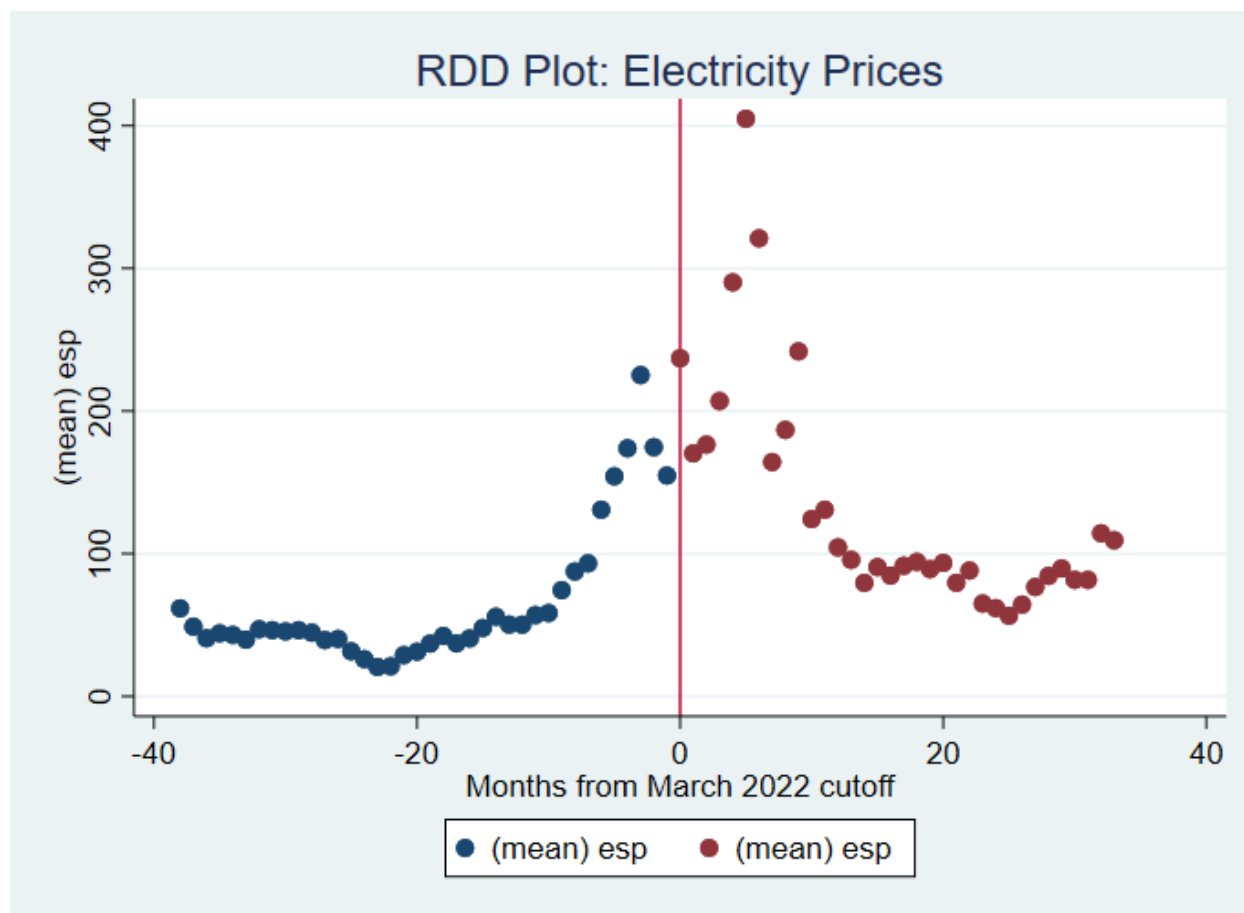


Figure 2

Natural Gas Price (TTF) Analysis

7.1 Main Results and Market Dynamics

The TTF natural gas price analysis reveals a complex market response pattern. This pattern combines statistical non-significance with clear evidence of short-term disruption followed by rapid adaptation, demonstrating the importance of integrating quantitative results with visual evidence in RDD applications. Treatment effect estimates range from 31.05 to 37.27 EUR/MWh across the three RDD specifications which represents potential average price increases of approximately 31-37 euros per megawatt-hour following the Ukraine conflict. However, none of these effects achieve statistical significance at conventional levels, with p-values ranging from 0.170 to 0.216 and confidence intervals that consistently include zero. The linear specification yields the largest point estimate ($\tau = 37.27$, $p = 0.170$), while the quadratic and different slopes specifications produce nearly identical treatment effects of approximately 31 EUR/MWh. These results suggest robustness in magnitude estimates despite limited statistical precision.

Visual inspection of the RDD plot reveals why these statistical results, while methodologically sound, mask important underlying market dynamics. Figure 3 shows a clear price spike immediately following the March 2022 cutoff, with TTF prices jumping to approximately 240 EUR/MWh in the immediate aftermath of the invasion, providing unambiguous evidence of initial market disruption. However, this shock was followed by rapid price correction within 3-4 months, bringing prices down to levels around 30-50 EUR/MWh that were actually below what the strong pre-existing upward trend would have predicted. The pre-invasion period demonstrates substantial underlying price pressures, with TTF prices rising from approximately 20 EUR/MWh to nearly 90 EUR/MWh, indicating that European gas markets were already experiencing significant inflationary dynamics that preceded the geopolitical shock.

The apparent contradiction between visual evidence of price disruption and statistical non-significance reflects the temporal averaging inherent in RDD estimation over the ± 9 month bandwidth. While the immediate price spike confirms market sensitivity to supply disruption concerns, the subsequent rapid correction and decline below trend levels demonstrates remarkable adaptive capacity within European gas trading mechanisms. The time trend (linear) coefficients provide additional evidence of these complex dynamics, with the different slopes' specification showing strong evidence of pre-existing upward trends (coefficient = 7.04, $p < 0.001$) and the quadratic specification revealing marginal evidence of curvature in price evolution (time trend quadratic = -0.49, $p = 0.079$). The post-treatment trend change coefficient (-5.76) in the different slopes model, while not statistically significant, is consistent with the visual evidence of price moderation following the initial shock.

These findings demonstrate that European natural gas markets experienced genuine disruption but exhibited sophisticated self-correcting mechanisms that ultimately achieved price stabilization below pre-conflict projections. Combined with the stable import volume results, this pattern suggests that TTF price dynamics reflected initial uncertainty and risk premiums rather than fundamental supply shortages. The role of market integration in facilitating price convergence and stability in European gas markets has been documented in prior research (Heather, 2019; Growitsch et al., 2014). Additionally, the pattern suggests that market integration and supply diversification strategies functioned effectively to restore equilibrium pricing. The contrast with electricity market results, where bandwidth sensitivity prevented clear causal inference, highlights both the methodological validity of the TTF analysis and the superior integration characteristics of European gas trading infrastructure compared to electricity grid complexities.

Table 6: RDD Results –TTF Natural Gas Price Analysis

	(1)	(2)	(3)
	Linear	Quadratic	Different Slopes
Treatment effect (post-invasion)	37.269	31.047	31.507
	-26.064	-24.226	-22.983
Time trend (linear)	3.704	3.704	7.040***
	-3.150	-3.150	-1.142
Time trend (quadratic)		-0.491*	
		-0.264	
Post-treatment trend change			-5.762
			-4.987
_cons	89.018***	107.030***	105.697***
	-16.031	-8.680	-6.201
N	475	475	475
R ²	0.507	0.568	0.529

Standard errors in parentheses

* $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

8. Discussion and Synthesis of Findings

8.1 Hypothesis Testing and Assessment

Our empirical analysis provides direct evidence regarding the two core hypotheses that form the foundation of this study. Also, it reveals patterns that inform broader questions about European energy market dynamics and resilience mechanisms.

Hypothesis H_1 , which predicted significant reductions in natural gas and oil import volumes following the Ukraine conflict, is decisively rejected by the empirical evidence. Both natural gas and crude oil imports show positive point estimates rather than the expected negative effects with treatment effects of 6-9% for gas imports and 68-72% for oil imports that remain statistically insignificant across all specifications. This finding contradicts expectations about immediate supply disruptions following geopolitical shocks and suggests that European energy markets demonstrated greater structural resilience than anticipated. In our view, the positive

point estimates may reflect strategic stockpiling behaviors, accelerated diversification efforts, or contractual obligations that prevented immediate import reductions despite geopolitical tensions.

However, methodological validation tests reveal mixed evidence regarding RDD identification validity for natural gas imports. While pre-trend analysis confirms smooth evolution in the pre-treatment period (monthly trend coefficient = -0.002, $p = 0.902$), falsification tests using a December 2021 placebo cutoff show a concerning discontinuity (placebo treatment effect = 0.194, $p = 0.014$) that suggests other factors were influencing gas import patterns during late 2021. This combination indicates that while the core RDD assumption of smooth counterfactual evolution is satisfied around the immediate treatment period, European gas markets were experiencing discrete adjustments in the broader pre-treatment window that warrant careful interpretation of our causal estimates.

As for Hypothesis H_2 , which predicted substantial increases in both gas and electricity prices, receives mixed empirical support that varies by outcome variable and methodological approach. TTF natural gas price analysis reveals a complex pattern of initial price spikes followed by rapid correction that results in statistically insignificant treatment effects when averaged over the analysis bandwidth. This is despite clear visual evidence of temporary market disruption reaching approximately 240 EUR/MWh immediately following the invasion. Electricity price analysis encounters significant methodological limitations due to extreme bandwidth sensitivity, with treatment effects ranging from -46.7 to +73.1 EUR/MWh across different temporal windows, preventing reliable causal inference about electricity market responses to the geopolitical shock.

The hypothesis testing results collectively support a narrative of European energy market resilience rather than disruption, with the primary evidence of market stress appearing in temporary price volatility that was subsequently corrected through market mechanisms. This pattern suggests that European energy policy frameworks, infrastructure investments, and market integration efforts provided sufficient flexibility to absorb a major geopolitical shock without creating sustained supply shortages or permanent market dislocations. However, temporary price effects created short-term affordability pressures that required policy attention. Our heterogeneity analysis reveals economically meaningful differential responses across dependency levels that provide important nuance to the aggregate null effects. High Russian-dependency countries show evidence of gas import reductions (combined effect $\approx -15.7\%$) while low-dependency countries increased imports (+15%). These results suggest reallocation mechanisms within European energy markets. Similarly, crude oil imports increased across both groups, but low-dependency countries showed larger increases (72% vs 43%), indicating sophisticated substitution and redistribution strategies during the crisis period

8.2 Market Response Patterns and Mechanisms

This study employs regression discontinuity design to examine the causal impact of the Ukraine conflict on European energy markets across multiple outcome dimensions. The comprehensive analysis reveals a nuanced pattern of market responses that challenges conventional expectations about geopolitical shock transmission through energy systems. Across natural gas and crude oil import volumes, our findings demonstrate remarkable market resilience, with treatment effects that are consistently small in magnitude and statistically indistinguishable from zero. Natural gas import volumes, the primary focus of this analysis, show treatment effects ranging from 0.066 to 0.089 across alternative RDD specifications that remain statistically insignificant. However, falsification tests indicate some concerns about discontinuous patterns in the broader pre-treatment period that require cautious interpretation of these null effects.

Similarly, crude oil imports exhibit larger point estimates of 68-72% increases, but these effects remain statistically insignificant due to reduced sample coverage and increased estimation uncertainty. The analysis of energy prices reveals more complex dynamics that outlines the mechanisms through which European markets absorbed the geopolitical shock. TTF natural gas prices demonstrate sophisticated market behavior characterized by an immediate price spike to approximately 240 EUR/MWh followed by rapid correction to levels below pre-conflict trend projections within three to four months. While RDD estimates suggest treatment effects of 31-37 EUR/MWh that are statistically insignificant when averaged over the analysis bandwidth, visual evidence confirms both initial market disruption and subsequent adaptive capacity that restored price stability. In contrast, electricity price analysis encounters significant methodological challenges, with treatment effects

exhibiting extreme sensitivity to bandwidth selection that ranges from -46.7 to +73.1 EUR/MWh across different temporal windows, preventing reliable causal inference about electricity market responses (Figure 3).

Overall, this analysis shows how remarkably sophisticated and resilient European energy markets have been in navigating a major geopolitical shock. Import volumes remained stable across both natural gas and oil commodities, suggesting that supply diversification strategies, strategic reserve utilization, and market integration mechanisms functioned effectively to maintain physical energy security during the initial crisis period. The effectiveness of diversification strategies in enhancing energy security resilience has been emphasized in energy policy literature (Cherp & Jewell, 2014; Winzer, 2012). Price dynamics reveal temporary volatility followed by market correction, indicating that pricing mechanisms absorbed uncertainty and risk premiums without creating sustained supply shortages or permanent market dislocations. These findings have significant implications for understanding European energy system resilience and provide empirical evidence for the effectiveness of pre-existing diversification and integration policies.

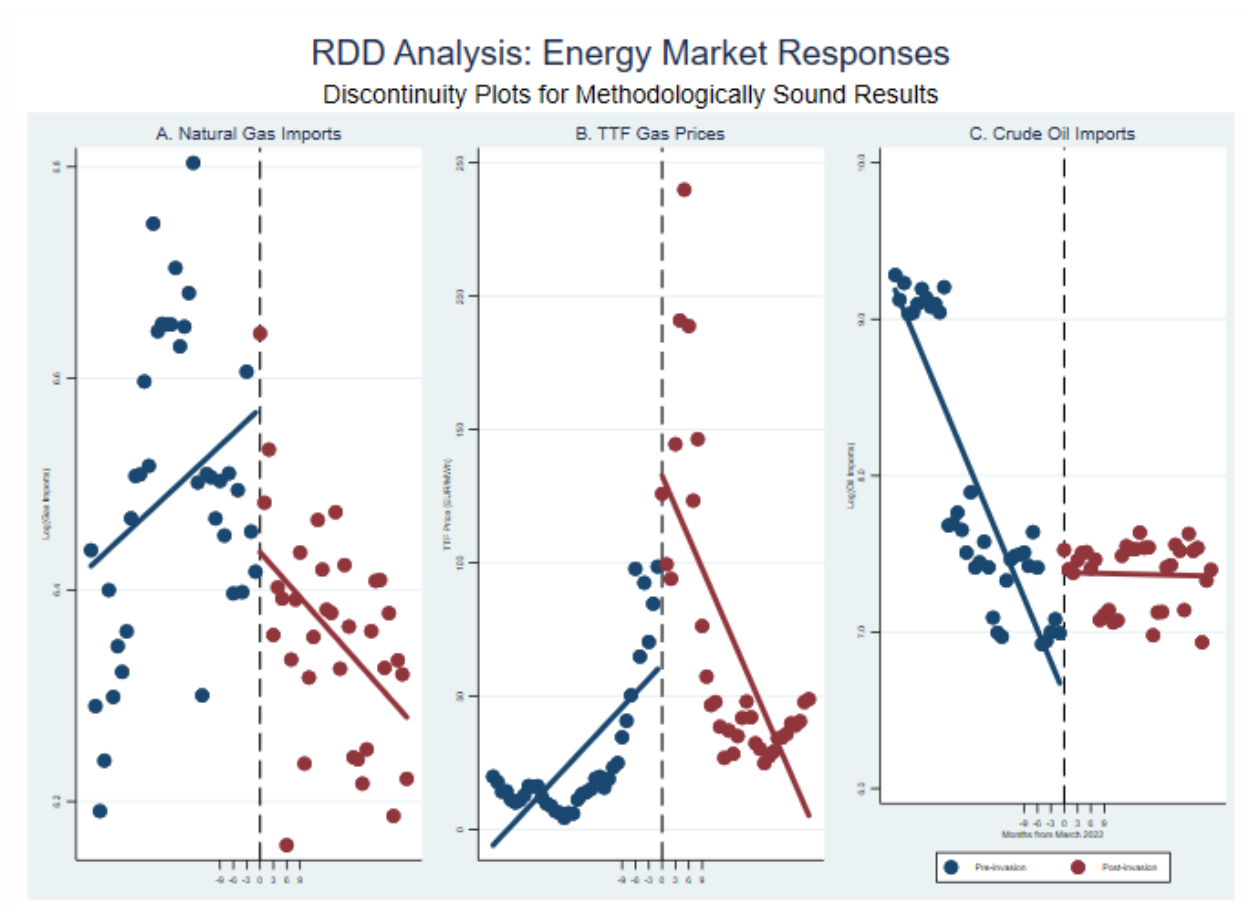


Figure 3

8.3 Policy and SDG Implications

The rejection of our supply disruption hypothesis and the mixed evidence for price impact hypothesis provide crucial insights for European progress toward Sustainable Development Goal 7. Additionally, it informs policy frameworks for energy security and crisis management. The demonstration of import volume resilience across both natural gas and crude oil commodities offers strong empirical support for SDG 7.3 objectives related to energy security and supply reliability. European energy systems successfully maintained physical supply continuity during a major geopolitical crisis. This suggests that existing diversification strategies, infrastructure investments, and emergency coordination mechanisms have created robust foundations for energy security. The

heterogeneity analysis demonstrates that this resilience operated through sophisticated reallocation mechanisms, with less Russian-dependent countries increasing imports to compensate for reductions among more dependent countries. This showcases the effectiveness of European energy market integration during crisis periods.

This resilience validates the long-term policy emphasis on supply source diversification and infrastructure redundancy that characterized European energy policy throughout the preceding decade. It demonstrates that these investments provided tangible crisis-period benefits. However, methodological validation tests suggest that multiple factors were influencing European gas markets during this period. This indicates that the observed resilience may reflect complex interactions between policy responses, market dynamics, and the geopolitical shock rather than pure causal effects of the conflict.

The complex price dynamics observed in TTF natural gas markets provide nuanced evidence regarding SDG 7.1 objectives concerning energy affordability and access. While the immediate price spike to 240 EUR/MWh represented a temporary threat to energy affordability, the rapid market correction to below pre-conflict trend levels demonstrates the effectiveness of competitive pricing mechanisms in restoring reasonable cost conditions for consumers. The relationship between energy price volatility and SDG 7 affordability objectives has been examined in sustainable development literature (McCollum et al., 2018; Nerini et al., 2018). The statistical insignificance of average treatment effects over the analysis period suggests that sustained affordability threats were avoided through market self-correction, though the temporary volatility highlights the continued importance of social protection mechanisms and strategic reserves to buffer vulnerable populations during crisis periods. The inability to draw reliable conclusions about electricity price impacts due to methodological limitations prevents definitive assessment of broader affordability implications across energy sectors.

The policy implications extend beyond immediate crisis management to longer-term energy transition planning under SDG 7.2 objectives for renewable energy development. The import volume resilience outlined in this analysis provides a foundation of energy security that can support ambitious renewable energy transitions without compromising supply reliability during the transition period. European policymakers can draw confidence from these findings that diversified fossil fuel systems with robust market integration can maintain stability while undergoing structural transformation toward cleaner energy sources. The evidence supports continued investment in cross-border infrastructure, market integration initiatives, and emergency coordination frameworks as essential complements to renewable energy deployment. This should ensure that decarbonization efforts do not compromise the energy security foundations that proved effective during the Ukraine crisis.

The methodological lessons from this analysis inform crisis preparedness frameworks and energy security planning across multiple dimensions. The consistent null effects for import volumes validate supply-side resilience strategies. Meanwhile, it highlights the continued importance of demand-side management and efficiency measures that can provide additional flexibility during crisis periods. The sophisticated price dynamics observed in gas markets showcased the value of transparent, competitive pricing mechanisms that can efficiently signal scarcity and coordinate adjustment responses across market participants. For global energy policy development, the European experience provides evidence that market integration, supply diversification, and infrastructure investment can create energy systems capable of maintaining SDG 7 progress even under extreme geopolitical stress. This should offer a model for other regions seeking to balance energy security with sustainability objectives in an increasingly uncertain geopolitical environment.

9. Conclusion

This study presents one of the first quasi-experimental analyses of how a major geopolitical shock—the 2022 Russian invasion of Ukraine—impacted European energy markets and Sustainable Development Goal 7 (SDG 7). In this study, we employ an RDD analysis on monthly data from 25 European countries between 2019 and 2024 to examine precisely how energy import volumes and prices responded to the invasion. Contrary to expectations of severe supply disruption, there are no statistically significant declines in imports of either natural gas or crude oil; both display modest,

optimistic point estimates. These findings reveal an unexpectedly robust degree of energy system resilience, supported by pre-existing diversification, infrastructure redundancy, and market integration across Europe.

Price dynamics tell a complementary story. TTF gas markets saw a brief spike to around 240 EUR/MWh, rapidly corrected, pointing to a high degree of adaptability in trading mechanisms. Electricity prices dramatically increased but reflect significant bandwidth sensitivity, making it impossible to draw firm causal inferences. Taken together, these results indicate that the shock was primarily absorbed through temporary price volatility rather than persistent supply failures—thus preserving energy security, SDG 7.3, but temporarily straining affordability, SDG 7.1. The heterogeneity analysis further suggests that high-dependency countries cut gas imports by some 16%, while low-dependency states increased them—a sign of a coordinated intra-European supply reallocation.

The study improves understanding of energy security under geopolitical stress through the combination of causal identification and analysis focused on sustainable development. It shows that Europe's liberalized energy architecture, viewed by many as vulnerable, actually possessed a quite substantial degree of adaptive capacity when tested. Nevertheless, several limitations remain: The analysis focuses on short-term effects around the invasion and may not capture longer-run structural adjustments in energy sourcing or renewables deployment. Aggregate national data may mask sub-sectoral or regional heterogeneity.

This has clear policy implications. Strengthening cross-border infrastructure, LNG capacity, and emergency coordination remains a priority to maintain supply resilience. Short-term price shocks underline the importance of social protection mechanisms and strategic reserves in mitigating affordability risks. Most importantly, the resilient performance found provides a platform for rapidly advancing the renewables transition (SDG 7.2) with confidence that security goals will not be compromised. Future research should use this approach for other regions and crises, adding insights from micro-level data, simulation models, and financial market interactions to further knowledge of how energy systems maintain stability in conditions of geopolitical turbulence.

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