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Monetary Tightening and the Energy Transition in Central and Eastern European Markets: A Difference-in-Differences Analysis of the 2022 ECB Rate Hike

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Kurzfassung

Die vorliegende Masterarbeit untersucht die Auswirkungen der restriktiven Geldpolitik der Europäischen Zentralbank im Jahr 2022 auf die Investitionsdynamik im Bereich erneuerbarer Energien in Mittel- und Osteuropa (MOE). Diese Region ist durch heterogene institutionelle Rahmenbedingungen, tiefgreifende wirtschaftliche und finanzielle Verflechtungen sowie im Vergleich zu Westeuropa strukturell schwächere Kapitalmärkte geprägt, verbindet sich jedoch mit diesem durch das Ziel des European Green Deal, bis 2050 der erste klimaneutrale Kontinent zu werden. Die MOE-Staaten sahen sich zu Beginn der Energiekrise 2021–2022 mit einer massiven Abhängigkeit von russischen Gasimporten konfrontiert. Daraus ergab sich die doppelte Herausforderung, einen inflationsgetriebenen geldpolitischen Schock zu bewältigen und gleichzeitig die Dekarbonisierung voranzutreiben. Mittels eines Länder-Panel-Datensatzes (2014–2024) und eines Differenz-von-Differenzen-Ansatzes wird analysiert, inwieweit die Zugehörigkeit zur Eurozone bzw. zur EU sowie länderspezifische Unterschiede im Erdgasverbrauch die Investitionsreaktionen auf verschärfte Finanzierungsbedingungen moderieren. Die Ergebnisse verdeutlichen, dass primär politisch-regulatorische Rahmenbedingungen und nicht die monetären Rahmenfaktoren die Investitionspfade prägten. Der EU Green Deal induzierte einen robusten Wachstumseffekt von 11,7 %, der unter Berücksichtigung des Gasverbrauchs bei signifikanten 8,2 % verbleibt. Damit wurde der dämpfende Druck der Zinswende effektiv neutralisiert.

Abstract

This thesis examines how the European Central Bank's 2022 monetary tightening shaped renewable-energy investment dynamics in Central and Eastern Europe (CEE), a region characterised by heterogeneous institutional arrangements, extensive economic and financial linkages, and structurally weaker capital markets compared with Western Europe with which it shares the European Green Deal's objective of becoming the first climate-neutral continent by 2050. The CEE economies entered the 2021–2022 energy crisis with high dependence on imported Russian gas and faced the dual challenge of responding to an inflation-driven monetary shock while accelerating their renewable-energy transition. Using a 2014–2024 country–year panel and a Difference-in-Differences framework, the analysis tests whether Eurozone membership, EU membership, and cross-country variation in natural-gas consumption condition the investment response to tighter financing conditions. The results reveal that policy frameworks, rather than monetary conditions, determined investment paths. The EU Green Deal generated a robust 11.7% growth effect that remains a significant 8.2% after accounting for gas consumption, effectively neutralizing the pressure of tighter monetary policy.

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1 Introduction

Europe has entered the 2020s confronting an exceptional combination of macroeconomic, geopolitical, and energy-market disruptions. The COVID-19 pandemic caused widely occurring supply-chain distortions, extraordinary fiscal stimulus, and an unpredictable economic recovery. Before inflationary pressures could stabilise, Russia's invasion of Ukraine in February 2022 led to the most intense energy shock in Europe in decades. Natural-gas prices climbed to record levels, inflation accelerated across the continent and concerns regarding the security of fossil-fuel supplies experienced a sharp escalation (International Monetary Fund, 2022a). For Central and Eastern European (CEE) economies, many of which had historically relied on Russian pipeline gas, the shock highlighted longstanding structural vulnerabilities and renewed policy urgency around accelerating the clean-energy transition (International Energy Agency, 2022a).

These developments occurred alongside a major shift in the monetary-policy environment. In July 2022, the European Central Bank (ECB) initiated its first interest-rate hike in more than eleven years, followed by a sequence of sharp increases (European Central Bank, 2023a). Higher interest rates increase the cost of capital for investment-intensive renewable-energy technologies, which depend heavily on long-horizon financing. However, the 2022 energy crisis made energy security a top priority, which meant that investment decisions were no longer strictly tied to interest rate changes. Consequently, the coincidence of sharp energy-price volatility, geopolitical uncertainty, and monetary tightening created an environment in which renewable-energy investment decisions were shaped by a set of structural and macroeconomic forces (International Energy Agency, 2025). Understanding how these channels interact in the CEE region is essential for examining the resilience of energy-transition pathways under macroeconomic and geopolitical stress.

This thesis investigates the effects of the ECB's 2022 monetary tightening on renewable-energy transition in the CEE region, with particular attention to whether institutional affiliation and cross-country variation in natural-gas consumption contributed to heterogeneous adjustment patterns. Specifically, it examines whether the membership of the Eurozone and the EU conditioned the adjustment patterns of the countries after 2022, and whether gas consumption served as a dominant fundamental driver of the change in investment dynamics during the energy crisis. Although the broader drivers of investment behaviour are well understood, the combined role of monetary conditions, institutional differences and energy-security vulnerability during the 2021–2022 energy crisis remains underexplored, particularly in the structurally distinct CEE region. This thesis addresses this gap by analyzing these channels within a combined empirical framework.

The empirical analysis begins with baseline Two-way fixed-effects (TWFE) Difference-in-Differences models that separately compare Eurozone and non-Eurozone countries, and EU and non-EU countries, to investigate institutional contrasts in the post-2022 adjustment of renewable energy transition. These baseline estimates are complemented by pooled DiD benchmarks that provide descriptive mean contrasts. By expanding the analysis into a two-policy framework, this study integrates the post-2022 Eurozone monetary channel with the post-2020 EU Green Deal indicator to reflect the broader institutional and fiscal environment, while simultaneously accounting for specific energy-system characteristics through robustness checks that exclude the Baltic states. In a final step, the empirical strategy embeds a measure of gas consumption metric to distinguish institutional effects from deeper structural drivers associated with cross-country vulnerability to the 2022 gas-price shock.

This layered empirical approach is particularly well suited to the CEE region, where renewable-energy investments remains shaped by structural constraints, institutional arrangements vary substantially across EU, non-EU, Eurozone, and non-Eurozone countries, and several economies are still navigating the process of EU integration. Despite this heterogeneity, the region is characterised by strong economic and energy-market interdependence, making policy spillovers likely and reinforcing the need to separate institutional asymmetries from broader regional dynamics. The focus on the CEE region is further justified by its strategic importance in the context of the European Union's pursuit of climate neutrality by 2050 under the European Green Deal. As the European Green Deal imposes rigorous decarbonization mandates, the energy transition within CEE economies becomes a decisive factor for the success of the continent's collective environmental strategy. Examining these markets is therefore essential to understand whether institutional frameworks can effectively mitigate structural path dependencies and align diverse national investment trajectories with common European objectives.

The empirical analysis reveals three distinct patterns. First, monetary tightening did not generate a consistent differential response between Eurozone and non-Eurozone countries, suggesting that the rising cost of capital was not the primary determinant of investment divergence. Second, the EU Green Deal emerges as a statistically significant accelerator, associated with a 11.7% and 8.2% (once controlled for gas consumption) increase in the growth rate of renewable-investment intensity in EU countries relative to non-EU countries. Third, while structural gas consumption follows a positive trend aligned with energy-security arguments, its impact remains heterogeneous across the region and lacks uniform statistical significance once country-level variance is fully accounted for.

2 Stylized Facts: Renewable Energy Investment and Real Interest Rates in CEE Markets

This section provides a descriptive and intuitive overview of renewable-investment patterns and financing conditions across Central and Eastern Europe (CEE) between 2014 and 2024. Its purpose is to establish the economic context of the 2022 monetary tightening, motivate the identification strategy, and visually assess the plausibility of the parallel-trends assumption. By combining descriptive trends with first-stage evidence on real interest rates, the section bridges the abstract with the formal Difference-in-Differences (DiD) econometric framework developed in Section 4. Before examining renewable-investment dynamics, real-interest-rate trends, and their interaction, it is useful to outline the institutional structure of the CEE region. Table 1 summarises the institutional configuration of the nineteen CEE countries included in the sample, distinguishing between EU and non-EU members as well as Eurozone and non-Eurozone economies.

Table 1: Institutional Status of CEE Countries

EU, Eurozone	Croatia, Estonia, Latvia, Lithuania, Slovakia, Slovenia
EU, Non-Eurozone	Bulgaria, Czechia, Hungary, Poland, Romania
Non-EU	Albania, Belarus, Bosnia, Moldova, Montenegro, North Macedonia, Serbia, Ukraine

The sample contains eleven EU member states and eight non-EU countries. Among the eleven EU members, six have adopted the euro and therefore fall under the ECB's monetary policy framework, while the remaining five EU countries retain their own currencies and operate outside the Eurozone. All non-EU countries in the sample are, by definition, also outside the Eurozone, which means that a total of thirteen economies do not use the euro and are not directly exposed to ECB monetary transmission.

The institutional heterogeneity within the CEE region summarized in Table 1, provides natural variation for a Difference-in-Differences design. Countries differ in their exposure to ECB monetary policy and EU-level climate frameworks, while still sharing broadly comparable regional, economic, and market conditions. This combination of structural differences and shared regional characteristics makes the setting well suited for credible causal inference.

2.1 Renewable Energy Investment Dynamics in CEE

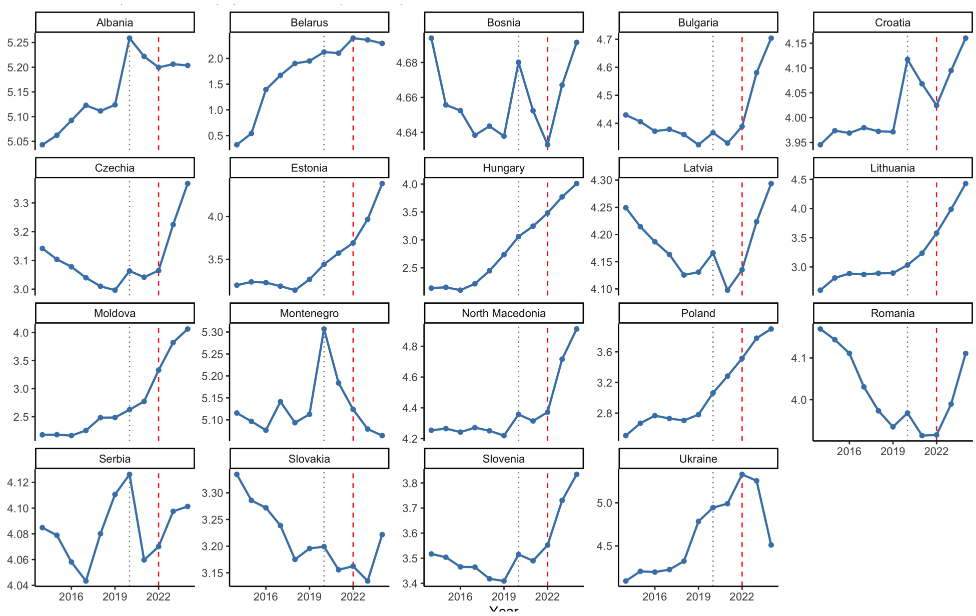


Figure 1: Renewable Energy Capacity Intensity in CEE

Figure 1 plots renewable-energy capacity intensity, defined as the logarithm of installed renewable energy capacity (in megawatts) relative to real GDP, for nineteen CEE countries over the period 2014–2024.[1] The capacity data are sourced from the International Renewable Energy Agency (IRENA) and refer to the total installed stock of renewable technologies, including solar photovoltaic, onshore wind, hydropower and bioenergy. Aggregating technologies into a single measure is an analytical choice that allows the analysis to focus on the overall scale of renewable energy capacity, rather than on technology-specific fluctuations. This variable in levels is presented for descriptive purposes, providing an overview of cross-country and within-country evolution over time. Its first differences constitute the main dependent variable in all subsequent Difference-in-Differences specifications, capturing year-to-year changes in renewable investment intensity. Displaying the level dynamics at this stage helps clarify underlying within-country patterns and supports the identification strategy employed in the empirical analysis.

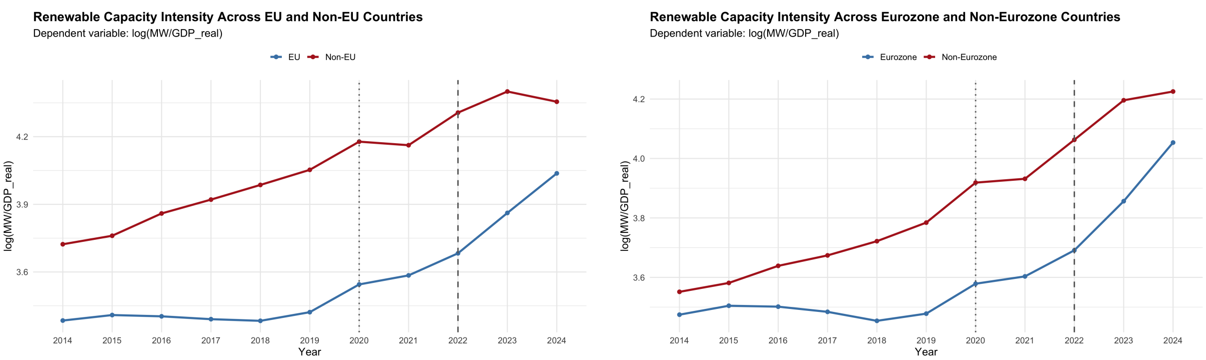
The descriptive evidence highlights several spesific patterns. A large share of CEE economies demonstrate gradually increasing capacity intensity, $\log(\text{MW}/\text{GDP}_{\text{real}})$, throughout the late 2010s, reflecting improving regulatory frameworks, maturing auction systems, and, in the case of EU member states, growing access to EU-level financing instruments such as the Innovation Fund and the Modernisation Fund (European Investment Bank, 2023).

[1] Log-normalization is standard in panel-econometric analyses of growth-type outcomes; see Angrist and Pischke (2009); Wooldridge (2021).

After 2020, renewabls accelerate noticeably in many countries, including Estonia, Lithuania, Poland, Slovenia and Czechia. These increases align with three major drivers: the introduction of the EU Green Deal in 2019, the post-pandemic return to growth in infrastructure investment, and rising uncertainty about energy security following the collapse of Russian gas deliveries (International Energy Agency, 2023). Other economies, such as Romania, Slovakia and Serbia, display more cyclical or "stop-and-go" patterns, shaped by permitting delays, investment barriers and project-level financing constraints.

The Baltic states form a particularly distinct cluster. Estonia, Latvia and Lithuania exhibit exceptionally sharp post-2022 increases in renewable-capacity intensity. This pattern reflects their rapid shift away from Russian pipeline gas, made possible by the Klaipėda LNG terminal[2] and newly strengthened regional interconnectors (European Commission, 2025a; Grigas, 2017). The region specific trajectory in the Baltic countries is likely driven by structural reasons, including their comparatively low reliance on Russian gas and their strong integration with Nordic energy systems.

Crucially, Figure 1 shows no evidence of a region-wide decline in renewable capacity intensity after the ECB raised interest rates in 2022.



(a) EU vs Non-EU

(b) Eurozone vs Non-Eurozone

Figure 2: Group-level trends in renewable capacity intensity (log(MW/GDP))

A synchronized downturn would be expected if higher borrowing costs transmitted uniformly across CEE markets. Instead, trajectories continue to rise or stabilise in most countries, suggesting heterogeneous monetary-policy transmission shaped by differences in financial-market depth, institutional frameworks and country-specific energy-security pressures (Falagiarda et al., 2015; Moder, 2017).

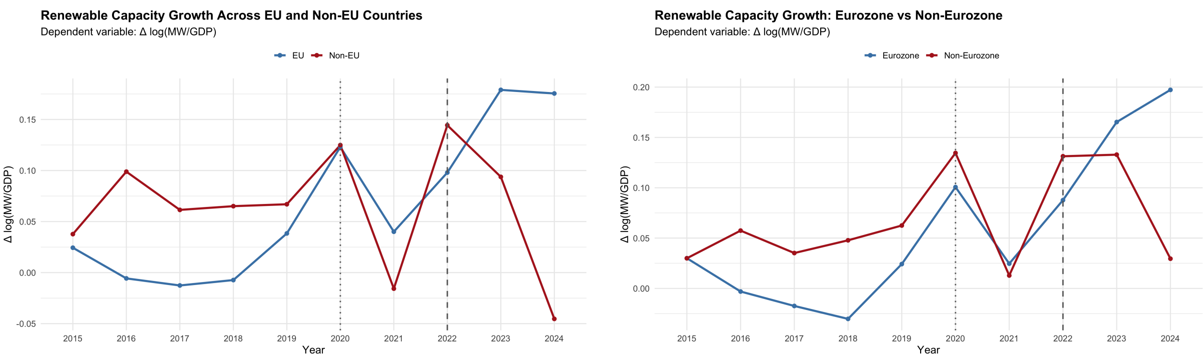
[2] The Klaipėda LNG (liquefied natural gas) terminal, Lithuania's FSRU-based import facility, was introduced in 2014 to secure access to global gas markets and reduce dependence on Russian pipeline supplies.

The next step aggregates the nineteen CEE economies into institutional groupings and examines how renewable capacity intensity evolved for EU versus non-EU members and for Eurozone versus non-Eurozone countries. This classification is directly motivated by the identification logic of the Difference-in-Differences framework developed later in the thesis. EU and Eurozone membership capture several structural characteristics relevant for renewable energy transition, including access to EU-level funding programmes, the credibility and stability of regulatory frameworks, and the degree of financial integration with European capital markets. These institutional features shape both baseline investment conditions and the transmission of macro-financial shocks, particularly the 2022 tightening of ECB policy rates.

Before estimating causal effects, it is essential to verify visually whether these institutional groups exhibit broadly comparable pre-treatment dynamics and whether observed shifts around 2020 and 2022 align with the timing of major policy interventions. The pattern for EU versus non-EU countries reveals persistent and gradually widening differences in renewable-capacity intensity. Throughout the sample, non-EU countries exhibit systematically higher renewable energy capacity intensity. This pattern primarily reflects scale effects associated with lower GDP levels rather than higher absolute renewable deployment. Importantly, while these level differences remain broadly stable prior to 2020, the post-2020 period is characterised by a stronger and more sustained increase in capacity intensity among EU member states, in line with enhanced policy support, improved financing conditions, and the institutional framework of the EU Green Deal. However, this interpretation remains descriptive and is examined more formally in the subsequent econometric analysis. Importantly, both groups follow largely parallel trajectories before 2020, which provides supportive visual evidence for the parallel-trends assumption underlying the Difference-in-Differences strategy.

A closely related pattern emerges when grouping countries by Eurozone membership. Non-Eurozone economies follow a smoother and more monotonic upward trajectory, while Eurozone members display more pronounced fluctuations at notably lower levels. Even though Eurozone countries were directly exposed to stronger real monetary tightening after 2022, investment intensity does not decline, instead it continues to rise. This suggests that deep and integrated capital markets, stable policy frameworks and long-term financing structures insulate renewable investment from short-run fluctuations in interest rates.

Non-Eurozone members also exhibit an upward post-2020 shift, which may be indicative of the strong degree of intergration of European energy markets and of a shared need to respond to the gas-supply shock, alongside the broader continental objective of achieving climate neutrality by 2050. The timing of observed changes is nevertheless consistent across groups.



(a) EU vs Non-EU

(b) Eurozone vs Non-Eurozone

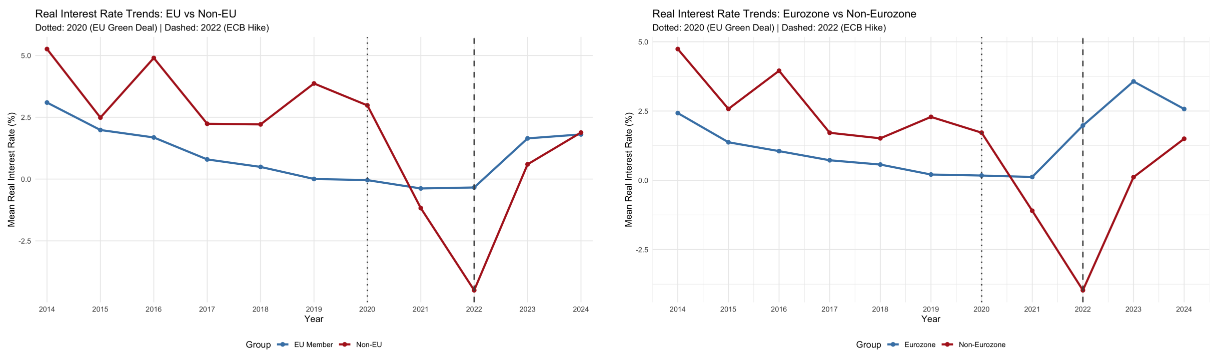
Figure 3: Group-level trends in renewable capacity intensity growth ($\Delta \log(MW/GDP)$)

Figure 3 illustrates the first difference of the logarithm of installed megawatts normalized by the real GDP. This variable serves as the main dependent variable in the analysis and is employed as a proxy for the growth rate of renewable investment intensity. All groups show a temporary acceleration around 2020, consistent with early policy impulses surrounding the EU Green Deal, followed by a sharp decline in 2020–2021, likely linked to COVID-19 disruptions. After 2022, growth strengthens more consistently within EU and Eurozone countries, while the non-member groups display renewed volatility and a notable slowdown in 2024. Overall, the patterns suggest that institutional membership is associated with more stable investment trajectories, whereas non-member countries experienced a more irregular growth.

These stylised facts motivate the need for an econometric approach that separates monetary, institutional and energy-vulnerability channels, which in turn justifies the Difference-in-Differences strategy developed in Section 4.

2.2 Real Interest Rate Trends in CEE

Figure 4 traces the evolution of real interest rates across country groups and provides the first-stage foundation for the identification strategy. Prior to 2020, real rates were systematically higher in non-EU and non-Eurozone economies, reflecting tighter domestic monetary conditions, weaker policy credibility and less developed financial markets. In contrast, EU and especially Eurozone members benefited from structurally lower real borrowing costs due to stronger institutional credibility and the spillover of accommodative ECB policies through integrated financial channels (Falagiarda and McQuade, 2015b).



(a) EU vs Non-EU

(b) Eurozone vs Non-Eurozone

Figure 4: Real interest rates (group means)

Between 2019 and 2021, real interest rates in both institutional groups converged toward zero, reflecting the exceptionally expansionary monetary and financial conditions that characterised the COVID-19 period. This pattern is consistent with the broad yield compression observed across Central and Eastern Europe, driven by coordinated global monetary easing, historically low policy rates, and a surge in liquidity provision by major central banks. In the euro area, the ECB's large-scale liquidity operations and the flexibility of the Pandemic Emergency Purchase Programme (PEPP)[3] contributed significantly to shrinking sovereign and corporate yields, reducing risk premia, and supporting particulary favourable financing conditions (European Central Bank, 2021). Although non-Eurozone CEE countries were not directly subject to ECB monetary policy, their real interest rates followed a broadly similar downward trajectory prior to and during the pandemic, reflecting global monetary easing.

[3]The Pandemic Emergency Purchase Programme (PEPP) was an extraordinary ECB asset-purchase programme launched in March 2020 in response to the COVID-19 crisis. It provided flexible and large-scale purchases of public and private-sector securities to stabilise financing conditions, prevent market fragmentation, and ensure smooth monetary-policy transmission across the euro area (European Central Bank, 2022a).

However, the magnitude of this decline differed substantially across groups: non-EU and non-Eurozone economies experienced a much sharper compression in real borrowing costs between 2017 and 2019, with real rates falling from positive territory into deeply negative values, while EU and Eurozone members exhibited a more moderate decline, according to the graph. This divergence is consistent with weaker domestic monetary-policy credibility, higher inflation volatility, and stronger sensitivity to global financial conditions in non-EU CEE economies. It also aligns with evidence indicating that euro-area financial conditions generate significant spillovers on neighbouring countries through cross-border bank lending and capital markets (Bank for International Settlements, 2021).

The group-level real interest rate profiles reveal a clear and economically meaningful divergence in 2022, precisely at the moment of the ECB's interest rate hike that serves as the policy shock in the empirical strategy. This occurred in response to the sharp increase in euro-area inflation, leading the ECB to begin tightening monetary policy in 2022, including a 75-basis-point rate increase in September. (European Central Bank, 2022b). Following the ECB's tightening, Eurozone and EU countries exhibit an increase in real borrowing costs, reflecting the direct and indirect transmission of higher nominal policy rates. In contrast, non-EU and non-Eurozone economies experience a sharp fall of real rates into deeply negative territory because inflation spikes outpaced their domestic nominal rate adjustments (International Monetary Fund, 2022b). Although all countries were exposed to the same external inflationary environment, the evidence in Figure 4 points to real monetary tightening occurring mainly within the treated groups (Eurozone/EU), whereas the control groups exhibit dynamics consistent with effective real monetary loosening. After 2022, real rates in both groups begin to rise, and the divergence gradually narrows through 2023–2024 as inflation moderates and non-Eurozone central banks increase nominal rates with a delay.

These patterns provide strong first-stage support for the identification strategy. The 2022 ECB tightening acted as a common external shock, but its transmission was heterogeneous: Eurozone members transmitted the shock directly through sovereign yields and lending rates, while non-EU economies, which were facing higher inflation pass-through and weaker monetary credibility, experienced real-rate declines. These opposite-signed responses across groups are precisely the configuration required for a DiD framework, where treatment and control units are exposed to the same shock but adjust differently.

2.3 Real Interest Rates and Renewable Energy Investment

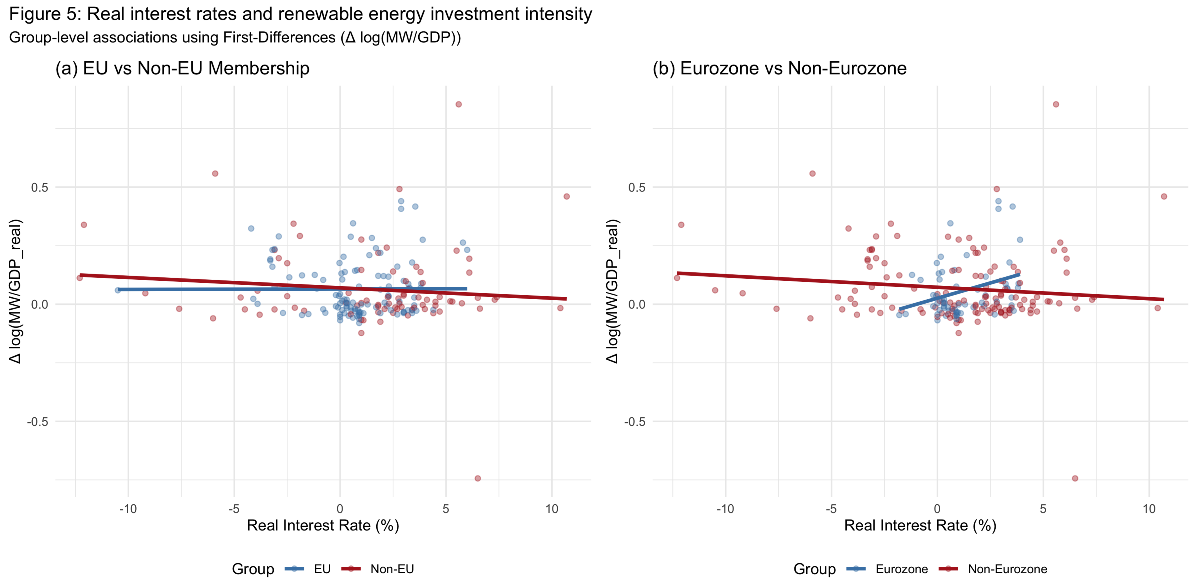


Figure 5: Real interest rates and growth in renewable energy investment intensity

Figure 5 illustrates how real interest rates co-move with the growth rate of renewable-energy investment intensity across institutional groupings in Central and Eastern Europe (CEE). This growth is defined as first difference of the logarithm of installed renewable capacity of each country relative to real GDP, the main dependent variable used throughout the empirical analysis. The figure plots yearly group means computed directly from the underlying panel dataset, while the fitted OLS lines summarize the average within-group association between real financing conditions and renewable-investment intensity. This descriptive relationship provides a visual preliminary step to the identification strategy developed later in the thesis, highlighting how financing conditions may differentially matter across EU, non-EU, Eurozone, and non-Eurozone economies.

The slopes of these fitted lines offer a reduced-form indication of the sensitivity of renewable investment to the cost of capital. A negative relationship demonstrates the standard mechanism in investment theory, where higher real interest rates increase the user cost of capital and weaken investment activity. In theory, when real rates fall, either through monetary easing or high inflation, firms face lower discount rates, which raises the present value of expected future returns and supports investment (Jorgenson, 1963; Bernanke and Gertler, 1995). Empirical evidence confirms that real-rate movements operate through credit costs, risk premia and expectations (Gilchrist and Zakrajšek, 2012; Hofmann and Peersman, 2017), although the strength of these channels varies with financial-market development.

In less integrated or emerging economies, weaker banking sectors and more constrained access to external finance tend to increase interest-rate sensitivity (Égert and MacDonald, 2009), whereas deeper financial systems and strong institutions moderate these effects.

Monetary and energy-market developments after 2022 intensified these contrasts. The Russian invasion of Ukraine triggered a pronounced increase in fossil-fuel prices and inflation, prompting the European Central Bank (ECB) to shift rapidly from a decade of exceptionally loose policy to a tightening cycle beginning in mid-2022 (European Central Bank, 2023b). Before linking real interest rates to renewable investment dynamics in the CEE region, it is useful to recall the underlying mechanism. As nominal interest rates were raised and inflation gradually started to ease in 2023, real interest rates in Eurozone countries increased substantially. By contrast, many non-Eurozone and non-EU economies experienced inflation spikes that outpaced domestic policy-rate adjustments.(International Monetary Fund, 2023).

The visual patterns in Figure 5 reflect this institutional heterogeneity through the lens of investment growth. Among non-EU countries, the renewable investment intensity declines as real rates rise, consistent with the standard mechanism where higher borrowing costs dampen investment in financially constrained environments. EU member states, however, display a remarkably resilient, almost flat relationship, suggesting that deeper capital markets and EU-level funding instruments, reinforced by the European Green Deal for example, shield investment growth from fluctuating financing conditions. The contrast is most striking when comparing Eurozone and non-Eurozone groups. While non-Eurozone economies show the expected negative association, Eurozone countries exhibit a slightly positive slope: the rate of investment continued to accelerate even as real rates rose. This counter-cyclical pattern suggests that for Eurozone members, the institutional architecture of the monetary union, combined with targeted fiscal cushions like the Recovery and Resilience Facility and the REPowerEU plan (European Commission, 2026), provided a stable environment that allowed energy-security imperatives to outweigh the countervailing pressure of tighter monetary policy. Since all Eurozone members in the sample are also EU member states, this resilience likely reflects a synergistic effect of stable monetary frameworks and robust institutional climate mandates.

These patterns imply that renewable investment, which is highly capital-intensive and dependent on long-term debt financing (International Energy Agency, 2023), is not uniformly sensitive to interest rate shocks. Instead, the results suggest that institutional membership, specifically within the EU and Eurozone, acts as a critical moderator, mitigating the negative impact of the 2022 tightening cycle on the green transition.

3 Event Study Results: ECB 2022 Hike and Renewable Energy Investment in CEE

3.1 Objective

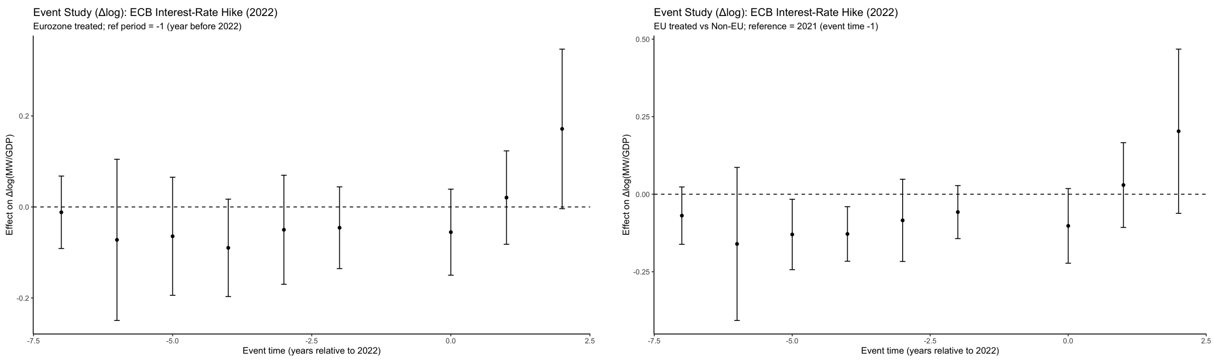
This event study examines whether the European Central Bank (ECB) 2022 interest rate hike affected the growth of renewable energy investment, measured as $\Delta \log(MW/GDP)$, in Central and Eastern European (CEE) countries, and is complemented by an event-study analysis of renewable-energy capacity intensity, measured as $\log(MW/GDP)$. The analysis compares Eurozone and non-Eurozone economies, which differ in their direct exposure to ECB monetary policy, as well as EU and non-EU members, where institutional and financial-integration spillovers may shape intensity responses. The event-study approach is introduced here as a preliminary diagnostic step before the formal Difference-in-Differences framework presented in Section 4. By visually assessing pre-treatment dynamics, the event study allows to evaluate whether countries follow sufficiently similar trends prior to the shock, which is a necessary condition for credible Difference-in-Differences estimation. In addition, joint Wald tests of pre- and post-event coefficients formally assess the null hypothesis of no differential pre-trends and no dynamic treatment effects. Verifying these requirements helps justify the identification strategy adopted in the following analysis.

More broadly, the objective of this section is to establish an empirical baseline for the subsequent causal analysis by documenting the dynamic evolution of renewable-energy investment intensity around the 2022 ECB tightening.

By combining event-study evidence in first differences and levels, the analysis clarifies whether short-run investment growth and longer-run capacity dynamics exhibit comparable pre-treatment trends and whether any post-2022 movements are sufficiently pronounced to warrant a Difference-in- Differences interpretation. Rather than delivering causal estimates, the event-study results serve to discipline the identification strategy, guide the choice of institutional comparisons, and inform the interpretation of the formal DiD estimates presented in Section 4.

3.2 Interpretation of the $\Delta \log(\text{MW/GDP})$ Event-Study

Table 2 and Figure 6 present the event-study results estimated in first differences, using $\Delta \log(\text{MW/GDP})$ as the primary proxy for investment intensity growth. By focusing on year-to-year changes, this specification offers a diagnostic assessment of immediate short-run dynamics around the 2022 ECB monetary tightening, complemented by the level-based analysis discussed later in the study.



(a) Eurozone vs. Non-Eurozone

(b) EU vs. Non-EU

Figure 6: Event-Study in First Differences Around the 2022 ECB Hike

Table 2: Joint Post-Event Wald Tests (DV: $\Delta \log(\text{MW/GDP})$)

Design	Post-event window	$F(\text{df}_1, \text{df}_2)$	p	SEs
Eurozone vs. Non-Eurozone	$k = 0, 1, 2$	1.628 $(3, 152)$	0.185	Clustered by country
EU vs. Non-EU	$k = 0, 1, 2$	1.461 $(3, 152)$	0.228	Clustered by country

Notes: Dynamic TWFE models with country and year fixed effects; base year $k = -1$ (2021). Inference relies on country-clustered standard errors following Sun and Abraham (2021) and Roth (2022b).

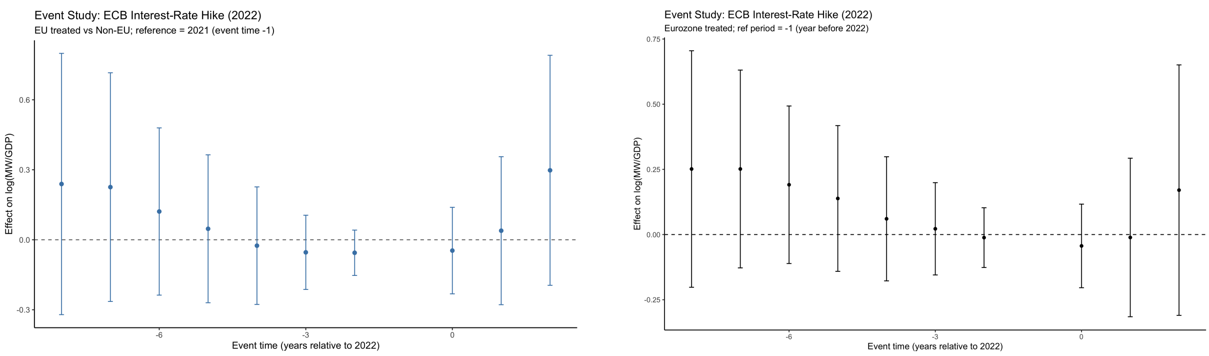
Regarding the validity of the identification strategy, Figure 6 shows that the pre-treatment coefficients ($k < 0$) are relatively flat and statistically indistinguishable from zero across both specifications. This lack of pre-event divergence indicates that investment intensity in both treated and control groups followed broadly comparable trajectories prior to the policy shock, satisfying the parallel-trends requirement necessary for a causal interpretation. In the post-event period ($k \in \{0, 1, 2\}$), each coefficient $\hat{\beta}_k$ measures the difference in investment intensity relative to the 2021 baseline. For both the Eurozone and EU splits, the point estimates display a mild upward tilt. However, they remain imprecisely estimated with wide confidence intervals that encompass zero.

This visual pattern is confirmed by the joint Wald tests in Table 2, which fail to reject the null hypothesis that all post-event coefficients are jointly equal to zero ($p = 0.185$ and $p = 0.228$, respectively).

Taken together, these results reveal no sharp or statistically robust break in investment intensity immediately following the 2022 tightening. Rather than indicating the absence of any real-world impact, this muted adjustment likely reflects the gradual implementation typical of large-scale energy projects and the limited precision inherent in annual frequency data. Ultimately, the results point to a high degree of regional co-movement and synchronized short-run adjustments in investment intensity, reflecting the financial integration and overlapping macroeconomic shocks shared across Central and Eastern Europe.

3.3 Interpretation of the log(MW/GDP) Event-Study

Figure 7 plots the event study dynamic of renewable-energy capacity intensity around ECB´s 2022 interest rate hike for the EU–non-EU and Eurozone–non-Eurozone groupings. Across both specifications, the pre-treatment coefficients are relatively flat and statistically indistinguishable from zero, suggesting that treated and control groups moved along broadly comparable trajectories prior to the policy shock. This pattern provides supportive visual evidence for the plausibility of the parallel-trends assumption required for the Difference-in-Differences framework introduced in Section 4.



(a) EU vs Non-EU (b) Eurozone vs Non-Eurozone

Figure 7: Event study estimates of the ECB's 2022 interest rate hike on renewable energy investment capacity intensity

In the years following 2022, the estimated coefficients do not display pronounced or systematic divergence between the institutional groups. Although point estimates vary in magnitude across event years, the associated confidence intervals remain wide and consistently include zero. This indicates that, within the limits of the available variation, the interest-rate shock did not generate statistically discernible differences in renewable-investment intensity between Eurozone and non-Eurozone countries, nor between EU and non-EU members.

The muted post-treatment response is in line with the descriptive trends documented earlier, where investment trajectories continued to rise or stabilise despite the tightening in financing conditions. This limited divergence is consistent with the idea that the increase in real financing costs in 2022 overlapped with substantial policy support across the region, reinforcing this interpretation. EU-level instruments, national subsidy schemes, and accelerated energy-security measures following the disruption of gas markets may have mitigated sensitivity to higher capital costs, particularly in member states with access to broader fiscal and institutional support. These factors, which were also mentioned earlier in the texts, could have softened the transmission of tighter monetary policy into the renewable-energy sector.

Table 3: Joint Wald Tests for Event–Study Coefficients

Design	Hypothesis	$F(\mathrm{df}_1, \mathrm{df}_2)$	p	SEs
Eurozone vs. Non-Eurozone	Pre-trends ($k \leq -2$)	1.88 $(4, 169)$	0.116	Clustered by country
Eurozone vs. Non-Eurozone	Post-event ($k \geq 0$)	1.78 $(3, 169)$	0.152	Clustered by country
EU vs. Non-EU	Pre-trends ($k \leq -2$)	2.49 $(4, 169)$	0.045	Clustered by country
EU vs. Non-EU	Post-event ($k \geq 0$)	1.70 $(3, 169)$	0.169	Clustered by country

Notes: Base period is $k = -1$ (2021). Hypotheses test whether all pre-event (leads) or all post-event (lags) coefficients equal zero in dynamic TWFE specifications with country and year fixed effects. Inference follows joint pre-trend testing guidance for event studies and dynamic DiD (Sun and Abraham, 2021; Roth, 2022b).

For the Eurozone comparison, the joint pre-trend test does not reject the null that all pre-event coefficients equal zero, $F(4, 169) = 1.88$, $p = 0.116$. This supports the plausibility of the parallel-trends assumption for this grouping. The post-event coefficients are likewise jointly insignificant over $k = 0, \ldots, 3$, $F(3, 169) = 1.78$, $p = 0.152$, indicating no statistically detectable divergence between Eurozone and non-Eurozone countries in the 2022–2024 window. This muted dynamic response is consistent with monetary-policy spillovers operating through regional financial linkages and with the slow adjustment typical of capital-intensive renewable-energy projects (Falagiarda and McQuade, 2015b).

For the EU split, the joint pre-trend test rejects the null of zero pre-event coefficients, $F(4, 169) = 2.49$, $p = 0.045$, suggesting that EU and non-EU countries already exhibited differential dynamics before 2022. This weakens the credibility of the parallel-trends assumption, and the estimates should therefore be interpreted descriptively rather than causally. As in the Eurozone case, the post-event coefficients are jointly insignificant, $F(3, 169) = 1.70$, $p = 0.169$, implying that there is no sharp divergence in the immediate aftermath of the policy shock.

Taken together, these diagnostics indicate that the Eurozone grouping provides the more credible basis for formal identification, while the EU split documents broader regional co-movement shaped by financial integration and overlapping contemporaneous shocks.

The failure to reject the joint post-event effects should not be interpreted as evidence that the true impact of the ECB's tightening was exactly zero. Rather, it reflects limited statistical precision given the annual frequency of the data and the inherent variability of renewable-investment series. The wide confidence intervals in Figure 7 illustrate this uncertainty: although point estimates fluctuate around zero, they remain within overlapping bounds, meaning that the observed movements may stem from sampling noise rather than systematic post-2022 shifts.

Even if statistically inconclusive, the pattern remains economically informative in the context of post-2022 renewable investment dynamics. The absence of a clear downward break indicates that renewable-investment intensity in non-EU countries did not decline relative to EU peers following the tightening. Combined with the nearly flat pre-2022 event-time coefficients, the evidence is consistent with broad regional co-movement rather than sharply divergent shocks. In other words, any underlying effect is likely small, short-lived, or driven by limited within-group variation and the gradual adjustment typical of large-scale investment projects such as renewable energy infrastructure investments. Figure 7 and the joint-test results in Table 3 therefore provide a transparent assessment of pre-trend validity and post-event precision, in accordance with best-practice guidance for event-study inference (Sun and Abraham, 2021; Roth, 2022b).

4 Data Approach and Methodology

As discuseed eralier, the empirical analysis relies on a balanced country–year panel of 19 Central and Eastern European (CEE) countries covering the period 2014–2024. Renewable investment intensity growth, the primary dependent variable in the analysis, is constructed as the first difference of the log-transformed ratio of renewable capacity (MW) to real GDP, which is defined as $\Delta \log(MW/GDP)$. This construction captures the annual growth in investment intensity, normalizing renewable energy expansion by economic size, providing a practical proxy for renewable-energy investment outcomes. In addition, the level of renewable-energy capacity intensity, measured as $\log(MW/GDP)$, is constructed as a complementary outcome variable in the main model. This construction normalizes renewable-energy capacity by economic size and provides contextual information on the accumulation of deployment over time.

To recall, the data set was collected from national central banks of each country, Eurostat, Word Bank, IRENA (International Renewable Energy Agency), the European Central Bank and subsequently harmonized in RStudio. The variables were transformed into logarithmic first differences and ratios to account for the scale heterogeneity between countries. In addition to macroeconomic controls that are collected for the descriptive purposes such as real interest rates, inflation, real GDP growth and unemployment rate, the dataset is extended with measures of gas-price consumption. These capture energy dependence and serve as robustness checks: (i) log(1+consumption), (ii) the consumption share relative to GDP, and (iii) the logarithm of this share. The empirical strategy follows a quasi-experimental design. As a first step, an event-study framework is implemented to assess the plausibility of the parallel-trends assumption that forms the basis of the subsequent Difference-in-Differences (DiD) analysis in Section 3.

Once pre-trend behaviour is evaluated, the DiD specification is introduced to estimate whether institutional exposure to ECB policy, captured through EU or Eurozone membership, is linked to differential changes in renewable investment intensity after 2022. The baseline model employs a two-way fixed-effects structure with country and year dummies, and beyond the baseline DiD and event–study estimates, several complementary analyses are implemented to frame the empirical results and clarify the mechanisms behind the observed patterns. Alongside the baseline specifications, a pooled OLS model is included as a descriptive benchmark that provides a contrast without relying on identifying assumptions.

This serves as a benchmark for understanding unconditional differences across institutional groups. The analysis then incorporates a joint monetary–institutional specification interacting the 2022 ECB tightening with the EU Green Deal indicator, allowing the exploration of whether concurrent policy regimes intensify or dampen the estimated effects.

Several sensitivity analyses further clarify the structure of the results. Excluding the Baltic states, whose energy systems exhibit structural characteristics that differ remarkably from those of the rest of the region, tests whether the baseline patterns are driven by this atypical subgroup. Finally, models including gas consumption measures account for cross-country heterogeneity in energy-dependence risk, helping distinguish monetary-policy effects from structural vulnerabilities related to the regional gas shock. These complementary specifications do not aim to produce additional causal estimates but rather to explain why coefficient magnitudes and significance vary across models, thereby strengthening the interpretation of the main empirical findings.

Table 4: Data Summary Statistics

Variable	**Min**	**1st Qu.**	**Median**	**Max**
Year	2014	2016	2018	2024
RE Investment (MW)	69.0	832.2	2096.0	27935.0
MW/GDP	1.028	19.571	43.678	171.279
MW/GDP (real)	1.380	23.020	52.990	206.350
Real Interest (%)	-12.300	0.070	1.340	10.700
Inflation (%)	-1.600	0.725	2.550	48.700
GDP Growth (%)	-28.800	1.800	3.100	13.900
Unemployment (%)	0.500	4.725	7.000	28.200
Log(MW/GDP)	0.322	3.136	3.970	5.330
Δ Log(MW/GDP)	-0.744	-0.023	0.017	0.853

Note: The dataset additionally includes gas consumption measures used in later sections and robustness checks: log(1+consumption), Consumption/GDP, and log(1 + Consumption/GDP). Summary statistics for these variables are reported separately to conserve space.

Table 4 reports the summary statistics for the key variables used in the analysis. The sample covers 19 Central and Eastern European countries between 2014 and 2024, resulting in a country–year panel dataset.

Renewable-energy stock variable exhibits substantial variation across the region: the installed capacity ranges from as little as 69 MW to almost 28 GW, reflecting differences in economic size, market maturity, and policy support.

The dataset distinguishes between several related measures of renewable-investment intensity. Renewable-energy stock (MW) represents the absolute physical amount of installed renewable capacity. A full overview is provided in Appendix Section A.1, to which the analysis will refer where relevant. While this measure captures the scale of activity, it does not control for country and economy size, such as Poland or Romania, which naturally exhibit higher capacity additions. Specification MW/GDP normalizes capacity additions by nominal GDP, expressing the volume of investment relative to the economy's size and allowing for meaningful cross-country comparison.

However, because it relies on nominal GDP, part of its variation may reflect inflation rather than real investment effort. To address this, MW/GDP (real) divides installed capacity by real (constant-price) GDP, producing a real intensity measure. This adjustment isolates genuine intensity changes from nominal effects and therefore serves as the main specification in the econometric analysis. Finally, log(MW/GDP) is the logarithmic transformation of deployment intensity and functions as the dependent variable in the regression models. The log transformation standardizes scale across heterogeneous economies, mitigates the influence of outliers, and enables a proportional interpretation of coefficients, so that estimated effects can be read as approximate percentage changes in renewable-energy deployment intensity. Together, these measures capture the physical, nominal, and real dimensions of renewable-energy investment across the CEE region. The observed heterogeneity across countries and over time provides an essential source of variation for credible identification in the subsequent Difference-in-Differences and event-study analyses.

Real interest rates range from –12.3 to 10.7 percent, capturing the sharp policy reversal following the 2022 monetary tightening. Inflation varies dramatically as well (–1.6 to 48.7 percent), highlighting the heterogeneity of post-pandemic price dynamics and the impact of the energy crisis. GDP growth rates fluctuate between –28.8 and 13.9 percent, indicating the combined influence of the COVID-19 recession and the uneven recovery that followed. Labor-market conditions differ markedly across the sample, with unemployment rates ranging from 0.5 to 28 percent, consistent with structural gaps between EU and non-EU economies.

The logarithmic transformation of capacity intensity, used in the empirical analysis, yields a median log(MW/GDP) of 3.97, which corresponds to moderate renewable-capacity intensity in the typical CEE country.

The first-differenced variable, $\Delta \log(MW/GDP)$ serves as the main dependent variable in the econometric analysis. With a mean value of 0.064 and a median of 0.017, this measure indicates that while the typical CEE country experienced a modest annual increase in investment intensity growth, the substantial range (from -0.744 to 0.853) highlights periods of both rapid acceleration and relative stagnation across the panel. The wide range of the variable, from a minimum of -0.744 to a maximum of 0.853, shows that renewable energy investment growth does not happen at a steady pace. This is because energy projects are often large and occur in cycles. Negative values indicate periods when new capacity additions slowed down compared to economic growth. In contrast, the high maximum value of 0.853 represents years of rapid acceleration in growth, where some countries nearly doubled their investment intensity.

Overall, the statistics indicate substantial variation across countries and over time, a key requirement for credible identification in the following Difference-in-Differences and event-study analyses. The unemployment rate was initially considered for inclusion in the baseline specification, as it represents an important macroeconomic indicator of cyclical conditions and aggregate demand (Blanchard and Fischer, 2000). However, renewable-energy investment decisions are typically long-term and policy-driven rather than directly responsive to short-term labor-market fluctuations. The inclusion of real GDP growth already captures the business-cycle component of investment activity, making unemployment largely redundant from an explanatory standpoint. Summary statistics for the gas-exposure variables appear in Section 6, which introduces these measures within the extended robustness specifications.

4.1 Rationale for the Difference-in-Differences (DiD) Design

The Difference-in-Differences (DiD) framework is a widely used quasi-experimental method in applied economics. It estimates causal effects by comparing changes in outcomes for a treated group with changes for a control group over time (Angrist and Pischke, 2009; Imai and Kim, 2019). By differencing both across time and between groups, DiD removes unobserved, time-invariant heterogeneity that affects both groups similarly, yielding an average treatment effect conditional on standard identification assumptions.

In this thesis, the 2022 interest-rate hike by the European Central Bank (ECB) provides an exogenous monetary-policy shock that naturally lends itself to a DiD approach. While the tightening was common to the Eurozone, its spillovers to the broader Central and Eastern European (CEE) region depended on each country's degree of institutional and financial integration. Eurozone members were directly exposed to the policy change, whereas non-Eurozone and non-EU countries were affected only indirectly through capital flows, trade channels and investor expectations. This heterogeneity in exposure generates a well-defined treatment and control structure that allows the DiD design to isolate how financing conditions and policy mandates differentially shaped the renewable investment response. The DiD estimator measures the average difference in outcome changes between treated and control groups before and after the shock. With country and year fixed effects, the specification absorbs time-invariant national characteristics and common macroeconomic shocks, mitigating confounding influences (Angrist and Pischke, 2009). In practice, it tests whether renewable-investment intensity in Eurozone or EU members evolved differently after 2022 relative to comparable non-member countries. A central advantage of DiD is the clarity of interpretation.

The interaction term between the post-2022 period and the treatment indicator captures the causal effect of the monetary-policy shock under the parallel-trends assumption. This assumption requires that treated and control groups would have followed similar developments in the absence of the shock. Its validity is formally assessed using an event-study specification, which enables both visual and statistical testing of pre-2022 parallelism. This has already been assessed in Section 3.

The framework also accommodates richer forms of heterogeneity. Continuous variables such as gas consumption allow the estimation of differential effects across countries with varying macro-financial vulnerabilities.

Moreover, incorporating both the ECB tightening and the EU Green Deal as policy dimensions enables the analysis to disentangle monetary from institutional or fiscal influences, which is particularly relevant in a multi-country, multi-shock setting such as the CEE region.

Potential limitations must be considered. Spillover effects, anticipation of policy changes and deviations from parallel pre-treatment trajectories can bias DiD estimates if left unaccounted for (Roth, 2022a). Given the degree of financial openness in the CEE region, non-Eurozone countries may still react to ECB policy through indirect channels, including exchange-rate movements and shifts in economic climate, which can dampen measured treatment effects in this study. The event-study analysis and subsequent robustness checks help mitigate these concerns by investigating pre-trends, dynamic effects and stability across alternative specifications. In this empirical analysis, the event-study results show flat and statistically insignificant pre-2022 coefficients for both treatment definitions, supporting the parallel-trends assumption. Following the shock, a clear and precisely estimated divergence emerges in the Eurozone specification, whereas the EU–non-EU contrast exhibits a weaker dynamic response. This pattern is consistent with the stronger monetary-policy transmission among Eurozone members relative to broader EU institutional heterogeneity.

Overall, the DiD framework offers a transparent and conceptually grounded empirical strategy for studying how exogenous monetary-policy shocks pass through diverse economies. By leveraging both temporal and cross-country variation, it is appropriately designed for analysing the asymmetric transmission of ECB policy within the institutionally diverse CEE region.

4.2 Difference-in-Differences Model: Theoretical Framework and Empirical Strategy

Building on the conceptual rationale presented in Section 4.1, this subsection formalizes the Difference-in-Differences (DiD) design and outlines its econometric interpretation. In a panel-data framework, DiD exploits variation across units and over time to identify causal effects in the absence of randomized treatment assignment. The approach separates treatment-related changes from factors that are either constant over time or shared across all units.

Formally, the baseline empirical model is a standard two-way fixed-effects (TWFE) Difference-in-Differences specification, expressed as follows:

$$y_{it} = \alpha_i + \lambda_t + \gamma(Post_t \times Treated_i) + \varepsilon_{it},$$

where y_{it} denotes renewable-investment intensity growth for country i in year t. The terms α_i and λ_t represent country and year fixed effects, respectively, which control for time-invariant national characteristics (such as geography, institutional quality, and resource endowments) and for shocks common to all countries in a given year, such as broad macroeconomic or regional energy-market developments. The interaction term $(Post_t \times Treated_i)$ equals one only for treated countries after the policy shock, and its coefficient γ captures the average treatment effect on the treated (ATT). In a simple two period Difference-in-Differences setting, the ATT corresponds conceptually to the difference between the change in the outcome for the treated group before and after the shock and the analogous change for the control group. In the TWFE panel specification, this generalizes to the coefficient γ, which aggregates these differences across all pre- and post-treatment years.

Before introducing fixed effects, the core intuition of the DiD estimator can be illustrated using its pooled representation:

$$y_{it} = \alpha + \beta Post_t + \delta Treated_i + \gamma(Post_t \times Treated_i) + \varepsilon_{it},$$

where β reflects aggregate time shocks, δ captures systematic differences between treated and control groups, and γ again measures the ATT. This pooled model corresponds directly to the canonical two-by-two DiD estimator:

$$\hat{\gamma} = (\bar{y}_{T,post} - \bar{y}_{T,pre}) - (\bar{y}_{C,post} - \bar{y}_{C,pre}),$$

This highlights the logic of differencing across time and across groups to remove confounding influences. Although the pooled two-by-two DiD estimator and the multi-period TWFE specification differ in implementation, the coefficient γ has the same interpretation in both settings: it represents the average treatment effect on the treated under the parallel-trends assumption.

In multi-country macroeconomic panels, such as the one used in this study, the pooled model imposes restrictive assumptions. Enduring institutional, structural, or geographic differences between treated and control countries may correlate with treatment status, leading to omitted-variable bias. The TWFE approach addresses these concerns by incorporating both country-specific and period-specific unobservables (Imai and Kim, 2019; Wooldridge, 2021). Thus, the TWFE specification includes the pooled model as a special case while providing stronger internal validity. Despite these constraints, the pooled DiD remains a valuable analytical benchmark within the scope of this research. It provides a straightforward baseline grounded in standard DiD logic and operates as a comparison point for understanding how fixed effects alter the interpretation of the estimates. For this reason, both specifications are reported in this thesis: the pooled model illustrates raw differences in means, whereas the TWFE model forms the preferred empirical framework for the multi-country CEE panel and serves as the main causal model in this analysis.

Within this empirical context, the ECB's 2022 interest-rate hike functions as an exogenous monetary-policy shock. Eurozone countries experienced direct tightening of financing conditions, whereas non-Eurozone countries were affected indirectly through cross-border financial linkages, exchange-rate adjustments, and investor expectations. This institutional asymmetry provides a natural setting for identifying the causal impact of monetary policy on renewable-investment intensity growth in the CEE region. A complementary comparison between EU and non-EU countries captures a distinct institutional channel. EU members benefit from supranational policy frameworks such as European Green Deal, which can partially offset tighter credit conditions. Non-EU countries, rely more heavily on domestic financing and lack access to EU-level fiscal support. The EU contrast therefore isolates how institutional integration modulates investment responses independently of monetary transmission. Econometrically, the fixed-effects structure strengthens identification by controlling for unobserved heterogeneity that is constant across time, as well as shocks common to all countries. The coefficient γ can therefore be interpreted as the differential change in renewable-investment intensity growth attributable to the ECB shock. Given the logarithmic specification of the dependent variable, γ approximates a percentage change relative to a scenario without the intervention.

The DiD framework also accommodates extensions, such as the incorporation of continuous treatments (e.g., country-level gas consumption) and macro-financial covariates. These enrich the analysis by capturing heterogeneous exposure to energy dependence and varying intensity of monetary transmission. Although potential challenges include spillovers, anticipatory behavior, and dynamic treatment effects, the event-study design and robustness checks implemented in this thesis help mitigate these concerns (Imai and Kim, 2019; Roth, 2022a).

Overall, the Difference-in-Differences framework provides a theoretically grounded and econometrically transparent approach for identifying the causal impact of the ECB's 2022 monetary tightening on renewable-energy investment growth. By exploiting variation across Eurozone vs. non-Eurozone and EU vs. non-EU countries, the model distinguishes between monetary-policy transmission and institutional-policy mechanisms. This makes the DiD approach particularly well suited for analyzing how macro-financial shocks interact with structural policy environments during the green transition.

Building on the theoretical framework developed in Section 4.2, this subsection sets out the empirical implementation of the Difference-in-Differences (DiD) design for the Central and Eastern European (CEE) panel dataset. The presentation introduces the variables used in the analysis, outlines the econometric specifications, and establishes the identifying assumptions that support causal interpretation.

The main outcome of interest is the growth in renewable-investment intensity,

$$y_{it} = \Delta \log\left(\frac{MW_{it}}{\text{Real GDP}_{it}}\right),$$

which measures the change in renewable installations relative to country´s economic size. Expressed in log-difference form, it captures approximate percentage changes and reduces the impact of cross-country scale differences, allowing for a focused analysis of investment acceleration across the region

Treatment status and policy timing are defined through indicator variables. The variable $Post_t$ equals one for all years from 2022 onward and captures the period after the European Central Bank's monetary tightening. Eurozone membership is denoted by EZ_i, while EU_i identifies membership in the European Union.

A second policy window is defined by $PostGreenDeal_t$, which equals one from 2020 onward and represents the implementation phase of the EU Green Deal. Introduced as the EU's central climate and industrial strategy, the Green Deal seeks to accelerate decarbonisation, expand renewable-energy capacity, and realign investment incentives across EU Member States. Incorporating this policy dimension into the model helps differentiate monetary-policy effects from broader, structural shifts in renewable-investment behaviour driven by EU-wide policy commitments.

The treatment indicators are defined as follows:

$$Post_t = \mathbf{1}\{\, t \geq 2022 \,\}, \tag{1}$$

$$EZ_i = \mathbf{1}\{\, i \text{ is a Eurozone member}\}, \tag{2}$$

$$EU_i = \mathbf{1}\{\, i \text{ is an EU member}\}, \tag{3}$$

$$PostGreenDeal_t = \mathbf{1}\{\, t \geq 2020 \,\}. \tag{4}$$

The corresponding DiD interaction terms are constructed as

$$D_{it}^{EZ} = Post_t \times EZ_i, \tag{5}$$

$$D_{it}^{EU} = Post_t \times EU_i, \tag{6}$$

$$D_{it}^{GD} = PostGreenDeal_t \times EU_i. \tag{7}$$

Equations (1) and (4) define post-period indicators, whereas (2) and (3) define country-specific membership dummies. The Difference-in-Differences treatment variables in (5)–(7) are constructed as interaction terms that assign treatment to member countries in the respective post periods.

By distinguishing Eurozone from EU membership, these indicators identify differences in monetary-policy transmission versus institutional integration. Together, these treatment definitions create a clear treated–control structure in which treatment status is fixed over time, avoiding staggered adoption complications and ensuring that monetary and institutional channels can be identified separately within the DiD framework. To account for cross-country differences in vulnerability to energy-price shocks, a gas consumption variable is summarized in detail in Section 6.

This variable serves as a macro-financial control that captures differences in dependence on natural gas consumption and exposure to European energy-market pressures. Models are estimated both with and without this control, since gas-price vulnerability may itself have been influenced by policy shocks during 2020–2022.

The baseline empirical specification compares Eurozone members with non-members using a two-way fixed-effects (TWFE) Difference-in-Differences model, which also serves as the main model in this research:

$$y_{it} = \alpha_i + \lambda_t + \gamma\left(Post_t \times EZ_i\right) + \varepsilon_{it}, \tag{8}$$

where α_i are country fixed effects and λ_t year fixed effects. The interaction term $(Post_t \times EZ_i)$ equals one only for Eurozone countries after 2022 and its coefficient γ reflects the excess post-shock change in renewable-investment intensity among treated units. This specification isolates the monetary transmission channel of the 2022 ECB tightening, as it differences out all time-invariant cross-country heterogeneity through α_i and removes common macroeconomic shocks through λ_t. Identification therefore relies on comparing the within-country change in renewable-investment intensity in Eurozone members to the corresponding change in non-members.

A parallel institutional contrast compares EU and non-EU countries,

$$y_{it} = \alpha_i + \lambda_t + \gamma\left(Post_t \times EU_i\right) + \varepsilon_{it}, \tag{9}$$

which captures a broader institutional and fiscal dimension. When pre-treatment trends differ, this coefficient is interpreted as a reduced-form institutional contrast rather than a strict causal effect.

For descriptive comparison, pooled DiD benchmarks without fixed effects are estimated,

$$y_{it} = \alpha + \beta Post_t + \delta Group_i + \gamma(Post_t \times Group_i) + \varepsilon_{it}, \tag{10}$$

where $Group_i$ corresponds to EZ_i or EU_i. This pooled specification aligns with the classical two-by-two DiD estimator and illustrates raw mean contrasts. It is reported as a descriptive complement rather than as the primary model, since it assumes away unobserved country heterogeneity.

The baseline models will be extended with gas interaction term,

$$
\begin{aligned}
y_{it} = \alpha_i + \lambda_t + \gamma(Post_t \times EZ_i) \\
+ \theta[\log(GasConsumptionShare_{i,2021}) \times Post_t] + \varepsilon_{it},
\end{aligned} \tag{11a}
$$

$$
\begin{aligned}
y_{it} = \alpha_i + \lambda_t + \gamma(Post_t \times EU_i) \\
+ \theta[\log(GasConsumptionShare_{i,2021}) \times Post_t] + \varepsilon_{it}.
\end{aligned} \tag{11b}
$$

which improves precision when gas consumption proxies macro-financial vulnerabilities not absorbed by the fixed effects. The gas variable is fixed at its pre-crisis (2021) level and interacted with the $Post_{2022}$ indicator to capture energy-related vulnerabilities following the shock. A detailed discussion of this variable's construction and its role as a proxy for macro-financial stability is provided in Subsection 6.

A joint monetary–institutional specification incorporates both policy environments,

$$y_{it} = \alpha_i + \lambda_t + \gamma_1(Post_t \times EZ_i) + \gamma_2(PostGreenDeal_t \times EU_i) + \varepsilon_{it}, \tag{12}$$

as well as its variant including gas consumption variable,

$$
\begin{aligned}
y_{it} = \alpha_i + \lambda_t + \gamma_1(Post_t \times EZ_i) + \gamma_2(PostGreenDeal_t \times EU_i) \\
+ \theta[\log(GasConsumptionShare_{i,2021}) \times Post_t] + \varepsilon_{it}
\end{aligned} \tag{13}
$$

These models distinguish the direct monetary transmission channel from the institutional and fiscal channel linked to the Green Deal.

Taken together, the specifications in (8)–(13) implement the DiD framework in a manner consistent with the structural and macro-financial characteristics of the CEE region. The baseline specification is also estimated on the CEE sample excluding the Baltic states. This restriction is motivated by observable differences in the energy-system profiles of the Baltic countries, including their gas consumption patterns and the evolution of renewable-capacity additions. Including them would introduce strong leverage points and reduce the comparability of pre-treatment trajectories across the remaining CEE countries. A detailed discussion is provided in Section 5.5.

5 Empirical Results

Building on the two-way fixed-effects Difference-in-Differences framework developed in the previous section, this part of the analysis presents the estimation results for the Central and Eastern European (CEE) panel. The results are organized in the following way. First, the analysis begins with the baseline two-way fixed-effects (TWFE) Difference-in-Differences models, which constitute the primary causal estimates. These specifications measure the differential post-2022 effect of the ECB's monetary tightening on renewable investment intensity by comparing Eurozone and EU member states to their respective control groups, while absorbing all time-invariant country characteristics and common year shocks. Second, pooled DiD models are reported as descriptive, non-causal complements. These estimates illustrate unconditional post-2022 shifts across country groups without controlling for country or year fixed effects. They serve to contrast aggregate patterns with the within-country causal variation captured by the TWFE models.

Third, the analysis extends the baseline model by jointly incorporating the ECB's 2022 tightening and the EU Green Deal (2020). These extended TWFE specifications evaluate whether monetary and institutional policy shocks generated distinct or reinforcing effects on renewable investment intensity. This first-difference TWFE framework examines short-run dynamics and assesses whether policy interventions affected annual changes in investment intensity. To ensure a comprehensive analysis, level-based specifications are included as a complementary diagnostic to capture long-run structural shifts. Furthermore, to account for potential heteroskedasticity and the small number of clusters within institutional groupings, the statistical significance of the estimates is validated using bootstrap clustering.

Finally, a series of robustness checks evaluates the sensitivity of the results. In particular, the models are re-estimated after excluding the Baltic states (Estonia, Latvia, and Lithuania), to verify that the findings do not hinge on countries with markedly different energy structures and transition paths. Together, these results offer a comprehensive view of how monetary and fiscal–institutional shocks interacted to shape renewable-energy investment dynamics across the CEE region.

The empirical results are structured into seven subsections: Subsection 5.1 (Baseline TWFE DiD), Subsection 5.2 (Pooled contrast), Subsection 5.3 (EU Green Deal background), Subsection 5.4 (Joint monetary–institutional effects), Subsection 5.5 (Robustness checks) and Subsection 5.6 (Summary).

5.1 Baseline Causal Effects: TWFE Difference-in-Differences Models

Table 5 presents the baseline two-way fixed-effects (TWFE) Difference-in-Differences estimates for the Eurozone and EU country groups based on first differences. The specification compares the post-2022 evolution of renewable energy investment intensity between treated and control countries, controlling for time-invariant country characteristics and common year shocks. The estimated coefficients capture the differential impact of the 2022 shocks on the growth rate of renewable investment intensity following the ECB's monetary tightening, reflecting whether Eurozone or EU members experienced distinct post-shock dynamics relative to non-members, with level estimates included for comparison.

Table 5: TWFE Difference-in-Differences Estimates: Baseline TWFE Results

	(1) EZ vs. non-EZ	(2) EU vs. non-EU
Panel A: First Differences : Baseline Results ($\Delta \log(MW/GDP)$)		
$\text{Post}_t \times \text{Eurozone}_i$	0.0881	
	(0.0633)	
$\text{Post}_t \times \text{EU}_i$		0.1207
		(0.0716)
Observations	190	190
Countries	19	19
Country FE	Yes	Yes
Year FE	Yes	Yes
Adj. R^2	0.255	0.276
Within R^2	0.0245	0.0519
RMSE	0.1184	0.1167
Panel B: Levels : TWFE ($\log(MW/GDP)$)		
$\text{Post}_t \times \text{Eurozone}_i$	-0.0790	
	(0.2275)	
$\text{Post}_t \times \text{EU}_i$		0.0218
		(0.2269)
Observations	209	209
Countries	19	19
Country FE	Yes	Yes
Year FE	Yes	Yes
Adj. R^2	0.899	0.898
Within R^2	0.0035	0.0003
RMSE	0.2747	0.2751

Notes: Panel A reports the baseline estimates based on first differences, $\Delta \log(MW/GDP)$, capturing short-run within-country adjustments following the 2022 monetary tightening. Panel B represents the level variable.

Taking into account the fixed effects of country and year, the estimated $\text{Post}_t \times \text{Eurozone}_i$ interaction in first differences is

$$\hat{\gamma} = 0.0881 \quad \text{(bootstrap SE} = 0.0633),$$

and the corresponding $\text{Post}_t \times \text{EU}_i$ interaction equals

$$\hat{\gamma} = 0.1207 \quad \text{(bootstrap SE} = 0.0716).$$

In logarithmic terms, these estimates correspond approximately to an +8.8% and +12.1% post-2022 change in renewable energy investment intensity, respectively, relative to the non-member control groups. In economic terms, a coefficient of 0.0881 implies that, conditional on the model's controls, Eurozone members experienced a moderately stronger short-run post-2022 adjustment in renewable investment intensity than comparable non-Eurozone countries.

Conversely, the coefficient of 0.1207 suggests that EU members recorded a post-2022 increase in growth rate of renewable investment intensity of about 12.1% relative to non-EU countries. However, both estimates are statistically insignificant when inference is based on bootstrap standard errors, indicating that the results fail to reach statistical significance at standard levels. In practical terms, this suggests that neither Eurozone nor EU membership was associated with a systematically different short-run post-2022 path of renewable-energy investment intensity compared to non-member countries.

For context, inference is conducted using a country-level bootstrap procedure, which is well-suited to panels with a limited number of countries. In the fully specified TWFE framework, identification arises from within-country deviations relative to the common time path, so the estimated interactions capture differential post-2022 changes between treated and control groups after netting out time-invariant country characteristics and common year shocks. The results therefore indicate no systematic short-run divergence between Eurozone/EU members and their respective control groups once common shocks and unobserved, time-invariant heterogeneity are accounted for.

The adjusted R^2 values (0.255 and 0.276) reflect the explanatory contribution of the two-way fixed effects, while the relatively low within R^2 values (EZ: 0.0245, EU: 0.0519) confirm that the policy-treatment interactions contribute only modestly to explaining residual within-country variation in $\Delta \log(\text{MW/GDP})$. Overall, post-2022 changes in renewable investment intensity appear broad-based across the CEE region rather than driven by institutional membership.

Panel B of Table 5 reports the results in levels ($\log(MW/GDP)$), providing a contextual comparison to the main first-difference estimates. While the first-difference approach captures the immediate acceleration in investment intensity, the level estimates reflect the overall stock of renewable energy. In this specification, the Eurozone interaction term yields a negative coefficient ($\hat{\gamma} = -0.0790$), contrasting with the positive growth signal seen in the flow-based variables of Panel A. However, similar to the main results, these estimates remain statistically insignificant and fail to reach conventional significance thresholds ($p > 0.1$). This reinforces the conclusion that once time-invariant country characteristics and common regional shocks are absorbed, institutional membership does not exhibit a dominant or statistically discernible impact on the levels of renewable investment intensity.

In TWFE, γ is identified from within–country deviations relative to the common time path, sharply reducing omitted–variable bias from fixed country traits and region–wide shocks. By contrast, the pooled model does not control for country or year fixed effects: its γ mixes within–country changes with between–country level differences, and any unmodelled common shocks or time–invariant heterogeneity can load onto β, δ, or γ. Hence the pooled estimates are reported as a transparent, descriptive complement, whereas the first-difference TWFE results constitute the main causal evidence. Interpretation of pooled coefficients in the following section should be cautious and non–causal, with the TWFE table guiding the substantive conclusions.

5.2 Descriptive Contrasts: Pooled Difference-in-Differences Models

Table 6 reports the pooled DiD estimates for both institutional groupings (EU vs. non-EU and Eurozone vs. non-Eurozone). These specifications serve as a descriptive complement rather than a causal benchmark, illustrating how the average post-2022 shift in renewable-investment intensity compares across groups when unobserved heterogeneity is not explicitly controlled for. The inclusion of the post-treatment dummy ($Post_t$) captures the overall regional shift in renewable investment following the ECB's tightening, while the interaction term ($Post_t \times Group_i$) isolates the differential response of treated countries relative to their controls.

The pooled OLS estimates, specified in first differences ($\Delta \log(\text{MW/GDP}_{\text{real}})$), provide a descriptive overview of the investment growth dynamics across the CEE region.

Table 6: Pooled DiD Estimates: EU vs. Non-EU and Eurozone vs. Non-Eurozone

Variable	(1) EU Pooled $\Delta \log(MW/GDP)$	(2) EZ Pooled $\Delta \log(MW/GDP)$
Intercept	0.0627***	0.0651***
	(0.0192)	(0.0210)
Post-tightening ($Post_t$)	0.0015	0.0082
	(0.0672)	(0.0650)
Group Dummy ($Group_i$)	-0.0341	-0.0215
	(0.0363)	(0.0380)
$Post_t \times Group_i$ (DiD)	0.1207	-0.0790
	(0.0716)	(0.0750)
Observations	190	190
R-squared (Adj.)	0.067	0.035
Method	Pooled OLS	Pooled OLS
Standard Errors	Country-level Bootstrap	Country-level Bootstrap

Notes: Standard errors in parentheses are obtained via a country-level bootstrap with 999 replications ($N = 19$). Significance levels: *p $<$ 0.1, **p $<$ 0.05, ***p $<$ 0.01.

The estimated coefficients for the post-treatment variable ($Post_t$) are 0.0015 ($p = 0.966$) in the EU model and 0.0082 ($p = 0.901$) in the Eurozone model. However the use of country-level bootstraped standard errors leaves these coefficients statistically insignificant.

The interaction terms for both EU ($\hat{\beta} = 0.1207$, bootstrapped $SE = 0.0716$) and Eurozone ($\hat{\beta} = -0.0790$, bootstrapped $SE = 0.0750$) groupings are statistically imprecise. Even though the EU interaction term suggests a positive growth trend of approximately 12% relative to the control group, the bootstrapped standard errors indicate that this effect is not robust. In conclusion, when accounting for the small number of clusters and the inherent heterogeneity of the CEE markets, we find no credible evidence of a differential post-2022 investment response between treated and control groups. These findings highlight that investment dynamics were likely dominated by country-specific factors, such as energy security needs, rather than institutional membership alone.

Notably, both models yield positive and highly significant intercepts ($p < 0.01$), which reflect a robust baseline growth in investment intensity across the control groups. This suggests that, prior to the 2022 tightening, investment intensity was already expanding at an average annual rate of approximately 6.3% to 6.5% for the control groups.

Economically, the statistically insignificant post-treatment coefficients in the first-difference pooled model reflect the high degree of heterogeneity in the region-wide response to the 2022 shocks. While the estimated growth trend remains positive, the lack of statistical significance after accounting for country-level variance through bootstrapping suggests that energy-security concerns and renewable-investment acceleration did not follow a uniform path across Central and Eastern Europe. The lack of significant interaction effects in this specification further corroborates the TWFE findings: institutional membership (EU or Eurozone) did not materially amplify or dampen the investment adjustment following the ECB's tightening. The consistency between the pooled results and the TWFE estimates strengthens the robustness of the analysis, as both specifications yield statistically insignificant interaction terms.

5.3 Institutional Background: The EU Green Deal as a Structural Policy Shock

The European Green Deal, introduced in December 2019 and operationalised from 2020 onward, represents the European Union's central long-term strategy for achieving the continent´s climate neutrality by 2050. It integrates a comprehensive set of regulatory, fiscal, and investment initiatives intended to catalyze the green transformation, boosting renewable-energy capacity, and reducing fossil-fuel dependence across member states. The Green Deal should be understood not merely as an environmental policy initiative but as a broad macro-structural policy package with far-reaching economy-wide implications for investment, innovation, and financial flows (European Council, 2025).

A core component of the Green Deal is its investment pillar, which includes the Sustainable Europe Investment Plan[4] , the Just Transition Mechanism[5] , the Recovery and Resilience Facility (RRF)[6] , and reforms within the EU Emissions Trading System (ETS)[7]. These initiatives collectively mobilise up to EUR 1 trillion in public and private funding over the decade 2021–2030, with a substantial share targeted explicitly at renewable energy, grid expansion, and permitting reforms (European Commission, 2020b; European Investment Bank, 2022). The European Investment Bank (EIB), rebranded as the EU "climate bank," has simultaneously amplified green lending, disproportionately benefiting EU member states and accelerating capital reallocation towards clean technologies.

For Central and Eastern Europe (CEE), the Green Deal represents a particularly relevant institutional shock. Many CEE countries entered the decade with legacy coal capacity, underdeveloped grid infrastructure, and lower baseline renewable share (International Renewable Energy Agency, 2021). By providing both regulatory certainty and favorable access to green financing, the Green Deal reduces investment frictions, lowers the cost of capital for renewable projects, and facilitates the scaling-up of solar and wind installations. This targeted support is instrumental in enabling the CEE region to align with the continent-wide goal of carbon neutrality by 2050.

[4] *Sustainable Europe Investment Plan* denotes the EU's long-term strategy to channel public and private funds into projects that support sustainable growth, competitiveness, and innovation across member states (European Parliament, 2020).

[5] *Just Transition Mechanism* provides targeted financial assistance to regions and industries that face the highest adjustment costs in the shift toward a low-carbon, climate-neutral economy (European Commission, 2020a).

[6] *Recovery and Resilience Facility (RRF)* is the EU's main post-COVID instrument offering grants and loans to support structural reforms and investments that strengthen economic resilience and advance green and digital transitions (Pecorari, 2026).

[7] *EU Emissions Trading System (ETS)* is the Union's carbon-pricing framework based on a cap-and-trade model, which limits total emissions and allows trading of allowances to p romote cost-efficient greenhouse-gas reductions (Directive (EU) 2023/959).

Empirical work confirms that EU-wide regulatory frameworks and green finance can generate measurable increases in renewable-energy investment, especially in economies with constrained domestic capital markets. This aligns with the findings of Hepburn et al. (2020), whose research ranks sustainable infrastructure projects among the most effective fiscal measures for stimulating the economy while supporting a rapid transition to a low-carbon system.

From an econometric perspective, the Green Deal introduces policy variation along an institutional dimension which is EU membership, that is distinct from the monetary-policy channel associated with the ECB's 2022 tightening. While the ECB shock primarily affects financing conditions through interest-rate and credit-cost channels, the Green Deal operates through fiscal transfers, regulatory harmonisation, and targeted green-finance mechanisms. This duality motivates the inclusion of a separate $PostGreenDeal_t \times EU_i$ interaction term within the empirical model. The indicator isolates whether EU member states, which directly receive Green Deal funds and fall under its regulatory mandates, experienced a differential shift in renewable investment after 2020 relative to non-EU CEE countries.

The relationship is not necessarily one-to-one. As Falagiarda and McQuade (2015a) note, financial and policy spillovers within the CEE region are substantial, meaning that non-EU economies may partially benefit from EU-wide investments and regulatory spillovers. Nonetheless, EU membership remains the primary margin of direct exposure to Green Deal instruments, while non-EU countries rely on domestic policies and external borrowing to fund their energy transitions. For this reason, the Green Deal serves as a plausible institutional treatment in a Difference-in-Differences framework, complementing the monetary-policy treatment associated with the ECB 2022 hike.

Overall, the Green Deal provides a structural, forward-looking policy environment that is likely to influence renewable-investment paths across the region. For instance, the EU has committed, in period 2021-2027, around €600 billion for climate-related spending. This positions the EU on a pathway compatible with its 2030 target of a 55% reduction in greenhouse-gas emissions relative to 1990. (European Commission, 2025b). Its inclusion in the empirical strategy allows the analysis to isolate monetary-policy transmission from fiscal-regulatory support mechanisms and to assess whether EU membership provides an additional, institution-specific boost to renewable investment beyond common regional dynamics.

5.4 Joint Monetary–Institutional Policy Effects (ECB Tightening × EU Green Deal)

Table 7 reports the two-policy two-way fixed-effects (TWFE) Difference-in-Differences estimates, jointly examining the effects of the European Central Bank's 2022 monetary tightening and the EU Green Deal launched in 2020. Both policy shocks are modeled within the same framework to assess whether monetary and fiscal–regulatory interventions produced distinct or reinforcing effects on renewable investment intensity across Central and Eastern Europe. The inclusion of $Post_t \times EZ_i$ captures the Eurozone-specific exposure to the 2022 tightening, while $Post_t^{GreenDeal} \times EU_i$ isolates the potential acceleration associated with the EU's green transition agenda. Country and year fixed effects control for persistent heterogeneity and region-wide shocks.

Table 7: Two-Policy TWFE: EU Green Deal (2020) and ECB Monetary Shock (2022)

Variable	Dependent Variable: $\Delta \log(MW/GDP_{real})$
EU Green Deal ($Post2020 \times EU$)	0.1173**
	(0.0568)
ECB Shock ($Post2022 \times EZ$)	0.0262
	(0.0433)
Observations	190
Country Fixed Effects	Yes (19)
Year Fixed Effects	Yes (10)
Adjusted R^2	0.2841
Within R^2	0.0684
Method	FD-TWFE
Standard Errors	Country-level Bootstrap

Notes: Standard errors in parentheses are obtained via country-level bootstrap with 999 replications. Significance levels: *p $<$ 0.1, **p $<$ 0.05, ***p $<$ 0.01.

The results of the Two-Policy FD-TWFE model (Table 7) provide a crucial enhancement to the previous findings. By simultaneously accounting for the 2020 EU Green Deal and the 2022 ECB monetary shock in a first-difference framework, the specific impact of institutional policy frameworks has been isolated from short-term monetary fluctuations. Unlike the previous levels-based or baseline specifications, the EU Green Deal coefficient is now both economically sizable and statistically significant ($\hat{\beta} = 0.1173, p = 0.039$). This suggests that the 2020 policy shift induced a robust acceleration in renewable energy investment, increasing the growth rate by approximately 11.7% in EU member states relative to non-EU peers.

This finding indicates that long-term regulatory commitments and the European Green Deal's structural support provided a significant impetus for the energy transition in the CEE region, even prior to the 2022 energy crisis.

In contrast, the ECB monetary shock interaction term remains small and statistically insignificant ($\hat{\beta} = 0.0262, p = 0.545$). This lack of significance implies that once the positive momentum of the Green Deal is controlled for, the ECB's interest rate hikes did not generate a detectable differential response in Eurozone countries compared to the rest of the region. Economically, this suggests that the institutional incentives of EU climate policy were a more dominant driver of investment trajectories than the financial constraints imposed by monetary tightening.

The Within $R^2 = 0.0684$ and the overall Adjusted $R^2 = 0.2841$ indicate that while country-specific characteristics still explain a moderate portion of the variance, the inclusion of the Green Deal as a separate policy shock improves the model's explanatory power. This contrast highlights that the post-2022 dynamics were not merely a uniform regional phenomenon, but were partially underpinned by the cumulative effect of EU-wide institutional frameworks that favored member states well before the 2022 shock materialized.

5.5 Robustness to Sample Restrictions: Excluding the Baltic States

To examine whether the baseline results are driven by the distinctive energy structures and post-2022 dynamics of the Baltic countries, the models are re-estimated on a restricted sample that excludes Estonia, Latvia, and Lithuania. The Baltic economies experienced unusually sharp adjustments in gas dependence, electricity imports, and renewable deployment following the Russian supply shock, raising the possibility that their trajectories exert disproportionate influence on the baseline estimates. The reduced sample contains 16 countries and preserves the panel structure used in the main specifications.

Table 8: Robustness Check: FD-TWFE Estimates Excluding Baltic States

Variable	(1) EZ vs. non-EZ $\Delta\log(MW/GDP_{real})$	(2) EU vs. non-EU $\Delta\log(MW/GDP_{real})$
Interaction ($Post_{2022} \times Group_i$)	-0.0421	0.0515
	(0.0500)	(0.0663)
Observations	160	160
Countries	16	16
Year Fixed Effects	Yes	Yes
Country Fixed Effects	(FD-accounted)	(FD-accounted)
Adjusted R^2	0.0227	0.0284
Method	FD-TWFE	FD-TWFE
Standard Errors	Bootstrapped	Bootstrapped

Notes: Baltic states (Estonia, Latvia, Lithuania) are excluded to ensure results are not driven by small-market outliers. Standard errors in parentheses are obtained via country-level bootstrap . *p $<$ 0.1, **p $<$ 0.05, ***p $<$ 0.01.

The results in Table 8 demonstrate that excluding the Baltic states does not significantly change the primary conclusion: institutional membership is not associated with a statistically significant post-2022 growth in renewable investment intensity. In this restricted sample, the EU interaction coefficient remains small and statistically insignificant ($\beta = 0.0515$, $p > 0.1$), while the Eurozone interaction term likewise remains insignificant ($\beta = -0.0421$, $p > 0.1$). This stability suggests that the baseline findings are not driven by the specific investment dynamics of small-market outliers.

The decision to isolate the Baltic countries in this study is motivated by the unique structure of their gas systems. As the only CEE subregion able to substitute Russian pipeline gas almost immediately after the 2022 supply shock, the Baltics possessed a degree of energy resilience not shared by the rest of the region. This was primarily due to the Klaipeda floating LNG [8] terminal, which has provided an autonomous import route independent of Russian transit infrastructure since 2014. By condensing gas into a liquid state at -162°C, the LNG process achieves a 600-to-1 volume reduction, making long-distance sea transport both feasible and efficient (U.S. Energy Information Administration, 2024). By leveraging this technological transition, countries can diversify their energy procurement beyond rigid pipelines, establishing a vital safeguard against supply routes disrupted by geopolitical tensions. Such resilience was further reinforced by strategic cross-border infrastructure under the Baltic Energy Market Interconnection Plan (BEMIP), including the Gas Interconnection Poland–Lithuania (GIPL) and the Balticconnector, which represents the first cross-border gas link between Finland and Estonia, with the objective of ending Finland's structural gas isolation by connecting it to the wider European transmission system. (European Commission, 2025a; Grigas, 2017). According to the European Commission, the Balticconnector enhances both the security of gas supply and the integration of the Baltic energy market by promoting competitive conditions. The 152 km pipeline operates in both directions with a capacity of 7.2 million cubic meters per day, facilitating reliable cross-border gas transmission.

The fact that the interaction terms remain statistically indistinguishable from zero even after removing these fast-adjusting economies strengthens the robustness of the analysis. It indicates that the lack of a detectable divergence between member and non-member states is a consistent feature across the CEE region, regardless of the inclusion of the Baltic states.

However, the unusual adjustment path of the Baltics underscores the importance of controlling for heterogeneity in natural-gas consumption. Their ability to pivot rapidly toward global LNG markets highlights how variation in energy-system exposure can shape post-shock investment responses. To isolate this channel, Section 7 extends the baseline TWFE specifications with gas consumption measures relative to GDP. Incorporating this variable allows the analysis to distinguish institutional membership effects from differences in vulnerability to the 2022 gas shock, providing a more accurate interpretation of renewable-investment dynamics across the CEE region.

[8] LNG - Liquefied Natural Gas

5.6 Summary of Baseline Empirical Results

The empirical results across all specifications reveal that institutional membership, either in the EU or the Eurozone, was not the primary driver of the post-2022 investment surge. While the pooled DiD and baseline TWFE models show a general regional increase in renewable energy investment intensity, the interaction terms remain statistically insignificant. This suggests that the treatment of being an EU or Eurozone member did not produce a statistically significant divergence in investment intensity compared to non-member states in the CEE region.

A significant distinction is obesrved in the two-policy model, where the EU Green Deal interaction ($\beta = 0.1173, p = 0.039$) shows a robust and significant acceleration in growth rate of investment intensity, which indicates that, following the introduction of the Green Deal, investment intensity in EU member states increased by approximately 11.7% relative to non-EU counterparts, holding other factors constant. This suggests that long-term structural support and regulatory frameworks provided a more powerful stimulus than the immediate 2022 monetary shock. Furthermore, robustness checks excluding the Baltic states confirm that these results are stable and not driven by small-market outliers with unique energy infrastructures.

Despite these insights, a fundamental theoretical challenge remains: the high degree of unexplained variance across countries with similar institutional statuses. The differing investment paths, even within the EU, suggest that a common underlying factor is missing from the baseline model. A theoretically grounded candidate is the variation in national energy structures, specifically the degree of dependence on natural gas.

Economies with significant gas dependence were more exposed to the price fluctuations triggered by the 2022 supply disruptions, which amplified the impact of rising natural gas costs. This increased threat to energy security appears to have functioned as a catalyst, potentially triggering an accelerated transition toward renewable investment that operated independently of institutional membership. To resolve this, Section 7 introduces gas consumption controls to disentangle institutional support from the direct pressure of the energy crisis, providing a more detailed understanding of the drivers of the energy transition in Central and Eastern Europe.

6 Construction of the Gas Consumption Variable

Assessing the extent to which national economies are vulnerable to fluctuations in international energy markets requires a transparent and comparable measure of consumption. In this study, a gas consumption variable is constructed to capture the degree of cross-country sensitivity to natural-gas market shocks. The logic of the indicator follows a simple "price × quantity" approach, with an additional normalization by economic size in order to make comparisons across economies with varying characteristics meaningful. The resulting measure can be interpreted as a burden-type indicator: it reflects the theoretical cost of gas dependence, valued at the European benchmark price, in relation to the size of a country's economy. The European benchmark gas price is taken from the World Bank commodity price series *Natural Gas Europe Price* (USD per million British thermal units, */mmBtu*).[9] National gas consumption is measured in terajoules (TJ), consistent with official energy statistics such as those provided by Eurostat and the International Energy Agency (IEA).[10] To ensure consistency across measurement units, the following conversion is applied, allowing benchmark prices (quoted per mmBtu) to be directly aligned with gas consumption volumes expressed in TJ.

$$1 \text{ TJ} = 1000 \text{ GJ} = 947.817 \text{ mmBtu}.$$

Table 9: European Benchmark Natural Gas Price, 2014–2024

Year	**Natural Gas Europe Price ($/mmBtu)**
2014	9.29
2015	6.97
2016	4.85
2017	5.88
2018	7.54
2019	4.83
2020	3.31
2021	14.73
2022	34.35
2023	11.49
2024	9.52

Source: World Bank Commodity Price Data ("Pink Sheet"), Natural Gas Europe Price (USD per mmBtu).

[9] World Bank, *Commodity Price Data* ("Pink Sheet").

[10] Eurostat, *Energy Balances*; IEA, *World Energy Balances*.

Table 9 reports the annual European benchmark natural gas prices used in the construction of the gas consumption variable. The data are taken from the World Bank's "Pink Sheet" series and expressed in U.S. dollars per million British thermal units (mmBtu).

The data in Table 9 show pronounced variation in European natural gas prices over the last decade. Following a period of relative stability between 2014 and 2020, prices fell to historical lows amid weak demand during the COVID-19 pandemic. From a theoretical standpoint, the 2020 price collapse can be interpreted as a pandemic-induced demand shock in the European gas market (Güntner et al., 2024). The sudden decline of industrial output and transport activity sharply reduced energy consumption, while gas supply remained largely inflexible in the short run due to technical and contractual constraints. Declining demand alongside a resilient supply framework placed a substantial downward pressure on prices, a trend further intensified by record-high gas storage levels observed across Europe (International Energy Agency, 2021; European Commission, 2025c).

As shown in Table 9, a dramatic surge occurred in 2021–2022, when the benchmark price increased more than tenfold, peaking at 34.35 USD/mmBtu in 2022. This spike reflected the combined effects of post-pandemic supply constraints, reduced pipeline flows from Russia, and the geopolitical shocks as a result of the invasion of Ukraine. Subsequently, prices moderated in 2023–2024 but remained above pre-2020 levels, indicating a structurally tighter European gas market (Güntner et al., 2024).

For each country i and year t, the European benchmark gas price P_t^{EU} (in USD per mmBtu) is combined with national gas consumption G_{it} (converted from terajoules, TJ, to mmBtu) to construct a measure of potential monetary value of gas consumption. The resulting hypothetical monetary exposure is defined as:

$$\text{Gas Consumption Value}_{it} = P_t^{EU} \times G_{it} \tag{14}$$

This formulation captures the cost of gas dependence under prevailing EU market prices, thereby combining simultaneous market conditions (P_t^{EU}) with structural reliance on natural gas (G_{it}). While the measure does not equal actual import expenditure (since countries may secure different bilateral contracts and price terms), it provides a consistent and comparable proxy for the possible exposure of national economies to European gas price shocks. In the case of Central and Eastern European (CEE) countries, where energy dependence has historically been a key macroeconomic vulnerability, such a proxy is particularly informative.[11]

[11]See, e.g., European Commission (2022), *Energy Economic Developments in Europe*, which highlights the uneven burden of energy price shocks across EU member states.

To improve comparability across economies of different sizes, gas consumption value is normalized by real GDP (constant prices):

$$\text{Gas Consumption Share}_{it} = \frac{\text{Gas Consumption Value}_{it}}{GDP_{it}}. \tag{15}$$

The resulting indicator reflects the magnitude of gas consumption relative to national income. Economies with higher values of Gas Consumption Share_{it} are more vulnerable to international gas price shocks, since a greater share of their income is formally linked to energy dependence. To ensure dimensional consistency between the gas consumption value measure and GDP, both quantities must be expressed in the same monetary unit. In the dataset used for this analysis, real GDP is reported in billions of U.S. dollars, whereas the constructed gas variable is expressed in *U.S. dollars*. To make the denominator compatible with the gas measure, GDP values are therefore converted from billions to absolute U.S. dollars by multiplying by 10^9:

$$GDP_{it}^{USD} = GDP_{it}^{(billions)} \times 10^9.$$

The normalized exposure share is then computed as

$$GasConsumptionShare_{it} = \frac{GasConsumptionValue_{it}}{GDP_{it}^{USD}}.$$

This adjustment ensures that the ratio represents a true proportion (ranging between 0 and 1) of national output hypothetically exposed to gas-price shocks. Without this scaling correction, dividing values in U.S. dollars by GDP in billions of U.S. dollars would overstate the gas consumption share by a factor of one billion.

Because the distribution of consumption shares is highly skewed, and to accommodate zero or near-zero values, a logarithmic transformation with an offset is applied:

$$\log(GasConsumptionShare_{it}) = \log\big(GasConsumptionShare_{it} + 1\big). \tag{16}$$

The +1 offset ensures that economies with minimal consumption share are included in the analysis. The transformation also stabilizes variance and facilitates semi-elastic interpretations of regression coefficients.

Subsequently, the sample is restricted to the 2014–2023 period to avoid partial data availability for 2024, and Montenegro is excluded due to incomplete energy statistics. The resulting dataset, referred to as `CEE_gas`, contains all remaining CEE economies with non-missing gas consumption data. For each country, summary statistics of *log_gas_-consumption* are computed to illustrate the heterogeneity of gas dependence across the region. This analysis is presented in Subsection 6.2 and refers to the absolute measure of consumption, which is not standardized by GDP. The variable thus captures the total nominal magnitude of gas-related vulnerability, prior to normalization by economic size. As outlined in the following Subsection 6.1, the preceding discussion of gas-capacity patterns provides the descriptive basis for this measure.

6.1 Visualization and Descriptive Trends of Gas Capacity

Before analyzing the relative effective consumption indicators, it is useful to illustrate the underlying evolution of gas consumption capacity across Central and Eastern European (CEE) economies. Figure 8 presents annual total gas capacity (measured in terajoules, TJ) for the period 2014–2023. Each panel corresponds to one country, allowing for a visual comparison of both the absolute magnitude and the dynamic trajectory of gas consumption over time.

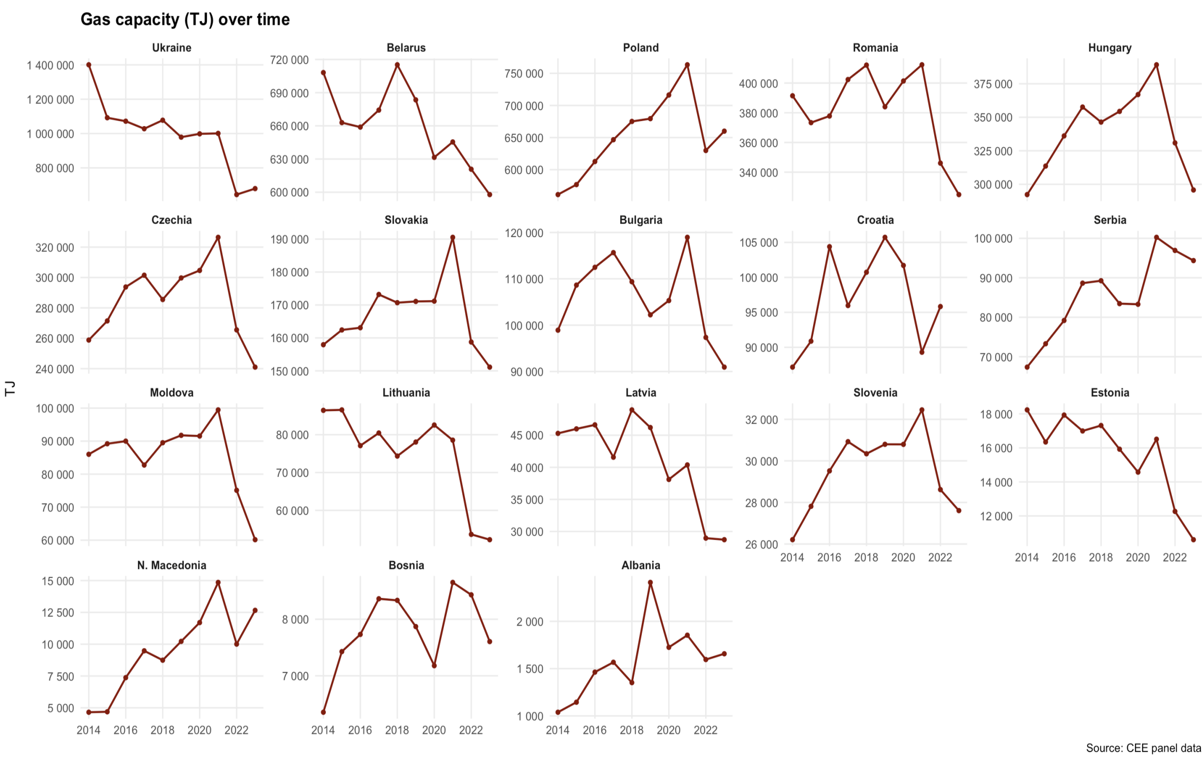


Figure 8: Gas capacity (TJ) over time, 2014–2023.

The trajectories reveal substantial cross-country heterogeneity. High-capacity systems such as Ukraine, Poland, Belarus, and Romania consistently record several hundred thousand terajoules annually, reflecting historically energy-intensive industrial structures and extensive gas networks. Medium-range consumers, including Czechia, Slovakia, Hungary, and Bulgaria, exhibit moderate capacities with fluctuations that often align with broader economic cycles or periods of energy-efficiency adjustment. Smaller CEE economies such as Croatia, Serbia, and the Baltic states, display markedly lower volumes, typically between 50,000 and 100,000 TJ, while Bosnia and North Macedonia maintain minimal capacities below 10,000 TJ. The lowest values are observed for Albania and Estonia, where limited gas infrastructure and a greater reliance on alternative energy sources translate into very low natural-gas use.

Across most CEE countries, the period 2021–2022 is characterized by a clear stagnation or decline in gas capacity, consistent with the region-wide contraction in gas demand following the 2022 European energy crisis and the associated price surge. This downturn reflects a combination of factors, including disrupted Russian gas flows, unprecedented wholesale price increases, and accelerated diversification toward non-Russian supply. Together, these developments underscore the structural vulnerability of CEE economies to external gas-market shocks and provide the conceptual basis for constructing the *Gas Consumption Value* and *Gas Consumption Share* variables examined in the subsequent sections.

6.2 Gas Consumption Value

To visualize cross-country variation in the constructed consumption variable, the values are summarized and presented in Table 10.

The visualization illustrates how the intensity of gas dependence differs across CEE economies over time, highlighting both structural and temporal patterns of vulnerability. To account for the high skewness of the consumption distribution, a logarithmic transformation with an offset was applied, yielding the variable $\log(GasConsumptionValue_{it}+1)$. This transformation reduces the influence of extreme values and facilitates a clearer comparison between countries with large and small gas consumption levels. The magnitude of the resulting values is substantial, as the European benchmark gas price is denominated in U.S. dollars per million British thermal units (USD/mmBtu), while national gas consumption is originally measured in terajoules (TJ). To ensure unit consistency, the latter is converted to mmBtu using the standard factor 1 TJ = 947.817 mmBtu, resulting in large numerical products when multiplied by the price term.

Consequently, the constructed variable represents the hypothetical total cost of national gas use in U.S. dollars under prevailing European market prices, which naturally yields values in the order of billions of USD for larger energy consumers.

Table 10 reports the corresponding summary statistics by country (mean, standard deviation, minimum, and maximum), providing an overview of cross-sectional heterogeneity in gas dependence across the CEE region. The results indicate a clear cross-country hierarchy in the intensity of gas dependence. Countries with larger industrial bases and higher total energy demand, such as Ukraine, Poland, Belarus, and Romania, display the highest average consumption levels, with mean log values around 22–23. These figures reflect substantial national gas consumption volumes relative to other economies in the region. Similarly, Hungary, Czechia, and Slovakia record relatively high values, consistent with their larger energy use and greater integration into regional gas networks. In contrast, smaller CEE economies, including Albania, Serbia, North Macedonia, and Estonia, show considerably lower mean values, ranging between 16 and 18. These results indicate that, in relative terms, their total gas consumption, and therefore the hypothetical monetary exposure to European gas prices, is substantially lower. Intermediate exposure levels are observed for Bulgaria, Lithuania, Latvia, and Slovenia, falling between these two groups.

While the logarithmic transformation compresses the scale of values, the underlying differences in actual effective consumption levels remain substantial. For instance, a value of 16 (e.g., Albania) corresponds to an effective gas consumption of approximately $e^{16} \approx 8.9 \times 10^6$ USD (around 9 million USD), whereas a value of 22 (e.g., Ukraine) implies roughly $e^{22} \approx 3.6 \times 10^9$ USD (around 3.6 billion USD). This corresponds to an approximately four-hundredfold difference in the magnitude of gas consumption between the two countries. Thus, even seemingly small differences in logarithmic values translate into large differences in the economic burden associated with natural-gas dependence.

To better capture the relative macroeconomic burden of gas dependence, the gas consumption variable is normalized by real GDP, yielding the indicator $GasConsumptionShare_{it} = \frac{GasConsumptionValue_{it}}{GDP_{it}}$. This transformation expresses each country's hypothetical gas expenditure as a share of its total economic output, allowing for meaningful cross-country comparison despite large differences in economic size. The resulting measure, therefore, reflects the proportion of national income that would be exposed to fluctuations in European gas prices under prevailing market conditions. For visualization purposes, the indicator is presented in percentage terms, illustrating how the gas consumption share of GDP evolves over time across CEE economies.

However, for empirical estimation, the logarithmic transformation $\log(GasConsumptionShare_{it} + 1)$ is used. This specification mitigates the influence of extreme values, ensures a more symmetric distribution, and allows regression coefficients to be interpreted as semi-elasticities, i.e., the percentage-point change in renewable-energy investment intensity associated with a one-unit increase in the log-transformed gas consumption share (Wooldridge, 2010).

Table 10: Summary of log(Gas Consumption Value) by Country, 2014–2023

Country	Mean	SD	Min	Max
Albania	16.3	0.69	15.5	17.8
Belarus	22.4	0.65	21.4	23.7
Bosnia	17.9	0.71	16.9	19.4
Bulgaria	20.5	0.65	19.6	21.9
Croatia	18.4	6.48	0.0	21.9
Czechia	21.5	0.64	20.7	22.9
Estonia	18.6	0.61	17.6	19.8
Hungary	21.7	0.66	20.9	23.1
Latvia	19.6	0.57	18.6	20.7
Lithuania	20.2	0.57	19.4	21.3
Moldova	20.3	0.63	19.5	21.6
N. Macedonia	18.0	0.83	17.2	19.6
Poland	22.3	0.67	21.5	23.7
Romania	21.8	0.64	21.0	23.1
Serbia	17.2	0.74	16.3	18.8
Slovakia	21.0	0.66	20.1	22.4
Slovenia	19.2	0.66	18.4	20.7
Ukraine	22.7	0.58	21.9	23.8

Notes: Values refer to the logarithm of the constructed gas consumption indicator $\log(\text{GasConsumptionValue}_{it} + 1)$, averaged over the 2014–2023 period. The variable reflects the intensity of national consumption to European benchmark gas prices, combining annual consumption (TJ) with World Bank gas price data (USD/mmBtu). High values correspond to greater structural dependence on natural gas.

6.3 Gas Consumption as a Share of GDP

To complement the analysis of physical gas consumption, Figure 9 displays the evolution of gas consumption value as percentage of GDP for all CEE economies between 2014 and 2023. This variable reflects the relative burden of gas dependence on national income and is constructed by dividing each country's Gas Consumption (valued in USD) by its real GDP.

Figure 9: Gas Consumption Value as % of GDP over time, 2014–2023.

Because the underlying GDP data in the source dataset are expressed in billions of U.S. dollars, they are converted to absolute USD values to ensure consistent scaling with the gas consumption variable. The resulting indicator quantifies the notional share of national output exposed to fluctuations in the price of European gas, allowing direct comparison between economies of varying sizes. The figure highlights a common structural pattern across the region: most CEE countries exhibit a sharp peak in 2022, coinciding with the European energy crisis and the unprecedented rise in gas prices following the Russia–Ukraine war. This surge reflects both the exceptional volatility of international energy markets and the limited ability of many CEE economies to quickly substitute away from natural gas.

Countries with high industrial gas use and lower energy diversification, such as Hungary, Slovakia, Romania, and Serbia, record ratios exceeding 4–6 % of GDP in 2022. Smaller or more diversified systems (e.g. Albania, Slovenia, Estonia) remain below 1 %, while Ukraine and Belarus show unusually large fluctuations possibly due to wartime disruptions and data volatility. By 2023, most economies show a clear decline, consistent with price stabilization and reduced gas demand.

The cross-country variation visible in the chart underscores why normalization by GDP was essential: it reveals that even moderate changes in physical gas consumption can imply disproportionate macroeconomic exposure for smaller economies. This preprocessing ensures that the consumption variable is consistently defined across countries and time, avoiding distortions from outliers or incomplete observations. The final dataset (`CEE_gas`) thus provides a balanced and harmonized panel suitable for regression analysis.

While the descriptive analysis covers the 2014–2023 period to validate the scale of the shock, the regression model specifically fixes the gas consumption variable at its 2021 level. This choice is fundamental for ensuring the internal validity of the model. Using data from years prior to 2021 would fail to capture the most relevant structural dependency just before the crisis, while using data from after 2021 would introduce severe endogeneity issues. In this context, endogeneity refers to a "circular" relationship: in 2022 and 2023, countries did not just react to gas prices, they also actively reduced their gas consumption through tactical responses such as fuel switching, industrial curtailments, or emergency energy efficiency measures. If the model used these later years, it would be impossible to distinguish whether high gas prices caused more renewable investment, or if the observed drop in gas use was simply a byproduct of the transition toward renewables and other immediate adjustments. By fixing the variable in 2021, the model isolates each country's inherited vulnerability, treating the energy crisis as an external test on a pre-existing economic structure. This approach ensures that the model measures the impact of the crisis based on the situation countries were actually in when the shock started.

To operationalize this approach, the gas interaction term is defined as:

$$\log(\text{Gas Consumption Share}_{i,2021}) \times Post_t \tag{17}$$

where $Post_t$ is a dummy variable equal to 1 for the years 2022 and 2023. The 2021 gas share is interacted with $Post_t$ because structural dependency only becomes an active economic pressure once the shock occurs. Without this interaction, the model would treat gas dependence as a constant characteristic. Including it can isolate how that specific vulnerability changed the investment trajectory starting in 2022.

7 Empirical Results - Gas Consumption Share included

The following section sets out a difference-in-differences strategy for a country–year panel, beginning with a two-way fixed-effects (TWFE) specification that absorbs time-invariant country heterogeneity and common year shocks through country and year fixed effects. Identification in the TWFE model derives from the post-2022 excess change among Eurozone members relative to non-members, while conditioning on a GDP-normalized measure of gas consumption share to prevent simultaneous variation in energy dependence from confounding the treatment effect. The econometric models estimated in this section are the following:

$$\begin{aligned}\Delta \log\left(\frac{MW_{it}}{GDP_{it}}\right) &= \alpha_i + \lambda_t + \gamma_{\text{EZ}}(\text{Post}_t \times \text{Eurozone}_i) \\ &\quad + \theta\left[\log(\text{GasConsumptionShare}_{i,2021}) \times \text{Post}_t\right] + \varepsilon_{it}\end{aligned} \tag{18}$$

$$\begin{aligned}\Delta \log\left(\frac{MW_{it}}{GDP_{it}}\right) &= \alpha_i + \lambda_t + \gamma_{\text{EZ}}(\text{Post}_t \times \text{EU}_i) \\ &\quad + \theta\left[\log(\text{GasConsumptionShare}_{i,2021}) \times \text{Post}_t\right] + \varepsilon_{it}\end{aligned} \tag{19}$$

To account for the heterogeneity in energy dependence across countries, the baseline TWFE specification is extended with a control for gas consumption share. This variable captures the relative sensitivity of each economy to consumed natural gas divided by the respective GDP and helps prevent simultaneous energy-dependence shocks from biasing the estimated treatment effect. Because the main effects of the treatment and time dummies ($Post_t$ and EZ_i / EU_i) are perfectly collinear with country and year fixed effects (α_i, λ_t), identification relies solely on their interaction term. The coefficient γ therefore captures the average treatment effect of Eurozone (or EU) membership after 2022, conditional on time-invariant country characteristics and common year shocks. Since the dependent variable is in first-differences of logs and the gas variable is in logarithmic form, θ reflects the elasticity of the growth rate. Specifically, it measures how a 1% difference in initial gas consumption scales the subsequent acceleration in investment intensity.

In this specification, the gas consumption share variable is intentionally fixed at its pre-treatment level from the year 2021 ($\text{GasShare}_{i,2021}$). As noted by Wooldridge (2010), fixing the regressor at its initial value is a robust methodological choice to mitigate potential endogeneity concerns. This ensures that the estimated coefficient θ reflects the impact of structural energy dependency rather than simultaneous adjustments in gas consumption that might occur in response to the macroeconomic shocks themselves. While preliminary runs with time-varying gas data yielded statistical significance, this fixed-year approach provides a more rigorous identification of the treatment effect by isolating the initial consumption.

Table 11: TWFE Regression Results with Bootstrap Standard Errors

Dependent Variable:	$\Delta \log(MW_{it}/GDP_{it})$	
	(1) Eurozone	(2) EU
Post × Treatment	0.0247	0.0506
	(0.0410)	(0.0558)
Gas Interaction Term	0.1451	0.3813
	(0.6905)	(0.7351)
Country Fixed Effects	Yes	Yes
Year Fixed Effects	Yes	Yes
Observations	162	162
Within R^2	0.0017	0.0075
Bootstrap Iterations	999	999

Note: Bootstrap standard errors are reported in parentheses.
p-values: (1) $p = 0.547$, (2) $p = 0.365$. Significance: *p<0.1, **p<0.05, ***p<0.01.

Table 11 presents the estimation results from the two-way fixed effects (TWFE) models, incorporating bootstrap standard errors to ensure robustness given the sample size constraints. In this refined specification, the gas consumption variable is fixed at its 2021 baseline level and the dependent variable is expressed in first differences, $\Delta \log(MW_{it}/GDP_{it})$, representing the growth rate of renewable-energy investment intensity.

Across both the Eurozone and EU specifications, the interaction terms capturing the post-2022 policy shock remain statistically insignificant. Specifically, the estimate for the Eurozone treatment is 0.0247 ($p = 0.547$), while the EU-wide effect is estimated at 0.0506 ($p = 0.365$). These results align with the earlier findings that institutional membership did not result in a statistically detectable divergence in renewable investment trajectories following the 2022 monetary tightening.

The use of bootstrap standard errors further validates that once structural gas dependency and country-year fixed effects are controlled for in the model, the differential impact of the policy shock across institutional groupings is trivial.

The coefficient for the gas interaction term, fixed at the 2021 consumption share values for each country, is positive in both models but fails to reach standard levels of statistical significance. In the Eurozone model, the coefficient is 0.1451, while in the EU specification, it is 0.3813. While the positive sign of these estimates is aligned with energy-security arguments, suggesting that countries with higher initial gas consumption share might have a greater vulnerability to increase renewable investment, the lack of statistical precision prevents a definitive conclusion.

The insignificance of the treatment interaction terms, which remain small in magnitude, indicates that the post-2022 shift in renewable investment intensity was not heterogeneously distributed across Eurozone or EU countries relative to their respective control groups. These findings suggest that the 2022 shock did not trigger a distinct institutional response in terms of monetary-policy transmission to the energy sector. Instead, the results point towards a more uniform regional response, where renewable energy investment dynamics are likely driven by broader structural factors or synchronized EU-wide policy frameworks rather than specific institutional status within the Eurozone or the Union.

7.1 Two-Policy Specification for Gas Consumption as a Share of GDP

The econometric model estimated in this section is the following:

$$\begin{aligned}\Delta \log\left(\frac{MW_{it}}{GDP_{it}}\right) &= \alpha_i + \lambda_t + \gamma_1(Post_t \times Eurozone_i) \\ &\quad + \gamma_2(GreenDeal_t \times EU_i) \\ &\quad + \theta[\log(GasShare_{i,2021}) \times Post_t] + \varepsilon_{it}\end{aligned} \tag{20}$$

The results in Table 12 provide a comparative assessment of institutional and market-based drivers of renewable investment intensity. By isolating the effects of the EU Green Deal, Eurozone membership, and gas consumption, these estimates identify which factors fundamentally accelerated the green transition in the CEE region.

Table 12: Two-Way Fixed Effects (TWFE) Results: Monetary Policy vs. Green Deal

Dependent Variable:	$\Delta \log(MW_{it}/GDP_{it})$
Policy Variables	
EU Green Deal (γ_2)	0.0821**
	(0.0364)
Post $\times$ Eurozone (γ_1)	-0.0088
	(0.0411)
Control Variables	
Gas Share Interaction (θ)	0.4880
	(1.7166)
Country Fixed Effects	Yes
Year Fixed Effects	Yes
Observations	162
Within R^2	0.0266
Bootstrap Iterations	999

Note: Bootstrap standard errors in parentheses.
Significance: *p<0.1, **p<0.05, ***p<0.01.

The empirical estimates reveal a pronounced hierarchy among the analyzed drivers. The most prominent result is the coefficient on the EU Green Deal (γ_2), which is positive (0.0821) and statistically significant at the 5% level.

This suggests that the centralized regulatory and financial framework of the Green Deal acted as a robust catalyst for the growth in renewable investment intensity across the CEE region, effectively outweighing other macroeconomic factors. Specifically, this estimate implies that, holding all other factors constant, the implementation of the EU Green Deal framework is associated with an approximately 8.2% increase in the annual growth rate of renewable investment intensity relative to GDP. This magnitude underscores that the transition was not merely a passive trend, but a statistically significant shift accelerated by targeted supra-national climate policy. Such a result suggests that the "certainty" provided by the Green Deal effectively lowered the barriers to entry for renewable projects, providing a more influential signal to investors than regional monetary conditions or fluctuating energy prices.

In contrast, the Post × Eurozone interaction ($\gamma_1 = -0.0088$) and the Gas Share Interaction ($\theta = 0.4880$) both fail to reach statistical significance. The lack of significance for the Eurozone coefficient again indicates that membership in the monetary union did not provide a differential stimulus for green investment following the 2022 shock in this model. Similarly, while the positive direction of the gas interaction term is conceptually aligned with the energy-security literature (International Energy Agency, 2022b), its high standard error suggests that national responses to gas consumption were too heterogeneous to constitute a uniform regional driver. Collectively, these findings imply that institutional mandates from the EU were more decisive in shaping the transition path than either monetary frameworks or direct market-based energy risks.

7.2 Excluding the Baltic States

As a robustness check, the TWFE specification is re-estimated excluding Estonia, Latvia and Lithuania. These countries experienced a sharp and atypical structural shift in gas supply conditions following the activation of the Klaipėda LNG terminal, which makes their post-2022 dynamics not fully comparable to the rest of the region.

Table 13: The Impact of Monetary Policy and Gas Exposure on Renewable Investment (Excluding Baltic States)

	Dependent Variable: $\Delta \log(\text{MW/GDP})$	
	(1) Eurozone Model	(2) EU Model
Post-2022 × Eurozone	-0.0412	
	(0.0472)	
Post-2022 × EU		0.0260
		(0.0559)
Gas Interaction Term	0.1587	0.4326
	(2.0243)	(2.0353)
Country Fixed Effects	Yes	Yes
Year Fixed Effects	Yes	Yes
Observations	135	135
Adjusted R^2	0.3228	0.3215
Within R^2	0.0055	0.0036

Note: Standard errors in parentheses are obtained via clustered bootstrap
*** p<0.01, ** p<0.05, * p<0.1.

The results in Table 13 show that excluding the Baltic states does not alter the core findings. In the Eurozone model (1), the coefficient is negative (-0.0412), suggesting a potential downward pressure on renewable investment growth due to increased capital costs, although the effect is not precisely estimated. Conversely, the EU model (2) shows a small positive coefficient (0.0260).

The gas interaction term remains positive across both specifications (0.1587 and 0.4326), indicating that higher exposure to gas prices may have incentivized investment as a matter of energy security. However, these estimates also lack statistical significance. The high standard errors obtained through the bootstrap procedure suggest that when the Baltic outliers are removed, the response of CEE countries to the interest rate shock is highly varied, likely due to the neutralizing influence of energy independence policies and national subsidies.

7.3 Summary of Gas-Adjusted Empirical Results

The empirical analysis utilized a Two-Way Fixed Effects (TWFE) Difference-in-Differences strategy to isolate the impact of institutional membership on renewable investment intensity while explicitly controlling for structural energy dependence. By fixing gas consumption shares at 2021 levels to mitigate endogeneity, the model successfully captures the structural push factor of energy security following the 2022 geopolitical shock.

The baseline results from the TWFE specification reveal a consistent lack of statistical significance for the monetary policy shock across both Eurozone and EU groupings. With coefficients of 0.0247 for the Eurozone and 0.0506 for the EU, the findings suggest that the institutional membership did not trigger a divergent trajectory in renewable energy investment intensity. Despite the increased cost of capital associated with monetary tightening, the policy shock did not result in a statistically detectable decline. This points toward a uniform regional response rather than one dictated primarily by currency union status.

The introduction of a multi-policy framework in Section 7.2 provides a clearer hierarchy of investment drivers. While the Eurozone interaction and gas interaction terms remain insignificant, the EU Green Deal emerges as a robust and statistically significant catalyst ($\gamma_2 = 0.0821$, $p < 0.05$) once again. This indicates that the centralized regulatory certainty and financial frameworks provided by the Green Deal were more influential than regional monetary conditions. Specifically, the implementation of the Green Deal is associated with an 8.2% increase in the growth rate of renewable investment intensity, which effectively outweighed the negative pressures of capital costs.

Finally, robustness checks excluding the Baltic states confirm the stability of these findings. Removing these countries because they experienced atypical energy supply shifts leads to a negative, though still insignificant, coefficient for the Eurozone (-0.0412). The gas interaction terms are consistently positive but do not reach statistical significance. Consequently, the model does not provide empirical grounds to reject the null hypothesis regarding the impact of energy security on investment growth. However, the consistent positive sign of the coefficients across all specifications tentatively suggests that energy security concerns may have played a supporting role, even if this effect cannot be robustly confirmed at standard confidence levels.

8 Limitations of the Empirical Strategy and Data

While the empirical analysis offers preliminary insights into the interplay between monetary policy, institutional membership and gas consumption, the results must be interpreted with caution. Several limitations inherent to the data and the specific regional context of Central and Eastern Europe may explain why certain expected relationships did not reach full statistical significance.

First, the study relies on a relatively short annual panel (2014–2024). This restricts the ability to observe long pre-treatment dynamics, limits the statistical power of pre-trend tests, and constrains the identification of medium- and long-run adjustment processes following the ECB's 2022 monetary tightening. Second, the empirical strategy exploits a single treatment year for the monetary-policy shock (2022). Static TWFE specifications therefore capture average post-treatment level shifts rather than the full time path of the monetary transmission, while dynamic specifications are informative but remain limited by the short post-shock window and the possibility that monetary effects emerge with multi-year lags.

Third, group-level variation is limited: both the Eurozone and EU categories contain few countries, reducing within-group heterogeneity and lowering statistical power. This is particularly relevant for detecting small treatment effects. Furthermore, CEE economies in this dataset are strongly interconnected through energy, financial, and infrastructure networks, implying that cross-country spillovers may violate the SUTVA assumption[12] inherent in Difference-in-Differences designs.

Fourth, the measure of renewable energy investment intensity is defined as the first difference of the log-ratio between installed capacity and GDP. This specification effectively captures the joint dynamics of capacity expansion and economic growth, reflecting how the scale of green investment shifts relative to the overall size of the economy. However, it does not distinguish between different renewable technologies, such as the varying capital costs of wind versus solar power. Additionally, because it relies on the moment capacity becomes operational, it may not perfectly reflect the timing of the actual financial investments, which often occur months or years prior to grid connection.

[12] The Stable Unit Treatment Value Assumption (SUTVA) requires that (i) each unit's potential outcomes depend only on its own treatment status and (ii) the form of the treatment is the same across units. In the context of cross-country panels, violations typically occur when policy shocks spill over across borders, causing one country's outcome to be affected by another country's treatment status (Rubin, 1980).

Moreover, the construction of the gas consumption variable is subject to measurement limitations. Gas consumption share is approximated using imported-gas consumption data and global gas-price benchmarks, normalised by real GDP. Although this variable captures macroeconomic vulnerability to gas-price shocks, it remains a proxy and may not fully reflect country-specific contractual arrangements, storage levels, infrastructure constraints, or intra-year variation in gas consumption patterns. Additionally, gas consumption may itself be influenced by policy changes, raising the possibility of unobserved endogeneity.

In addition, the annual frequency of the data limits the ability to capture intra-year adjustments or very short-run responses to the 2021–2022 energy-price spike. Renewable-energy projects also involve multi-year planning and construction horizons, meaning that part of the observed investment response may reflect earlier project decisions rather than the immediate impact of monetary or energy-market shocks. Cross-country differences in renewable-support mechanisms (such as auction design or investment incentives) are not fully observable in the available data, which may lead to residual omitted-variable bias.

Finally, although several robustness checks are performed including sample restrictions, alternative functional forms, and the incorporation of gas consumption controls, other advanced DiD estimators (such as interaction-weighted or doubly robust designs) were not implemented in this study. Given that all treated countries share the same treatment onset year, the bias concerns emphasised by Sun and Abraham (2021) are limited, but future work could explore these estimators for completeness.

9 Conclusion

This thesis investigated whether the ECB's 2022 monetary tightening, institutional affiliation, and cross-country differences in natural-gas consumption shaped renewable-energy investment dynamics in the Central and Eastern European (CEE) region. The question is particularly relevant in a period marked by post-pandemic recovery, the surge in European energy prices, and the economic consequences of Russia's invasion of Ukraine, all of which heightened concerns about energy security and the pace of the clean-energy transition.

The empirical results, refined through country-level bootstrapping to account for regional heterogeneity, point to three central findings. First, the ECB's 2022 tightening did not generate a robust differential adjustment in renewable-investment intensity between Eurozone and non-Eurozone economies. Across all specifications, the interaction terms for monetary policy remained statistically insignificant, suggesting that the increased cost of capital did not trigger a detectable divergence in investment trajectories within the region. Second, the EU Green Deal emerged as the most robust and consistently significant institutional factor associated with investment growth. In the baseline two-policy specification, the EU Green Deal interaction indicates a robust acceleration in renewable investment intensity, with EU member states experiencing an approximately 11.7% higher post-introduction growth relative to non-EU counterparts. When extending the framework with the gas interaction term, the Green Deal effect remains statistically significant, although its magnitude declines to approximately 8.2%. This reduction suggests that part of the initial investment response reflected heightened energy-security pressures, while a substantial and independent role of long-term regulatory certainty and EU-level structural support persists.

Third, while gas interaction term was introduced as a key structural control, its role as a uniform driver across the region remains heterogeneous. Although the coefficients are consistently positive, aligning with the energy-security argument that higher vulnerability triggers an accelerated transition, these estimates did not reach conventional levels of statistical significance after accounting for country-level variance. This suggests that while energy-security needs likely acted as an offsetting force against rising interest rates, the national responses were too heterogeneous to constitute a singular, region-wide driver.

The broader macroeconomic and geopolitical context helps clarify why the tightening of monetary policy failed to suppress investment and why energy-security concerns overlap with institutional support. For CEE economies, many of which have historically relied on Russian natural-gas imports, the combination of war-related disruptions and price spikes led to a rapid revaluation of energy-security risks. In such an environment, investment behavior seems less sensitive to higher interest rates, as it is primarily shaped by the need for energy security and the long-term regulatory support of the Green Deal.

These insights should nonetheless be interpreted with appropriate caution. The analysis relies on annual data and a relatively short post-treatment window, which limits the ability to capture intra-year adjustments or long-run dynamic responses. Moreover, the dependent variable captures the growth rate of renewable investment intensity and serves as a proxy that cannot distinguish between technology types or project-specific characteristics. The gas consumption measure, although theoretically grounded, is also a proxy and may not fully capture bilateral supply agreements, contractual structures, storage capacities or intra-year consumption patterns. These constraints do not undermine the core results but suggest that the estimated magnitudes should be viewed as macro-level relationships rather than precise micro-level responses.

In conclusion, the evidence presented in this thesis indicates that the green transition in Central and Eastern Europe is primarily shaped by the structural influence of EU-wide regulatory frameworks rather than national energy-security vulnerabilities or monetary-policy alignment. While institutional membership in the Eurozone did not dictate investment paths, the EU Green Deal acted as a decisive catalyst, effectively shielding renewable investment growth within Central and Eastern Europe from the headwinds of monetary tightening. These findings suggest that for CEE economies, the path toward climate neutrality is determined more by strategic policy commitments and institutional integration than by common monetary transmission channels or gas consumption dependencies.

A Appendix

A.1 Renewable-Energy Capacity Levels (MW)s

Figure 10: Annual renewable-energy investment by country (MW, absolute levels).

Figure 10 presents the evolution of renewable-energy capacity stock (MW) for each CEE country over the period 2014–2024. These absolute capacity values serve as the raw input for constructing the proxy measure of renewable-investment intensity used in the empirical analysis. Specifically, the MW series is standardized by real GDP to account for differences in economic size across countries, and the resulting ratio is subsequently log-transformed to align with the log-level and first-difference specifications in the main econometric models.

A.2 Macroeconomic Indicators Included in the Dataset

The following three figures display the variables from the dataset, providing a descriptive overview and facilitating a clearer understanding of the underlying macroeconomic conditions.

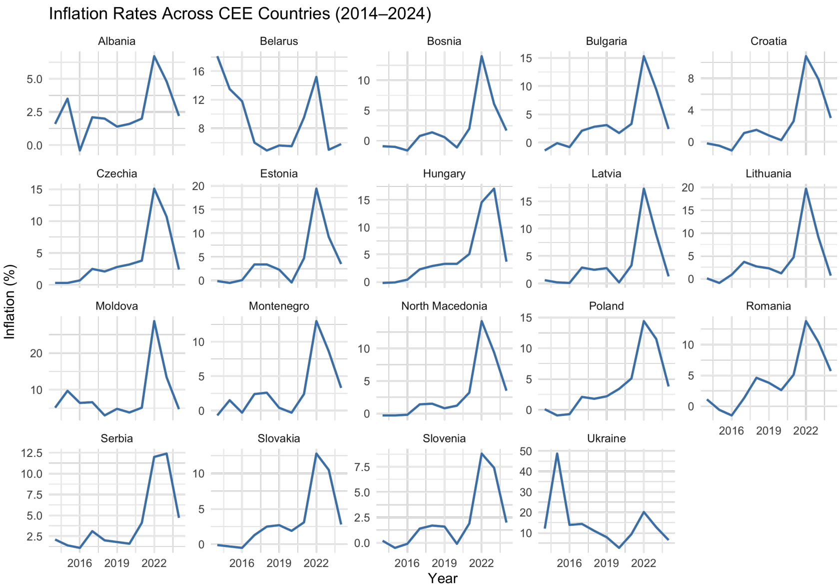


Figure 11: Inflation rates across CEE countries, 2014–2024

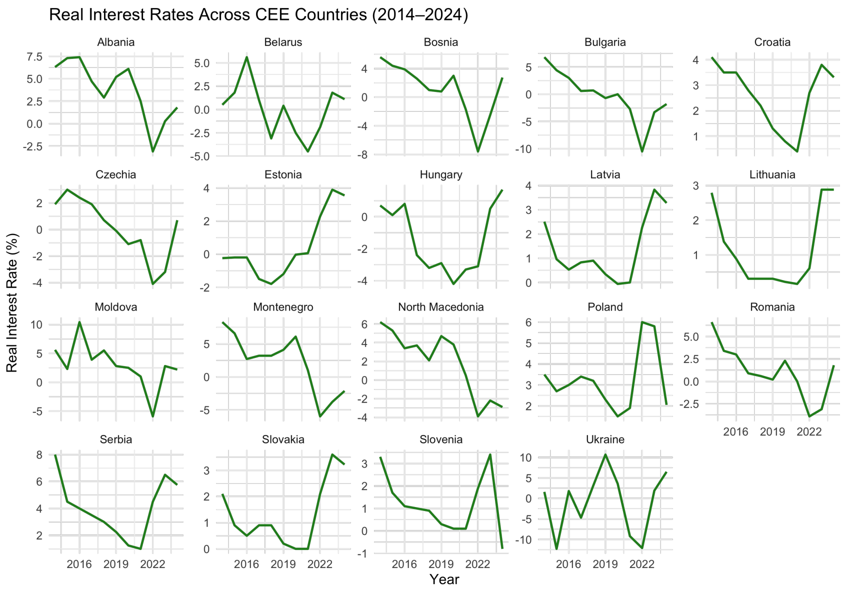


Figure 12: Real interest rates across CEE countries, 2014–2024

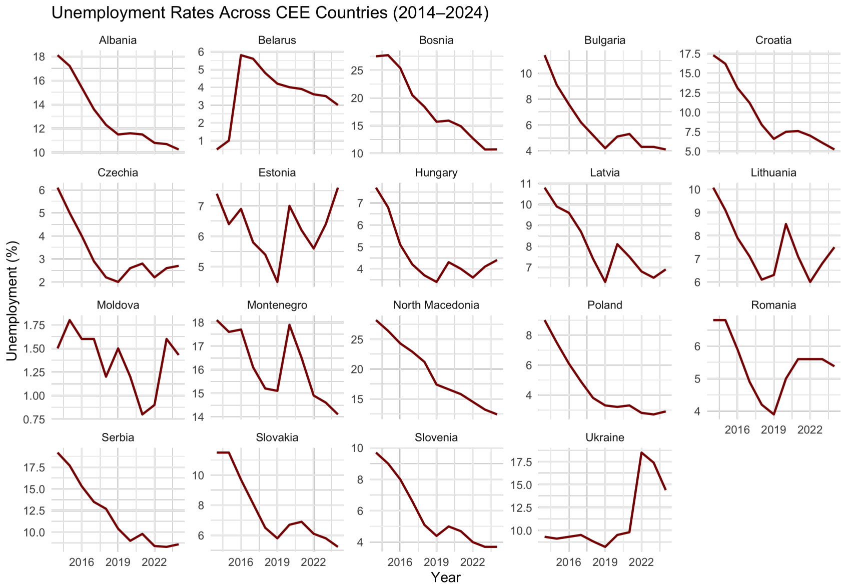


Figure 13: Unemployment rates across CEE countries, 2014–2024

Although inflation and unemployment are not included as explanatory variables in the econometric models, they are reported here to provide additional context and a clearer understanding of the macroeconomic environment in which renewable-energy investment evolved.

A.3 R Code: Event Study

```
# ============================================
# EVENT STUDY: LEVELS (log(MW/GDP))
# ============================================

library(fixest)
library(dplyr)
library(ggplot2)
library(stringr)

# EU vs Non-EU
es_eu_level <- feols(
  log_mw_gdp_con ~ i(rel_year_ecb, eu_control, ref = -1) | country + year,
  data     = CEE_levels,
  cluster = ~ country
)

# Eurozone vs Non-Eurozone
es_ez_level <- feols(
  log_mw_gdp_con ~ i(rel_year_ecb, eurozone_control, ref = -1) | country + year,
  data     = CEE_levels,
  cluster = ~ country
)

par(mfrow = c(1, 2))

# (a) EU vs Non-EU
iplot(
  es_eu_level,
  main = "Event_Study_EU",
  ylab = "Effect_on_log(MW/GDP)",
  col     = "steelblue",
  ci_col = "steelblue"
)
abline(h = 0, lty = 2, col = "grey60")

# (b) Eurozone vs Non-Eurozone
iplot(
  es_ez_level,
  main = "Event_Study_Eurozonetreated",
  xlab = "Event_time_years_relative_to_2022)",
  ylab = "Effect_on_log(MW/GDP)",
  col     = "black",
  ci_col = "black"
)
abline(h = 0, lty = 2, col = "grey60")
```

```r
par(mfrow = c(1, 1))

# ============================================
# EVENT STUDY: FIRST DIFFERENCES (Delta log(MW/GDP))
# ============================================

es_ez_diff <- feols(
  log_diff_mw_gdp ~ i(rel_year_ecb, eurozone_control, ref = -1) |
    country + year,
  data    = CEE_changes,
  cluster = ~ country
)

es_eu_diff <- feols(
  log_diff_mw_gdp ~ i(rel_year_ecb, eu_control, ref = -1) |
    country + year,
  data    = CEE_changes,
  cluster = ~ country
)

par(mfrow = c(1, 2))

# (a) EU vs Non-EU
iplot(
  es_eu_diff,
  main = "EventStudy_EU_Differences",
  xlab = "Eventtime_years_relative_to_2022)",
  ylab = "Effect_on_Delta_log(MW/GDP)"
)
abline(h = 0, lty = 2, col = "grey60")

# (b) Eurozone vs Non-Eurozone
iplot(
  es_ez_diff,
  main = "EventStudy_EZ_Differences",
  xlab = "Eventtime_years_relative_to_2022)",
  ylab = "Effect_on_Delta_log(MW/GDP)"
)
abline(h = 0, lty = 2, col = "grey60")

par(mfrow = c(1, 1))
```

A.4 R Code: Econometric Models

```
# ==============================================================================
# APPENDIX: R CODE
# Project: Master Thesis
# Author: Ana Gracanin
# ==============================================================================

# ------------------------------------------------------------------------------
# LOADING LIBRARIES
# ------------------------------------------------------------------------------
library(readxl)
library(dplyr)
library(ggplot2)
library(scales)
library(janitor)
library(fixest)
library(broom)
library(stringr)
library(patchwork)

options(scipen = 999)
eps <- 1e-6

# ------------------------------------------------------------------------------
# 2. DATA LOADING
# ------------------------------------------------------------------------------
df_raw <- read_excel(
  "/Users/anagracanin/Panel_Data_Master_Thesis_Final_Version.xlsx",
  sheet = 1
)

colnames(df_raw) <- c(
  "country", "year", "re_investment_mw", "mw_gdp", "mw_gdp_con",
  "real_interest", "inflation", "gdp_growth", "gdp", "gdp_constant",
  "unemployment", "eu_control", "eurozone_control", "post_treat",
  "did_interaction_eu", "did_interaction_zone", "gas_capacity_tj",
  "gas_price_exposure", "gas_exposure_gdp"
)

CEE_data <- df_raw %>%
  mutate(
    country = as.character(country),
    country = case_when(
      country %in% c("N.Macedonia", "N.Macedonia") ~ "NorthMacedonia",
      TRUE ~ country
    ),
```

```r
    country          = factor(country),
    year             = as.integer(year),
    eu_control       = as.integer(eu_control),
    eurozone_control = as.integer(eurozone_control),
    post_treat       = as.integer(post_treat)
  )

# ------------------------------------------------------------------------------
# 3. VARIABLE CONSTRUCTION (Levels & First Differences)
# ------------------------------------------------------------------------------
CEE_processed <- CEE_data %>%
  mutate(
    log_mw_gdp_con = log(mw_gdp_con + eps),
    eu_green_deal  = as.integer(eu_control == 1 & year >= 2021),
    rel_year_ecb   = year - 2022
  ) %>%
  group_by(country) %>%
  arrange(year) %>%
  mutate(
    level_change_mw   = re_investment_mw - lag(re_investment_mw),
    log_diff_mw       = log(re_investment_mw + eps) - log(lag(re_investment_mw +
    eps)),
    log_diff_gdp      = log(gdp_constant + eps) - log(lag(gdp_constant + eps)),
    # Dependent Variable: Growth in Capacity Intensity
    log_diff_mw_gdp   = log_diff_mw - log_diff_gdp
  ) %>%
  ungroup()

# Subsets for Level and Growth analysis
CEE_levels  <- CEE_processed %>% filter(!is.na(log_mw_gdp_con))
CEE_changes <- CEE_processed %>% filter(!is.na(log_diff_mw_gdp))

# ------------------------------------------------------------------------------
# 4. PRIMARY ECONOMETRIC SPECIFICATIONS
# ------------------------------------------------------------------------------

# First-Difference Two-Way Fixed Effects (FD-TWFE)
# Eurozone vs Non-Eurozone
mod_fd_ez <- feols(log_diff_mw_gdp ~ post_treat:eurozone_control | country + year,
                   data = CEE_changes, cluster = ~country)

# EU vs Non-EU
mod_fd_eu <- feols(log_diff_mw_gdp ~ post_treat:eu_control | country + year,
                   data = CEE_changes, cluster = ~country)

# Levels Two-Way Fixed Effects
# Eurozone vs Non-Eurozone
```

```
mod_lvl_ez <- feols(log_mw_gdp ~ post_treat:eurozone_control | country + year,
                    data = CEE_levels, cluster = ~country)

# EU vs Non-EU
mod_lvl_eu <- feols(log_mw_gdp ~ post_treat:eu_control | country + year,
                    data = CEE_levels, cluster = ~country)


# Pooled Difference-in-Differences
mod_pooled_eu <- feols(log_diff_mw_gdp ~ post_treat * eu_control,
                        data = CEE_changes, cluster = ~country)

mod_pooled_ez <- feols(log_diff_mw_gdp ~ post_treat * eurozone_control,
                        data = CEE_changes, cluster = ~country)

# Model 3: Two-Policy Framework (Green Deal + ECB Tightening)
mod_two_policy <- feols(log_diff_mw_gdp ~ eu_green_deal + post_treat:eurozone_control
    | country + year,
                         data = CEE_changes, cluster = ~country)

# ------------------------------------------------------------------------------
# EXCLUDING BALTICS FROM THE DATA SET
# ------------------------------------------------------------------------------
CEE_diff_nobalt <- CEE_changes %>%
  filter(!country %in% c("Estonia", "Latvia", "Lithuania"))

# ------------------------------------------------------------------------------
# 2. FIRST-DIFFERENCE TWFE MODELS (Without Baltics)
# ------------------------------------------------------------------------------

# Model A: Eurozone vs Non-Eurozone (First Differences)
# Investigating the growth rate of capacity intensity ( log(MW/GDP))
fd_ez_nobalt <- feols(
  log_diff_mw_gdp ~ post_treat:eurozone_control | country + year,
  data    = CEE_diff_nobalt,
  cluster = ~ country
)

summary(fd_ez_nobalt)

# Model B: EU vs Non-EU (First Differences)
fd_eu_nobalt <- feols(
  log_diff_mw_gdp ~ post_treat:eu_control | country + year,
  data    = CEE_diff_nobalt,
  cluster = ~ country
)
```

```r
summary(fd_eu_nobalt)
# ----------------------------------------------------------------------------
# 5. ROBUSTNESS: CLUSTERED BOOTSTRAP (B=999)
# ----------------------------------------------------------------------------
run_bootstrap <- function(data, treat_var, B = 999){
  set.seed(123)
  countries <- unique(data$country)
  nC <- length(countries)
  betas <- numeric(B)

  for(b in 1:B){
    draw <- sample(countries, nC, replace = TRUE)
    d_boot <- do.call(rbind, lapply(seq_along(draw), function(i){
      tmp <- data[data$country == draw[i], ]
      tmp$id_boot <- paste0(as.character(tmp$country), "_", i)
      tmp
    }))

    fml <- as.formula(paste0("log_diff_mw_gdp~post_treat:",
    treat_var,"|id_boot+year"))
    m_b <- try(feols(fml, data = d_boot), silent = TRUE)
    if(!inherits(m_b, "try-error"))betas[b]<-coef(m_b)[1] else betas[b]<- NA
  }
  return(list(
    boot_se = sd(betas, na.rm = TRUE),
    ci_95   = quantile(betas, c(0.025, 0.975), na.rm = TRUE)
  ))
}

# Executing bootstraps
boot_results_ez <- run_bootstrap(CEE_changes, "eurozone_control")
boot_results_eu <- run_bootstrap(CEE_changes, "eu_control")

# ----------------------------------------------------------------------------
# 6.ADDING GAS CONSUMPTION
# ----------------------------------------------------------------------------
# Restricting to years with available gas data (pre-2024)
CEE_gas <- CEE_processed %>%
  filter(year <= 2023, country != "Montenegro") %>%
  group_by(country) %>%
  mutate(gas_base_2021 = first(log(gas_price_exposure + 1)[year == 2021])) %>%
  ungroup() %>%
  mutate(gas_interaction = gas_base_2021 * post_treat)

# Model 1: Eurozone vs Non-Eurozone (First Differences + Gas Control)
mod_fd_ez_gas <- feols(
  log_diff_mw_gdp ~ post_treat:eurozone_control + gas_interaction | country + year,
```

```r
  data = CEE_gas, cluster = ~country
)

# Model 2: EU vs Non-EU (First Differences + Gas Control)
mod_fd_eu_gas <- feols(
  log_diff_mw_gdp ~ post_treat:eu_control + gas_interaction | country + year,
  data = CEE_gas, cluster = ~country
)

# Model 3: Two-Policy Framework + Gas Control
# (Green Deal + ECB Tightening + Gas Exposure)
mod_two_policy_gas <- feols(
  log_diff_mw_gdp ~ eu_green_deal + post_treat:eurozone_control + gas_interaction |
    country + year,
  data = CEE_gas, cluster = ~country
)

# ---------------------------------------------------------------------------
# 3. ROBUSTNESS: GAS MODELS WITHOUT BALTICS
# ---------------------------------------------------------------------------
CEE_gas_nobalt <- CEE_gas %>%
  filter(!country %in% c("Estonia", "Latvia", "Lithuania"))

mod_ez_gas_nobalt <- feols(
  log_diff_mw_gdp ~ post_treat:eurozone_control + gas_interaction | country + year,
  data = CEE_gas_nobalt, cluster = ~country
)

mod_eu_gas_nobalt <- feols(
  log_diff_mw_gdp ~ post_treat:eu_control + gas_interaction | country + year,
  data = CEE_gas_nobalt, cluster = ~country
)

# ===========================================================================
# BOOTSTRAP ANALYSIS FOR GAS MODELS
# ===========================================================================

run_gas_bootstrap <- function(data, formula_str, B = 999) {
  set.seed(123)
  countries <- unique(data$country)
  nC <- length(countries)
  initial_mod <- feols(as.formula(formula_str), data = data)
  var_names <- names(coef(initial_mod))
  boot_betas <- matrix(NA, nrow = B, ncol = length(var_names))
  colnames(boot_betas) <- var_names

  cat("StartingBootstrapfor:", formula_str, "\n")
```

```r
  for(b in 1:B) {

    draw <- sample(countries, nC, replace = TRUE)


    d_boot <- do.call(rbind, lapply(seq_along(draw), function(i) {
      tmp <- data[data$country == draw[i], ]
      tmp$id_boot <- paste0(as.character(tmp$country), "_", i)
      tmp
    }))


    boot_formula <- as.formula(gsub("\\|country", "|id_boot", formula_str))


    m_b <- try(feols(boot_formula, data = d_boot), silent = TRUE)

    if(!inherits(m_b, "try-error")) {
      boot_betas[b, ] <- coef(m_b)
    }

    if(b %% 100 == 0) cat("Iteration:", b, "/", B, "\n")
  }

  results <- lapply(var_names, function(v) {
    list(
      variable = v,
      boot_se  = sd(boot_betas[, v], na.rm = TRUE),
      ci_95    = quantile(boot_betas[, v], c(0.025, 0.975), na.rm = TRUE)
    )
  })

  return(results)
}

# ----------------------------------------------------------------------------
# EXECUTION: RUNNING BOOTSTRAPS ON KEY GAS MODELS
# ----------------------------------------------------------------------------
fml_ez_gas <-
    "log_diff_mw_gdp~post_treat:eurozone_control+gas_interaction|country+year"
fml_eu_gas <- "log_diff_mw_gdp~post_treat:eu_control+gas_interaction|country+year"

boot_gas_ez_results <- run_gas_bootstrap(CEE_gas, fml_ez_gas, B = 999)

boot_gas_eu_results <- run_gas_bootstrap(CEE_gas, fml_eu_gas, B = 999)
```

```
print(boot_gas_ez_results)

# --------------------------------------------------------------------

# ------------------------------------------------------------------------------
# END OF SCRIPT
# ------------------------------------------------------------------------------
```

Listing 1: Full R code used in the analysis

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