An analysis of the Russia–Ukraine energy shock on firm-level greenhouse gas intensity

Geopolitics for Business
Group Project
May 10, 2026

Data Group 2

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1 Introduction and Research Question

Russia's full-scale invasion of Ukraine in February 2022 constituted one of the most significant energy supply disruptions in recent European history. The sanctions imposed on Russia and the subsequent re-routing of European energy procurement transformed what had been a decade-long exposure to cheap Russian natural gas into an acute strategic liability, particularly for countries and industries that had built their production models around it. At the same time, the shock arrived against a backdrop of intensifying climate commitments: the EU's Fit for 55 package and the corporate disclosure obligations under the Corporate Sustainability Reporting Directive (CSRD) were already pushing firms to reduce their greenhouse gas emissions per unit of output.

This paper asks how the Russia–Ukraine energy shock affected firm-level greenhouse gas intensity. Specifically, we are interested in whether European firms, and in particular, energy-intensive manufacturers, reduced their direct GHG emissions per unit of revenue in the aftermath of the shock, and whether this adjustment was shaped by the degree to which their host country was exposed to Russian gas imports. The core research question is therefore: *Did the Russia–Ukraine war trigger a change in firm-level GHG intensity among European energy-intensive firms, and did this effect vary for firms operating in countries that were more or less dependent on Russian gas?*

The question sits at the intersection of two literatures that have thus far developed in relative isolation: the economics of energy market disruptions and the firm-level determinants of environmental performance. It also carries direct policy implications. The analysis proceeds as follows. Section 2 situates the paper in the relevant literature. Section 3 describes the data construction and treatment assignment. Section 4 presents the empirical strategy. Section 5 discusses results and their interpretation. Section 6 outlines limitations and avenues for future research. Section 7 concludes.

2 Literature Review

2.1 Theoretical Framework

Academic and professional notions of the condition of globality, widespread first during the 1980s (see Robertson, 1983), emerged along with an increasing cross-border integration of the global economic system resulting after the II World War (Hover et al., 2025). Indeed, the characterisation of a liberal regime of financial and trade relations based on the principles of cooperation, mutual interdependence, and openness, prompted the flourishing of multinational enterprises (MNEs) in the international business (IB) environment (Petricevic and Teece, 2019; Lessard et al., 2016). The liberal school of thought, acknowledging the increasing "flatness" of the system (see Friedman, 2005; Rugman and

Oh, 2008), argued that the resulting deepening of economic integration would diminish the likelihood of inter-state confrontation due to high opportunity costs from the disruption of trade (Mansfield and Pollins, 2010; Choi and Kim, 2021; Gartzke and Li, 2003; Goldsmith, 2013). This political perspective was operationalised, for instance, through Germany's "change through trade" approach that encouraged the construction of several gas pipelines with the Soviet Union and later Russian Federation between the 1970s and the early 2000s (Blumenau, 2022; Wood, 2024). In light of this, energy infrastructure projects such as Nord Stream 2 were "never just business" (Schmidt-Felzmann, 2016). However, geopolitical developments over the past fifteen years have revealed the limitations of the liberal theory, indicating a reversal of an assumption that is reshaping the business landscape once again.

In this context, several authors have put forward that the current world order is entering a de-globalisation phase (Livesey, 2018; James, 2018); one that is putting at risk, by direct means, the way MNEs operate and do business (Petricevic and Teece, 2019). More specifically, this period of disintegration is making the IB landscape fraught with unprecedented levels of volatility, uncertainty, complexity, and ambiguity (VUCA) (Bennett and Lemoine, 2014; Cavusgil et al., 2021; Schoemaker et al., 2018; Tulder et al., 2020). As established by Sénquiz-Díaz (2025), the most important contribution to the VUCA framework in the IB context is that of Bennett and Lemoine (2014). For these authors, volatility can be described as a state of "relatively unstable change", while uncertainty is the "lack of knowledge as to whether an event will have meaningful ramifications" (Bennett and Lemoine, 2014, p. 313). Furthermore, complexity, in the IB environment, reflects the idea that there is no single arrangement, but rather a constellation of systems that interact altogether in an exhaustive "network of information of procedures" (Bennett and Lemoine, 2014, p. 313). Lastly, ambiguity is depicted as the absence of clear guidelines for decision-making, and the margin for independent interpretation in cause-and-effect relationships.

MNEs are currently operating in such one highly challenging context that not only disrupts routine business operations but also complicates the management of exceptional circumstances. As put forward by Cavusgil et al. (2021), apart from traditional commercial, financial, cultural, and political risks, companies are now dealing with additional and greater threats, including technological obsolescence, cyber security issues, trade wars, sustainability concerns, social challenges, and, more importantly, "black swan" events (see Taleb, 2010). Indeed, in the systems risk literature, exogenous shocks such as interstate armed conflicts or extreme weather events emerge as "crises" once actual harms are materialised (Homer-Dixon et al., 2015). Nevertheless, as put forward by Lawrence et al. (2022), today, the causal activation of a given risk in a given system into an actual crisis does not remain confined to the system in which it originates, but it spreads and reinvigorates onto other systems.

The concept of *polycrisis* reflects the confluence and intertwining of these individual crises that “interact, exacerbate, and reshape one another (. . .) that must be understood and addressed as a whole” (Lawrence et al., 2022). The conceptual transition from systemic risk to the notion of polycrisis can be understood through the maximisation of the broader defining properties embedded in the systems that the latter emphasise. Based on the scholarship analysis of Lawrence et al. (2022), the five distinct characteristics of polycrises are: extreme complexity and dynamism; disproportional cause-effect relationships, transboundary causal links, and profound uncertainty (Renn et al., 2022, 2019; Schweizer and Renn, 2019). Precisely, as put forward by Collste et al. (2025), the identification of valid causality relationships between these crises under such uncertain conditions makes it hard to assess and overcome the challenges derived from it. The research scope is narrowed by applying the "limits to growth" model, which is designed to identify causal trends within complex systems. In the context of a growing size of economic operations, certain operation constraints and external pressures such as scarce resources or climate-related externalities constrain the expansion capacity of operations of businesses. Furthermore, in light of this increased complexity, Rapoza (2019) argues that MNEs might already be shifting toward decoupling from their global and regional value chains, a strategy also envisioned by Collste et al. (2025) to manage the implications of polycrises.

This strategic decoupling from global and regional value chains cannot be fully understood without first examining the theoretical architecture that has governed the organisation of international production over the past decades. Global Value Chain (GVC) theory and Global Production Network (GPN) theory provide complementary analytical lenses through which the structural vulnerabilities and strategic reconfiguration of MNEs can be assessed in light of compounding exogenous shocks. The foundational contribution to GVC governance was advanced by Gereffi et al. (2005), who identified distinct governance types ranging from low to high levels of explicit coordination and power asymmetry, determined by transaction complexity, codifiability, and supply-base capabilities. In the context of the VUCA landscape described above, these determinants are precisely the variables most susceptible to disruption: geopolitical fragmentation raises transaction complexity, energy and trade shocks erode the codifiability of cross-border exchanges, and climate-related pressures strain supplier capabilities across multiple geographies simultaneously. Yeung and Coe (2015) advanced GPN 2.0, a more explicitly causal and dynamic theory designed to explain why and how the organisation and coordination of global production networks varies significantly within and across industries, sectors, and economies. The relational and power dimensions of these networks further illuminate how shocks propagate and are redistributed across chain actors (see Kano, 2018; Humphrey and Schmitz, 2002). Ponte (2022) further demonstrates that lead firms’ pursuit of environmental upgrading frequently results in the upstream displacement of sustainability compliance costs and risks onto suppliers, a finding directly pertinent to our research question: climate shocks do not affect GVC actors uniformly, but interact with pre-existing governance asymmetries to produce differentiated strategic and financial outcomes across the network.

2.2 Empirical Approach and Choice of Metrics

A growing literature shows that geopolitical shocks affect firms not only through standard financial variables such as investment, financing costs, and profitability, but also through sustainability-related outcomes. In particular, recent firm-level studies generally find that higher geopolitical risk and geopolitical conflict are associated with weaker ESG performance, including poorer environmental outcomes, although some evidence suggests that firms may increase selected ESG activities as a risk-management response while environmental performance deteriorates (see Abdullah et al., 2024; Saharti et al., 2024; Erzurumlu et al., 2025). This means that environmental performance is not a peripheral variable in this setting, but one of the firm-level margins through which geopolitical stress can be observed.

Methodologically, difference-in-differences (DiD) has become a widely used approach for identifying causal effects of shocks and policy changes. Fan et al. (2022) use the 2018 US–China trade war as a quasi-exogenous shock and compare U.S. firms with direct Chinese suppliers to firms without such suppliers in a DiD framework, focusing on operating-performance outcomes such as inventory days and return on assets.

More relevant to our specification is the triple-difference extension. Fan et al. (2022) also estimate a DDD to assess whether the trade war effect on US firms was moderated by the degree of supply-chain diversification, exploiting variation across firms within the treatment group (U.S. firms with direct Chinese suppliers) and the control group (those with no direct Chinese suppliers).

Once environmental outcomes are accepted as relevant, the next issue is how to measure them. Total capital expenditure (CAPEX) and CSR spending are both informative, but neither is a direct measure of environmental performance. Total CAPEX does not distinguish between investments that reduce environmental harm and investments that maintain or expand emissions-intensive activity. Meanwhile, CSR expenditure often reflects communication or stakeholder management rather than operational performance. For that reason, an environmental metric tied directly to emissions is closer to the underlying object of interest (see Abdullah et al., 2024). This is consistent with the broader climate-finance literature, where carbon emissions and carbon intensity are regularly used to capture firms' exposure to climate-related risks and their environmental footprint (Sautner et al., 2023; Bolton and Kacperczyk, 2023; Perdichizzi et al., 2024).

Within that class of metrics, Trucost's GHG Direct Intensity captures greenhouse-gas emissions generated by the firm's own operations (Scope 1) relative to revenue. This makes it an operational environmental-performance variable. It measures how emissions-intensive a firm's own production is, rather than how exposed it is to controversies or how strong its sustainability communication appears to be (S&P Global Sustainable1, 2025; U.S. Environmental Protection Agency, 2026). RepRisk was considered as an alternative metric, but it measures externally reported environmental controversies rather than firms' underlying operational environmental efficiency. Its methodology is explicitly outside-in and issues-driven, making it suitable for tracking incident exposure but less directly tied to emissions intensity. In addition, Barkemeyer et al. (2023) show that the odds of controversy coverage are five times higher for firms headquartered in English-language countries, introducing a systematic media-selection bias. For that reason, RepRisk is better interpreted as a controversy measure than as a measure of operational environmental performance. There is also a measurement reason to focus on direct emissions: Network for Greening the Financial System (2024) finds that inconsistencies across emissions datasets are lowest for Scope 1, while discrepancies increase substantially for Scope 2 and especially Scope 3. The main limitation of Trucost GHG Direct Intensity is frequency, assessments are aligned with firms' annual reporting cycles, but the main studies linking geopolitical shocks to ESG outcomes also rely on annual panels (Abdullah et al., 2024; Saharti et al., 2024; Erzurumlu et al., 2025), so the use of an annual environmental variable is consistent with the frequency that already dominates this literature.

Building on this theoretical and empirical foundation, our study focuses on the Russia–Ukraine energy shock as a concrete instance of polycrisis dynamics, exploiting cross-country variation in Russian gas dependency and cross-sector variation in energy intensity to identify its effect on firm-level GHG performance.

3 Data

3.1 Overview of the Panel Dataset

The final dataset is a firm-year panel covering publicly listed European firms in selected manufacturing and resource sectors. It combines three data sources: proprietary ESG firm-level data from S&P Global TruCost; country-year macroeconomic data from the World Bank. The panel spans the years 2018–2024 and covers 28 European countries (EU-27 plus Norway, Switzerland, and the United Kingdom). After filtering for the relevant sector universe, removing duplicate firm-year observations, excluding singleton firms (which contribute no within-variation under a firm-fixed-effects estimator), and restricting to years with complete data on all controls, the final panel contains 972,979 firm-year observations.

3.2 Outcome Variable: GHG Direct Intensity

The primary outcome variable is *GHG Direct Intensity*, defined as Scope 1 (direct) greenhouse gas emissions in tonnes of CO_2-equivalent per USD 1 million of revenue, as reported by TruCost. As argued in detail in Section 2, this measure is the most appropriate for our setting: it captures the operational emissions efficiency of the firm, is directly linked to energy input decisions, normalises for firm size, and benefits from the lowest measurement noise across emissions categories.

Table 1 presents descriptive statistics for the key variables.

Table 1: Descriptive Statistics

Variable	N	Mean	SD	p25	p50	p75	Min	Max
GHG Direct Intensity (tCO2e/$M)	972,979	120.96	203.74	16.52	88.67	188.42	0.00	15225.42
GHG Scope 1 Absolute (tCO2e)	972,979	15043.36	682995.18	30.02	156.69	654.47	0.00	176690921.22
Revenue (USD M)	972,979	85.74	2218.97	0.65	2.39	10.03	0.00	400222.89
GDP per Capita (EUR)	972,979	48140.18	12768.36	40353.41	46680.39	54687.55	8362.13	140739.45
Inflation (%)	972,979	3.21	3.17	0.98	1.87	5.52	-1.25	19.40

Sample restricted to 2018–2024. GHG Direct Intensity measured in tCO_2e per USD million of revenue.

GDP per Capita and Inflation are country-year level controls.

3.3 Treatment Assignment 1: Country-Level Russian Gas Exposure

The first treatment dimension captures the degree to which a firm's host country was structurally dependent on Russian natural gas prior to the 2022 shock. We compute an annual country-level *exposure ratio* defined as:

$$\text{Exposure}_{c,t} = \frac{\text{Russian gas imports}_{c,t}}{\text{Gross Inland Consumption}_{c,t}}$$

For that we are using Eurostat datasets `nrg_ti_gas` (natural gas imports by partner country, in TJ gross calorific value) and `nrg_bal_c` (complete energy balances, Gross Inland Consumption in TJ). Both series are at annual frequency and cover EU-27 countries from 2015 to 2024.

To define the treatment group, we compute each country's average pre-shock exposure over the window 2018–2021 and classify countries in the top quartile ($\geq$ p75 = 14.1%) as treated. This threshold yields eight treated countries: Hungary, Latvia, Slovakia, Italy, Czech Republic, Germany, Lithuania, and Bulgaria — precisely the group that features most prominently in policy discussions about Russian gas dependency. Figure 1 shows the full distribution of pre-shock average exposure across EU countries and the treatment threshold.

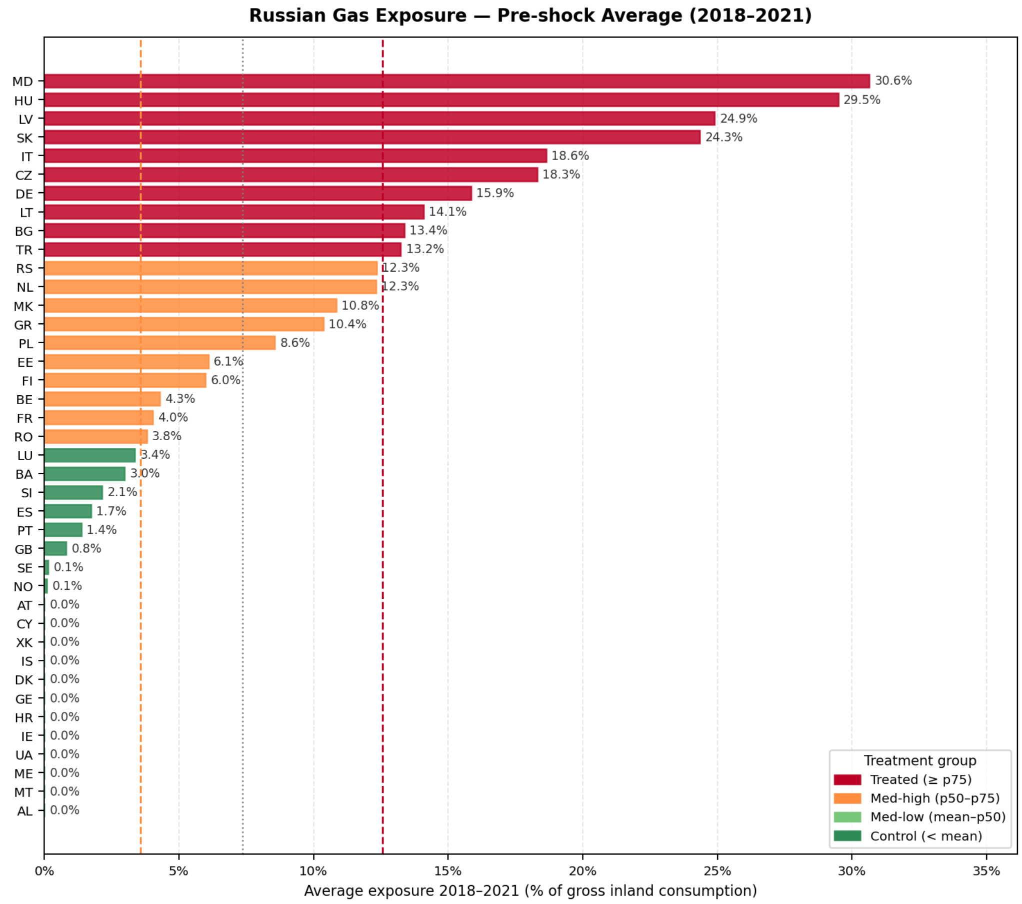

Figure 1: Average Russian gas exposure by country, pre-shock window 2018–2021. Exposure is Russian gas imports as a share of gross inland energy consumption (Eurostat). Treated group (red): countries above the 75th percentile. Dashed lines mark the p75 and p50 thresholds.

Figure 2 further illustrates the relevance of this classification by plotting the average gas exposure over time for treated and control countries. The divergence between the two groups is stark: treated countries had systematically higher exposure throughout the pre-shock period, and their exposure dropped sharply only after 2022 — precisely as Russian pipeline flows were curtailed.

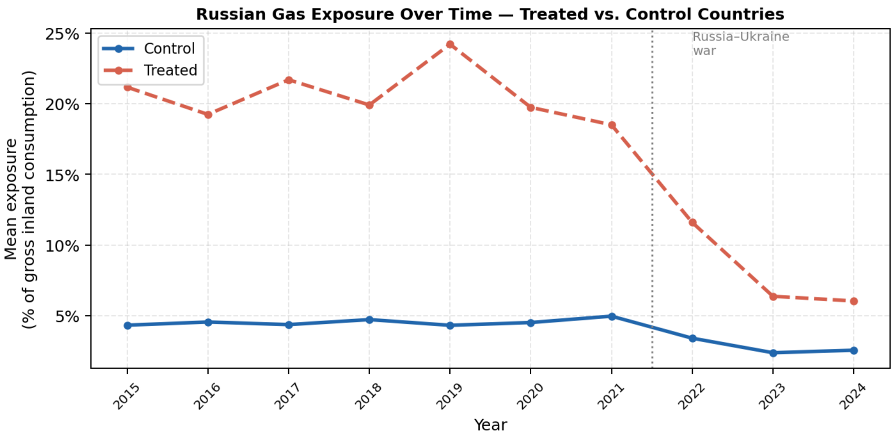

Figure 2: Average Russian gas exposure over time for treated vs. control countries. Treated = top-p75 pre-shock exposure group (Hungary, Latvia, Slovakia, Italy, Czech Republic, Germany, Lithuania, Bulgaria). Dotted line: February 2022 shock.

3.4 Treatment Assignment 2: Energy-Intensive Sectors

The second treatment dimension captures whether a firm belongs to a sector that is structurally energy-intensive. We classify sectors following the official Energy-Intensive Industries (EII) definition used by the OECD (based on energy input cost shares from the ICIO input-output tables), the European Commission (the EU EII Industrial Ecosystem), and the IEA (high-temperature process classification). Specifically, the following NACE Rev.2 two-digit codes are assigned EII = 1:

NACE	Sector
C16	Manufacture of wood and wood products
C17	Manufacture of paper and paper products
C19	Manufacture of coke and refined petroleum products
C20	Manufacture of chemicals and chemical products
C22	Manufacture of rubber and plastic products
C23	Manufacture of other non-metallic mineral products (cement, glass, ceramics)
C24	Manufacture of basic metals

The control group (EII = 0) consists of structurally comparable manufacturing sectors that are not classified as energy-intensive: pharmaceuticals (C21), machinery and equipment (C28), motor vehicles (C29), fabricated metal products (C25), furniture (C31), and printing and media reproduction (C18). These sectors share key structural features with EII sectors — capital intensity, trade exposure, manufacturing scale — but have substantially lower energy input cost shares, making them suitable counterfactuals. In the final panel, 647,026 observations (66.4%) belong to EII sectors and 327,299 (33.6%) to the control group.

4 Methodology

4.1 Difference-in-Differences Framework

We estimate the effect of the Russia–Ukraine energy shock on firm-level GHG Direct Intensity using a difference-in-differences (DiD) design. The identifying variation comes from comparing the change in GHG intensity for treated firms (those exposed to the shock through the two treatment dimensions defined above) relative to control firms, across the pre-shock (2018–2021) and post-shock (2022–2024) periods.

The baseline specification takes the form:

$$Y_{i,t} = \alpha_i + \lambda_t + \beta \cdot \text{Post}_t \times D_i + \gamma' X_{c,t} + \varepsilon_{i,t} \tag{1}$$

where $Y_{i,t}$ is GHG Direct Intensity for firm i in year t; α_i are firm fixed effects, absorbing all time-invariant firm characteristics; λ_t are year fixed effects, absorbing aggregate time trends; D_i is one of the treatment indicators defined above; $\text{Post}_t = \mathbf{1}(t \geq 2022)$; and $X_{c,t}$ includes time-varying country-level controls — GDP per capita (in EUR) and the annual consumer price inflation rate. Standard errors are clustered at the country level to account for within-country correlation across firms and years.

We estimate three specifications. Models (1) and (2) each use a single binary treatment: country-level gas exposure (`gas_exposed`) and sector energy intensity (`energy_intensive`). Model (3), our most informative specification, includes both treatment-post interactions simultaneously:

$$Y_{i,t} = \alpha_i + \lambda_t + \beta_1 \,\text{Post}_t \times \text{GasExp}_i + \beta_2 \,\text{Post}_t \times \text{EII}_i + \beta_3 \,\text{Post}_t \times \text{GasExp}_i \times \text{EII}_i + \gamma' X_{c,t} + \varepsilon_{i,t} \tag{2}$$

This triple-interaction specification allows us to decompose the country-level and sector-level channels and estimate whether the two dimensions of treatment reinforce or partially offset each other.

4.2 Identification: Exogeneity of the Shock

A central advantage of this design is the exogeneity of the treatment timing. The Russia–Ukraine war and the associated energy disruptions were not driven by firm-level decisions: they represent a geopolitical shock that was unanticipated by firms in its timing and severity. This is in contrast to, for example, a carbon tax, which firms may anticipate and respond to in advance of implementation. Under this assumption, the 2022 shock constitutes a quasi-natural experiment, and the DiD estimator identifies the causal effect of exposure to the shock on GHG intensity.

4.3 Parallel Trends Assumption

The validity of the DiD estimate rests on the parallel trends assumption: in the absence of the treatment, treated and control firms would have followed similar trends in GHG intensity. We provide two pieces of evidence in support of this assumption. Figure 3 plots mean GHG Direct Intensity over time, separately for treated and control groups under each treatment definition. The left panel shows the trajectories of firms in gas-exposed versus non-exposed countries; the right panel shows the trajectories of energy-intensive versus non-energy-intensive sectors. Both panels show a general decline in GHG intensity throughout the sample period, with a notable acceleration after 2022 for the energy-intensive sector group — a pattern our DiD specification is designed to identify. It also shows that treated and control firms exhibited broadly parallel declining trends in GHG intensity over the pre-shock period 2018–2021, with no systematic pre-shock divergence.

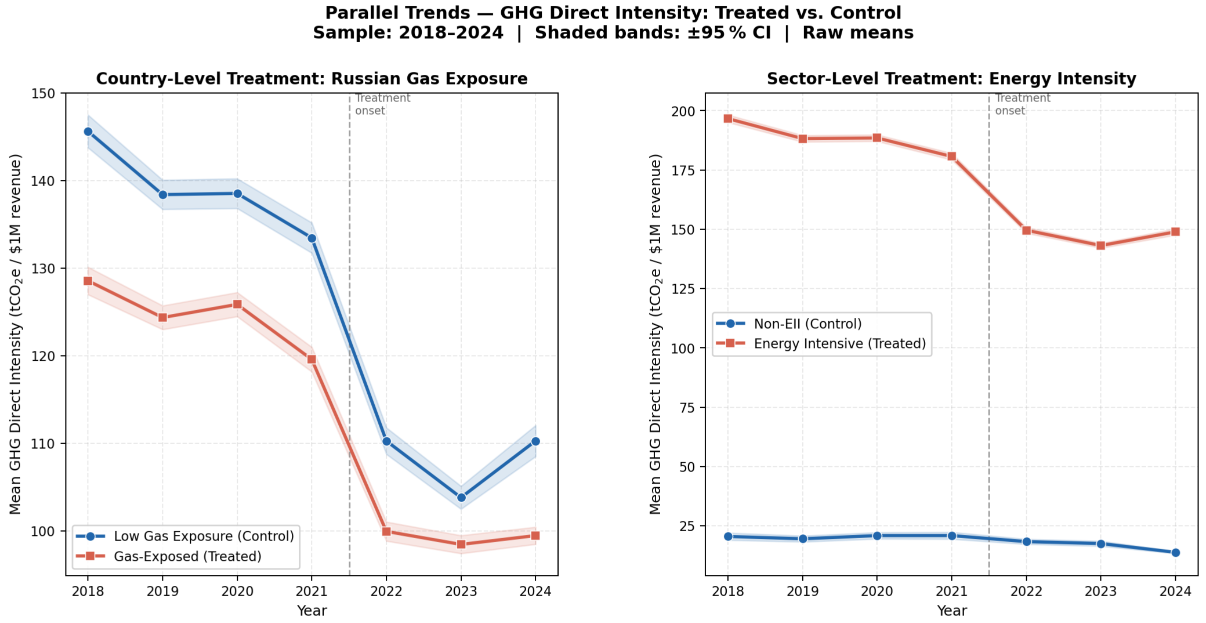

Figure 3: Mean GHG Direct Intensity over time, by treatment group. Left: gas-exposed vs. control countries. Right: energy-intensive (EII) vs. control sectors. Dotted vertical line marks the Russia–Ukraine shock (February 2022).

5 Results and Discussion

Table 2 presents the four DiD estimates.

Table 2: Difference-in-Differences: Effect on GHG Direct Intensity

	(1) Gas Exposed	(2) Energy Intensive	(3) Triple
Post × Gas Exposed	5.209***	-38.461***	-2.611
	(1.089)	(2.209)	(2.498)
Post × Energy Intensive			-43.480***
			(1.643)
Post × Both Treated			9.863***
			(2.543)
GDP per capita (EUR)	0.000***	0.000**	0.000***
	(0.000)	(0.000)	(0.000)
Inflation (%)	0.217	0.393**	0.237
	(0.203)	(0.177)	(0.242)
Observations	972,979	972,979	972,979
Within R^2	0.011	0.048	0.049
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
SE clustered at	Country	Country	Country

Notes: Dependent variable: GHG Direct Intensity (tCO_2e per \$1M revenue). Firm and year fixed effects included in all specifications. Standard errors in parentheses, clustered at country level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

The results tell a clear and internally consistent story. Model (2) establishes the central finding: energy-intensive firms reduced their GHG Direct Intensity by approximately 38.5 tCO_2e per \$1M of revenue in the post-2022 period, relative to non-EII firms in the same countries and year ($p < 0.01$). This is a large and economically significant effect: roughly 32 percent of the sample mean intensity of 121 tCO_2e/\$M. The most natural interpretation is that the energy shock forced firms in high-energy-cost sectors to rethink their energy sourcing strategy: investing in energy efficiency, shifting to lower-carbon electricity contracts, or diversifying supply chains away from gas. Because natural gas is itself a GHG-emitting fuel, this diversification toward electricity (especially from renewable or nuclear sources) mechanically reduces Scope 1 emissions per unit of output.

Model (3), the triple-interaction specification, allows us to decompose the mechanism further. The coefficient on Post × EII ($\hat{\beta}_2 = -43.5$, $p < 0.01$) remains large and highly significant. The coefficient on Post × Both Treated ($\hat{\beta}_3 = +9.8$, $p < 0.01$) is positive and significant, indicating that the energy-transition effect is *attenuated* for energy-intensive firms located in countries that were more dependent on Russian gas. The net effect for a firm that is both in a gas-dependent country and in an EII sector is therefore $-43.5 + 9.8 = -33.7$ $tCO_2e/\$M$. It is substantial, but meaningfully smaller than the broader EII-sector average.

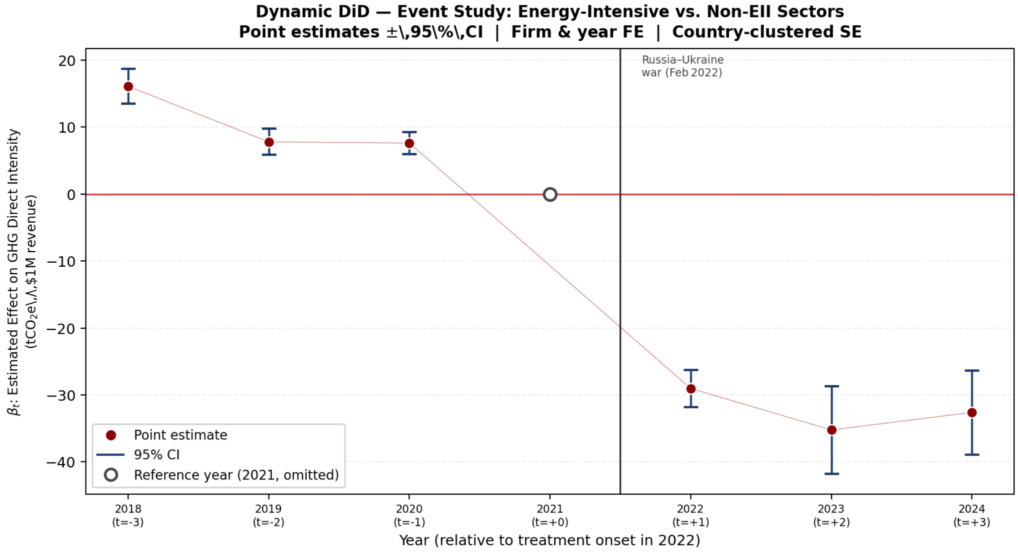

Figure 4: Event study estimates: year-by-year $\hat{\beta}_t$ coefficients for energy-intensive (EII) vs. non-EII sector firms, relative to reference year 2021 (normalised to zero). Pre-2022 coefficients test the parallel trends assumption. Firm and year FE; SE clustered by country.

The event study in Figure 4 reveals an important nuance. Post-2022 coefficients are large and negative (-29 to -35 $tCO_2e/\$M$), confirming a sharp post-shock divergence between EII and non-EII firms. The pre-period coefficients, however, are not uniformly flat: the 2018 estimate is elevated at approximately +16, declining to +8 in 2019–2020 and converging to zero by the reference year 2021. This suggests that EII firms entered the sample period with somewhat higher GHG intensity relative to non-EII firms, and that this differential was already narrowing before the shock. The declining pre-trend is a caveat to a strict parallel trends interpretation, though the post-shock treatment effect is an order of magnitude larger than any pre-period differential, making it unlikely that trend extrapolation alone accounts for the post-2022 estimates. We discuss this limitation in Section 6.

The attenuation effect is theoretically compelling. Countries with high pre-shock Russian gas exposure faced a more constrained energy transition path: the alternatives to pipeline gas (LNG imports, interconnectors, domestic renewable expansion) are subject to infrastructure bottlenecks and long lead times. For instance, the contrast between France, which could accelerate its nuclear fleet utilisation, and Italy, which at various points considered reopening mothballed coal capacity, illustrates the mechanism. Firms headquartered in more constrained energy systems had fewer viable low-carbon alternatives in the short run, limiting the GHG reductions they could achieve through energy diversification. This finding suggests that firm-level decarbonisation and country-level energy policy are deeply complementary: even when firms face strong incentives to reduce emissions, their ability to act is constrained by the energy infrastructure available to them.

Model (1) — the pure country-exposure specification — shows a small but significantly positive interaction coefficient ($\hat{\beta}_1 = +5.2$, $p < 0.01$). Taken in isolation, this seems to suggest that firms in gas-exposed countries increased their GHG intensity. However, Model (3) reveals that this is largely driven by the composition of sectors across countries: once we control for the EII/non-EII split, the standalone gas-exposure effect becomes statistically indistinguishable from zero (-2.6, $p = 0.30$). The apparent positive association in Model (1) reflects the fact that gas-dependent countries host proportionally more EII firms, and those firms' transition costs dominate the country-level average.

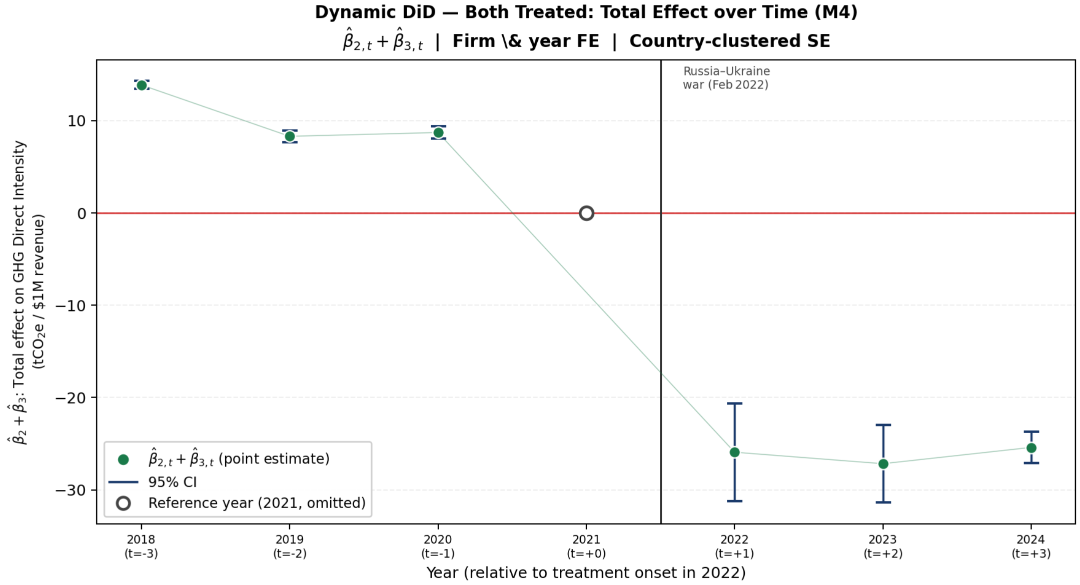

Figure 5: Dynamic DiD — total effect for *Both Treated* firms (Model 3). Each point plots $\hat{\beta}_{2,t} + \hat{\beta}_{3,t}$: the year-specific net effect on GHG Direct Intensity for energy-intensive firms headquartered in gas-exposed countries, relative to reference year 2021 (normalised to zero). Firm and year fixed effects; standard errors clustered at the country level.

Figure 5 translates the static Model (3) estimate into a dynamic picture, plotting the year-specific total effect $\hat{\beta}_{2,t} + \hat{\beta}_{3,t}$ for firms subject to both treatments — that is, energy-intensive firms headquartered in gas-exposed countries. The country-level gas exposure arm ($\hat{\beta}_1$) is excluded from the sum, as it is statistically indistinguishable from zero in Model (3) specification.

Two features of the figure are worth noting. First, the post-shock trajectory is consistent with the static estimate: the total effect drops sharply to approximately -26 tCO$_2$e/\$M in 2022, deepens to -27 in 2023, and remains stable at -25 in 2024. The estimates are precise and remain well below zero throughout the post-shock window, confirming that the decarbonisation effect is sustained rather than a one-off adjustment. The slight attenuation relative to the broader EII average (approximately -34 $tCO_2e/\$M$ in the static model compared to -38 for EII-only firms) is consistent with the supply-side constraints on energy substitution discussed above.

Second, the pre-shock period reveals a declining positive differential: the 2018 estimate stands at $+14tCO_2e/\$M$ and falls to approximately +8 by 2019–2020 before converging to zero at the reference year 2021. This pattern reflects the fact that doubly-treated firms, concentrated in heavy industry sectors within gas-dependent economies, entered the sample period with above-average GHG intensity relative to the broader EII population, a gap that was already narrowing before the shock. This pre-trend is a caveat to the parallel trends assumption and is discussed further in Section 6; however, the post-shock drop of roughly 25–27 units is an order of magnitude larger than the pre-period differential, making it unlikely that trend extrapolation alone can account for the post-2022 estimates.

6 Limitations and Further Research

Several limitations of the current analysis are worth acknowledging. First, and most importantly, the country assignment is based on each firm's registered headquarters location. For MNEs, this may poorly capture the true geography of production and energy consumption. A firm registered in Germany but operating primarily in Poland faces the energy mix of Poland, not Germany. In this way, Germany's high gas exposure score would be attributed to a firm that may not bear that exposure operationally. Correcting for this would require facility-level data on production locations, which is not available in TruCost.

Second, the analysis cannot distinguish between genuine decarbonisation and carbon leakage. If firms in gas-exposed countries reduced their measured Scope 1 emissions by outsourcing the most emission-intensive production steps to lower-cost jurisdictions outside Europe, our estimate would overstate the true environmental impact of the energy shock. A Scope 3 analysis or trade-adjusted emission accounting would be needed to address this.

Third, the parallel trends assumption for the sector-level treatment is only partially supported by the event study. The 2018 pre-period coefficient for energy-intensive firms is elevated relative to the reference year 2021, suggesting that EII and non-EII firms may have been on somewhat different trajectories before the shock. Results should therefore be interpreted as capturing the *acceleration* of an ongoing sectoral divergence rather than its initiation.

This interpretation is also consistent with the broader timing of the European gas crisis. The 2022 shock did not occur after a fully stable pre-period: gas prices had already increased sharply in 2021, as the post-COVID reopening generated a rapid recovery in energy demand while supply remained tight. At the same time, Europe remained structurally exposed to Russian gas: in 2021, the EU still imported around 155 bcm from Russia, roughly 40% of its gas imports. The invasion therefore transformed an already tight and expensive market into a full supply-security crisis, as Russian pipeline flows fell sharply and European gas prices reached historical highs in 2022, peaking at around €350/MWh in August. Energy-intensive firms may therefore have started adjusting before the invasion, through efficiency measures, fuel switching, or production rationalisation, with the war acting less as the starting point of adjustment than as its geopolitical acceleration. This helps explain the pre-trends observed in the event study and reinforces a cautious interpretation of our estimates: they capture the incremental effect of the war-related escalation rather than the full effect of the broader 2021–2022 European gas crisis. This interpretation is consistent with the evidence presented in the guest lecture on the geopolitics of fossil fuels.

A natural extension of this work is to examine the medium-term trajectory. The current panel extends to 2024, capturing only two full years of the post-shock period. It is plausible that the transition away from Russian gas is a multi-year process, with the full decarbonisation effect materialising over a longer horizon as firms complete capacity investments in renewables and energy efficiency. A repeated analysis with data from 2025 and beyond would allow for a richer dynamic specification.

7 Conclusion

This paper provides firm-level evidence that the Russia–Ukraine energy shock triggered a significant reduction in GHG intensity among European energy-intensive firms. Using a difference-in-differences design on a panel of approximately 973,000 firm-year observations, we find that energy-intensive firms reduced their direct GHG emissions per unit of revenue by approximately 38–43 tCO_2e per \$1M in the post-2022 period, relative to comparable non-EII firms. The most plausible mechanism is that the sharp increase in energy prices (and the strategic imperative to diversify away from Russian gas) pushed firms to invest in energy efficiency and lower-carbon energy sources, reducing Scope 1 intensity as a by-product.

Critically, this effect is not uniform. Firms headquartered in countries with higher pre-shock Russian gas dependency experienced an attenuation of roughly 10 $tCO_2e/\$M$, leaving them with a smaller but still substantial net reduction. This finding highlights the strategic interdependence between firm-level environmental performance and country-level energy infrastructure. Countries with more diversified, flexible energy systems (nuclear, renewables, well-connected grids) were better positioned to channel the energy price shock into genuine decarbonisation gains. Countries locked into pipeline gas dependency experienced slower transitions, constraining the environmental improvements their industrial firms could achieve even when strong price incentives were in place.

The policy implication is dual. At the country level, investment in energy diversification is not only an energy security imperative but also an enabler of corporate decarbonisation. At the firm level, companies constrained by their location should place strategic emphasis on energy-mix flexibility and long-term power purchase agreements as tools to decouple their GHG performance from the energy endowment of their host country.

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